INVESTIGATION OF THE RELATIONSHIP BETWEEN TRANSIT NETWORK STRUCTURE AND THE NETWORK EFFECT – THE TORONTO & MELBOURNE EXPERIENCE

By

Karen Frances Woo

A thesis submitted in conformity with the requirements for the degree of Master of Applied Science

Department of Civil Engineering

University of Toronto

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Department of Civil Engineering
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2009

Abstract

The main objective of this study was to quantitatively explore the connection between network structure and network effect and its impact on transit usage as seen through the real-world experience of the Toronto and Melbourne transit systems. In this study, the comparison of ridership/capita and mode split data showed that Toronto’s TTC has better performance for the annual data of 1999/2001 and 2006. After systematically investigating travel behaviour, mode choice factors and the various evidence of the network effect, it was found that certain socio-economic, demographic, trip and other design factors in combination with the network effect influence the better transit patronage in Toronto over Melbourne. Overall, this comparative study identified differences that are possible explanatory variables for Toronto’s better transit usage as well as areas where these two cities and their transit systems could learn from one another for both short and long term transit planning and design.
Acknowledgments

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1. Introduction
Public transit and transit planning has become an important field of study as the concern for the environment and the sustainability of urban areas rises. By taking people out of their cars, which in turn takes cars off the road, public transit can assist in relieving road congestion, reducing fuel consumption and providing an alternate means for those people to travel to their destinations. Because public transit plays an important role in urban cities, best practice in creating functional public transit networks is an area of research and of public and political interest. To develop this best practice, it is becoming more common to compare peer cities with respect to transit and its usage because of the numerous opportunities to learn from other systems. Within this context, this study makes an effort to contribute to research in public transit benchmarking by conducting a comparative analysis between Toronto, Canada and Melbourne, Australia with the focus on network structure and its impact on transit usage.

1.1. Motivation for Study
As a whole, this study aims to quantitatively benchmark the public transit experience in both the Toronto and Melbourne areas. This reflects the two major classes of network structure, the grid network of Toronto and the radial network of Melbourne, while exploring their ridership levels and associated network effects. The network effect, within the context of this study, refers to the delicate balance of supply and demand resulting from a state of operation where the number of people that use the system has reached a critical mass that supports a certain service level and/or development of direct or overlapping routes which can induce further demand (See Section 3.1 for further explanation). These two real world urban areas and transit systems are used for this in-depth cross-sectional analysis of network structures since micro-simulation can only partially model reality due to many unknown influential factors. Even though there are many variables that can affect transit ridership, transit characteristics, usage and network structure a better understanding of differences that can arise from different network structures.

In the past, similar studies have investigated the transit experience in Toronto and Melbourne. However, these previous comparative studies have been more qualitative in nature due to data limitations leading to debatable conclusions. At present, some of these data limitations have been overcome by travel surveys and technological advances making quantitative comparisons more feasible. By carefully evaluating the factors that affect ridership, transit characteristics, usage and network structure a better understanding of transit behaviour in relation to network structure can be gained.

The main premise of this study stems from past research work done on Toronto by Paul Mees in 1997. In his work, the author qualitatively speculates that it is the network effect that gives Toronto’s transit system (operated by the
Toronto Transit Commission (TTC)) an advantage in capturing higher patronage in comparison to Melbourne’s transit (Mees, 1997). By re-comparing these two systems based on more recent data using a three part approach that first looks at urban characteristics, then at network characteristics and lastly at network design aspects, the goal here is to take a more quantitative approach in identifying the effect the network structure has on transit usage.

1.2. Background on the Case Study Cities
The transit systems of Toronto and Melbourne were selected because of numerous similarities and previous studies on these two cities. The following sections provide background information on these two cities from a social and transit perspective.

1.2.1. Social Background
From a quality of life perspective, Toronto and Melbourne rank closely according to The Economist’s World’s Most Liveable Cities and Mercer’s Quality of Living Survey. Both these surveys use numerous qualitative and quantitative indicators of living conditions to determine which cities are the most liveable. While the two surveys focus on similar aspects, they use relatively different approaches to measurement. The Economist uses 30 different qualitative and quantitative indicators that help measure stability, health-care, education, infrastructure, culture and environment (The Economist, 2007). Whereas, the Mercer Survey uses more specific categories and divides quality of life into 39 indicators that help define the political, social, economic, socio-cultural, health, schools and education, public services and transportation, recreation, consumer good, housing and natural environment aspects of a city (Mercer Survey, 2008). In the 2008 Economist’s list, Melbourne and Toronto rank two and five, respectively, and only differ by 1.2% from one another. In the 2008 Mercer Survey, Melbourne and Toronto are 17 and 15 respectively and differ by 0.4 points on the rank list. While the ranking of cities produced by these two surveys are not the same, the relative positions of Melbourne and Toronto to one another are relatively similar and show that the two cities share similar high qualities of life.

In addition to the similar quality of life, both cities are found within English speaking first world British Commonwealth countries and are the capitals of their state or province. Both cities were founded at roughly the same time, Melbourne in 1835 (City of Melbourne, 2008) and York in 1793, which was renamed Toronto in 1834 (Fort York, 2007). They have had roughly the same amount of time to develop into their present states.

Both the City of Toronto and the City of Melbourne also serve as the urban core to their own larger urbanized areas. In the Melbourne area, the central business district (CBD), located in the City of Melbourne with an area of 36.5 km², makes up only 2.75 km² of the full Metropolitan Melbourne Area (MMA) that is 8,806.6km². The MMA should not be confused with the Melbourne Statistical Division (SD), which is 7,694 km² differing from the MMA because it does not include the scarcely populated portions of the Yarra Ranges. The Melbourne SD is further subdivided into Local Government Areas as seen in Figure 1-1.
In Toronto, the CBD is again a small area occupying roughly 3.8 km$^2$ in the downtown core. The terminology of the urbanized Toronto area is significantly different from that in Melbourne because of the evolution of the Toronto area, the planning boundaries and the census collection. The current City of Toronto refers to the area created in 1998, when Downtown Toronto amalgamated with its five neighbouring suburbs namely North York, Etobicoke, York, East York and Scarborough. Prior to 1998, this area was referred to as Metropolitan Toronto (City of Toronto, 2000). The City of Toronto makes up 630.2 km$^2$ of two larger planning areas known as the Greater Toronto Area (GTA) as well as the Toronto Census Metropolitan Area (CMA). These two areas should not be confused with one another as they do not refer to the same geographic areas. Similar to how the Melbourne SD is a smaller portion of the MMA, the Toronto CMA is 5,904 km$^2$ of the 7,124 km$^2$ that makes up the GTA. The GTA is a provincially defined planning area, whereas the Toronto CMA is an area defined by Statistics Canada which includes neighbouring municipalities around a major urban core that has at least 100,000 people (Statistics Canada, 2001). The GTA and Toronto CMA are shown overlapped below in Figure 1-2 to illustrate the differences between the two geographic areas (U of T library Services, 2001).
From a cultural perspective, Canada and Australia are both countries that resulted from colonization and have relied heavily on immigration to build up their populations. Immigration and multiculturalism play a significant part in defining both Melbourne and Toronto’s city characters. Figures 1-3 to 1-6 show the percentage of population born outside the country and the language spoken at home for Melbourne SD and Toronto CMA, which are indicators of immigration and multiculturalism. From these figures, it is visible that many of the immigrants to both city areas are very similar; most notably, immigrants from Italy, China and the United Kingdom. Both these cities have embraced their immigrants and identify themselves as multicultural cities (City of Melbourne-Multicultural Strategy, 2005; City of Toronto, 2008) where cultural precincts such as Little Italy, Greek Town and China Town are found. Aside from the culture integrated from different major ethnic groups, both cities have developed their own artistic and cultural ambience where street festivals, fashion weeks, sporting events and film festivals thrive. In this respect, both cities have very similar cultural spirit.
From an economic perspective, Melbourne and Toronto do not hold the same position on a national level. Often hailed as the economic engine of Canada, Toronto is the financial centre of Canada and the third largest in North America. In 2007, the gross domestic product (GDP) was an estimated CAD$133 billion (City of Toronto, Economic Indicators, 2008). With the major industry clusters primarily in financial and business services, biomedical and biotechnology, information and communication technology, fashion, film, food and beverage and tourism, Toronto clearly hosts a wide range of industries. Although these industries support the economy, education plays a large role as well. University of Toronto, Ryerson University, York University and numerous colleges make up the large number of secondary school education options. Although Melbourne does not generate as much economically as Toronto, its AUD$85.5 billion in 2007 (reported in 2001 dollars) of gross regional product (GRP) is substantial (City of Melbourne, Business Melbourne, 2008). Toronto and Melbourne share many of the same industries that play key roles in their economies with the exception that Australia’s major financial sector is located in Sydney rather than Melbourne. As with Toronto, education also plays a large role in Melbourne with a large number of post-secondary education facilities. Melbourne, a “knowledge city,” has eight major university campuses for which they pride themselves in where more than 40% of city residents have a post secondary degree whereas in Toronto only 30% fall in that category (Business Melbourne, 2008, Statistics Canada, 2008).
Naturally, not every aspect of these two cities is similar. Most notably, they differ geographically because they are located in different parts of the world. Seasons occur at different times of the calendar year, and it does not snow in Melbourne. However, both Melbourne and Toronto are situated near large bodies of water. Melbourne is on Port Phillip, which opens onto the Indian Ocean, and Toronto is on the north side of Lake Ontario, one of the five great lakes. Climate in both these areas is influenced by these bodies of water and their geographic locations. Melbourne experiences variable ocean-influenced weather which is often referred to as "four seasons in a day". Typically, Melbourne experiences dry summers and colder winters due to its more southern location in the southern hemisphere in comparison to its fellow Australian cities. Toronto experiences lake-moderated weather with humid summers and less snow in the winter but often with temperatures that feel colder due to dampness (See Table 1-1 for average seasonal temperatures; City of Melbourne, 2008; Environment Canada, 1971-2000). The weather conditions experienced by Melbourne and Toronto differ mostly by the extreme winter experienced in Toronto but are otherwise not drastically different in the Spring, Summer and Fall months.

**TABLE 1-1: TORONTO AND MELBOURNE CLIMATE COMPARISON**

<table>
<thead>
<tr>
<th></th>
<th>Spring</th>
<th>Summer</th>
<th>Fall</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Toronto</td>
<td>Melbourne</td>
<td>Toronto</td>
<td>Melbourne</td>
</tr>
<tr>
<td>Max °C</td>
<td>12</td>
<td>22</td>
<td>27</td>
<td>26</td>
</tr>
<tr>
<td>Min °C</td>
<td>4</td>
<td>8</td>
<td>18</td>
<td>13</td>
</tr>
<tr>
<td>Average Rainfall (mm)</td>
<td>58</td>
<td>62</td>
<td>71</td>
<td>52</td>
</tr>
<tr>
<td>Average Snowfall (cm)</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

From the above, Toronto and Melbourne are relatively similar with respect to quality of life, development and culture. This similarity provides a unique opportunity for comparison of their transit systems which have different network structures; with the Melbourne transit network being predominantly radial while the Toronto transit network predominantly a grid-like structure.

**1.2.2. Transit Background**

This section presents an overview of the urban transit available in these two case study cities with performance indicators that describe the service within these two cities. While these performance indicators are inclusive of all urban transit modes, it should be noted that only some modes and parts of the network are used for the analysis portion of this study as detailed later in Chapter 3.

Although there are numerous social similarities between Toronto and Melbourne, there are two distinct differences with respect to the transit services and system, the first being the overall network structure. As already touched
upon, Toronto’s TTC network has a distinct grid-like structure which is planned as a connected network with an emphasis on connectivity between modes and lines. Buses and streetcars in this system feed the subway resulting in a network that closely follows the road network layout of the city. This creates a grid-like appearance, as seen in Figure 1-7, and it operates on a flat fare system for services within the City of Toronto. The GO Transit system also provides bus and commuter rail transit services, but on a regional level. It provides radial transit services between adjacent suburbs and the downtown core of Toronto. GO Transit is not included in the network analysis of this study because this mode captures only 0.4% of the mode split for the City of Toronto residents and is radial in nature which detracts from comparing more distinct structures. However, because GO Transit has such a small share, it has been included in the mode split results in Chapter 4 to provide context to the overall transit usage in Toronto.

In the Metropolitan Melbourne Area (MMA), the modes of transit are similar to the TTC, including buses, trams and trains with bus routes acting as feeders to train lines as well as providing transit coverage where train and tram lines are not available. However, the overall network structure is more radial in nature, with intermodal connectivity between train and tram lines mostly located in the city centre.

The second distinction between these two city transit systems is the organization and delivery of transit services. In the GTA, transit is locally owned and operated by the respective local municipalities. There are nine transit agencies in total and one regional transportation provider known as GO Transit (The Big Move, 2008). Each agency operates transit within the boundaries of its municipality with minimal connectivity and coordination with transit outside their boundaries. Of these nine transit agencies, the largest and the focus of this study’s analysis is the TTC which mostly serves the City of Toronto but has limited routes that extend into adjacent municipalities that require supplementary fares, as shown in Figure 1-7. For the MMA, the transit system is organized on a regional level by mode with integrated zone based fares where the train, tram and bus services are franchised to private operators. This organization has the main advantage of avoiding cross-boundary coordination issues, which is common in the GTA. The Melbourne transit network can be seen below in Figure 1-8.
FIGURE 1-7: TORONTO TTC TRANSIT SYSTEM

FIGURE 1-8: MELBOURNE URBAN TRANSIT SYSTEM
From a historical perspective, these two transit systems have had relatively similar development timelines as seen in the timeline comparison in Figure 1-9. The historical data were compiled from relevant government and operator websites for the two cities (TTC, Milestones, 2009; History & Heritage, Department of Transport, 2009; History of Yarra Trams, Yarra Trams, 2009). As seen from this comparison, both transit services have had roughly the same length of time to develop and faced many similar milestones such as fare system changes and electrification of streetcars and trams. One particular milestone that has already been discussed as a distinction between the transit systems in these two cities is the difference between the TTC and Melbourne’s delivery of transit services. While the TTC has maintained public ownership, operation and planning of the service in Toronto, for the Melbourne transit system, service delivery is contracted out to private operators since 1999 (Public Transit Information, Department of Transport Victoria, 2009). The train services are franchised by Connex Trains, tram services are franchised by Yarra Trams and the bus services are divided by service area amongst 25 smaller private operators. However, this difference in service delivery does not significantly change transit service from a passenger’s perspective because of the integrated fare system Melbourne adopts.
While the historical contexts of transit in these two cities are important, the current comparative transit system performance is of equal interest. The overall performance of these two transit systems and other service related information is provided in Tables 1-2 and 1-3 as background information. These tables also provide the rolling stock
information as additional background context for the number of vehicles required to provide the transit service in these respective areas.

**TABLE 1-2: TTC ROUTE CHARACTERISTICS & ROLLING STOCK INFORMATION**

<table>
<thead>
<tr>
<th>Location</th>
<th>2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toronto</td>
<td></td>
</tr>
<tr>
<td>Annual Boardings(^1)</td>
<td>724,000,000</td>
</tr>
<tr>
<td>Annual Revenue Ridership(^3)</td>
<td>445,000,000</td>
</tr>
<tr>
<td>Cost Recovery Ratio(^1) (Operating Revenue/operating Expense)</td>
<td>0.75</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fare System</th>
<th>Flat Fare for continuous journey</th>
</tr>
</thead>
<tbody>
<tr>
<td>TTC Service Hours(^2)</td>
<td>Start</td>
</tr>
<tr>
<td>Monday to Saturday</td>
<td>6:00am</td>
</tr>
<tr>
<td>Sunday &amp; Holidays</td>
<td>8:00am</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Number of Routes(^3)</th>
<th>Number of Routes</th>
<th>Average length of Route (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus Routes</td>
<td>138</td>
<td>52.17 (round trip)</td>
</tr>
<tr>
<td>Streetcar Routes</td>
<td>11</td>
<td>7.20</td>
</tr>
<tr>
<td>Subway lines</td>
<td>3</td>
<td>20.63</td>
</tr>
<tr>
<td>Scarborough RT lines</td>
<td>1</td>
<td>6.40</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Kilometres of Route or Line(^2)</th>
<th>Average Speed (km/hr)</th>
<th>Average stop Spacing (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus route</td>
<td>19.9</td>
<td>305.0</td>
</tr>
<tr>
<td>Streetcar routes</td>
<td>14.4</td>
<td>238.5</td>
</tr>
<tr>
<td>Subway (including RT)</td>
<td>32</td>
<td>975</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Annual Revenue Vehicle Kilometres(^4)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus</td>
<td>105,899,000</td>
</tr>
<tr>
<td>Streetcar/Tram</td>
<td>11,610,000</td>
</tr>
<tr>
<td>Subway</td>
<td>77,689,000</td>
</tr>
<tr>
<td>Scarborough RT</td>
<td>4,110,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rolling Stock(^5)</th>
<th># of Vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buses</td>
<td>1543</td>
</tr>
<tr>
<td>Streetcar Vehicles (CLRV+ALRV)</td>
<td>247</td>
</tr>
<tr>
<td>Heavy rail cars</td>
<td>678</td>
</tr>
<tr>
<td>Scarborough Rail Transit Vehicles</td>
<td>28</td>
</tr>
</tbody>
</table>

**TABLE 1-3: MELBOURNE TRANSIT ROUTE CHARACTERISTICS & ROLLING STOCK INFORMATION**

<table>
<thead>
<tr>
<th>Location</th>
<th>2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melbourne</td>
<td></td>
</tr>
<tr>
<td>Bus Boardings (zone 1 +2)(^4)</td>
<td>86,000,000 (for 2006)</td>
</tr>
<tr>
<td>Tram Boardings (zone 1 +2)(^4)</td>
<td>158,000,000</td>
</tr>
<tr>
<td>Train Boardings (zone 1 +2)(^4)</td>
<td>203,000,000</td>
</tr>
<tr>
<td>Revenue Ridership</td>
<td>Not available</td>
</tr>
<tr>
<td>Cost Recovery Ratio (Operating Revenue/operating Expense)</td>
<td>Not Available due to privatization of service operation</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fare System</th>
<th>2-hour-Zone fares (zone 1, Zone 2 &amp; Zone 1+ 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melbourne Transit Service Hours(^6)</td>
<td>Start</td>
</tr>
<tr>
<td>Monday to Thursday</td>
<td>5:00am</td>
</tr>
<tr>
<td>Friday &amp; Saturday</td>
<td>5:00am</td>
</tr>
<tr>
<td>Sunday &amp; Holidays</td>
<td>7:00am</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Number of Routes(^6)</th>
<th>Number of Routes</th>
<th>Average length of Route (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus Routes (Zone 1 &amp; 2)</td>
<td>314</td>
<td>32.57 (round trip)</td>
</tr>
<tr>
<td>Tram Routes</td>
<td>27</td>
<td>13.71</td>
</tr>
<tr>
<td>Train Routes (Zone 1 + Zone 2)</td>
<td>15</td>
<td>24.8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Kilometres of Route or Line(^7)</th>
<th>Average Speed (km/hr)</th>
<th>Average stop Spacing (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus Routes</td>
<td>unknown</td>
<td>539.8</td>
</tr>
<tr>
<td>Tram Routes(^7)</td>
<td>16.8</td>
<td>234.4</td>
</tr>
<tr>
<td>Train Lines(^8)</td>
<td>60</td>
<td>1763</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Revenue Vehicle Kilometres</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus</td>
<td>Unknown</td>
</tr>
<tr>
<td>Streetcar/Tram(^7)</td>
<td>22,150,000</td>
</tr>
<tr>
<td>Train(^8)</td>
<td>30,000,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rolling Stock(^8)</th>
<th># of Vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buses(^6)</td>
<td>1472</td>
</tr>
<tr>
<td>Tram Vehicles(^4)</td>
<td>501</td>
</tr>
<tr>
<td>Train(^8)</td>
<td>331</td>
</tr>
</tbody>
</table>

\(^1\) Source: CUTA Factbook – 2006 Operating Data
\(^2\) Source: Service Summary, TTC Report Nov. 2008
\(^3\) Source: Service hours, TTC website, www.ttc.ca
\(^4\) Source: Transportation Demand Information Atlas for Victoria-Volume 1- Melbourne, 2008
\(^5\) Source: Service Hours, Metlink Melbourne, www.metolinkmelbourne.com.au
\(^6\) Source: Public transit Information, Department of Transport Victoria.
\(^7\) Source: Route Data, Yarra Trams, 2007
\(^8\) Source: Facts and figures, Connex Trains website, www.connexmelbourne.com.au
It should be noted that the revenue ridership information is not available in Melbourne due to the 2-hour ticket fare type used in Melbourne making it difficult to calculate the revenue ridership. Also, the cost recovery information is not available due to the service delivery being privatized making revenue information confidential. For further detailed information regarding the operational network data, see Appendix A.

1.3. Objectives and Scope of Study
The main goal of this study is to quantitatively describe the relationship between the transit network structures of Toronto and Melbourne within the context of transit usage. Previous research has suggested that Toronto’s grid network positively influences ridership through a theorized phenomenon referred to as the network effect (Mees, 1997). While this theory is interesting, isolating the influence of the network structure and service on ridership and mode split is very difficult as other aspects of urban characteristics and travel behaviour also have an influence. Overall, this study aims to provide a complete comparison of transit systems and the various factors that affect it with emphasis on exploring, quantitatively, the various factors that may influence transit usage with the focus on the effects of network structure in an attempt to capture the associated network effects. At its core, this study is a benchmarking and peer city comparison that investigates the system performance at one instance in time as well as compares the future direction of transit in these two areas.

The approach taken to achieve this objective is a systematic comparison that is grouped into three parts. In addition to examining ridership and mode share, the first part of the analysis looks into the socio-economic, demographic and trip characteristics of the residents living in Toronto and Melbourne that are related to transit usage. The second part of the analysis examines the network structure and varying forms of evidence of the network effect through different measures. This will identify distinctions that could explain the network structure’s relationship with the network effect and its influence on transit usage. The third and last part of this study examines the service standards, other network design features and the direction of the transportation plans in these two cities to provide a comparison on these aspects that are not quantifiable through performance measures. Using well defined study areas for Toronto and Melbourne, ridership and mode split performance as the context for this study, this three part approach will provide a cross-sectional comparison of these two cities. It will also provide insights into the relationship between network structure, the network effect and other influential factors of transit usage.

1.4. Organization of Thesis
The remainder of this document is organized in the following manner. First, Chapter 2 presents the literature review that assisted in the identification of the most appropriate methods for comparing the network structure and capturing the evidence of the network effect. The methodology behind this study is then covered in Chapter 3 followed by an in-depth analysis of ridership and mode split in Chapter 4. Chapter 5 presents the associated factors that can influence transit use from a socio-economic, demographic and trip characteristic perspective. The calculation
process and analysis of the networks in the form of performance indicator pairs and service level comparisons are provided in Chapter 6 where connectivity and transfer rate, theoretical and observed directness, revenue service kilometres and passenger kilometres, and area and population coverage are investigated. Because the network structure is only one aspect of transit design and planning, other features of transit design must also be considered as they are also influential factors of transit usage and network effect. Therefore, Chapter 7 discusses these other aspects which include transit service standards, station and stop design, signage and fare structure, as well as the future direction of transit in these two case study cities. Finally, Chapter 8 concludes this thesis with a summary of the findings from the three part approach as well as discusses possibilities for improving this study with future work.
2. Literature Review
The literature review assisted in the formulation of the approach taken in this research. The following sections provide a review of previous work that relates to this study in the areas of peer comparison, network structure and network effect and other Melbourne and Toronto comparative studies.

2.1. Peer Comparison Literature
Peer system comparisons can be challenging to carry out particularly because it is important to understand the value and recognize the issues that can arise in comparing existing international systems. According to Vuchic (2005), these types of studies are useful for transit because performance, costs and patronage measured are reflective of reality, whereas modelling may introduce many assumptions and errors about performance. However, Vuchic (2005) does caution that to avoid arriving at misleading conclusions “differences among systems caused by different operating concepts (needs separation) from those attributable to different transit mode characteristics” (p. 526). In light of this insight, careful socio-demographic and economic factors along with other factors that closely affect mode choice are evaluated and compared in this study to account for these factors as well as differences experienced in the network.

Vuchic (2005) notes that this type of comparison has not been fully explored in North America. In Europe, considerable effort has been made towards peer comparison of public transit systems and is usually referred to as benchmarking with the purpose of developing best practices (Wobbe, 1999). The High Level Group on Benchmarking (HLGB) understands benchmarking as not only a way of assessing one’s performance, methods and system compared to another but is also: “Normative” (p. 10) in providing guidance on practices, “Analytic” (p. 10) in developing measures to understand how certain methods become best practice, “Action-related” (p. 10) where it spurs progress, and “Continuous learning” (p. 10) that stem from successes and failures in performance that prompts the streamlining of processes (Wobbe, 1999).

Benchmarking can be a challenging task to complete effectively if the goal or objective of the benchmarking is not well identified (Bärlund, 1999). With clearly established goals and objectives, measures can be created and used to track successes and inefficiencies and be compared with competitors when they have the same or similar goals (Bärlund, 1999). Bärlund (1999) has noted that international comparisons of railway systems are difficult because performance and efficiency depend heavily on geographic, climatic, socio-economic and demographic factors, which substantiates the inclusion of these factors in this study. However, as seen by W.R. Clarke’s study on public transport benchmarking, benchmarking can be very useful (1999). Since 1994, a number of international metro or subway systems have joined forces to collect a common set of data that record their system activities (Clarke, 1999). The joint effort created two groups called COMET and NOVA where all of the collected data are housed at the Railway Technology Strategy Centre at the Imperial College at the University of London (Anderson et al., 2009). From an
operational context, the two groups acknowledge that in order for the benchmarking to be effective several factors must be in place. These are:

- “The transit agencies must have similar objectives, cultures, problems and expectations.
- Time and effort are needed to establish key performance indicators (KPIs) that are comprehensive, accurate and produce good comparative data.
- Successful implementation is essential and depends on good analysis of specific practices, sharp focus and continuing commitment” (Clarke, 1999, p. 149).

Toronto and Melbourne are both experiencing similar problems of auto-dependency where they both have 24-hour auto-mode shares of approximately 50% (see Table 4-4) as well as transit systems struggling with operational challenges, such as right-of-way as well as capacity issues (Currie & Shalaby, 2006). Their objectives of making transit a more viable alternative and approach to the environment and climate change are also similar (The Big Move, 2008, The Victoria Transport Plan, 2008). Clearly, the transit operators in both Toronto and Melbourne share similar objectives, problems and expectations and are suitable for benchmarking as per the prerequisites of the COMet and Nova initiatives.

The experience in public transportation in Europe has also led to another useful best practice set of guides produced by HiTrans in 2005. These guides stem from the successful experiences in Europe and other medium sized cities around the world. Volume 2 of the set provides a best practice guide for transit network planning regarding network structure and the different factors that influence performance. The best practice guide condenses the learning experience from transit leading countries learning from both success stories and failures. In this respect, peer comparisons are useful for benchmarking performance with other systems while allowing systems to learn from others’ experiences in hope to overcome their own challenges.

The HiTrans guide (2005) also advocates that, for medium-size cities that may not have the density to have extensive metro networks, best practice is to have a simple network that uses all modes with easy and comfortable transfer points. These simple networks should have direct route alignments and a select few high performance lines that act as a backbone for the system providing efficient travel across the city (HiTrans Best Practice Guide, vol.2: Public Transport Planning the Networks, 2005). Based on this best practice description, it foreshadows that the better transit usage in Toronto may be attributed to the design of Toronto’s TTC network since it is already a real world example of the best practice network planning advocated by this guide. However, even though the TTC network has the basis for best practice, there are still areas that can be improved, particularly in the case of its streetcars. Melbourne provides an excellent case study where an extensive tram network has been embraced and successful in providing transit in less dense areas. This provides support for the TTC’s decision to pursue light rail as the approach to network improvement issues currently being dealt with. Given that the HiTrans best practice guide
supports the theory that network structure can influence transit use, the literature on structure and network effect was extensively researched with the relevant information summarized in the following section.

### 2.2 Transit Network Structure & Network Effect Literature

Given that the HiTrans best practice guide supports the theory that network structure can influence transit use, the literature on structure and network effect was extensively researched with the relevant information summarized in this section. This section reviews some of the relevant past work in transit network structure and transit network effect in the two subsections below.

#### 2.2.1. Transit Network Structure

In this study, the transit network structure refers to the pattern in which the transit lines are mapped to the area they serve. Within this context, network geometry is often the term used to describe this characteristic. Both structure and geometry is used interchangeably in this study and refer to this transit characteristic. Because all transit systems have some degree of dominant network structure, it was important to review the general types of network structures that are used to classify them. Based on this review, Vuchic’s classification was adopted and is summarized below.

According to Vuchic (2005), there are four major classifiable groups for transit networks. These four classes are listed, described and illustrated below.

1. **Radial networks** – This type of network is formed when the majority of lines that make up the network are radial or diametrical in nature. This means that all the lines start in the suburbs and all terminate at one station or small area in the urban core of the city essentially providing more direct travel to the core. Diametrical lines have terminals at opposite ends of the city. See Figure 2-1.

2. **Radial and Circumferential Networks** – This type of network is similar to the radial network with the exception of an additional circular or tangential line that connects the radial lines without having to pass through the city centre. See Figure 2-2 for illustration.
3. Rectangular or Grid Network – This type of network is made up of evenly spaced parallel lines that run in two major alignment directions which are perpendicular to one another. The transit lines look topographically like the lines on a grid, which is where the name comes from. These networks provide more even coverage over the service area, but relies more on passengers transferring to get to their destination particularly if headed towards the urban core. See Figure 2-3 for illustration.

4. Ubiquitous Network – This type of network is the supposedly most ideal as it is a combination of diametrical lines that branch into the suburban areas. Transfer points are spread out across the system and not just in the central urban area. This network type is characterized with wide coverage, good connectivity and multiple opportunities for transfers. For illustration, see Figure 2-4.

Other recent research that combines both network structure aspects and peer comparison is the work done by Thompson and Tomas (2003) on mid-sized cities or metropolitan areas. The authors suggest that the major transit systems mostly fall into either the radial network or multi-destinational network category. Multi-destinational networks in this context refer to timed-transfer system and grid networks. Often multi-destinational networks that do not use timed-transfer systems, such as grid networks, are ones that offer frequent service such that coordinated arrivals at transfer hubs are not necessary. In their efforts to address which approach had better transit user performance, Thompson and Thomas (2003) compared nine transit systems from nine different United States metropolitan areas of roughly the same population size, three of which were multi-destinational systems (Portland, Sacramento and San Diego) and the other six were radial (Houston, Minneapolis, Seattle, Columbus, Cleveland, Pittsburgh). In comparing the nine systems by annual vehicle miles per capita, annual passenger miles per capita, passenger miles per vehicle mile, average operating cost per passenger mile and peak service to base service ratio, the authors concluded that the network structure explains much of the performance difference between the systems. In their study, the systems that used the multi-destinational approach to transit planning were more effective, almost as efficient as and more equitable than those that used the radial approach (Thompson and Thomas, 2003). This study substantiates the hypothesis that the network structure influences and gives a leading edge to the ridership of a transit system. It also provides supporting motivation for this comparative investigation of Toronto and Melbourne to further analyze the effect of the network structure. Thompson and Thomas’ (2003) study also gives good examples of performance indicators that can be used in this study, particularly the passenger miles per vehicle mile. Because this indicator
had the most explanatory power in Thompson and Thomas’ study, it was adopted in this study as one of the analytical measures used for network structure comparison.

Cervero’s work (1993) and the HiTrans Best Practice Transit Network Planning Guide (2005) also supports Thompson’s findings, where both suggest timed-transfer systems are a good approach to transit solutions in medium density areas if a high frequency grid-like network cannot be provided. The suggestion here is that if transit is only tailored towards work and CBD travel, there is a largely untapped market of possible passengers. Equity or equal access issues also arise when transit is strictly tailored to the CBD. To make grid and multi-destinational networks work, HiTrans (2005) stresses the importance of an integrated network. Both radial networks and grid or multi-destinational networks have the ability to be well integrated or connected, however if they are not, both network types will function poorly. Because the grid and multi-destinational networks rely on transfers more heavily, travel behaviour theory suggests that these types of networks will suffer more than radial systems if good connections are not provided. This information provides good context for assessing the Toronto and Melbourne transit systems as well as support the hypothesis that Toronto’s network structure may contribute to its better performance in which its connectivity plays a large role.

The summarized relevant literature thus far has implied that connectivity plays an important role in network structure. Graph theory can provide some insight into methods of measuring connectivity and using this measure to describe network structure. The connectivity index, which is also known as the gamma index in graph theory, is the ratio of the number of edges in the graph to the maximum number of edges which can exist in a planar graph (Morlok, 1967). Mathematically, connectivity is represented as:

$$\gamma = \frac{e}{3(v - 2)}$$

where:

- $\gamma$ = gamma index or connectivity;
- $e$ = number of edges that exist in the planar graph or alternatively the number of links in a transit network; and
- $v$ = number of vertices in the planar graph, or alternatively the number of stations or stops in a transit network.

In Morlok’s work (1967), where he applied these measures of connectivity to transportation networks, he found that different network types, mainly spinal, grid and delta networks, have different ranges of the connectivity index. These different types of network structures can be seen in Figure 2-5. From this figure, it can be observed that there is increasing connectivity as networks proceed from spinal to grid and delta networks.
FIGURE 2-5: MORLOK RADIAL/SPINAL, GRID & DELTA NETWORKS

The upper and lower limits or ranges of these three network types as Morlok (1967) mathematically proved are:

- **Spinal**: \( \frac{1}{3} \leq \gamma \leq \frac{1}{2} \), when the number of interchanges (transfer stations) is \( I \geq 4 \);
- **Grid**: \( \frac{1}{2} \leq \gamma \leq \frac{2}{3} \), when \( I \geq 4 \);
- **Delta**: \( \frac{2}{3} \leq \gamma \leq 1 \), when \( I \geq 3 \).

These limits are reference points for evaluating how well connected the stations and stops are to one another in the purest theoretical sense and relating them to specific network structures. Because this index has a number of advantages such as index categorization of network structures and quantitatively comparing connectivity of networks, this index was adopted for use in this study.

Vuchic (2005) also suggests that a relationship exists between network structure and the proportion of direct travel opportunities where radial networks often provide a higher proportion of direct opportunities than grid networks which are more dependent on transferring. Based on this work, the following measure was adopted for use as an indicator of theoretical directness of travel, \( \delta \):

\[
\delta = \frac{OD_d}{OD}; 0 < \delta \geq 1
\]

where: \( OD_d = \frac{1}{2} \left( \sum_{i=1}^{q} n_i(n_i-1) - \sum_{j=1}^{q-1} n_{mj}(n_{mj}-1) \right) \) and \( OD = \frac{1}{2} N \times (N-1) \)

- \( OD_d \) = number of direct station-to-station paths
- \( OD \) = total number of station-to-station paths (Direct and transfer)
- \( n_i \) = number of stations on line \( I \);
- \( q \) = number of lines in network;
- \( n_{mj} \) = number of joint stations on each section that each line \( j \) shares with any already counted line;
- \( q_m \) = number of lines in the network that have a shared station; and
- \( N \) = total number of stations in the network.
Vuchic (2005) also suggests that area coverage is related to the network structure. Therefore the following formula was also used to evaluate the difference between Toronto and Melbourne and their respective grid and radial structures to see if there is a relationship with transit usage. The area coverage indicator, $A_c$, is calculated as follows:

$$A_c = \frac{N \times S_i}{S_u}$$

Where:
- $N$ = number of stations in the network;
- $S_i$ = catchment area; and
- $S_u$ = total urban area.

These indicators of network structure are used in this study. In the next section, the literature on network effects, network synergy and externalities is reviewed with insights into the approach to measuring this demand related phenomenon and relating it to network structure.

### 2.2.2. Network Effect, Synergy & Externality

With regards to the concept of network effect, several terms can be found that generally refer to similar concepts. The three terms that consistently appear in the literature are “network effect”, “network synergy” and “network externality.” With respect to network effect and network synergy, there is general consensus in the literature that these two terms are synonymous with one another and refer to the benefit that arises when two or more services, consumers or producers of compatible nature join forces and become more than purely the sum of their services, consumption or products. In other words, it essentially captures the situation where the whole is more than the sum of its parts or as mathematically phrased by R. Capello and P. Rietveld (1998) "synergy breaks the value additivity principle of utility (that is, $1+1 > 2$)” (p. 58).

The first known reference to the network effect is found in the communications industry in the 1970’s when Jeffrey Rohlf’s investigated the utility or user benefits that arise as others subscribe to telephone services. Rohlf’s (1974) concluded that there is a directly proportional relationship between an individual telephone subscriber’s utility and the number of telephone service subscribers. This relationship is reasoned from growth in the telephone communication network that allows a larger number of people available to connect with, thus increasing the utility of the telephone service beyond the utility originally subscribed to. M. Katz and C. Shapiro (1985) did further work in this area and concluded that there are many different products and services that exhibit the same phenomenon giving rise to what they refer to as “consumption externalities”. Katz and Shapiro (1994) refer to network effects and network externalities as one and the same. However, whether they are the same is debatable because the literature on this subject does not always use them interchangeably. E. Osiowy (2006) says that “network effects may incorporate network externalities, but they are not the same thing” (p.10) and goes on to state that “externalities are costs or benefits that neither the operator nor user can internalise” (p.10). From the review of the literature on this subject, the difference between the two concepts of network synergy or effects and externalities appear to be within the
connotation of the words. Network externality is the general term that is used to describe the utility or disutility that can arise from the consumption of network services whereas network effect, with its positive connotation, is only used to describe the utility or positive network externalities.

While the meanings of these terms, network synergy and network externality, are consistent with those used by Capello and Rietveld (1998) in their research on the concept of network synergies with respect to transport networks, Capello and Rietveld (1998) also add another layer of complexity to relate the term back to their origins in the telecommunications industry. Capello and Rietveld (1998) define network synergy as the increase in benefits or positive externalities that a certain number of users in a network receive when there are additional users. The key notion here is that network synergy not only refers to the value of the whole transit network being more than the sum of its lines or routes, but, also requires the added ingredient of being consumed (Capello & Rietveld, 1998). Logically, without users of the network, synergy will not exist. The evidence of synergy they use in the context of transit includes the increase of the frequency on a transit route when the number of additional users is enough to justify higher capacity and creating a more direct route between a certain origin and destination if the demand is sufficient (Capello & Rietveld, 1998). These two forms of evidence of the network effect are significant considerations when trying to quantify the relationship between network structure and effect. While these two examples of network synergy illustrate the concept well, in reality such results of network synergy in transit are slow in terms of realization. Capello and Rietveld (1998) recognize this lag time and define network congestion (synonymous with negative network externality) as the opposite of network synergy, which usually occurs before the network synergy can be realized.

In another study on network synergy, C. Capineri and D. Kamann (1998) also recognize that while networks can exist in both the physical and non-physical contexts and are subject to many of the same properties, the establishment of links within each context is different. In physical networks, like transit networks, the physical links take much longer to establish and are even more difficult to change because of high investment costs in establishing each link. Given this insight, Capineri and Kamann (1998) conclude that synergy only arises when there is a positive relationship between demand relative to capacity on the one hand and network cohesion on the other. In this context, cohesion refers to the cooperation between a network’s connectivity, mobility and operation. While this helps define the concept of synergy and stipulates the importance of the relationship between demand and supply, measuring this relationship is still illusive.

While extensive research work has investigated network effect in transit systems and other economic contexts, no real quantitative measure has been established to capture these effects. One often referenced research on this subject matter is the Squaresville theoretical example proposed by P. Mees (1997). In this example, Mees (1997) compares the difference between isolated transit lines and the provision of a network. Using this theoretical example
of a square 8km by 8km, he systematically contrasts the impact of increasing service along the isolated transit line compared to providing new services that connect the parallel, isolated lines into a grid. Mathematically, he shows this difference by assuming a fixed mode split and change in available destinations by transit, where he shows that it is much more advantageous to connect the routes together than increase service along isolated lines (Mees, 2000) (For more details see Mees’ book A Very Public Solution, 2000). The example, as Mees (1997) points out, is only theoretical and assumes that people are willing to transfer and that bus frequencies are at a rate that make transferring somewhat attractive. With this emphasis on transfers playing a central role to this explanation, it is speculated that transferring is another possible type of evidence that can indicate the presence of the network effect.

In Frank Goetzke’s (2008) work, a spatially autoregressive mode choice model was used to try and capture the utility of network effects in public transit usage in the New York Metro system. The spatially auto-regressive logit model helped describe an individual’s choice in conjunction with their neighbour’s mode choice, where the positive significant parameter estimation for this variable showed the correlation between the influence from neighbouring people using transit on the individual’s choice to use transit. Indeed, Goetzke (2008) found that the network effect does exist in the New York Metro system, however, the model only works in binary mode choice situations and does not reflect the geometric structure of the network. Even though modelling and simulation can indicate the existence of network effect, it does not answer the question of whether certain network structures can give rise to more advantageous synergy or effect which can influence transit usage.

It is clear from the literature review on network structures and network synergies, that much work has been done in both areas, but little work has attempted to quantitatively link the two together. As reviewed, there is a general consensus that “multi-destinational” transit systems, whether it be a grid system or timed transfer system, has the potential for being more advantageous than other network structures. In comparing the two major network types radial and grid, through the real world experience from Toronto and Melbourne, the research here intends to quantitatively describe the network effect’s relationship between supply and demand.

2.3 Previous Melbourne & Toronto Studies

The peer city comparison between Toronto and Melbourne is not a new endeavour. Paul Mees examined Toronto and Melbourne within the context of land use and public transportation policy from 1950 to 1990 in an attempt to explore why Toronto’s public transit system had not experienced the same patronage decline as Melbourne. In his comparison, he concluded that the patronage success in Toronto is not due to land use policies or planning in which Melbourne appeared to favour a more public transit oriented approach. The higher ridership found in Toronto was due to the integration of service technology, according to Mees (1997), which incorporates higher service level frequency and better bus connectivity with rail. Based on this observation, Mees (1997) theorized that Toronto’s grid network created a “network effect”, which contributed to the higher ridership found in Toronto. Increased transit ridership due to the “network effect” remains a purely theoretical concept until proven empirically. The qualitatively
discussed aspects of Mees' research serve as part of the motivating factor for this study where the effort is to quantitatively substantiate his qualitative-based theory.

A more recent study done by Currie and Shalaby (2006) explored the successes and challenges of modernizing streetcar systems as seen through the experience of Melbourne and Toronto. This study found that these two systems share many similar challenges. Aside from the orientation of traffic, left hand in Melbourne versus right hand in Toronto, operations are very similar as both operate streetcars in the median lanes. Furthermore, they both have performance challenges due to mixed traffic operations where poor reliability and low operational speeds are common (Currie & Shalaby, 2006). The study indicates that much can be learned from the transit experience in these two cities, therefore a network wide system comparison would be a useful exercise for both transit systems.
3. Study Methodology & Data

The following sections outline the approach to investigating the relationship between the network effect and network structure as experienced through Toronto’s grid system and Melbourne’s radial system. First, the term network effect is defined within the context of this study. Next, an overview of the method based on the objectives detailed in Section 1.3 is outlined. The available data are then described followed by the study area definition.

3.1. What is the network effect?

The network effect (synonymous with network synergy and will be used interchangeably), in the context of public transit, is a loosely defined term that usually refers to high frequency services integrated in a manner that make transferring less undesirable. It is also sometimes referred to as a network that facilitates travel to many destinations and not just the urban core. Because this term is used in many different contexts, it is important to clearly define its context used in this research. In order to define the network effect, an explicit definition of the term network is also deemed important. In this research, network is defined as a collection of nodes that are connected together in some manner, through which goods or information can flow and can also be referred to as graphs (Capineri & Kamann, 1998; Larson & Odoni, 1997; Morlok, 1967).

The network effect in this research, as understood from the literature review, refers to a two pronged phenomenon. The first is that the given transit network, a connection of transit lines or routes that share a common goal or performance, attracts some amount of transit patrons. The second is that as these users use the system, it attracts others to also join the system resulting in an increase of the overall benefit to all users that is, as defined by Capello and Rietveld (1998), higher than what the individual users expect. In other words, the network effect or synergy is essentially a delicate balance of supply and demand resulting from a state of operation where the number of people that use the system have reached a critical mass that supports a certain service level and/or development of direct or overlapping routes, as Capello and Rietveld (1998) explains, which can induce further demand. There are two important assumptions underlying this definition and are listed below:

- The first assumption is that the transit networks are not being operated at extreme deficits with much higher service levels than are demanded for. In reality, transit systems are financially demanding and are usually publicly subsidized. In Toronto, public transit is subsidized by 25%. In Melbourne, the subsidy is unknown due to the services being contracted to private operators, but it is suspected to be higher than the subsidy in Toronto. However, the definition of the network effect assumes that a large portion of the supply of services is a product of the demand or ridership of such services.

- The second assumption is that the provided transit network has not reached operational capacity. The implication of this assumption is that the operational capacity will not limit growth in demand.

While the two systems in this study do require public funding assistance, services are well used as shown in Tables 1-2 and 1-3, which satisfies the first assumption. Some local users of these transit systems may argue that the
services have reached capacity. However these capacity limitations may only be on certain sections of the networks, which make the second assumption still applicable to the networks in Toronto and Melbourne.

Evidence of the network effect can present itself in several ways as suggested in the review of past research. The evidence is as follows:

- **Transferring**: This is a reflection of reliability and trust in the transit service provided, where customers would be willing to transfer despite the disutility involved with transferring. Increased transferring also creates interdependence between the transit routes causing demand to be shared amongst lines creating increased need for cooperation between the lines. When the lines function well together they can give rise to a network effect.

- **Directness of travel or overlapping routes**: When consumption of transit service is concentrated to common origins and destinations it can justify the establishment of new more direct services to the benefit of the network and its users producing a more localized network effect. Most transit systems have a strong orientation towards the CBD providing direct routes from the suburbs.

- **Service levels**: As more people use the transit network, one method of increasing capacity is increasing the frequency of service. This improvement reduces the wait time to the benefit of all user and users transferring from other routes which can also give rise to the network effect.

The approach to quantitatively compare the network effect with respect to network structure is based on measuring the evidence as well as the relevant aspects of the network structure.

### 3.2. Method

To achieve the objective of this study, a systematic approach was used to compare Toronto and Melbourne within the context of transit networks and factors that influence transit usage. The steps that formulate the analytical approach based on the identified geographic study areas are outlined below.

First, the ridership and mode split of the Toronto and Melbourne study areas were compared to identify which city, if any, has better transit usage. Even though previous studies have shown that Toronto has better transit usage than Melbourne, the ridership and mode split performance needed to be compared for the time period of analysis used in this study, which is mostly 1999 or 2001 with the exception of the area coverage and service level analysis that are from 2006 and 2008 data respectively.

Next, the characteristics of the residents living in each of the study areas were investigated because research in the past has shown that various socio-economic, demographic and trip characteristics do influence an individual’s choice to use transit. The factors examined in this study, at an aggregate level, are:

- **Socio-Economic and Demographic characteristics, mainly**:
  - Population density
  - Age
  - Workforce participation rate
  - Residential density
Network Structure and Network Effect – Toronto & Melbourne Experience

- Average Household size
- Average Household Income
- Average Vehicle Ownership
- Trip characteristics, mainly:
  - Trip rate
  - Trip Purpose
  - Time of Day
  - Trip Length
  - Origin and Destination

The Melbourne data used for this analysis were obtained from the 1999 Victoria Area Travel Survey (VATS) while the Toronto data used came from the 2001 Transportation Tomorrow Survey (TTS). While the study data are not recent, in Melbourne, this was the only data available for use because the more recent 2007 Victorian Integrated Survey of Travel and Activity (VISTA) survey was not yet available. To keep within a similar time period, the closest TTS data were chosen.

To compare the network structure and related network effect in the Toronto and Melbourne study areas, the next step was to use network indicators to measure various aspects of this relationship. Given that the network effect arises from the interaction between the physical network and users of the network, network indicator pairs, each having a supply and demand component, were formulated to capture this interaction. Four network analysis indicator pairs were selected based on the available data and literature review. They include:

1. **Connectivity & Transfer rate**: This indicator pair explores the relationship between how well connected the transit lines are and whether passengers make use of this connectivity.

2. **Theoretical Directness of Service & Observed Directness**: This indicator pair contrasts the first indicator pair by exploring how the increased provision of direct routes of travel affects passenger behaviour.

3. **Revenue Service Kilometres & Passenger Kilometres**: Similar to the measures used in Thompson and Thomas (2003), this indicator pair attempts to quantify the relationship between the service level provided and utilization of the service.

4. **Area Coverage & Population Coverage**: The network structure has implications for area coverage and transit accessibility as described by Vuchic (2005) and Thompson & Thomas (2003). This network indicator pair looks at the portion of population that is within the transit service area.

In addition to these network indicator pairs, frequency of service is also analyzed for each of the transit networks to provide an alternative method for assessing service level other than the measure used in the third network indicator pair. This is because service levels are made up of not only the number of services provided but the frequency of service as well.

However, not all aspects that influence transit usage can be quantified or measured. To account for these aspects, the final part in this study compares the service standards and other network design features along with the future
direction transit is taking in these two case study areas. This final portion of analysis identifies valuable learning experience opportunities for Toronto and Melbourne alike.

### 3.3. Data Description & Limitation

The data used for analysis in this study were obtained from a number of different sources. A brief description of the different data sources used for each case study city is outlined below.

#### 3.3.1. Toronto Data

The ridership, service kilometres and passenger kilometre data for the TTC were obtained from the Canadian Urban Transit Association (CUTA) Canadian Transit fact book – 2001 operating data. CUTA compiles operating data every year for all transit systems in Canada and obtains the data directly from all transit agencies. The data also include costs, fares, rolling stock and a list of calculated performance indicators. However, this data are not broken down by mode, thus restricting comparison to other systems by mode.

The socio-economic, demographic, trip characteristics as well as the demand side of the network indicator pairs were calculated using the Transportation Tomorrow Survey (TTS) data for 2001 as well as the 2001 Canada census data at the census tract level. The TTS is a travel survey that has been carried out every 5 years since its first collection in 1986 (TTS Data Guide, 2003). The years of TTS data correspond to the Canada census data for compatibility. The surveys take a 5% sample of all households in the regions that are participating in the survey. The general content of the survey covers person, trip and household information. The University of Toronto-Urban Transportation Research and Advancement Centre (UTRAC) Data Management Group (DMG), who organizes, stores and manages the Transportation Tomorrow Survey Data, expand this data to account for the entire population of the areas surveyed. The content of the data varies from year to year and has progressively become more detailed as the survey process becomes streamlined. The available data include:

1. Household Data
   a. Location
   b. Type of dwelling unit
   c. Number of persons
   d. Number of vehicles available for personal use

2. Person Data
   a. Gender
   b. Age
   c. Possession of a driver’s license
   d. Possession of a transit pass
   e. Employment status
   f. Occupation
g. Usual work location
h. Availability of free parking at place of work
i. Status as a student
j. Usual school location
k. Origin of first trip

3. Trip Data (Only collected for trips made by persons 11 and older on the previous day)
   a. Locations of origin and destination
   b. Purpose
   c. Start time
   d. Method of travel

4. For Trips made by Public Transit
   a. Method of access
   b. Sequence of transit routes (maximum of 5)
   c. Method of egress
   d. Boarding station (when a car is used for access to a rail route)
   e. Egress station (when a car is used for egress from a rail route)

One limitation of this data is that it does not include household income or personal income information. However, because the years of collection correspond with the census years, this information is available from Statistics Canada but for aggregate geographic units. Also, the data are only collected for those 11 years of age and older and are mainly geared toward capturing motorized trips, particularly for discretionary and non-home based trips. This focus causes walk and bike trips to be inadequately captured by the survey. Also, there is an under reporting of trips, which has been estimated to be as high as 30%, due to the manner in which the survey is carried out, where only one member of the household is asked to respond to the questions for all members of the household as well as only some information asked about walk and bike trips (TTS Data Guide, 2003). These limitations can cause discrepancies when comparing these modes to other travel behaviour data that make more effort to capture these types of trips.

Geographic Information Systems (GIS) data and stop sequence were used extensively to calculate the index for the supply side of the network indicator pairs. The GIS and stop sequence information were obtained from the TTC for 2006. Because most of the demand side indicators are for 2001, the 2006 stop information had to be modified to reflect 2001’s conditions. Between 2001 and 2006, the single most significant addition to the network was the introduction of the Sheppard subway line in 2002. This not only changed the subway network, but also altered the alignment of some bus routes. Using the 2001 TTC ride-guide map, the stop sequence was modified to reflect the network prior to the addition of the new subway line. Other stop information may have been modified from 2001 to 2006, however, because of the vast number of stops and the supply indicators being calculated, slight errors in the
total number of bi-directional stops do not significantly change the calculated index. The GIS data were also used for the area coverage analysis.

Lastly, for the frequency of service quantification, the service summary for the period of November 23, 2008 to January 3, 2009 along with route stop sequence were used. The service summary summarizes by route the headway, number of transit units, cycle time, round trip route length, average speed, type of transit unit for each service period, and first and last run times, which allowed for the frequency counts at each stop within the TTC network.

### 3.3.2. Melbourne Data
The data available for the Melbourne area are fairly similar to Toronto’s data. For ridership data, the Transport Demand Information Atlas for Victoria Volume 1: Melbourne 2008 was used. Plots are provided by year for the passenger boardings by mode. The passenger boardings were estimated from the plots because the numeric annual totals were not provided and therefore may contain slight error due to estimation. The ridership data also have the additional limitation in that it is only reported by mode and not by zone. This limitation did place some restriction on the modes included in the analysis in this study. Details on this restriction are further discussed in the study area definition in section 3.4.

The socio-economic, demographic, trip characteristics as well as the demand side of the network indicator pairs were compiled from both the 1999 Victorian Activity & Travel Survey (VATS) and 2001 Australia Census at the Local Government Area (LGA) level. The Australian census data is similar to the Canadian census collection process except it offers more options for enumeration methods of census tabulation in addition to the usual place of residence. The VATS size and scope on the other hand is smaller than the TTS size and scope, but the type of data collected is similar. The VATS has been carried out every year from 1994 to 1999 and is owned, organized and managed by the Transport Research Centre (TRC) and RMIT University in Melbourne. This survey collects travel and activity information on 1% of the households in the MMA and covers all 365 days of the year to account for seasonal and daily travel variations (VATS User Manual Vol. 1, 2001). The travel and activity information that was of access to this study includes:

1. Household Data
   a. Number of members
   b. Number of visitors
   c. Family structure
   d. Family type
   e. Youngest age
   f. Number of full time and part time workers
   g. Number of licensed drivers
h. Dwelling type
i. Ownership of dwelling
j. Number of bicycles, passenger vehicles, motorcycles, other vehicles and company cars
k. Household Location

2. Person Data
   a. Year of birth
   b. Age group
c. Gender
d. Relationship to person 1 of household
e. Household member status (resident or visitor)
f. Country of birth
g. Region of birth
h. Type of driver's licence
i. Employment status
j. Educational status or other
k. Occupation
l. Personal income

3. Stop Data
   a. Arrival/departure from stop
   b. Origin/destination purpose
c. Type of goods purchased at stop
d. Mode of travel to stop
e. Parking location at stop
f. Parking cost
g. Number of people in car
h. Walk time
i. Transit ticket type
j. Ticket fare type
k. In-vehicle Travel time
l. Origin/destination location

4. Trip Data
   a. Trip number
   b. Start/end time
c. Origin/destination purpose
d. Mode of travel
e. Mode with longest travel time
f. Trip time
g. In-vehicle travel time
h. Straight line distance (km)
i. Trip type
j. Origin/destination location
k. Trip link number by mode

One particular difference that should be noted is that unlike the TTS data, which focuses on motorized modes, this survey collects data on all modes. Therefore, the result from this survey may not be comparable with that of the TTS for non-motorized modes. A major limitation of this data is that it is not available for more recent years. Ideally, the 2007 VISTA data would have provided much more recent travel behaviour data. However, this data was not available in time for this study.

To calculate the index for the supply side of the network indicator pairs, GIS data for the transit systems from 2006 were used as well as the most recent stop sequence information provided by the Institute of Transport Studies at Monash University and Metlink Melbourne. Stop information for 1999 or 2001 was not available. However, because rail systems are large capital investments, stop or station locations are not easily moved for both rail and tram networks. Therefore, for the purposes of this analysis, it was assumed that the 2006 stop locations are still representative of the 2001 location. The GIS data was also used for the area coverage analysis.

Lastly, the data used for the frequency of service quantification was from the Transnet database. This database is the basis for Metlink’s online Journey Planner. It contains all of the scheduling information for all routes, runs and stops for 2008 services. From this database, the frequency count per stop was calculated.

### 3.4. Study Area Definition

Before any analysis could take place, specific geographic study areas were identified so that a consistent comparison could be made between the two case study cities. Because of the difference in scale and size of the systems, defined comparable areas were necessary to avoid bias in the network comparison due to scale differences as well as urban and suburban bias as areas further away from the urban centres are included.

Even though Toronto and Melbourne are relatively similar urban areas, the scale difference in network area coverage does pose a challenge when comparing the two areas and their transit networks. While different network aspects can be compared on a per unit basis, when looking at population characteristics such as density, the results may be unfairly biased towards Toronto because the TTC mostly serves an urbanized area. Whereas in Melbourne, transit extends far out into the outer suburbs, which are not as developed as neighbourhoods closer to the city centre and...
may unfairly illustrate Melbourne as being less transit supportive. To minimize the bias that can be introduced with using dissimilar areas for comparison, the study area definition carefully considered the following aspects in parallel:

- Area coverage of transit network and fare structure
- Data limitations

These aspects are discussed below in the following sections followed by the resolved study areas that arose from the transit area coverage, fare structure and data limitation considerations.

### 3.4.1. Transit Area Coverage & Zone Fares

As already mentioned, there is a significant difference between the transit area coverage of the TTC and Melbourne’s transit system. Not only is Melbourne’s transit network coverage much larger than that of the TTC, but it also employs a zone based graduated fare system. The zone boundary can be seen in Figure 3-1 as identified by a yellow outline that indicates the zone 1 boundary. Transit outside of zone 1 is part of zone 2.

**Figure 3-1: Melbourne Zone 1 Boundary**

The TTC, the smaller of the two systems, has a flat fare system except for those few routes that cross the boundary of the City of Toronto. To capture the grid structure, the TTC network area of the City of Toronto clearly defined the study area for Toronto. Based on the established Toronto study area being the inner urbanized area of the GTA and having a flat fare transit fare structure, it was concluded that the comparable Melbourne area should also have a flat fare system as well as cover the inner urbanized area of the MMA. Zone 1 of the Melbourne transit system satisfies...
both requirements and by coincidence is comparable in area size to the City of Toronto. However, data limitations and other associated complications imposed additional restrictions.

**3.4.2. Data Limitations**

Data limitations with respect to ridership information by zone made the Melbourne zone 1 comparison with the Toronto study area of the City of Toronto infeasible. As briefly discussed in Section 3.3.2, ridership data, in Melbourne, is collected by mode and not by zone. This collection method makes it very difficult to separate the ridership in zone 1 only, zone 2 only and zone 1 and 2 inclusive. Without this separation, ridership per capita statistics appears biased if only a zone 1 population is used. Because the train network and many of the bus routes cross the zonal boundaries, it was concluded that these two modes would not be useful in defining the study area boundaries. The tram network, operated by Yarra Trams, on the other hand is almost entirely within the zone 1 boundary, with only a few portions of tram lines in the zone 2 area as seen in Figure 3-1. It was deemed the best approach to use the tram network to define the Melbourne study area. Therefore, the Local Government Areas (LGAs) that receive tram service comprise the Melbourne study area resulting in a geographic size that is moderately comparable to the City of Toronto’s geographic size.

**3.4.3. Defined Study Area**

Based on the conclusions drawn from the aspects discussed above, the following study areas were identified as the best compromise for use in this study’s analysis.

Given that City of Toronto is the service area of the TTC; the City of Toronto defines the Toronto study area used in this research. Routes that extend beyond the municipal boundary are truncated at the boundary for the network analysis providing a study area that contains a single flat fare that does not change by distance in this service area. The City of Toronto, which will be used synonymously with the Toronto study area, is 630 km² and is defined by the region after the 1998 city amalgamation as being the area built up from the districts of:

- Old City of Toronto
- North York
- Etobicoke
- York
- East York
- Scarborough

The Toronto Study Area is shown below in Figure 3-2. To maintain consistency with the terminology used to refer to certain area within and around the city, these terms are explicitly identified here. Within the study area, a commonly referred to area is **Central Business District (CBD) of Toronto**, which can be seen in the bottom right part of Figure 3-2. This part of Toronto is often referred to as the downtown core of Toronto and contains a vast majority of higher-order jobs such as those of the financial sector. However, to be clear and consistent with terminology used for Melbourne, **Toronto CBD** will be used. Other areas such as the **Toronto Census Metropolitan Area (Toronto CMA)** and **Greater Toronto Area (GTA)** as seen in Figure 1-2 will be referred to only as these terms. As already discussed, all modes operated by the TTC will be included in the study to capture its grid-like network structure.
The Melbourne study area definition was not as easily determined as the Toronto study area due to the much larger service area of the various modes of transit. Based on the previously discussed considerations, the study area for Melbourne as shown below is largely defined by the tram network, where all Local Government Areas (LGAs) that are served by tram routes have been included. The Melbourne study area is 545km² and is comprised of the following Local Government Areas (LGAs) as seen below in Figure 3-3:

- Banyule
- Bayside
- Boroondara
- Darebin
- Glen Eira
- Maribyrnong
- Moonee Valley
- Moreland
- Melbourne
- Port Phillip
- Stonnington
- Whitehorse
- Yarra
For clarity regarding the terminology used in this study, other areas such as the Metropolitan Melbourne Area (MMA) or Melbourne Statistical Division (MSD) as shown in Figure 1-1 will be referred to as these terms only. The Melbourne CBD, also known as the city centre is identified in Figure 3-3 within the red box. When referring to this area, CBD will be predominantly used. This area again is the location of the vast majority of higher-order jobs such as those belonging to the financial sector.

It should be reiterated that, because the tram network defines the study area, this does not imply that the network analysis is restricted to the tram network. The data limitations do restrict some of the study to the tram network only, however, where possible, network indicators are inclusive of all modes, particularly with respect to the transit service level analysis.
4. Ridership & Mode Split

Ridership and mode split are two of the most commonly used measures in evaluating the demand for transit services. By comparing ridership data between different systems, transit agencies can benchmark their system’s performance with others. Mode split also gives context to how well the transit service is competing with other modes of transportation and often provides a more complete view of how transit fits into the lives of the people in the area it serves. In this study, annual ridership per capita and mode split are used as the basis of reference for the performance comparison.

It has been found in past studies that Toronto has better ridership performance and mode split than Melbourne with respect to transit. However, for the time period investigated here, it has been re-evaluated to verify the relative performance of Toronto and Melbourne within the study areas defined here. Before ridership and mode split comparisons can be done, the ridership data collection issue that was already discussed in Section 3.4.2 needed addressing. As a compromise to the ridership data limitation, it was resolved that using the tram ridership for the comparison is the best approach. To substantiate this resolution, a market share analysis of multi-modal travel was done and is detailed in the following section.

4.1. Market Share and Mode Analysis

The ridership data in Melbourne is collected in the form of boardings by mode, which makes the annual ridership for the Melbourne study area, closely resembling zone 1, impossible to obtain. To resolve this issue, it was decided that using just the tram network and its ridership to carry out this comparison may be the most appropriate compromise. To rationalize this compromise, the market share between the modes (i.e. the percentage of people that use multiple modes or single modes) for the Melbourne Study Area was analyzed using travel survey data and was compared to the results of the TTC market share to benchmark transit market share performance.

The analysis in this section investigates the market interaction between modes and whether or not passengers of the TTC and passengers of Melbourne transit use their provided transit networks as one network regardless of mode. Both Melbourne transit and the TTC claim to have integrated transit planning regardless of mode. However, passenger behaviour does not always reflect planning intentions. Both study areas have integrated fares, which can create a non-physical connection between transit routes and lines by allowing free transfers. However physical connections are also required for the network and free transfers to be fully utilized. The utilization of different modes per transit trip for the Melbourne study area is illustrated in the market share analysis between modes as shown below in Table 4-1. The market share represents the percentage of passengers that use particular modes or multiple modes on their transit trips.
The 1999 VATS data was used to analyze the market share of the transit usage in the Melbourne study area. The largest passenger share shown in the table above is the train only trips with 37.28% of the passengers using only the train mode, whether it be a single link (direct) trip by train or multi-link (trips involving transfers to additional train routes) trip. Likewise, 34.62% of the passengers make tram only trips and only 13.79% of passengers make bus only trips. Only a small portion of passengers use multiple modes to complete their transit trips as shown by the 6.37% of passengers who use both train and tram modes, the 4.74% of passengers that use both bus and train modes and the 3.00% of passenger that use bus and tram modes in 1999. The proportion of trips that use all three modes to complete their transit trip is almost negligible, although this behaviour may have changed in more recent years. However, for this study’s time period, from the market share analysis above, 86% of the people living in the Melbourne study area do not use the modes as a cohesive network, but use the networks separately as defined by the modes.

In contrast to the market share found in the Melbourne study area, the Toronto study area market share analysis shows very different results as presented in Table 4-2. The 2001 TTS data was used to analyze the market share of the transit usage in the Toronto study area. A route link analysis was done to separate bus and streetcar trips from one another causing some of the data’s integrity to be lost which is made evident by the percentages adding up to 99.82% instead of 100%. The largest passenger share is with those who complete their trips multi-modally using both the bus and subway modes with a market share of 30.78%. Bus only trips and subway only trips also hold a large portion of market share as shown in Table 4-2. The much lower market share of streetcar only, streetcar and bus trips, and streetcar and subway trips are consistent with the much smaller area coverage that the streetcar mode has in comparison to the rest of the network. The TTC system has made significant efforts to plan its network as a multi-modal one, where each mode has a role and functions with the other modes as a team. The efforts of this integrated planning is clearly reflected in the behaviour of passengers using the TTC network where transfers are free but is also supplemented and encouraged by the physical coordination between routes and modes. Transferring between surface transit routes is done at street intersections where the transit stops are located. At 38 out of 69
subway stations, buses and some streetcar routes connect with the subway within the proof of payment area so that no extra proof to transfer is required making transferring more convenient (Cervero, 1998). In comparison to Melbourne’s multimodal transfer points, the TTC makes it much easier to use all modes as a network as is evident in the market share analysis if the TTC patrons.

<table>
<thead>
<tr>
<th>Model</th>
<th>Toronto Market Share Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subway Only</td>
<td>20.46</td>
</tr>
<tr>
<td>Streetcar Only</td>
<td>6.79</td>
</tr>
<tr>
<td>Bus Only</td>
<td>29.29</td>
</tr>
<tr>
<td>Subway &amp; Streetcar</td>
<td>4.76</td>
</tr>
<tr>
<td>Subway &amp; Bus</td>
<td>30.78</td>
</tr>
<tr>
<td>Streetcar &amp; Bus</td>
<td>3.96</td>
</tr>
<tr>
<td>All 3 modes</td>
<td>3.78</td>
</tr>
</tbody>
</table>

The market share results show that a lower percentage of Melbourne residents make multi-modal transit trips in comparison to the residents of Toronto. This result is plausible, given the dominating radial nature of the Melbourne transit system, and substantiates the compromise made to the ridership comparison being reduced to the tram network only within the study area. However, the difference in market share could also be due to the role that each mode plays in the urban setting. At first glance comparing the entire radial network of Melbourne and the grid network of Toronto may seem ideal because they also have similar modes of transit. Both have bus, tram or streetcar and train or subway modes of transit, which seem to parallel one another. However, upon closer inspection, there are several major differences between roles that these modes play, which are discussed in the following sections.

4.1.1. Connex Train versus TTC Subway

The first distinction between these two cities is with the high-order transit. Melbourne’s train system services a very large area and extends well beyond the Melbourne study area and as already mentioned earlier, is many times more extensive than the TTC’s subway network. It operates mostly at the surface level except for a small portion of underground tracks found within what is called the city loop, which is a loop that circles the Melbourne CBD as shown in Figure 1-1. The train network was built as a commuter rail to connect the suburbs with the city centre and is radial in nature (The Victoria Transport Plan, 2008). In the context of Australian cities, land divisions known as suburbs or state suburbs, as formally referred to by the Australian Bureau of Statistics, make up Local Government Areas (LGAs) similar to how different neighbourhoods make up districts in the City of Toronto. Historically speaking, the train network was built before the suburbs were developed and therefore were constructed above ground (Mees, 2000) and has many at-grade crossings.
Initially, it was thought that the train network in Melbourne is comparable to that of the TTC’s subway in Toronto, as suggested by Mees (2000). However, upon closer inspection, these two modes are not as comparable as once thought. Firstly, the frequency of service along the train network is highly variable. Even though it was originally built as commuter rail, over time demand has increased for this service resulting in higher frequency of service making it much closer to what Vuchic (2005) calls regional rapid transit. Vuchic’s (2005) description of this form of rapid transit matches that of Connex Trains that have “long rail lines into the suburbs with long station spacings, high operating speed, and heavy reliance on bus feeders, park and ride and kiss and ride. They penetrate centre city through tunnels and have a number of stations in the central area…enclosed stations with short headways and high capacity… it is a bridge between regional rail and rail rapid transit (metro/subway)” (p. 605). The very extensive lines have varying frequencies depending on the degree of overlap with other lines and a headway that ranges from five to 15 minutes (Metlink Melbourne Journey Planner, 2009). This level of frequency is much lower than that of the TTC’s subway but higher than traditional commuter services like GO rail services in Toronto. Along with frequency, the Melbourne train network offers a number of mixed services, mainly local, limited express and express services forcing passengers to follow a timetable as opposed to the random arrival that Toronto’s subway allows for. Because of the hybrid nature of rail services in Melbourne, the passenger behaviour and role of the rapid transit lines in these two cities are different.

Another operational difference between the lines is the operational speed achieved by the lines. Because the Melbourne train system offers a combination of express services, limited stopping services and services that stop at all stations, the average speed on the train network is 60 km/hr, which is much faster than a subway’s average speed. In Toronto, the TTC subway only achieves an average speed of 30 km/hr. This speed is much slower than that of the Melbourne train network because all trains in Toronto stop at all stations. Also the inter-station spacing is much shorter making the overall speed performance lower. The average speed differentiates between the types of service offered making the train service in Melbourne not comparable to the subway service in Toronto.

It has been argued that the city loop of the train network is similar to a subway system. However, this operational characteristic is debatable. Within the city loop, the underground stations have multi-level platforms. Upon entry of the station, passengers must be aware of the information screens that indicate the next train line and arrival time at each platform and which stations it will stop at along the way. The amount of information that needs processing by passengers is a lot more than the amount that subway passengers process. Also, within the city loop, the time, stopping stations and platform number are all important information particularly because of the complex route schedule that Connex trains employ. Train services will traverse the city loop in a variety of ways depending on the time of day and day of the week and is done in either a clockwise fashion, a counter-clock wise fashion or sometimes terminate at Flinder’s Street Station. This complexity alone is not characteristic of a subway system and therefore is not comparable to the TTC’s straightforward subway system. While both cities have rapid transit service, the number
of differences between the provided services along with the market share analysis substantiates the compromise made in the ridership comparison.

4.1.2. Yarra Tram versus TTC Streetcar
Similar to the Connex train versus TTC subway dilemma, the tram network in Melbourne is approximately three times larger than the streetcar network in Toronto (Currie & Shalaby, 2006). The size in this case is not a particular issue because the tram lines and streetcar lines both service the inner urban areas and suffers from many of the same operational difficulties as discussed by Currie and Shalaby (2006). The services provided by the tram and streetcar lines are similar in terms of the service and frequency they provide. As shown by the Melbourne study area market share analysis, the tram system is a stand alone system comparatively and is suitable for ridership comparison with the TTC on a per capita basis.

4.1.3. Melbourne Bus versus TTC Bus
The Melbourne bus transit is comparable to the TTC bus transit provided. Both are used as feeders to higher quality rail modes. However, in Melbourne, issues associated with the zone 1 and zone 2 ridership data still exist. In addition, the service levels of the bus services in Melbourne tend to be more variable than the TTC. Outside of the peak hour some regular service buses operate at very low frequencies and are sometimes as low as one per hour. Low frequencies can be found in TTC bus routes as well, but with a policy headway of 30 minutes now being changed to 20 minutes in Fall 2009; no bus routes have one hour headway unless it is a special service. As far as mode compatibility is concerned, it appears as though the Melbourne bus mode and Toronto bus mode do parallel one another. However, as the market share between the modes shows, the role of buses in Melbourne does not fit the same role as buses in the TTC network which supports the decision for comparing the tram ridership data to the TTC ridership as the best compromise to these issues.

4.2. Ridership Comparison
In terms of the urban setting, it appears that the role of the tram network fits the most closely with the role of the TTC, as speculated by Mees (1997), where he resolves that the tram network’s service is the most comparable with the TTC. Because the market share between modes is also very low in the Melbourne study area, restricting much of this study’s analysis to investigate the network comparison between the tram network and the TTC network is appropriate given the data limitations. The tram network is also radial in nature which provides sufficient opportunity to compare the various effects of network structure. Therefore, ridership and much of the network analysis comparison (Chapter 6) between the Melbourne study area and Toronto study area is between the tram network and all modes in the TTC network.

Although the above analysis supports the reduction in Melbourne transit network scope to the tram network, it is well recognized that the other two modes of transit do provide transit service to areas within the study area that do not
have tram services. Therefore as a compromise to the data challenges, the market analysis and provision of transit service, where possible, all modes of transit are investigated so long as data limitations do not exist and ridership data are not the context of performance comparison. This section provides an explanation for the ridership accounting method used in this study and it presents the ridership results comparison.

4.2.1. Reporting Ridership

There are two main methods of reporting annual ridership. The first is annual revenue ridership per capita, which is the number of complete trips made on the transit system and is normalized by the population in the coverage area. If a trip is made up of multiple links, it is still only counted as one trip in the annual revenue ridership figure. The other method is to report the annual number of boardings per capita on the system. This method takes into account the number of links required to complete the trip. Both methods are appropriate for reporting ridership in comparing the data to previous historical data as long as the figures use consistent methods.

When comparing ridership between systems, as in this study, discrepancies can arise with using the annual number of boardings instead of annual revenue ridership. In grid systems most trips require transferring before the trip can be completed (Vuchic, 2005), which is often referred to as a forced transfer. If annual boardings are used to report ridership, clearly in a grid system, the ridership would appear much higher than the actual number of users of the system. If the annual boardings of a grid system are compared to that of a radial system, results would be biased towards the grid system making it appear to have better ridership performance because of the forced transfer phenomenon associated with these networks. Therefore, for this study it was rationalized that annual revenue ridership is a better measure for the comparison. In order to approximate revenue ridership from annual boardings, the annual boardings for the Melbourne Tram system was divided by the transfer rate as obtained from the 1999 VATS.

4.2.2. Ridership Results

The ridership results used in this study are for the years 1999 for Melbourne and 2001 for Toronto’s TTC to maintain consistency with the year of data used for the other portions of analysis in this study. Table 4-3 summarizes the ridership results from the Melbourne Tram system and Toronto’s TTC system. See Appendix B for annual trends from 2000 to 2008.
From the comparison of the ridership in Table 4-3, the ridership per capita from the respective study areas are quite close. However, Toronto’s TTC appears to have slightly better user performance than Melbourne’s Tram network, even when taking into consideration the difference in population within the service area. The population within the service area was calculated using ArcGIS, where the total population within census tracts or districts that intersect with the buffer area around each transit stop was used (bus stop = 400m, tram/streetcar stop=600m and train stop = 800m). Although user performance appears to be better in Toronto for the time period examined, it should be kept in mind that Melbourne’s tram boardings may contain some margin of error due to under validation of tickets. Therefore, to be prudent, the mode split is also evaluated to give additional context to the ridership numbers presented.

4.3. Mode Split Comparison

In addition to ridership, mode split also provides context for transportation system performance. Examining the mode split has the main advantage of providing a better understanding of how transit competes with other modes of transportation and how transit fits into the daily life of the urban society.

Again, the comparison is restricted to 1999 and 2001 for the Melbourne study area and Toronto study area, respectively. However, more recent data on journey to work mode split for 2006 is also available for the Melbourne study area as well as Toronto. This provides context for some aspects of the network analysis comparison to be carried out with more recent data such as the service frequency analysis. The mode split data shown for the Toronto and Melbourne study areas groups the various modes of transit together and are presented below in Tables 4-4 and 4-5.
The results show interesting characteristics of these two urban areas. It is clear that both Toronto and Melbourne are dominated by travel by private vehicles with a mode split of close 50% for both study areas. It also seems that the Melbourne study area in the 1999/2001 data comparison shows a much better walk/bike mode share than Toronto. This may be partially due to weather and climate or may reflect urban design where all suburbs contain a shopping strip located on a main street in the neighbourhood which provides all of the local amenities within a short walk of the residential areas. However, interpretation of the data with respect to the walk/bike mode should be done with caution because the TTS was not designed to capture this mode explicitly for discretionary and non-home based trips and therefore is likely under reported. When controlled for this under-representation, by examining the home-based work and school trips, the Toronto study area has comparable walk/bike mode splits to the Melbourne study area and a higher walk/bike mode share for home based work and school trips, respectively.

In terms of transit, the data show that the transit mode split is much higher in the Toronto study area than in Melbourne, particularly within the context of work and school trips, which are used as the main reference point to control for the under-reporting of discretionary, non-home based and non-motorized trips in the TTS data. This

### Table 4-4: 24 Hour Mode Split Percentage Comparison between Toronto and Melbourne Study Areas

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Auto-Driver</td>
<td>54.2</td>
<td>48.2</td>
<td>52.8</td>
<td>66.2</td>
<td>8.1</td>
<td>10.8</td>
</tr>
<tr>
<td>Auto-Passenger</td>
<td>15.3</td>
<td>20.6</td>
<td>9.3</td>
<td>6.4</td>
<td>14.9</td>
<td>41.6</td>
</tr>
<tr>
<td>Transit (inc. commuter rail)</td>
<td>22.0</td>
<td>8.2</td>
<td>30.6</td>
<td>19.9</td>
<td>39.3</td>
<td>22.5</td>
</tr>
<tr>
<td>Walk/Bike</td>
<td>7.9</td>
<td>22.6</td>
<td>7.2</td>
<td>7.6</td>
<td>34.1</td>
<td>22.8</td>
</tr>
<tr>
<td>Other</td>
<td>0.6</td>
<td>0.5</td>
<td>0.1</td>
<td>0.0</td>
<td>3.6</td>
<td>2.3</td>
</tr>
</tbody>
</table>

### Table 4-5: 24 Hour Home Based Work Mode Split Comparison between Toronto and Melbourne

<table>
<thead>
<tr>
<th></th>
<th>2006 - 24h Toronto Mode split – Home Based Work Trips</th>
<th>2006 - 24h Melbourne Mode Split - Home Based Work Trips</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auto-Driver</td>
<td>50.8</td>
<td>63.9</td>
</tr>
<tr>
<td>Auto-Passenger</td>
<td>8.6</td>
<td>4.9</td>
</tr>
<tr>
<td>Transit (inc. commuter rail)</td>
<td>32.6</td>
<td>21.0</td>
</tr>
<tr>
<td>Walk/Bike</td>
<td>8.0</td>
<td>8.9</td>
</tr>
<tr>
<td>Other</td>
<td>0.1</td>
<td>1.4</td>
</tr>
</tbody>
</table>
confirms the speculation that for the time period investigated, transit in the Toronto study area competes better with other modes of transportation. In conjunction with the ridership data provided above, it is clear that Toronto’s TTC has better user performance than the Melbourne transit system in general. Whether or not this better performance can be attributed solely to the network effect is not clear because, as seen in the following chapter, there are other socio-economic, demographic and trip factors that play a part. However as will be seen in the analysis later on in this study, evidence of the network effect is a part of the explanation.
5. Socio-Economic, Demographic and Trip Factors that Affect Transit Ridership

As past research has shown, there are several factors that can influence travel behaviour and mode choice. Even though the main focus of this study is to investigate the network structure’s relationship with the network effect, socio-economic, demographic and trip factors also need to be examined because they can also influence transit usage. These socio-economic, demographic and trip factors are explored in detail on the aggregate level and thematically for the Toronto and Melbourne study areas where possible. The statistics shown in this chapter are for the year 2001. The 2006 statistics were also investigated; however, the comparative results between the two study areas were similar and therefore only the 2001 results are shown here since most of the other transit related results are for 1999 and/or 2001. Socio-economic and demographic data were obtained from the respective census studies for these two areas. The trip factor data presented here are for the years 1999 and 2001 for Melbourne and Toronto from the VATS and TTS, respectively.

The thematic comparison uses ward boundaries for the Toronto study area to define the smaller aggregate areas and LGAs for the Melbourne study area. The parcels of LGAs vary in size whereas Toronto’s parcels are slightly smaller than LGAs. Therefore, to make the Toronto parcel size more comparable to Melbourne’s, wards were combined based on their names. A ward is an area unit represented by one city councillor in the City of Toronto. Depending on the population growth, wards were split over time. For example, as the population of the ‘Etobicoke North’ ward grew it was split into two wards and renamed as ‘Ward 1-Etobicoke north’ and ‘Ward 2- Etobicoke North.’ For the thematic comparisons, the split wards were rejoined into one boundary area. In this example, Ward 1-Etobicoke North and Ward 2- Etobicoke North statistics and boundaries were aggregated for the thematic representation. The resulting boundary areas are fairly similar in size to the LGA areas. This was done to reduce the bias that could be introduced by comparing different parcel sizes where smaller areas may show higher concentration of some factors than larger areas. The results of the comparative analysis are presented and discussed below.

5.1. Population Factors

Table 5-1 briefly summarizes the aggregate statistics in the Melbourne and Toronto study areas that are related to population characteristics and have been known to affect transit usage. Each of these factors is examined in more detail in the following sections.
### Table 5-1: Aggregate Summary of the 2001 Population Factors

<table>
<thead>
<tr>
<th></th>
<th>Toronto Study Area(^\text{a})</th>
<th>Melbourne Study Area(\text{s})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population (Millions)</td>
<td>2.481</td>
<td>1.317</td>
</tr>
<tr>
<td>Gross Population Density (people/km²)</td>
<td>3940</td>
<td>2423</td>
</tr>
<tr>
<td>Average Age</td>
<td>38</td>
<td>38</td>
</tr>
<tr>
<td><strong>Workforce proportion</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Employment Rate (%)</td>
<td>60.8</td>
<td>59.6</td>
</tr>
<tr>
<td>Unemployment Rate (%)</td>
<td>4.6</td>
<td>4.1</td>
</tr>
<tr>
<td>People not in Labour Force (%)</td>
<td>34.7</td>
<td>36.3</td>
</tr>
<tr>
<td><strong>Employment status</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full time (% of employed)</td>
<td>50.5 ~</td>
<td>40.5</td>
</tr>
<tr>
<td>Part time (% of employed)</td>
<td>10.3 ~</td>
<td>19.1</td>
</tr>
<tr>
<td><strong>Occupational Groupings</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Professional (% of Total Groups)</td>
<td>59.37</td>
<td>55.55</td>
</tr>
<tr>
<td>Trades (% of Total Groups)</td>
<td>19.0</td>
<td>17.75</td>
</tr>
<tr>
<td>Sales &amp; Services (% of Total Groups)</td>
<td>21.6</td>
<td>24.77</td>
</tr>
<tr>
<td><strong>Industry Shares (% of total Industry jobs)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 -Agriculture, Forestry, Fishing, Hunting</td>
<td>0.1</td>
<td>0.31</td>
</tr>
<tr>
<td>2 -Mining</td>
<td>0.1</td>
<td>0.21</td>
</tr>
<tr>
<td>3 -Manufacturing</td>
<td>14.5</td>
<td>11.43</td>
</tr>
<tr>
<td>4 -Utilities</td>
<td>0.5</td>
<td>0.43</td>
</tr>
<tr>
<td>5 -Construction</td>
<td>4.4</td>
<td>4.69</td>
</tr>
<tr>
<td>6 -Wholesale Trade</td>
<td>4.7</td>
<td>5.17</td>
</tr>
<tr>
<td>7 -Retail Trade</td>
<td>10.1</td>
<td>12.53</td>
</tr>
<tr>
<td>8 -Accommodation &amp; Food</td>
<td>6.2</td>
<td>5</td>
</tr>
<tr>
<td>9 -Transport &amp; Storage</td>
<td>3.9</td>
<td>3.34</td>
</tr>
<tr>
<td>10 -Finance &amp; Insurance</td>
<td>7.6</td>
<td>5.75</td>
</tr>
<tr>
<td>11 -Government &amp; public Administration</td>
<td>3.3</td>
<td>3.27</td>
</tr>
<tr>
<td>12 -Education Service</td>
<td>6</td>
<td>8.46</td>
</tr>
<tr>
<td>13 - Arts &amp; Recreation</td>
<td>7</td>
<td>6.06</td>
</tr>
<tr>
<td>14 -Health &amp; Community/Social Services</td>
<td>8.1</td>
<td>10.74</td>
</tr>
<tr>
<td>15 -Property &amp; Business</td>
<td>18.7</td>
<td>17.2</td>
</tr>
<tr>
<td>16 -Other</td>
<td>4.8</td>
<td>5.41</td>
</tr>
</tbody>
</table>

\(^\text{a}\) Source: Statistics Canada, 2001

\(~\) Source: TTS, 2001

\(\text{s}\) Source: Australian Bureau of Statistics, 2001
5.1.1. Population Density

Melbourne and Toronto are both urban areas that have experienced urban sprawling issues (Hall, 2000; Buxton, 2002). Low density areas are also more often auto-dependent and not well served by transit because of the distributed nature of the developments. Compact developments, walk-able neighbourhoods and higher density are all characteristics of Transit Oriented Development (TOD) (New Urbanism, 2008; TCRP-H-1, 1996). Population density is an important urban feature to explore when comparing different areas in the context of transit. As summarized by Table 5-1, the Toronto study area is substantially more densely populated (3940 person/km²) than the Melbourne study area (2423person/km²). These findings are consistent with previous Toronto and Melbourne comparative studies. More interestingly, the thematic distribution shows a bigger difference particularly with the distribution of population density within the urban core as seen in Figures 5-1 and 5-2.
The Toronto study area has a very densely populated urban core, and in contrast the Melbourne study area has a sparsely populated urban core. In fact, the City of Melbourne has the lowest population density out of all the LGAs included in the study area. The decentralization of populations from an urban area is common in the cycle of urbanization where the loss of population from the urban centre exceeds the growth in the suburban ring (Pacione,
This trend was particularly evident in the United States of America in the 1970s (Pacione, 2005). However, it is unusual that the city centre is the least populated region in the urban area. The highest density in the Melbourne study area is located near the waterfront and may be reflective of higher density development near this desirable residential location. Mees (2000) concluded that Toronto and Melbourne’s densities are different in the core but not as different when venturing out to the suburbs. This observation may be true; nevertheless, when higher quality transit is located in higher population density areas, ridership is likely to be higher because transit is available to more people.

In Figure 5-3, the mode share relationship with respect to transit mode share is shown. In the Toronto study area the wards with highest population density, as identified by the dark blue circles in Figure 5-3, are among the higher transit mode share areas. Whereas, in the Melbourne study area, the higher density areas have an assortment of higher and lower transit mode shares. The City of Melbourne has better transit mode share in comparison to its neighbouring LGAs. However, with a lower population density, less people make use of the good provision of transit services as compared to Toronto. The correlation in the data here shows that density is likely an influential factor in ridership where the provision of transit can better serve more people if they live closer together. The figure also shows that some of the lower density areas also have substantial mode shares, which suggests that there are other factors, such as service related aspects, that also affect transit usage. These factors are explored later in Chapter 6.
5.1.2. Age – the Young, the Old and the Aging

As population cohorts age, particularly the baby boomer and echo boomers, their travel behaviour changes over time. As Miller and Shalaby (2003) have shown in their examination of the evolution of personal travel in the GTA and Bush (2003) in her PhD thesis on forecasting the 65+ travel demand, age and aging populations have several implications on travel behaviour. Activity patterns change as individuals age. As these activities change, so does travel behaviour. How an individual gets from home to work, school or elsewhere of interest depends on whether they are able to drive, and mobility. Age is related to all of these aspects. As seen in Table 5-1, the average age in the Toronto study area is 38 years and is the same as that found in the Melbourne study area. This similarity indicates that the two study areas are likely facing similar age related travel issues. The mid-thirties is prime age for being part of the work force meaning that the home-based work trip is one of the most important trips made during the day. Figure 5-4 shows the age distribution for the Toronto and Melbourne Study Area.

![Graph showing age distribution of Toronto and Melbourne Study Areas](image)

**FIGURE 5-4: AGE DISTRIBUTION OF TORONTO AND MELBOURNE STUDY AREAS**

As indicated by Miller and Shalaby (2003), when the majority of people are within the work force age group, the demand on peak period transportation services is greater because people travel to work taking place during these periods. Clearly, both study areas of Toronto and Melbourne have a large portion of the population within this category. This age distribution has implications for regular work travel as will be seen in Section 5.3.2. Transit is most competitive with the car because of higher frequency services during that time (TTC-Service Summary, 2009; Metlink, 2009). This is true particularly if travel is oriented towards the CBD during the peak period commuting time because transit is primarily oriented in this direction. However, for an aging population, transit is also an important service because elderly people may not be able to drive. Both Toronto and Melbourne have a significant portion of
people over 65 years old. Therefore, transit must provide accessible transportation for those who do not have access to a car or cannot walk or bike to their destination.

When the thematic distribution of average age across the geographic study areas are analyzed, other similarities and a few differences are noted. The thematic distribution of average age can be seen below in Figures 5-5 and 5-6.
In general, older age groups are found closer to the end of transit rail lines as seen in the northern and western parts of the Toronto study area and the northern and eastern parts of the Melbourne study area. One distribution difference between the two areas is that the central area of the Melbourne study area has a much younger average age than that of the Toronto study area. This result may be related to the presence of the student population as well as the lower population density in central Melbourne. Overall the age distribution in these two study areas is similar and can be reasoned to have similar impacts on the transit systems and therefore does not lend any additional explanatory power to the higher ridership in the Toronto study area.

5.1.3. Work Force Participation Rate
As already mentioned in the discussion regarding age, employment/participation in the work force can affect travel behaviour and the propensity to take transit. Certain jobs are known to affect mode choice particularly if the job requires frequent travelling such as those in sales, or home services and contractors (Meyer & Miller, 2001). Because Statistics Canada and the Australian Bureau of Statistics have slightly different occupation and industry categories, careful consolidation of these categories was done to ensure the comparison of like terms. As shown in the aggregate statistics summary in Table 5-1, the City of Toronto’s work force participation, occupation types and industry share are all very similar to that of the Melbourne study area.

There are slight differences with regards to the share of professionals in the occupation breakdown. The term professional refers to those in business, finance, natural and applied science professions. Toronto has a slightly higher share of people with these types of occupations at 59.37% compared to 55.55% in the Melbourne study area. This may reflect the income discrepancy between the two areas that are shown later in Section 5.2.4. Within the industry grouping there are minor differences as well. The Toronto study area has slightly stronger manufacturing, finance and insurance, and property/business sectors, whereas the Melbourne study area has slightly stronger retail trade, education and community/social services sector. These differences may be attributed to the position Toronto holds as the financial centre of Canada whereas Sydney is the financial centre of Australia, resulting in a difference in industry breakdown (City of Toronto Economics, 2008; Mees, 2000). With these relatively small differences, ridership differences due to these factors are highly unlikely.

However, comparing the proportion of full-time to part-time workers, the data does show a more noticeable difference. In the Toronto study area, 10% of the employed people are part time workers as opposed to the 19% in the Melbourne study area. This difference in employment can indicate more flexible work hours, which are known to affect transit usage (Meyer & Miller, 2001). This is likely due to the part time work schedule not falling within peak period travels when more frequent transit service levels are present. Transit service levels during off-peak hours in Melbourne are lower, which can impact a part time worker’s choice to take transit.
5.2. Household Factors
Table 5-2 summarizes the aggregate statistics of household attributes for the respective case study areas. Each of these household factors is further reviewed below in detail in a separate section.

Table 5-2: Aggregate Statistics for the 2001 Household Factors

<table>
<thead>
<tr>
<th></th>
<th>Toronto Study Area</th>
<th>Melbourne Study Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population (millions)</td>
<td>2.481^</td>
<td>1.317 §</td>
</tr>
<tr>
<td>Gross Residential Density (dwellings/km²)</td>
<td>1497^</td>
<td>935 §</td>
</tr>
<tr>
<td>Housing unit Types – Proportions (% of total housing)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Separate house</td>
<td>32.2 ^</td>
<td>59.7 §</td>
</tr>
<tr>
<td>Semi-Detached, Row or Townhouse</td>
<td>15.3 ^</td>
<td>16.2 §</td>
</tr>
<tr>
<td>Apartment or flat</td>
<td>52.5 ^</td>
<td>23.4 §</td>
</tr>
<tr>
<td>Average Household size (prs/household)</td>
<td>2.5 †</td>
<td>2.4 §</td>
</tr>
<tr>
<td>Average Vehicle Ownership (Veh/Household)</td>
<td>1.1 †</td>
<td>1.4 §</td>
</tr>
<tr>
<td>Average Household Income (Respective Currency)</td>
<td>$69,125.00 CAD ^</td>
<td>$55,893.50 AUD §</td>
</tr>
</tbody>
</table>

^ Source: Statistics Canada, 2001
† Source: Transportation Tomorrow Survey, 2001
§ Source: Australian Bureau of Statistics, 2001

5.2.1. Residential Density & Housing types
Similar to population density (persons/km²), the residential density (households/km²) found in the Toronto study area is 1.6 times greater than that found in the Melbourne study area as seen in Table 5-2. As TOD suggests, compact design encourages transit use because individual stops and stations could serve more destinations when developments are placed closer together (New Urbanism, 2008). Residential density is an important aspect to examine because population density does not provide complete context for compact development because the number of people per dwelling unit can vary. As TOD guidelines suggest, transit stops and stations can better serve areas that are densely developed simply because of proximity to destinations. The variation of residential density can be seen in Figures 5-7 and 5-8 for the Toronto study area and Melbourne Study area, respectively.
Because the Toronto study area is much denser than Melbourne’s it can be argued that Toronto has a more transit supportive urban landscape. Some researchers have argued against this fact saying that the City of Melbourne has a vast amount of park/green space causing lower density values (Mees, 2000). A large portion of the City of Melbourne is taken up by an industrial container yard and large green spaces, but even with these areas taken into account the recalculated residential density still falls into the lower bracket of 600 to 1000 households/km², which is
still low for a downtown area. Downtown Toronto also has parks, green space and industrial areas that are not inhabited and yet the gross residential density shown for the Toronto study area is still higher.

An important distinction between the two areas is the type of housing that makes up these two study areas. Comparatively speaking, apartments make up a much larger proportion of housing in the Toronto study area than in Melbourne. As shown in Table 5-2, the data from 2001 show that the proportion of apartments in the Toronto study area is more than double the proportion of apartments in the Melbourne study area (52.5 % compared to 23.4 %). These results show that the housing type breakdown of the Melbourne study area versus that of the Toronto study area is significantly different producing much higher residential density values in Toronto. Given these results, it is not unexpected that Toronto’s transit system has better ridership performance.

### 5.2.2. Average Household Size

Household size also impacts travel behaviour. Theoretically, if only one person in the house can complete household errands by making a few trips, that person has saved other members of the household from making those trips as well, thus reducing the total number of trips for the household (Miller & Soberman, 2003). Miller and Soberman (2003) theorize that larger households have lower trip-rates per person for this reason. Therefore, it is important to examine whether the Toronto and Melbourne study areas have similar household sizes because this can affect the number of trips being made and consequently what mode is chosen to complete those trips.

As seen in Table 5-2 the average aggregate household size is remarkably similar with 2.5 persons/household in the Toronto study area and 2.4 persons/household in the Melbourne study area. When the distribution of household size is explored as seen below in Figure 5-9 and 5-10, very similar patterns are also present.
In both areas, it is clear that the CBD areas contain the smallest average household size. As distance from the CBD increases household sizes also increase. This trend may be a feature of the type of housing present where smaller sized housing units that are not appropriate for larger families are found closer to city centres. Both study areas have very similar patterns and spatial distribution. Therefore, it is assumed that the travel behaviour that arises from this
factor is similar for both populations and does not lend additional explanation for the higher ridership in the Toronto study area.

### 5.2.3. Average Household Vehicle Ownership

Household vehicle ownership is an important attribute to examine because it carries significant implications for travel behaviour. Discrete mode choice modelling and research has shown that the availability of private vehicles can significantly influence mode choice (Ben-Akiva & Lerman, 1985). In the absence of information regarding availability of a private vehicle to complete a trip, household vehicle ownership can act as a suitable substitute for both case studies. Logically, households own cars out of necessity because they are expensive commodities and depreciate in value. The ownership of a vehicle increases the likelihood of choosing to drive as the mode of choice if the car is available for the trip. Conversely, if no vehicle is owned, choosing to drive is unlikely because a car is not available unless one is rented. That said, it does not mean to say if many cars are owned, the likelihood of driving is higher because one person can only drive one car at a time and if good travel alternatives are offered to household these can also influence travel mode choice.

The Toronto study area has a lower average vehicle ownership rate than the Melbourne study area. On average, households in the Toronto study area have 1.1 vehicles per household in comparison to Melbourne’s 1.4 vehicles per household as shown in Table 5-2. The relationship between vehicle ownership and transit mode share is shown below in Figure 5-11. Clearly, as the theory states, as vehicle ownership increases the propensity to take transit, as shown by the transit mode share, decreases. This pattern is similar in both study areas.

![Relationship between Transit Mode Share and Vehicle Ownership](image-url)
However, as evident from the slope of the lines of best fit in Figure 5-11, transit mode share is more strongly affected by vehicle ownership in Toronto than in Melbourne. Given this trend, the TTC is helped by the fact that Toronto households on average own less cars. This may also be a reflection of the better transit service that the TTC provides, resulting in households not needing as many cars. If a fixed number of vehicles per household is examined, such as 1.3 vehicles/household, the data show that Toronto still has a higher transit mode share in comparison to Melbourne. This analysis supports the theory that transit in Toronto is more attractive than in Melbourne.
The thematic distributions of vehicle ownership over the study areas are shown below in Figures 5-12 and 5-13.

**FIGURE 5-12: TORONTO STUDY AREA AVERAGE HOUSEHOLD VEHICLE OWNERSHIP**

The two study areas do have similar distributions of household vehicle ownership across the city. The lowest vehicle ownership is in the centre of the urban areas. This is likely due to the close proximity to the surrounding developments, amenities and better availability of transit in these areas allowing people to either walk or take transit to complete their trips. The further away households are situated from the centre of the city, the higher the average...
household vehicle ownership. This pattern is the same in both study areas and may be consistent with less reliable forms of transit, mainly buses, being the primary mode of service in those areas causing people to require a private vehicle to get around. If this is directly correlated, then theoretically it indirectly shows that the TTC offers more reliable services in the suburbs than the corresponding Melbourne transit. However, perception of reliability can also play a factor here, where perhaps TTC bus services have a better transit image than Melbourne’s bus transit. Torontonians probably trust their bus system more than Melbournians do.

5.2.4. Average Household Income

Household income was chosen for comparison over personal income because decisions such as where to live and purchase a car often depend on household income and not just personal income. Those who live on their own still make these decisions based on their household income, which is equal to their personal income. The average income reported in this study was kept in its respective currency because the cost of goods in Canada is different than the cost of goods in Australia. In the Toronto Study area, the average household income in 2001 was $69,125 CAD (in 2001 dollars). The Melbourne study area’s average household income in 2001 was $ 55,894 AUD (in 2001 dollars), which is significantly lower than Toronto’s average. In 2001, one Canadian dollar was worth approximately 1.25 Australian dollars. Based on these household averages, it is evident that Melbourne households make less money than Toronto households.

The 2006 Australian and Canadian census data also shows a continued disparity between the two cities. The average Toronto study area household in 2006 made approximately $80,483 CAD (in 2006 dollars) while the average household in the Melbourne study area only made approximately $63,890 AUD (in 2006 dollar). Income usually reflects the cost of living. If Melbourne’s cost of living is less than Toronto’s, then this could explain the difference in income between two urban areas that are so similar in terms of workforce participation, occupation and industry. According to the Mercer Cost of living survey in 2006, Melbourne was ranked 74 and Toronto ranked 47 meaning that Toronto is more expensive than Melbourne. However in 2005 and 2007, Melbourne was ranked 68 and 64 where Toronto was ranked 82 both years, which shows that typically Toronto has a lower cost of living. Possible explanation here for the income disproportion is due to Toronto being the financial capital of Ontario and Canada, where in Australia this position is held by Sydney. This hold on the financial sector can be seen in the industry breakdown of jobs where a slightly higher percentage of jobs are in this category in Toronto than in Melbourne. Given the larger population in the City of Toronto, this could translate in too many more households with a member in the financial sector causing higher household incomes overall.

Figures 5-14 and 5-15 show the distribution of income averages over the study areas for 2001 in 2001 dollars.
The wealthier incomes in both study areas appear to be mostly located more in areas neighbouring the central core. Toronto has more households in the higher income brackets as reflected in the higher aggregate average. The result here is interesting because in the Melbourne study area, households own more cars but make less money. Vehicles are expensive commodities and although households may not be able to afford a car, they still require one to carry out their day-to-day activities. Homes closer to higher quality transit can also be more expensive due to land value.
uplift. Those who cannot afford homes near transit may live in less expensive homes but incur the cost of needing a car. For this reason it is important to offer good quality or at least reliable transit of all mode types across urban areas so that this disparity does not occur.

The fare cost of transit service also can factor into the decision to take transit. The relative cost of transit as normalized by the average household hourly wage is 0.056 cost of transit/hourly household wage and 0.09 cost of transit/hourly household wage for the Toronto and Melbourne study areas, respectively. The average household hourly wage was calculated based on a regular 37.5 hour week. Clearly from an affordability standpoint, Toronto’s transit is more affordable than Melbourne’s zone 1 transit in 2001 with respect to household income. In 2001, a single adult TTC fare was $2.00 CAD and in Melbourne, it was $2.60 AUD for a zone 1 adult fare. Relatively speaking, the transit service is more affordable in Toronto than in Melbourne and can affect an individual’s choice to take transit.

5.3. Trip Factors

Trip factors can also have various impacts on travel behaviour. The length, purpose, time of day and the destination of the trip all affect what mode is chosen to undertake the trip. In this section the various trip factors listed below are compared to investigate differences between the two cities. These factors are:

- Trip rate;
- Trip purpose;
- Trip length;
- Time of day; and
- Origin & destination.

Each is explored in a separate section and reveals several patterns that explain some key differences in travel behaviour that may influence transit usage.

5.3.1. Trip Rate

The average trip rate is essentially the average number of trips per day that individual people make. The higher the average, the more stress there is on the transportation system depending on what modes are being taken due to the sheer volume of travel. Based on the analysis of the 1999 VATS and 2001 TTS data, the average trip rates are calculated in Table 5-3. The trip rate in the Melbourne study area is substantially higher than in the Toronto study area. Part of the reason for this discrepancy may be due to the seasonal effects during data collection. In Melbourne, the VATS data collection takes place year round to account for seasonal variation (VATS User Manual, 2001). TTS on the other hand does data collection during the fall under the premise that it averages the more active travelling in the summer with the less active in the winter (TTS Data Guide, 2001). This greater seasonal discrepancy may be more of an issue in Canada than in Australia because of the greater seasonal variation.
TABLE 5-3: TORONTO AND MELBOURNE TRIP RATE COMPARISON

<table>
<thead>
<tr>
<th></th>
<th>2001 Toronto Study Area</th>
<th>1999 Melbourne Study Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated total number of trips per day</td>
<td>4,763,893</td>
<td>5,139,880</td>
</tr>
<tr>
<td>Population from Survey (million)</td>
<td>2.37</td>
<td>1.37</td>
</tr>
<tr>
<td>Trip Rate (# of trips/person/day)</td>
<td>2.01</td>
<td>3.76</td>
</tr>
</tbody>
</table>

The Toronto TTS data on trip rates is also subject to under-reporting that affects the mode split comparison as well with respect to discretionary, non-home based trips and non-motorized trips for these two trip purposes. The trip rates shown here for the Toronto study area may not be reflective of all daily trip-making behaviour that is comparable to the Melbourne VATS data because of this shortfall. However, given what the data show, even with a smaller population, there is high demand for transportation services in the Melbourne study area as exhibited by the daily number of trips.

5.3.2. Trip Purpose

Some trip purposes are better captured by certain modes of transportation because of the travel variability caused by the trip purpose. Work trips generally follow a more predictable routine as already discussed in Section 5.1.3. The origin is usually home and destination is work place location which is usually the same depending on the nature of the occupation. Similarly, school trips are also routine based trips where students travel between home and school, particularly in the morning. These types of trips are better served by transit because of their routine as well as the time of day that the trip takes place. Higher-order work places are often located centrally because of agglomeration economies (Pacione, 2005), which make the people who work there prime candidates for taking public transit since transit historically develops from and serves these areas. In the case of Toronto and Melbourne, higher order transit is oriented towards the CBD and therefore can compete well with other forms of transportation for work trips as seen in Tables 4-4 and 4-5. On the other hand, discretionary trips and non-home based trips are almost the opposite where there is less routine associated with these trips because shopping, errands and entertainment can happen in many different places depending on the activity taking place. In this respect, transit does not handle these types of trips as well as cars do, particularly in suburban areas.

The VATS survey breaks trip types into many different categories. To compare the Melbourne data to the Toronto data in similar terms, consolidation of these trip types was done. The following table shows the reclassification of categories of the VATS data into comparable TTS categories.
TABLE 5-4: VATS TRIP PURPOSE CONSOLIDATION

<table>
<thead>
<tr>
<th>VATS trip Purpose Categories</th>
<th>New Categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>Home Based Work</td>
<td>Home-Based Work</td>
</tr>
<tr>
<td>Home Based Education</td>
<td>Home-Based School</td>
</tr>
<tr>
<td>Home Based Shopping</td>
<td>Home-Based Discretionary</td>
</tr>
<tr>
<td>Home Based Recreation</td>
<td></td>
</tr>
<tr>
<td>Home Based chauffeuring</td>
<td></td>
</tr>
<tr>
<td>Home Based other</td>
<td></td>
</tr>
<tr>
<td>Work Based Work</td>
<td>Non-Home Based</td>
</tr>
<tr>
<td>Work Based Shopping</td>
<td></td>
</tr>
<tr>
<td>Work Based other</td>
<td></td>
</tr>
<tr>
<td>Shopping Based Shopping</td>
<td></td>
</tr>
<tr>
<td>Shopping Based Other</td>
<td></td>
</tr>
<tr>
<td>Non home Based other</td>
<td></td>
</tr>
</tbody>
</table>

Based on the re-grouping, the comparison of the breakdown of trip types for the Toronto and Melbourne study areas are shown in Table 5-5. As expected, both study areas show that home-based discretionary trips make up the largest portion of trips. However, home-based work trips make up a surprisingly small portion of all trips in the Melbourne study area. Originally it was thought that this might have been a coding process of the data, but after comparison between the TTS' method and the corresponding VATS' method it was found that a similar process was used. It is likely that the under-representation of discretionary and non-home based trips in the TTS data causes some of this difference by shifting the proportion of trips toward home-based work. However, when work trips make up such a small proportion of the daily trips made, this would definitely impact the transit ridership and mode split based on the fact that transit is better at capturing work trips (Miller & Shalaby, 2003). Therefore this result is a possible explanation for lower ridership and mode split in Melbourne.

TABLE 5-5: PERCENTAGE BREAKDOWN OF TRIP PURPOSE TORONTO-MELBOURNE COMPARISON

<table>
<thead>
<tr>
<th>Trip Purpose</th>
<th>2001 Toronto Study Area % breakdown</th>
<th>1999 Melbourne Study Area % breakdown</th>
</tr>
</thead>
<tbody>
<tr>
<td>Home Based Work</td>
<td>35.6</td>
<td>16.1</td>
</tr>
<tr>
<td>Home Based School</td>
<td>12.2</td>
<td>6.0</td>
</tr>
<tr>
<td>Home-Based Discretionary</td>
<td>37.8</td>
<td>45.4</td>
</tr>
<tr>
<td>Non-Home Based</td>
<td>14.4</td>
<td>32.4</td>
</tr>
</tbody>
</table>

From a network structure perspective, it is often argued that grid transit systems are better at handling the various trip purposes because it is more evenly distributive in nature as opposed to the radial system that is oriented towards the CBD. That does not mean to say that radial systems cannot handle these other types of trips, but for the most part,
unless the discretionary trip’s destination is along the transit line or in the CBD, transit is an unlikely option. The characteristics of trip purpose by mode share from these urban areas are cross-classified in Table 5-6.

### TABLE 5-6: TORONTO AND MELBOURNE TRIP PURPOSES BY MODE SPLIT COMPARISON

<table>
<thead>
<tr>
<th>24H-mode Split by trip type</th>
<th>HB Work Trip</th>
<th>HB School Trip</th>
<th>HB Discretionary</th>
<th>Non Home Based</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TO MEL</td>
<td>TO MEL</td>
<td>TO MEL</td>
<td>TO MEL</td>
<td>TO MEL</td>
</tr>
<tr>
<td>Driver</td>
<td>52.8</td>
<td>66.2</td>
<td>8.1</td>
<td>10.8</td>
<td>63.9</td>
</tr>
<tr>
<td>Passenger</td>
<td>9.3</td>
<td>6.4</td>
<td>14.9</td>
<td>41.6</td>
<td>21.5</td>
</tr>
<tr>
<td>Transit</td>
<td>30.6</td>
<td>19.9</td>
<td>39.3</td>
<td>22.5</td>
<td>12.5</td>
</tr>
<tr>
<td>Walk/bike</td>
<td>7.2</td>
<td>7.6</td>
<td>34.1</td>
<td>22.8</td>
<td>1.9</td>
</tr>
<tr>
<td>Other</td>
<td>0.1</td>
<td>0.0</td>
<td>3.6</td>
<td>2.3</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Overall the driver mode share in the Melbourne study area is lower in most cases than Toronto’s except for the case of home-based work and school trips. Because home-based work trips make up a very small proportion of trips in the Melbourne study area and a very large proportion in the Toronto study area, the performance comparison here with respect to mode split is difficult to interpret. On the one hand less work trips are made by Melbournians that makes the dominance of driver mode split less demanding on the road network. On the other hand, work trips made by Torontonians make up a larger portion of overall trips, giving transit a more important and significant role in sustainable forms of transportation.

The consequence of under-representation in the TTS data of discretionary and non-home based trips are distinctly noticeable in Table 5-6, where for these trip types the walk/bike mode split is very low and should be negligible based on the data collection methods used. Because of the focus on motorized modes of travel for these types of trips, it is difficult to reason whether or not grid systems can better capture other trip non-work non-school purposes because of the provision of more evenly distributed services that are not all directed towards the CBD. This under-representation can also affect the overall breakdown of trip types resulting in the Toronto study area appearing to have a higher work trip purpose share. Overall, when controlled for the under-representation by examining only the work and school trip purposes by mode, transit appears to better compete with non-sustainable modes of transportation in the Toronto study area than in the Melbourne study area.

### 5.3.3. Time of Day

Time of day can also affect what mode is chosen for travel. During the peak periods transit service is usually more frequent to handle the higher volume of passengers. Congestion can also be a factor in what time people decide to leave for their trip, whether it is road congestion or transit system congestion. Conversely, travelling during off peak hours can also influence how a person decides to travel. Off peak transit service frequency is usually low, making it more inconvenient to take during those times. The following plots show the time distribution of trips by purpose.
From Figures 5-16 and 5-17 above, clearly there is similar peaking in the morning and afternoon peak periods with the afternoon more spread out than the morning likely due to constrained work arrival times in the morning. There is a minor difference between the two study areas during the mid-day where it is higher in the Melbourne study area than in Toronto. The larger amount of travel during this off peak time in Melbourne may negatively influence transit use because transit is unlikely to capture these trips well.

### 5.3.4. Trip Length

Trip length is another factor that is known to influence mode choice. If the trip being made is short, typically transit is not used because the total travel time including wait time is sometimes longer than walking, biking or driving for such
a short trip. Conversely, if the trip distance is very long individuals may want the comfort of their own car or want to take transit because driving may be stressful. Transit fits into a fairly niche area, where if transit service is available at the origin to the destination and the time tradeoffs of the trip length and convenience are acceptable, transit can be a good option. For the Melbourne and Toronto study areas, overall the straight-line trip distance profiles by trip purpose are fairly similar as seen in Figures 5-18 and 5-19 below.

**Figure 5-18: Melbourne Study Area Straight Line Distance by Trip Purpose**

**Figure 5-19: Toronto Study Area Straight Line Distance by Trip Purpose**

Work trips in both areas tend to have a flatter profile, which may due to the fact that people cannot always choose where they work and are often more willing to travel farther to work. In the case of all other trip purposes, generally these are closer to the origin of the trip as visible from the profiles heavily favouring the 0-2km bracket. In Melbourne, there is a large number of trips that are completed within the 1 km radius of the origin, which suggests
that the urban design of suburbs could possibly have amenities closer to residential areas than in Toronto. However, overall, there are no major differences with this trip factor that would lend additional explanation to why Toronto has better ridership and mode split with respect to transit than Melbourne.

**5.3.5. Origin & Destination**

The last trip factor compared is the origin and destination (O-D) trip matrix. This matrix shows the proportion of trips that start and end in certain locations. If many trips are directed to the city centre, then transit is a reasonable choice for many of these trips because transit systems are mostly oriented in this direction. The following tables present the proportional O-D trip matrix for the two study areas for general trips. These proportions are generated by the O-D pair divided by the total number of trips originating from that district or LGA. Some planning districts and LGAs have been grouped due to proximity and size. The yellow cells highlight intra-area travel (i.e. travel within the same district or LGA) and the green cells highlight the highest inter-area travel (i.e. travel outside the district or LGA).

**Table 5-7: 2001 Toronto Study Area General OD-Matrix Trip Proportion by Origin**

<table>
<thead>
<tr>
<th>2001 Total OD Proportion Summary by origin</th>
<th>Etobicoke</th>
<th>York &amp; North York</th>
<th>Toronto &amp; East York</th>
<th>Scarborough</th>
</tr>
</thead>
<tbody>
<tr>
<td>Etobicoke</td>
<td>67%</td>
<td>13%</td>
<td>18%</td>
<td>2%</td>
</tr>
<tr>
<td>York &amp; North York</td>
<td>6%</td>
<td>60%</td>
<td>24%</td>
<td>10%</td>
</tr>
<tr>
<td>Toronto &amp; East York</td>
<td>6%</td>
<td>17%</td>
<td>69%</td>
<td>8%</td>
</tr>
<tr>
<td>Scarborough</td>
<td>1%</td>
<td>13%</td>
<td>15%</td>
<td>71%</td>
</tr>
</tbody>
</table>
In the Toronto study area it is clear that besides the planning district of origin, the next highest trip destination is Toronto & East York. This shows that there is still quite a lot of interaction between the suburbs and the central part of the city. In Melbourne the case is slightly different with more randomness where some LGAs have better interaction with neighbouring LGAs. However, overall Melbourne shows a similar trip pattern to Toronto where most travel occurs within the LGA followed by interaction with the central area.

From the O-D Matrix by transit mode, summarized below in Tables 5-9 and 5-10, a similar distribution is observed with even higher proportions in the direction of the central area.

### TABLE 5-8: MELBOURNE STUDY AREA GENERAL OD-MATRIX TRIP PROPORTION BY ORIGIN

<table>
<thead>
<tr>
<th>1999 Total OD Proportions by origin</th>
<th>Banyule</th>
<th>Bayside &amp; Glen Eira</th>
<th>Boroondara &amp; Stonnington</th>
<th>Darebin</th>
<th>Maribyrnong &amp; Moonee Valley</th>
<th>Melbourne &amp; Port Phillip &amp; Yarra</th>
<th>Moreland</th>
<th>Whitehorse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Banyule</td>
<td>80%</td>
<td>0%</td>
<td>3%</td>
<td>9%</td>
<td>0%</td>
<td>6%</td>
<td>2%</td>
<td>1%</td>
</tr>
<tr>
<td>Bayside &amp; Glen Eira</td>
<td>0%</td>
<td>65%</td>
<td>8%</td>
<td>0%</td>
<td>0%</td>
<td>24%</td>
<td>0%</td>
<td>1%</td>
</tr>
<tr>
<td>Boroondara &amp; Stonnington</td>
<td>1%</td>
<td>6%</td>
<td>70%</td>
<td>1%</td>
<td>0%</td>
<td>16%</td>
<td>0%</td>
<td>6%</td>
</tr>
<tr>
<td>Darebin</td>
<td>8%</td>
<td>0%</td>
<td>4%</td>
<td>67%</td>
<td>0%</td>
<td>13%</td>
<td>6%</td>
<td>2%</td>
</tr>
<tr>
<td>Maribyrnong &amp; Moonee Valley</td>
<td>1%</td>
<td>1%</td>
<td>2%</td>
<td>2%</td>
<td>58%</td>
<td>23%</td>
<td>13%</td>
<td>1%</td>
</tr>
<tr>
<td>Melbourne &amp; Port Phillip &amp; Yarra</td>
<td>2%</td>
<td>6%</td>
<td>12%</td>
<td>4%</td>
<td>2%</td>
<td>68%</td>
<td>4%</td>
<td>3%</td>
</tr>
<tr>
<td>Moreland</td>
<td>2%</td>
<td>1%</td>
<td>1%</td>
<td>5%</td>
<td>1%</td>
<td>16%</td>
<td>73%</td>
<td>1%</td>
</tr>
<tr>
<td>Whitehorse</td>
<td>1%</td>
<td>2%</td>
<td>12%</td>
<td>1%</td>
<td>0%</td>
<td>7%</td>
<td>0%</td>
<td>76%</td>
</tr>
</tbody>
</table>

In the Toronto study area it is clear that besides the planning district of origin, the next highest trip destination is Toronto & East York. This shows that there is still quite a lot of interaction between the suburbs and the central part of the city. In Melbourne the case is slightly different with more randomness where some LGAs have better interaction with neighbouring LGAs. However, overall Melbourne shows a similar trip pattern to Toronto where most travel occurs within the LGA followed by interaction with the central area.

From the O-D Matrix by transit mode, summarized below in Tables 5-9 and 5-10, a similar distribution is observed with even higher proportions in the direction of the central area.

### TABLE 5-9: TORONTO STUDY AREA TRANSIT (INC. GO-TRANSIT) TRIP PROPORTION BY ORIGIN O-D MATRIX

<table>
<thead>
<tr>
<th>2001 Transit OD Proportion Summary by origin</th>
<th>Etobicoke</th>
<th>York &amp; North York</th>
<th>Toronto &amp; East York</th>
<th>Scarborough</th>
</tr>
</thead>
<tbody>
<tr>
<td>Etobicoke</td>
<td>41%</td>
<td>15%</td>
<td>42%</td>
<td>2%</td>
</tr>
<tr>
<td>York &amp; North York</td>
<td>5%</td>
<td>46%</td>
<td>41%</td>
<td>8%</td>
</tr>
<tr>
<td>Toronto &amp; East York</td>
<td>6%</td>
<td>18%</td>
<td>67%</td>
<td>9%</td>
</tr>
<tr>
<td>Scarborough</td>
<td>1%</td>
<td>12%</td>
<td>33%</td>
<td>54%</td>
</tr>
</tbody>
</table>
As seen from Tables 5-9 and 5-10, transit in both these study areas are used much more often for trips towards the central areas. These results are expected particularly in the case of Melbourne because of its radial network. In Toronto, buses, which form the grid network, feed to the radial subway system for effective travel to the downtown core. These findings reinforce the theory that transit can better capture work trips particularly if the work location is in the central area. Radial trips facilitate this direction of travel more as visible from the proportion of trips that end up in Melbourne/Port Phillip and Yarra being much larger than even the inter-LGA travel when transit is the mode of choice. In Toronto, large proportions of trips end up in Toronto and East York, however, the same if not higher proportion of trips are still found in the intra-district travel market, which shows that the grid system can possibly better serve a larger area due to its better more even coverage.

5.4. Summary

Overall, it appears that through the comparison of the socio-economic and demographic factors from these two study areas, the Toronto study area has a better transit supportive atmosphere than Melbourne’s. The major factors that possibly explain Toronto’s higher transit use appear to be linked with higher population and residential densities, lower vehicle ownership and higher full-time employed residents. Household income also indicates that the Toronto study area may have a more transit oriented development than the Melbourne study area for the time period investigated. The household income comparison illustrates this where certainly Toronto households can afford to drive, but have chosen to take transit more often than their Australian counterparts as shown by the mode split comparison in Tables 4-4 & 4-5. From the reviewed factors it seems that Toronto’s TTC is providing more competitive transportation services than Melbourne.
After reviewing the trip factors that are the product of travel behaviour, the findings also suggest that several of these factors provide supplementary explanation as to why transit usage is different in these two study areas. Trip purpose, time of day and origins and destinations of travel are three factors that influence mode choice and transit usage. A larger dominance of trips that are more variable in nature such as discretionary trips is not as well captured by transit. Also, less service during the mid-day can cause people to not take transit to complete their trips that occur during that time period. The dual nature of grid networks, where they can potentially provide high-quality transit service towards the CBD as well as more even coverage in the suburbs, allow transit to better capture trips of a variety of purposes that are destined to more places than just the CBD as shown by the origin-destination analysis. It is important to note that limitations in the TTS data may also create some bias in the results for Toronto where the under-representation of non-motorized modes and under-reporting of trips do affect the results shown in this Chapter. Therefore, the conclusions drawn here are only possible explanations for differences in transit use between these two study areas. Because the analysis from these factors do not fully explain the disparity in transit use in these two areas, a network analysis comparison is necessary to explore the influence of network structure and their related network effects to see if a relationship exists between network structure and transit usage.
6. Network Analysis & Comparison - Supply versus User Demand

The previously analyzed socio-economic, demographic and trip factors do lend some explanation to differences in transit usage between these two case study cities. However, these results leave open the possibility that the network structure and associated network effects are possible drivers of transit usage as well. This chapter looks at different performance indicators that try to quantify the relationship between network structure and their related evidence of the network effect. Based on the literature review presented in Chapter 2, there are several areas where different network structures have distinct features as well as different forms of the network effect.

The analysis of the network structure and relationship with the network effect in these two case studies was done in a two-part approach. First, network structure indicators were paired with logically corresponding demand indicators to reflect the relationship between supply and demand at a macro-scale level. The four network performance indicator pairs used in this study in an attempt to qualitatively capture the network effect are:

1. Connectivity & Transfer rate
2. Theoretical directness of travel & Observed directness
3. Revenue kilometres & Passenger kilometres
4. Area Coverage & Population Percentage Coverage

Each indicator pair is carefully detailed in Sections 6.1 to 6.4. Due to the data limitations and market share analysis rationale in Sections 3.3 and 4.1, the first three network performance indicator pairs compare the TTC network and the Melbourne Tram network within the context of transit ridership. The last indicator pair uses the context of mode split and incorporates data for all modes of transit in the Melbourne transit system. More background information on the operational data in the networks can be found in Appendix A and sample calculations can be found in Appendix C for the first three indicators.

The second part of this section also seeks to capture the supply and demand relationship between network structure and network effect by using a more micro-scale approach. Because evidence of the network effect can present itself through the frequency of transit service provided, as discussed in the literature review, examining the frequency difference between the TTC and Melbourne transit can provide insight into the service levels that are achieved by the respective grid and radial networks. Each of the following sections outlines the procedure of the calculation, results and discussion for each network indicator pair and the frequency analysis.

6.1. Connectivity & Transfer Rate

A transit network is only considered a network if the lines and routes provided connect in some manner. The connection of these lines (and consequently, the provision of a transit network) opens up the possibility for passengers to travel to many more destinations than the provision of isolated transit lines. Logically, transferring between lines can only occur at transfer points or where different transit services stop sufficiently close to one
another. Because transferring is inherently dependent on the connection of transit lines, or what is referred to as connectivity in this study, the pairing of connectivity and transfer rate is a natural one to examine the effects of the varying degrees of connectivity on passenger transferring behaviour.

As described in Section 2.2, transit networks can be simplified by Graph Theory where links and nodes are synonymous with inter-station paths and stations/stops, respectively (Vuchic, 2005; Morlok, 1967). By simplifying the network structure using Graph Theory, many of the physical network properties can be analyzed such as the number of nodes, number of links, patterns in which the nodes and links are connected and so on. Most transit maps are represented as graphs because they are simple and easy to understand. Connectivity, often represented in Graph Theory as $\gamma$, is an index that describes the proportion of existing links to the total number of possible planar links that could theoretically be established given the number of existing nodes. Morlok’s work (1967) proves that in a theoretical setting, delta systems (as shown in Figure 2-5) have the highest degree of connectivity. Grid systems have the next highest and radial or spinal, as he refers to it, have the lowest (Morlok, 1967). Given that the degree of connectivity corresponds with the network structure, this index was useful for the comparison of networks with different structures (since it is the pattern in which the connectivity occurs that classifies networks into the various network structure categories).

Transfers on the other hand can only occur at connection points, as already mentioned. Logically, it can be theorized that the degree of connectivity is correlated with transferring possibly influencing transit travel behaviour. This results in a higher observed transfer rate (boardings/trip). However, the concept and psychology behind transfers is complex and not well understood. The physical activity of transferring from one service to another is often regarded as a negative attribute of a transit trip. It is viewed in this light for several reasons. The first is that it lengthens the time it takes to complete an individual’s trip because of the additional wait time added to the passenger’s travel time (TCQSM, 1999; Vuchic, 2005). Transfers are inconvenient because a passenger has already waited for their first transit service and if the wait was unexpectedly long, transferring to another service also introduces additional wait time and the possibility of a missed connection resulting in further wait time (TCQSM, 1999). The second reason is the physical aspect involved with the transfer (Vuchic, 2005). Passengers that were already on board and travelling to their destinations must now get off their transit vehicle, re-acquaint themselves with the desired direction and walk there. Depending on the environment and design of the transfer, the inconvenience of the transfer can be increased or decreased.

According to Vuchic (2005), sometimes transfers are viewed so negatively that the planning of transit lines should attempt to reduce them, where possible, because they can be a deterrent to transit altogether. However, he is quick to point out that there is also an added benefit to highly connected transit systems (i.e. one with many transfer points) because they provide passengers with more travel path choices than those with less connectivity and overlapping
lines which reduce the need for transfers (Vuchic, 2005). More travel path choices provide passengers with more options that help distribute passenger loads and build in redundancy to the system in case of service disruptions. However, the design of these locations and the service they receive are important to minimize the hindrance they cause to taking transfer dependant transit. These design features include high frequency of connecting services or schedule coordination if frequency is not high enough on one or both lines to allow for random arrival rates, better signage, passenger information, and integrated fares (HiTrans, 2005).

Network structure can influence and impact passenger behaviour with respect to transferring and is visible with grid systems and radial systems. Grid systems are well known to be greatly dependant on transfers, where passengers using grid networks usually have to transfer at least once to travel to their destination (Vuchic, 2005). However, as Vuchic (2005) points out, rarely do passengers need to make more than one transfer, which reduces travel in a direction that is not progressive to the destination. Radial networks on the other hand are excellent in servicing trips towards the central area. This network structure is best suited to urban areas that are monocentric where trips to the core of the city are of high demand providing direct travel to this location. However, by capitalizing on this aspect, transferring becomes an even greater disutility by placing transfer points out of the way particularly if travel from one radial line to another outside the central area is required.

Graph theory suggests that there is a connectivity difference between grid network and radial network. As Vuchic (2005) has suggested, network structure also has a different effect on the passenger behaviour with respect to transferring. Based on this rationale, the first network indicator pair of connectivity and transfer rate attempts to capture the different network effects between Toronto’s TTC network and Melbourne’s tram network as illustrated from these measures.

6.1.1. Calculation Process – Connectivity, $\gamma$

The process used to calculate the connectivity index, for both the TTC network and Melbourne tram network, is as follows:

1. First, a bi-directional network of stops had to be identified. This was done by analysing each route in both directions, where only stops/stations that had corresponding locations in both directions were used and labelled as a node. Because the data for the transfer rate is from 1999 for Melbourne and 2001 for Toronto, every effort was made to only analyze routes/stops that existed in those years. However, due to some changes over time that are not well recorded, the bi-directional graphs may contain some route and stop information that does not belong to those years. These errors exist more in the TTC graph than Melbourne’s because of the opening of the Sheppard subway line in 2002, which changed the alignment of several routes passing through that area. However, the available data still provide a good estimate for the connectivity of these networks since the law of diminishing returns as more nodes are added to the network applies to this index.
Network Structure and Network Effect – Toronto & Melbourne Experience

2. The total number of nodes were then counted for each respective network (now graph) (represented by variable \( v \) for vertex as in the literature review (Morlok, 1967))

3. The total number of existing links were counted for each respective graph (represented by the variable \( e \) for edge as in the literature review (Morlok, 1967))

4. The ratio of the existing number of edges to the total number of theoretical edges possible in a planar network otherwise known as connectivity, \( \gamma \), was calculated for each respective graph using the following formula:
\[
\gamma = \frac{e}{3(v - 2)}
\]

### 6.1.2. Calculation Process – Transfer rate

The transfer rate (boardings/trip) was calculated based on the 1999 VATS data for Melbourne and 2001 TTS data for Toronto. For Melbourne, the total number of tram boardings per day by those living in the study area was generated from the VATS database for tram trips only where the weekday trip weight was multiplied by the total number of tram trip links for those trips (each link representing a required boarding). The Melbourne tram transfer rate was calculated by dividing the total number of boardings by the total number of trips taken by tram.

Similarly, the total number of daily TTC boardings for those who live in the Toronto study area was generated by a link analysis of the 2001 TTS TTC transit data. This data extraction generates the number of trips that used varying number of transit links per trip. By calculating the weighted sum, the total number of boardings was calculated. Similar to the Melbourne Tram transfer rate, the TTC transfer rate was calculated by dividing the total number of TTC boardings by the total number of trips taken on the TTC.

### 6.1.3. Connectivity & Transfer Rate Results & Discussion

Based on the methods of calculation described above, the Table 6-1 presents the results for the Toronto and Melbourne study areas.

#### Table 6-1: Degree of Connectivity VS. Transfer Rate

<table>
<thead>
<tr>
<th></th>
<th># of existing links</th>
<th># of nodes in system</th>
<th># of transit trips (Avg day)</th>
<th># of transit boardings (Avg Day)</th>
<th>Degree of Connectivity</th>
<th>Transfer Rate (Boardings/Trip)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001 – Toronto TTC network</td>
<td>3,467</td>
<td>3,047</td>
<td>1,020,664</td>
<td>2,001,538</td>
<td>0.38</td>
<td>1.96</td>
</tr>
<tr>
<td>1999 – Melbourne Tram network</td>
<td>856</td>
<td>820</td>
<td>144,514</td>
<td>167,594</td>
<td>0.35</td>
<td>1.16</td>
</tr>
</tbody>
</table>

Transferring is an evidence of the network effect because it shows whether people are using the system as a network. Because transfers are perceived so negatively, it also indirectly shows the trust or perception of the service
being provided. If passengers are willing to take the risk of transferring, this could be associated with better transit service or better perception of the transit service. Also if transfers are essential to the transit systems, transit operators should ensure routes function together as a network since passengers use multiple lines where either higher frequency service or schedule coordination is provided to facilitate transferring. Without these conveniences as part of these types of networks, it is likely that the system would not be well used because of the associated inconveniences due to transferring. Not surprisingly, Toronto has a higher transfer rate, which is indicative of the grid-like network structure. Melbourne’s transfer rate is much lower than Toronto’s, which was also expected given the radial network structure. The effects of the network are clearly visible in the comparison of this demand side indicator and help substantiate the theory behind these network structures.

The supply side of this network analysis pair revealed results that were surprisingly similar. This indicates that theory may not always apply to reality as illustrated by these two real world networks having similar connectivity indices. The result from the Melbourne radial network is within the theoretical range of 0.33 and 0.5, which was as expected. However, in the case of the TTC grid network, which should have yielded a much higher degree of connectivity ranging from 0.5 and 0.67 as suggested by the theory, resulted in a lower value similar to the Melbourne network as seen in Table 6-1. Upon closer inspection of the range of this index, it was noticed that the overall topographical pattern of network may appear to be grid-like in nature, but the $\gamma$ index could be substantially lower than the theoretical limits because of minor nodes (or stops/stations) placed in between the major connecting nodes. Also, it should be noted that as the total number of nodes in the system becomes substantially large, the $\gamma$ index follows the law of diminishing returns and tends to gravitate towards radial or spinal values depending on the number of links that are added as new node is added. Given this understanding, Figure 6-1 offers a pictorial view of how the index changes for both radial and grid networks.

**Figure 6-1: Variation of Degree of Connectivity**
Given the lack of a baseline reference for these values in the real world, the expected difference of $\gamma$ between varying real-world network structures is not known. However, as shown in Figure 6-1, a grid network can continue to have grid-like features even if the degree of connectivity appears to be within the radial graph’s range of theoretical values. Therefore, this supply side indicator may not allow for the categorization of network structure based on the calculated value. However, in the case of the compared networks in this study, the TTC does have more than 3 times the number of nodes in its graph than Melbourne’s tram system and still yielded a higher degree of connectivity than Melbourne, which shows that the routes are more connected.

The indices in Table 6-1 does show some minor relationship between connectivity and transfer rate where the connectivity index appears to be directly proportional to the transfer rate index. As this study is limited to only two networks, there is insufficient evidence to firmly conclude this relationship. However, it does suggest that it may be sufficient to visually classify a network structure as grid or radial and use the more visual classification of the network to compare with the transfer rate and benchmark the performance of similar structures with one another. The comparison can help reveal insights about service and quality of connections. From the comparison of the above results it can be seen that transferring is more evident of the network effect in grid networks as opposed to radial networks. Based on the higher ridership that the TTC’s grid network has, it can be reasoned that transferring should not be as negatively perceived as previous theories suggest.

6.2. Theoretical Directness of Service & Observed Directness

Directness of travel is the opposite concept to transferring. Directness, in the context of this study, is used to describe a trip that does not require transferring to another route (i.e. the transit trip is made up of only one transit link). Just as evidence of the network effect in grid systems is apparent from transfer rates, directness can be perceived as evidence of the network effect in radial system as theorized by Capello and Rietveld (1998). This is because demand is concentrated along common corridors where more direct services can be established to reduce the disutility of transferring to another service.

The theoretical directness, as suggested by Vuchic (2005), is the proportion of the net number of Origin-Destination paths that exist in a network without the need to transfer to another service (direct) to the total number of possible Origin-Destination paths that exist in a network (transfer + direct). This theoretical proportion is compared to the actual observed proportion to create this performance indicator pair. The observed data used here is again from the 1999 VATS for the tram network in the Melbourne Study area and 2001 TTS for the TTC network in the Toronto Study area. The subsections below describe the method of calculation for both of these indexes followed by the results.

6.2.1. Calculation Procedure – Theoretical Directness of Service, $\delta$

Based on Vuchic’s (2005) method, theoretical directness is calculated using the following steps:
1. First, the total number of O-D travel paths (OD) is calculated as given by the formula:
   \[ OD = \frac{1}{2} \cdot N \cdot (N - 1) \]
   where: \( N \) = total number of unique nodes that exist in the system

2. Next, the total number of direct O-D travel paths (OD_d) is calculated as given by the formula:
   \[ OD_d = \frac{1}{2} \left[ \sum_{i=1}^{q} n_i (n_i - 1) - \sum_{j=1}^{q_{m}} n_{mj} (n_{mj} - 1) \right] \]
   where:
   - \( n_i \) = number of stations/stops along line \( I \);
   - \( q \) = total number of lines;
   - \( n_{mj} \) = number of joint stations/stops on each section that each line \( j \) shares with any already counted line;
   - and
   - \( q_{m} \) = the number of lines that have joint sections with other lines.

3. Keeping consistent with Vuchic’s (2005) notation, the theoretical directness of service, \( \delta \), is calculated by dividing \( OD_d \) by \( OD \) as shown in the formula:
   \[ \delta = \frac{OD_d}{OD} \]
   This index ranges from \( \frac{2}{\text{#ofstations-spacing} + 1} \) to 1. For the case of the networks being calculated here only bi-directional nodes were considered as used in the previous performance indicator pair.

6.2.2. Calculation Procedure – Observed Directness

The observed directness was calculated based on the information obtained from the 1999 VATS and 2001 TTS. The procedure was the same in both cases where the total number of trips taken by transit for the respective surveys was extracted from the respective databases. Next, only those transit trips that used only one link on transit were extracted. By dividing the number of trips that only used one transit link in their transit trip by the total number of transit trips, the percentage or proportion of observed direct trips is calculated. Note that for Melbourne, again, only tram trips were used and for Toronto, TTC trips were used.

6.2.3. Theoretical Directness & Observed Results & Analysis

From the above calculation processes, the following results were obtained from the two transit systems investigated.

**TABLE 6-2: THEORETICAL DIRECTNESS VS. OBSERVED DIRECTNESS RESULTS COMPARISON**

<table>
<thead>
<tr>
<th></th>
<th>Total # of observed transit trips (avg day)</th>
<th>Total # of observed direct trips (avg day)</th>
<th>Theoretical Directness, ( \delta )</th>
<th>Observed Directness</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001 Toronto TTC</td>
<td>1,020,664</td>
<td>350,220</td>
<td>2%</td>
<td>34%</td>
</tr>
<tr>
<td>1999 Melbourne Tram</td>
<td>144,514</td>
<td>122,926</td>
<td>10%</td>
<td>85%</td>
</tr>
</tbody>
</table>

From the results it is clear that Melbourne’s radial tram system does have higher proportion of direct paths (10%) than the TTC’s grid system’s (2%). However, it is even more visible from the observed directness results how passengers use the system. The majority of tram trips in Melbourne do not use a transfer as seen from the results of
the previous indicator comparison, and is reconfirmed here from these results where 85% of the trips using trams are direct. From the TTS data it was found that only 34% of passengers in the Toronto study area complete their trip without transferring to another service. For Toronto, this observed directness in combination with the transfer rate reveals that that approximately 1/3 of passengers do not need to transfer services, 1/3 of passengers transfer among services once and 1/3 transfers twice in the TTC network.

The results here support the concept that radial systems do provide more direct travel to the city centre. Given that Section 5.3.5 showed that a fair number of trips are destined to the city centre, reducing the inconvenience of transferring seems logical from a planning perspective. However, in the case of the tram system in Melbourne, the integration of tram lines, also referred to as the overlap of the tram lines, along high demand sections can produce other issues. For example, along a substantial portion of St. Kilda Rd, which eventually turns into Swanston Street north of Flinders St., there are 8 tram routes that use the same track section. This high degree of overlapping serves two main purposes. The first is to funnel people from varying areas to this section without the need of transferring because of the high demand it generates. The second is that it increases the frequency of service along this section, which is warranted because of the high demand in the area. The integration of these lines seems logical, but over time the demand has increased causing three issues, mainly crowding, delays and services that are complex for passengers to understand.

The first issue, crowding, occurs because passenger loads are carried over long distances by transit vehicles that accumulate passengers till the popular destination is reached. If transit is oriented around these high demand destinations, passengers also alight in masses to these areas leaving transit vehicles fairly empty beyond these sections. This situation causes heavy crowding till this high demand section and then under used capacity after this section. The repercussions of situations like this is that it can discourage transit usage because of the discomfort that crowding causes.

The second issue that arises is related to the first and is with respect to headway regularity and delays. With crowded services, boarding and alighting take longer causing delay. Sometimes if services are too crowded to let more people on and no one onboard needs to alight, the service will pass that stop with waiting patrons so that the transit unit behind it will pick them up if they have room. Both these situations can cause headway irregularity and bunching not to mention the bunching of different services because of the shared track section. All of these issues can cause passenger aggravation and the reputation of the transit service to decline causing passengers to seek alternative means of travel. These problems have also been exhibited in Toronto on the streetcar system where increased frequency had a worse effect because of bunching (Currie & Shalaby, 2006). Higher vehicle capacity was found to be the key solution here and headway regularity was better restored and handled the load. While line
integration seems to make sense from a planning and transfer reduction perspective, it can also cause congestion along these track sections.

The third issue is passenger awareness. With so many overlapping services, it becomes more important for users to know information about the next arriving service and whether or not it is the service they would like to take. This communication with passengers is essential because it can significantly impact the passenger experience on the transit system. Confusion and uncertainty are inherent when travelling in unfamiliar transit systems because passengers do not necessarily feel they understand or in control of where transit goes. If maps and passenger information are not well or intuitively provided particularly on overlapping sections, it can perpetuate the fear of taking transit.

Logically, systems that try to reduce the need for transfers can also reduce a passenger’s willingness to transfer because of the nurtured behaviour. There is little research done in the area of willingness to transfer except for the understanding that people usually try to avoid them (TCQSM, 1999). In the case of Melbourne’s tram network, an extension of this behaviour is that the resistance to transferring cause people waiting for specific routes to wait at the same platform creating a crowded environment even though a high frequency of service at that stop is provided through the use of overlapping lines.

Toronto’s TTC grid system has generally avoided integrating lines even if demand shows a dominant overlap of travel. Instead, this grid system provides a more even distribution of services and where the flow of travel is high in demand, high frequency, high capacity, heavy rail lines provide the service. This feeder system can partially overcome the resistance to transferring because of the higher quality of service provided when transferring to the subway. However, it should be noted that a system like this does not allow as much convenience in the opposite direction of transferring from the subway to a bus because of connecting with a downgraded service. Crowding and headway regularity are still issues that affect the TTC as well, even on the heavy rail subway lines where crowding is substantial during peak hours. However, as advised in the HiTrans Best Practice Guidelines to Network Planning (2005), this feeder approach can provide better transit service particularly in areas with more evenly distributed density patterns, as is the case with most North American and Australian cities.

Overall, the results of this performance indicator pair shows that indeed radial systems have a network effect evidence in the form of more direct travel as opposed to the grid network’s passenger transfer network effect. These two performance indicator pairs show that the two network structure types have different dominating network effects as quantitatively shown here. As to whether one structure’s generated effect is better than another's is difficult to measure particularly if the generated effect is different. However, the ridership comparison suggests that radial services provide less advantageous network effect in comparison to grid-like service. The next two performance
indicator pairs look at the supply and demand in areas that measure the network structure and effects from different perspectives.

6.3. Revenue Service Kilometres & Passenger Kilometres

Based on the network performance indicators Thompson and Thomas (2003) used in their work as summarized in the literature review, revenue service kilometres and passenger kilometres formulate the third network indicator pair in this study. Revenue service kilometres reflect how much service is provided to the transit service area. It is a product of both frequency and network size that provides an indication of overall service level provided by the network. Comparing this measure of service to passenger kilometres, which shows how much travel is done on the system, can provide insight into the efficiency or utilization of the work done by the system. For instance, many passenger kilometres being travelled on very few service kilometres shows that the work done by the system is efficient because not much service needs to be provided for system to be well used. Essentially the ratio represents the degree of utilization of the service provided where the higher the ratio and more effective and tailored the service is to travel demand because more passenger kilometres are travelled for less service kilometres. The following sections describe how these measures were obtained and computed and the results of those calculations.

6.3.1. Revenue Service Kilometres

In the case of Toronto’s TTC, the Canadian Urban Transit Association compiles operating data from various transit agencies across Canada on a yearly basis. The 2001 annual revenue service kilometres for the TTC system were obtained from the 2001 CUTA Canadian Transit Fact Book – 2001 Operating Data.

In the case of Melbourne’s tram system, the 1999 data were harder to obtain because the trams were operated by two difference franchises, Swanston Trams and Yarra Trams. Within the franchise agreements the kilometres of service that must be scheduled is stated. According to these franchise agreements, approximately 21.4 million kilometres were to be scheduled in 1999 (Franchise Agreement, Swanston Trams, 1999; Franchise Agreement, Yarra Trams, 1999). This amount of service kilometres was assumed to be the amount delivered in 1999.

6.3.2. Passenger Service Kilometres

For Toronto’s TTC, the passenger service kilometres are also reported in the CUTA Canadian Transit Fact book 2001- Operating data.

For Melbourne, there are no records of passenger service kilometres. Therefore, the passenger service kilometres had to be estimated. The following estimation process was used:

1) All trips that involved a tram were extracted from the VATS 1999 database for the Melbourne study area.

2) The straight-line distance for the tram links were then averaged.

3) To estimate the passenger service kilometres, the number of passenger boardings found in the Transport Demand Information Atlas for Victoria (2008) was multiplied by the average distance per tram link.
6.3.3. Revenue Service Kilometres & Passenger Kilometres
Table 6-3 contains the results of the comparison between the Toronto’s TTC network and the Melbourne Tram Network.

<table>
<thead>
<tr>
<th></th>
<th>Revenue Service Kilometres (million-km/annum)</th>
<th>Passenger Kilometres (million-km/annum)</th>
<th>Work Done (Service Utilization)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001 Toronto TTC</td>
<td>189.3</td>
<td>4,241.9</td>
<td>22.4</td>
</tr>
<tr>
<td>1999 Melbourne Tram</td>
<td>21.4</td>
<td>487.7</td>
<td>22.8</td>
</tr>
</tbody>
</table>

From the comparison of the data, it appears that both systems reveal similar service utilization meaning the amount of work done by the systems are similar. Given the much larger system that the TTC has with most of it being buses, it could have been plausible that Melbourne would have a better performance measure here because trams have a better image and better used on a per distance basis. However, it could also be argued that the TTC should have been expected to have much better utilization than the Melbourne trams because of its better service coverage. Regardless of the expectations, these results show that the performance is similar between these two networks from a work perspective and that no additional insights into the network effects are revealed using this measure.

6.4. Area Coverage & Population Coverage
As mentioned in the literature review, Vuchic (2005) suggested that area coverage is related to network structure and inherently connected to population coverage. This performance measure looks at the area coverage and the transit population coverage together to investigate access to transit and whether a relationship does exist. The rationale of this indicator pair is that cities with larger portions of population located within the catchment areas of transit may have better transit usage because more people have better access to it. This performance indicator pair connects the network design with population density. For Melbourne, this comparison is inclusive of all transit modes located in the study area. Unlike the three indicators previously investigated, the only data available to support these calculations are from 2006 (GIS & Census data) because bus stop location data were not available in Melbourne for 1999 or 2001. The following sections outline the calculation methods for both these measures followed by presentation of the results.

6.4.1. Calculation Process – Area Coverage by Mode
To calculate the area coverage, each stop was categorized by mode to account for the various “willing to walk” access distance for stops/stations of each mode type. Area coverage for both networks was calculated using ArcGIS 9.1 in the following process:

1. Stops/stations were first classified by the mode that services it.
2. Next, buffer (same as radial distance) distances were applied in ArcGIS.
   For buses a radial distance of 400m was used as suggested by Vuchic (2005)
For trams/streetcars a radial distance of 600m was used as suggested by O’Sullivan and Morrall (1996) in their Calgary LRT walk distance study.

For trains and subway a radial distance of 800m was used as suggested by the TCRP-H-1.

3. The buffer areas were dissolved into one another to avoid double counting area coverage for mode specific stops/stations.

4. To produce area wide coverage inclusive of all modes, the 3 buffer areas of each respective study area were then dissolved into one another.

5. Lastly, the area coverage percentage was calculated.

This process produced four buffer areas used in this analysis, one for each mode type and one for the combination of all modes.

6.4.2. Calculation Process – Population Coverage
The population coverage was calculated in the following manner for each buffer area produced in the area coverage calculations.

1. The buffer areas were laid over the census tract boundaries (or census collection districts in the case of Melbourne).

2. Next, ArcGIS analyzed the census tracts/census collection boundaries for boundaries where the centroid was located within the buffer area. These census tracts/census collection districts were selected and summed to produce the population within the walk buffer to that mode’s stops.

3. Population coverage is expressed as the ratio or percentage of population within the buffer area to the total population within the study area.

The results from the procedure are shown below in the next section.

6.4.3. Area Coverage & Population Coverage Results & Analysis
Table 6-4 presents the results for the area coverage and population coverage for the Toronto and Melbourne study areas.
### TABLE 6-4: AREA COVERAGE VS. POPULATION COVERAGE COMPARISON

<table>
<thead>
<tr>
<th></th>
<th>2006 Toronto TTC</th>
<th>2006 Melbourne Transit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Area Coverage - % of total km² (km²)</td>
<td>Population w/in Area (% of total pop)</td>
</tr>
<tr>
<td><strong>Bus Mode</strong></td>
<td>85.2% (536.9)</td>
<td>81.2% (2,035,142)</td>
</tr>
<tr>
<td></td>
<td>3790.5</td>
<td>2588.75</td>
</tr>
<tr>
<td><strong>Tram/Streetcar Mode</strong></td>
<td>8.8% (55.4)</td>
<td>16.4% (410,919)</td>
</tr>
<tr>
<td></td>
<td>7417.3</td>
<td>3108.0</td>
</tr>
<tr>
<td><strong>Subway/Train Mode</strong></td>
<td>13.6% (85.6)</td>
<td>20.7% (518,895)</td>
</tr>
<tr>
<td></td>
<td>6061.9</td>
<td>2905.5</td>
</tr>
<tr>
<td><strong>All Modes Total</strong></td>
<td>87.2% (549.5)</td>
<td>84.4% (2,113,407)</td>
</tr>
<tr>
<td></td>
<td>3,846.1</td>
<td>2,443.46</td>
</tr>
<tr>
<td></td>
<td>630.3 km²</td>
<td>545.0 km²</td>
</tr>
<tr>
<td><strong>Total Population of Study Area</strong></td>
<td>2,503,280</td>
<td>1,375,854</td>
</tr>
</tbody>
</table>

The results from the GIS analysis show that Melbourne’s transit has much better area coverage both overall and with respect to each mode. In Melbourne, the radial networks of the tram and train modes do have higher coverage because of their extensiveness and are further supplemented by extensive bus transit routes, which give Melbourne the higher area coverage. More of Melbourne’s population is much closer to higher quality transit (tram and train) than in Toronto. It would be expected that transit would be better used because of this access, however as Section 4.3 shows Toronto is performing better with respect to the mode split. In terms of population density found within transit area coverage, the Toronto study area has higher values. This possibly reflects the more transit oriented development that is found in Toronto. Both these cities have public transportation that provides substantial transit coverage. Melbourne transit shows superiority in this performance indicator. Because this result does not correlate with the ridership and mode split results for these two areas, it does not lend any additional insight into Toronto’s better transit usage.
6.5. Service Level Quantification

The last effort in this study to quantitatively compare the network structures and network effect is a frequency of service comparison that helps to quantify the frequency aspect of service levels. There are different approaches that can be used to carry out this comparison such as service standards comparison, transfer penalty comparison or policy headway comparison. But many transit agencies do not necessarily have service standards or may not disclose due to privatization. While Toronto’s TTC has service standards, different private franchises operate the trams, buses and train systems in Melbourne and no known service standards exist except for the performance conditions outlined in the franchise agreements.

In this study, the frequency comparison examines the number of runs that services each stop over a certain period of time, also known as a frequency count for each stop and station. It is a simple but comprehensive way to compare the networks as a whole and can provide a reference point for the network effect based on the assumption that the supply of service reflects demand. By comparing this supply of service it is indirectly comparing the demand for the service assuming that service is not over provided as already explained Section 3.1. This comparison method looks at the three different modes of transit provided in the Melbourne study area in comparison to the TTC.

The following sections describe the process of how the frequency counts were carried out for the two systems. The data used for the two systems are for 2008 and provide a recent look at current service levels rather than the older data the performance indicator pairs used because this was the only data available for the Melbourne transit system.

6.5.1. Service Level Quantification Process

The service summary for the November 2008 to January 2009 review period was used for the TTC analysis, which contains the average headway, number of transit units, cycle time, time period of operation (morning peak, midday, p.m. peak, early and late evening) and first and last run times for all routes in service. The process used to calculate the daily service level per stop and station in the TTC network is as follows (note: overnight services are not included in this network comparison):

1. The total number of runs for each transit route was calculated by dividing the number of hours within the time period of operation by the corresponding headway for that period. See the sample calculation provided in Appendix D.
2. If the time period was not evenly divisible by the headway the following rule of thumb was used:
   a. If service was going to increase frequency in the following period or was the last time period of the day, the number of runs was rounded up to the next whole number.
   b. If the services were going to decrease in frequency in the following period, the number of runs was rounded down to the next whole number.
3. The calculated number of runs is the average number of runs between both directions where the first run start-times (one per direction) and end times (one per direction) were averaged for the two directions.
Therefore the calculated number of runs is the same for both directions meaning if 10 runs occur in the in-bound direction, it is assumed 10 occur in the out-bound direction (even though maybe 11 occur in-bound and only 10 occur out-bound). Note: Terminals have double the frequency.

4. The total number of runs for each bus, streetcar and subway service was calculated for each day of the 7-day week. TTC generally schedules the same services for Monday to Friday and different schedules for Saturday and Sunday.

5. Once the total number of runs was calculated for each route and each day, each route with all its branches were correlated with the stop sequence provided by the TTC.

6. Once correlated, a master list of unique stops was generated and the number of runs per stop were totaled using Microsoft Excel.

7. This master list was then brought into an ArcGIS map, where the geographic locations of all the stops are mapped. ArcGIS was then used to generated a thematic map to visually represent the following ranges of service level for the different days of the week:
   a. Less than 100 services per day ≈ 12 minute headway and longer
   b. 101 to 200 services per day ≈ 6 minute to 12 minute headways
   c. 201 to 300 services per day ≈ 4 minute to 6 minute headways
   d. Greater than 301 services per day ≈ 4 minute headways and shorter

It should be noted that generally peak hour services are more frequent than midday. However, for simplicity, this data aggregates the variation over the day.

The 2008 Transnet database was used for Melbourne’s analysis and was provided by Metlink Melbourne, which uses this database to support their online journey planner and contains all of the scheduled services in the Metropolitan Melbourne Area. The process used to calculate the daily service level for stops and stations in the Melbourne Transit network is as follows (note: overnight services are not included in this network comparison):

1. Using the Transnet database, the total number of runs for each service was queried in Microsoft Access and extracted.

2. Similar to the method used for the TTC, the number of runs per stop was then tabulated for a master-list of stops/stations on a daily basis.

3. Using the GPS (global positioning system) information provided in the Transnet Database, the stops/stations geographic locations were imported into ArcGIS and a thematic map for each day of the week was generated using the same service level ranges listed above in Section 6.5.1

The service level extraction from the Transnet database was provided courtesy of Chris Loader from BusVic. It should be noted that for the train stations, the service level is not per direction as in the case of the bus and tram stops and all TTC stops/stations. At train stations it is the total number of runs that service the station regardless of
direction (i.e. service levels at train stations is inbound + outbound service). This difference arises due to the multiple platform operation that the train service uses.

6.5.2. Service Level Results and Comparison

Figures 6-2 to 6-7 illustrate the service levels provided by the TTC and Melbourne Transit for an average weekday, Saturday and Sunday. These figures are available in larger scale in Appendix E and are presented on the next page in small scale for comparative purposes.
Network Structure and Network Effect – Toronto & Melbourne Experience

**FIGURE 6-2: AVERAGE WEEKDAY TTC SERVICE FREQUENCY**

**FIGURE 6-3: AVERAGE WEEKDAY MELBOURNE TRANSIT SERVICE FREQUENCY**

**FIGURE 6-4: SATURDAY TTC SERVICE FREQUENCY**

**FIGURE 6-5: SATURDAY MELBOURNE TRANSIT SERVICE FREQUENCY**

**FIGURE 6-6: SUNDAY TTC SERVICE FREQUENCY**

**FIGURE 6-7: SUNDAY MELBOURNE TRANSIT SERVICE FREQUENCY**
Comparatively, the graphical representations of the service frequency provided by these urban areas show very
different distributions of frequency. The TTC and its grid structured system provides higher frequency services
during the weekdays that are more evenly distributed across the entire study area as illustrated by the dark blue dots
that represent 301 services or more per day in Figure 6-2 compared to Figure 6-3. Grid systems, once it has
achieved sufficient demand to justify higher frequencies, has the advantage of transfer synergy because of the
provision of an increased number of high frequency services that reduce inconvenience of the necessary transferring
that needs to take place in these types of systems. If there is not enough demand, schedule coordination between
routes becomes essential so as not to discourage users due to unpredictable wait times. The Melbourne radial
transit system has a concentration of high frequency serviced stops close to the core of the city generated by the
overlap of its tram lines and train lines. Higher frequency is useful in the high demand core, but there is less network
advantage for higher frequencies in a radial system because trips using transit often do not require transferring. Also,
the majority of available transfer locations are within the city centre. This location can be well out of the way of the
direction passengers would like to travel, which counteracts the advantage that higher frequency services has on
transferring.

Bunching and associated delays are still an issue with higher frequency in any type of network. However, with such
a high degree of overlap any further increase in frequency to boost services in outer areas can cause delays in the
city centre due to congestion of transit vehicles. Also, there is the additional danger of delay propagation from one
route to many others because of the shared track sections.

On weekends, both study areas exhibit a decrease in transit service frequency and services provided. However,
comparatively, the majority of TTC services are maintained on both Saturday and Sunday with only minimal
decreases in frequency. The Saturday service in Melbourne is fairly similar to the weekday services; however,
Sunday services have the largest difference, where many of the bus stops appear to have little or no service at all.
With the removal of many services on Sunday, uncertainty can be introduced into people’s minds because of this
service irregularity, which may affect transit usage. People that are unaware of the service difference on Sunday
may find themselves stranded by the service, which can leave a negative impression in people’s minds.

Table 6-5 below summarizes the average frequency per stop by mode. In this table, it is clearly visible that the TTC
provides much higher services levels than Melbourne.
In all cases, Toronto’s TTC has higher frequency than Melbourne’s transit, particularly in the maintenance of weekend services. Even with the total (non-directional) count of the train services in Melbourne that makes the service provision higher than it is per direction, the subway services in Toronto are much higher because of the shorter headway resulting in the higher frequency.

If the breakdown in service levels for the average weekday is further analyzed, differences in the system can again be noted as seen in Figures 6-8 and 6-9. The figures illustrate the more variable distribution of the “All modes” percentage breakdown in Melbourne in comparison to the TTC. This shows that a large portion of the system has the lowest range of service levels, which is partially due to much of the transit system in the study area made up of bus routes. The “All mode” percentage breakdown for the TTC is not as variable because a well distributed range of services are provided as well as the larger number of stops/stations that are served by higher frequencies of service.
The bus modes from both study areas have similar distributions where most of the bus routes provide the lowest bracket of frequency. However, the TTC does have a larger number of higher-performance bus routes where 8% of these stops are in the highest frequency bracket of service. The major difference is in the higher quality transit modes where the majority of the stops in the TTC network have mid to high-level frequencies of service. Melbourne tram and train services are different where the majority of stops only have mid-level frequencies. Clearly, the service level comparison has provided the most insight into the network structure’s relationship with the network effect under the assumption that supply reflects demand.

6.6. Network Analysis Comparison Summary

From the exploration of the network structure through the four network indicator pairs as well as the service level comparison, several insightful findings are made. The first two network performance indicator pairs of connectivity
and transfer rate, and theoretical and observed directness established that radial networks and grid networks do generate different dominant forms of the network effect. In grid networks transfers occur more often, as shown by the analysis of the TTC network, which requires the networks to function together to reduce this inconvenience as much as possible. Because of the amount of transferring, the patronage on the lines is shared with one other. This can increase the volume on each line through the interdependence or sharing of demand, which can justify improved network services provided to this critical mass of users creating a network effect. Radial networks take the opposite approach, as shown by the analysis of the Melbourne tram network, and try to reduce the need for transferring as much as possible by creating direct routes to high demand areas and capitalizes on a particular critical mass of passengers travelling in these common directions to high demand areas. Because the evidence of the effect generated by these networks is different, they are difficult to compare. The last two performance indicator pairs of revenue service kilometres and passenger kilometres, and area and population coverage, try to move past this difference and compare the two networks from a different perspective. The service utilization results showed that the TTC and Melbourne tram network have similar ratios of passenger kilometres to service kilometres. The area coverage results also showed very similar results between the study areas did not add any insight to the better transit usage found in the Toronto study area.

Because transfers and directness are difficult to compare directly, service level as reflected through service frequency, which is known to be a significant influential factor of transit ridership (Kohn, 2000), can serve as solid grounds for comparison between different network structures. Both networks have a certain level of service that is established by the critical mass or demand of users. Service frequency reflects demand because it is one adjustment that can be made to supply the required capacity for that demand. Theory and best practice often suggests that grid networks need to have high frequency services to reduce the inconvenience of transferring as much as possible or if high frequency cannot be provided coordinated scheduling is necessary. Radial networks do not necessarily need frequency as high for the same purpose of reducing transfer inconvenience because transferring is already reduced in systems like this. However, moderate frequency is required because travel is more concentrated along fewer routes, which can cause capacity issues.

Through the comparison of service frequency, Toronto’s TTC network showed a more widely spread distribution of high frequency service and also cover all days on the week in more consistent fashion. In Kohn’s (2000) work, frequency of service was found to be a significant driver of transit ridership, which substantiates these findings as well. These results also quantitatively verify what Mees (1997; 2000) qualitatively speculated in his PhD and book, A Very Public Solution, as the leading reason to why Toronto’s transit usage outperforms Melbourne’s. However, the key advantage of higher frequencies or better service levels is not a singular answer to improving transit usage. For the TTC, higher frequency not only provides better service to the users, but also provides an advantage while travelling in a grid system. Because users of this type of system are more dependent on transferring, the higher
frequency not only shortens initial wait times, but also the necessary subsequent wait times making transfers less undesirable. Together, this produces an advantage in grid systems of this network effect that is quantitatively evident here. The TTC grid system is able to attract a critical mass of users to the TTC network, which enables the TTC to provide frequencies of service that do not need schedule coordination. The critical mass that established the service level frequency can better attract more users because of the advantage of the network effect.

It may be argued that private operating entities compared to public operating entities may influence the amount of service delivered to the public. This influence may be due to private entities seeking to maximize profits instead of maximizing welfare, as in the case of public entities. Investigating this aspect was outside the scope of this study and may be an area of future work.

While this analysis is useful in providing additional insight into the network effect, it still does not entirely quantify the utility or amount of additional ridership that this theoretical phenomenon can generate, except to say that through these various indicator pairs and frequency count comparisons there is evidence of network effects. This shortfall in this study leaves much room for future work to be done to exhaustively explore this phenomenon as discussed in Chapter 8.
7. Smart Network Design Features & Future Plans
Different network structures exhibit different types of network effects as shown from the analysis in Chapter 6. However, as much as the network structure can affect or even govern the type of network effect it generates, other aspects of the transit system design can also influence transit use. As previously mentioned, higher frequencies are not the only way of improving transit service. Other network design aspects, such as the use of standards, can overcome some of the disadvantageous features associated with each of the network structures. The features discussed here are service standards and other aspects, such as station/stop design, signage, stop location and the fare system. Because these aspects are not easily quantified, they are only qualitatively discussed in this chapter.

These highlighted network designs can also lead to innovations for future network features. The direction of the future of transit as shown through transportation plans provides interesting insights into what the transit planners see as priority areas for improvement. Both of the case study cities have recently released transportation master plans which outline the goals and direction for the coming years. The plans incorporate many aspects of transportation such as freight movement, active transportation and of most importance to this study, public transport.

The following sections discuss the current design aspects in the two case study cities and how they can encourage or discourage ridership growth, minimize network congestion and or stimulate network synergy. Following these sections is a brief summary of the future plans for the GTA and MMA as they pertain to public transit developments followed by a comparison of the directions these plans take and explore what they can learn from one another’s experience.

7.1. Service Quality – Service Standards and Performance Reviews
Standards and performance reviews are important to any business, and transit services are no different. Without guidelines and performance reviews, transit agencies or operators would have no reference point for how they are performing from an operational or customer perspective and whether there is room for improvement. Service quality, which includes reliability, service frequency, coverage, connectivity, safety etc., affects transit’s attractiveness as a transportation option (Vuchic, 2005; HiTrans, 2005). Service standards and performance reviews can establish and monitor the various aspects of service quality and help streamline the service across the network, as well as, even help resolve network wide issues. The following sections summarize and compare the methods used by the transit systems in the investigated case study cities.

7.1.1. TTC Service Standards & Review Process
The TTC is fairly well known world wide for its approach to planning transit service through the use of service standards. The following information is summarized from the TTC’s Service Improvements for 2008 Planning Transit Service report (2008) and as stated in this report, the two main objectives of the TTC are:
Network Structure and Network Effect – Toronto & Melbourne Experience

- “To maximize mobility within the City of Toronto by ensuring that public transit is provided in the right places at the right times, to satisfy the changing travel needs within the community.
- To ensure that all transit services operated by the TTC are as efficient and cost-effective as possible and therefore, affordable to both TTC customers and taxpayers” (p.7).

These objectives are well rounded in nature and seek to satisfy the two essential perspectives for any service industry, the user perspective and the operator perspective. To accomplish these objectives, the TTC service standards provide a set of guidelines that help establish, monitor and review services so that transit service offered within its service area is consistent and complementary to one another.

The basic standards that are used to schedule services are summarized below (TTC’s Service Improvements for 2008 Planning Transit Service report, 2008):

- Policy headway for regular bus and streetcar services is 30 minutes and 5 minutes for subway services (policy headway in 2009 may be adjusted to 20 minutes for buses and streetcars pending funding)
- Crowding standards for peak and off-peak periods as shown in Table 7-1. These represent the maximum acceptable limit of crowding on services and are compared to the average number of customers per vehicle during the busiest 60-minute period for the respective crowding periods (peak and off-peak).
- Financial standard of 0.23 customers gained or lost per dollar spent or saved is the benchmark for service changes, meaning that services will be added if the financial performance is above this level. Services are considered for removal if performance is below this level.

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Peak Period (# of customers/veh)</th>
<th>Off-peak Period (# of customers/veh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Floor Bus</td>
<td>47 to 50</td>
<td>35 to 38</td>
</tr>
<tr>
<td>High Floor Bus</td>
<td>51</td>
<td>36 to 39</td>
</tr>
<tr>
<td>Standard 15m streetcar (CLRV)</td>
<td>74</td>
<td>46</td>
</tr>
<tr>
<td>Articulated 23m streetcar (ALRV)</td>
<td>108</td>
<td>61</td>
</tr>
<tr>
<td>6 car Train</td>
<td>1000</td>
<td>500</td>
</tr>
<tr>
<td>4 car Train (T-series)</td>
<td>670</td>
<td>330</td>
</tr>
<tr>
<td>4 car Train (SRT - S-series)</td>
<td>220</td>
<td>130</td>
</tr>
</tbody>
</table>

* Source: TTC Service Improvements for 2008- Planning Transit Service

These basic service standards are complemented by the following four-part monitoring process (TTC’s Service Improvements for 2008 Planning Transit Service report, 2008):

- Ridership monitoring – to adjust service to fulfil customer needs while complying with the above listed basic standards
- Review of customer feedback – to be conscious of complaints and compliments submitted by customers
• Review of route efficiency – the evaluation of financial performance against the financial standards and productivity of runs and the first and last run times
• Route Management – the operation of the route and its service reliability monitored by observations of staff and input from customers

The introduction of new TTC services and service changes also has specific criteria that need to be met. These criteria are listed below (TTC’s Service Improvements for 2008 Planning Transit Service report, 2008):

- “new services will be provided only if they would service people beyond 300 metres of a service which is already in place (200 metres where there is a higher than average proportion of seniors)
- Surface routes should be designed to maximize interconnection with rapid transit stations
- Any service change must result in overall benefit for customers (measured by calculating the change in weighted travel time)” (p.8).

The weighted travel time used by the TTC is based on the MADITUC model parameters that were first calibrated by the 1996 TTS data (Dawson, 1999). The current weights being used are (TTC Service Improvements for 2008 Planning Transit Service report, 2008):

- In vehicle travel time weight = 1.0
- Wait time weight = 1.5
- Walk time weight = 2.0
- Transfer penalty = 10.0

These weights represent the perceived inconvenience caused by the different components of a transit trip, which lengthens the overall trip travel time. These weights are used to calculate the change in weighted travel time for the customers that will be affected by the new/changed service. The change must show a reduction of weighted travel time before it is considered for implementation. These new services are always introduced under a trial period of at least six months allowing enough time for the service to establish ridership (TTC Service Improvements for 2008 Planning Transit Service report, 2008). At the end of the trial period the service is reviewed using the four-part monitoring process before being made a regular service or cancelled. Overall, the TTC uses a streamlined process to transit planning and monitoring, as outlined above, which provides the TTC with a systematic method to reviewing and improving their services.

7.1.2. Melbourne Transit Service Standards & Review Process

Unlike the TTC, the Melbourne train, tram and bus systems do no have a unified set of service standards or any known individual standards. Without standards or a review process, improvements or changes to services can be difficult because of no established baseline references or methods of measuring the impacts of service changes. According to The Sunday Age, an article printed in September 2008 revealed that there have been no new peak
services added (i.e. higher frequency) to the tram network since 1999, (Sexton, 2008). No changes in service are often a product of not carrying out performance reviews.

While no known standards exist, the train, tram and bus operators do need to provide service performance information to the state government’s Department of Transport because they are privatized where each franchise looks after service delivery, infrastructure and rolling stock maintenance. The information reported is compared against targets outlined in their respective contracts in order to receive subsidies for good performance and to avoid penalties for below target performance from the government. Currently, the trains and trams are operated by the franchises, Connex Trains and Yarra Trams, respectively. The bus system services are divided among 25 smaller private operators (Department of Transport Victoria, 2009). The performance requirements that need to be met as outlined by the franchise agreements and contracts are reliability and punctuality along with supplementary customer service satisfaction surveys that are compliant with the standards in the customer service charter of the Victoria State Government (Department of Transport Victoria, 2009).

In the context of measuring punctuality and reliability the following definitions and measures are put forth by the Department of Transport Victoria Public Transport website under Performance Monitoring (2009):

- “Punctuality – measured as a percentage of the services arriving on time at specified monitoring points.
- Reliability – measured as a proportion of the timetabled train or tram services that have run.”

In addition to these two key criteria for service performance, customer service standards state a number of key obligations that need to be met. These obligations are summarized below (Department of Transport, Customer Service Charter, 2009):

- Clear service disruption notification to customers for both planned and unexpected circumstances
- Prominent display of information for “Key Public Transport Contacts” with contact information of other franchises and Metlink
- Clear display of monthly performance results 10 days after the end of the month
- Compensation for customers in the form of monthly, ½ year or yearly transit tickets in the event that services did not meet the Customer Service standards
- Clear instructions on how to submit customer comments to franchisees with a commitment to respond within 7 days of the receipt
- Provision of information brochures to customers on fares and ticketing.

Given the performance standards that have been outlined above, the more detailed performance standards that each franchisee must meet are summarized below as listed by the Department of Transport Victoria (2009).

Connex trains must:

- “Deliver 98% of train kilometres each month; and
• Ensure that 92% of services arrive at their destination no later than 5 minutes and 59 seconds after the time tabled arrival time” (Department of Transport Victoria, Public Transport-Performance Monitoring website, 2009).

Connex trains are manually monitored, where arrival times and cancellations are recorded and disclosed to the Public Transport Division of the Victoria Department of Transport.

Yarra Trams must have:
• “the average punctuality of services that is better than 80% (Average of 3 of 5 monitoring points along the route); and
• A 95% reliability in terms of kilometres of services delivered” (Department of Transport Victoria, Public Transport-Performance Monitoring website, 2009).

Tram monitoring is automated and electronic through the use of timing points along tram routes and is summarized and disclosed to the Public Transport Division of the Victoria Department of Transport.

Bus operations must guarantee that for their regular services:
• “no timetabled bus service operate early at any point on their routes;  
• No more than 5% of all services provided on any day or 10% of services provided on any route of any day will operate more than 5 minutes late at any point on the timetable; and
• 99% of all scheduled services on any day operate and are completed” (Department of Transport Victoria, Public Transport-Performance Monitoring website, 2009).

Bus operators keep records of punctuality and reliability in their own method that show they meet the requirements outlined by the Public Transport Division.

To supplement these performance indicators, random telephone customer surveys are conducted monthly and review various aspects of “service delivery, quality of stations and stops, passenger comfort, ticketing, the provided transit information, safety, value of for money and staff customer service” (Department of Transport, Public Transport-Performance Monitoring, 2009). These results are published in quarterly track record reports, which can be found on the Department of Transport’s website.

7.1.3. Standards & Review Comparison
The two case study cities provide an interesting opportunity for comparison with respect to their standards and review process. The TTC is focused on establishing frequency, crowding and financial performance standards to help maintain consistent and fair services across the network. Conversely, the Department of Transport Victoria is clearly focused on aspects of punctuality and reliability as they pertain to published schedules and contributes to their ability to provide an online journey planner. What one approach lacks, the other approach has, and therefore it would seem
that the combination of the two standards would create a strong, well-rounded approach for transit service standards and monitoring practice.

The TTC could learn from the reliability and punctuality monitoring in Melbourne as they are working towards providing an online journey planner just as Metlink does for Melbourne transit. The TTC does monitor reliability on their streetcar and bus routes using a performance standard of +/-3 minutes of the scheduled headway being considered as reliable with a target of 75% for this measure (TTC, Surface Route Management, 2005). This TTC target is much lower than that enforced by the Department of Transport Victoria for Melbourne transit as summarized in Section 7.1.2. The scheduled transit services need to be reliable and punctual if an online journey planner is going to be provided to the public because inaccurate information can deter transit usage and damage its image. Even if Global Positioning Systems (GPS) are used to assist the accuracy of the information provided by the new journey planner service (TTC, GIS Project Update, 2007), schedule punctuality and reliability is still important. This is because passengers are unlikely to know of any updates that are made to the arrival time of the service between the time a passenger checks the online journey planner and the time they arrive at the stop. If services arrive sooner than anticipated, passengers uninformed of the updated arrival time may find that they have missed their service, which can be aggravating. Conversely, when service is more reliable and punctual, better quality information is provided to passengers and can raise their confidence and trust in transit service (TTC, Surface Route Management, 2005) and encourage transit usage. The TTC can learn from the methods used in Melbourne for both the trip planner and the next service arrival information, both of which Metlink (the unifying agency that provides transit information, trip planner and handles fare collection) can provide with more confidence because of their high expectation approach to arrival and schedule performance monitoring.

In Melbourne, the two major franchises, Connex Trains and Yarra Trams, will be ending their lease of operations in November 2009. New tendering of franchises has begun with new contract details many of which are the same as already listed. However, some modifications have been made where the franchisees will be required to take a more active role in service planning with more emphasis on encouraging patronage growth as opposed to simply offering a set minimum level of service and monitoring the reliability and punctuality of those services (Department of Transport Victoria, Expression of Interest Brief, 2007). With the more active role in planning, crowd monitoring and patronage growth, the new franchisees can learn from the TTC’s crowding and service frequency standards and how they monitor them because it can improve customer satisfaction and encourage ridership growth.

One thing that both sets of performance review processes of the TTC and Melbourne transit have in common is the importance of customer feedback. Both the TTC and Melbourne transit use it as a supplementary method for obtaining passenger opinions on the services provided. In Melbourne, customer feedback is more actively sought after through telephone surveys, whereas the TTC relies on customers taking the initiative to provide feedback. Either way, customer feedback is valued and respected. Safety, cleanliness and the provision of information, such
as maps and service delays are also important aspects that the Melbourne transit, Metlink and the TTC all make an effort to provide. However, both can stand to learn from the differing approaches taken for monitoring their services, which can help these transit systems manage network congestion and even help their networks synergise.

7.2. Other System Design Aspects
In addition to standards and review processes, there are other system design aspects that can affect transit usage. The major ones touched upon in this study are station/stop design, signage, station/stop location, vehicle interior design and fares. Because these aspects are not easily quantifiable they are only discussed here with relation to how these designs can influence transit usage.

7.2.1. Station/Stop Design
Station and stop design can affect the overall image of transit, as well as the flow of passengers, intuitiveness and ease of transfer from service to service. The design of the space can make people feel comfortable and safe or just the opposite, where cleanliness, lighting, signage and visibility of the approaching transit vehicle play a large role in the overall transit experience. Transit already has a difficult time competing with private vehicle travel and all of these station/stop aspects when arbitrarily designed can add to that difficulty.

In Toronto, TTC subway stations serve two major roles. The first is that they are the access points to the subway platforms and the second is that they are often terminals and or the connection points between buses and/or streetcars and the subway system as seen in Figure 7-1. Cervero (1998) comments that this use of subway stations as multimodal points are part of the success of the TTC’s service and mode integration because buses and streetcars enter some stations within bus bay areas that do not require proof-of-payment and lead directly into the subway station decreasing the inconvenience of transferring through station design. Thirty-eight of the subway stations have this particular design. The remaining stations require a transfer, a paper ticket issued by bus drivers or dispensing machine that is used as proof-of-payment. Most are also well lit, have overhead cover to protect them from the weather elements, have garbage and recycling bins to keep the station clean and are staffed at the collector booth for customer service. All of these station design features provide a comfortable and relatively safe environment for passengers to use.
In Melbourne, no known Connex train station has a similar design to the TTC providing this type of multimodal transfer convenience. From personal experience, transfers are more inconvenient to make in Melbourne than in Toronto because Melbourne transfer points often involve walking farther distances than expected with relatively few signs to direct the way. Even though Metlink promotes transit in the Melbourne area as an integrated system, technically it is only integrated though the fare system and is not necessarily physically integrated except in the city centre where tram stops can be found just outside the station entrances. Even bus feeders that provide connection to rail station have stops that are quite distant from the actual station as can be seen from the picture below.

Most stations are outdoors and well lit with some over head cover as seen in Figure 7-4. Of the 211 stations in the train network, 72 are premium stations meaning they are staffed from the first service until the last service seven days a week. Twenty-eight stations are host stations that are staffed only during the morning peak period and the
rest are entirely un-staffed but have fare vending machines in case tickets need to be purchased. Since the number of stations in this system is so much larger than the number of TTC stations, it is reasonable to be less staffed. However, stations without staff can make passengers uncomfortable because there is no one to answer questions or to contact in the case of emergencies.

Aside from transit stations, which are much larger pieces of transit infrastructure, bus stop and streetcar/tram stop design is also important. In Toronto and Melbourne, these are mostly located curbside. Both Yarra trams and TTC's streetcars have some centre lane platforms where the service is given grade separation or partial right-of-way on certain routes. At these locations in both cities, stops can be found equipped with a shelter and sometimes seats. It is important that transit stops also make patrons feel safe so that they are not uncomfortable waiting there. To facilitate this comfort, in both cities, stops are in well lit areas and are open so that transit vehicles can see waiting passengers.

One advantage that Melbourne’s tram stops do have over the TTC is the low floor accessibility that complements their low floor vehicles. The TTC still uses old streetcars that have stairs which do not allow for the same accessibility. While not all of the trams in Melbourne are low floor, as they progress to being fully accessible, many of their tram stops are platforms that are level with their low floor vehicles to assist boarding as seen in Figure 7-5. The TTC has selected a new model for their streetcars that are low floor compliant and once in service, streetcar routes that have platform boarding will be similar to that found in Melbourne.
FIGURE 7-5: TRAM PLATFORM

Clearly, both the Melbourne transit and the TTC have similar trends in station and stop design. The TTC still has the advantage of better station design from an intermodal perspective where there is both physical connectivity and fare integration. The physical connectivity is important because even though Section 6.1 shows that the connectivity between the two systems is very similar, the presence of convenient connection points affect the utilization of connectivity as shown by the comparison of the transfer rates between TTC and the Melbourne tram system (The general transfer rate incorporating all modes within the Melbourne study area is 1.3 boardings/transit trip compared to the TTC's 1.96 boardings/transit trip for all modes). Accordingly, station design and connection point design should be carefully considered because it can also influence transit usage.

7.2.2. Signage

Signage is important because it is the main method of communication with passengers. When done well, signage can reduce the need for asking questions to customer service representatives making transit travel more efficient and intuitive.

In Toronto, TTC signs have a standard format. Subway terminals have black signs with white letters that provide direction to connecting services as seen in Figure 7-1. At bus and streetcar stops, a standard and recognisable sign is used to indicate the location of a stop, as seen below in Figure 7-6 and 7-7. These signs also help to brand the service where all signs and TTC stations use a consistent logo and colour coordination so that it is easy for passengers to recognize TTC services. HiTrans Best Practice in Network Planning (2005) refers to these as “soft measures” that are essential to successful communication with the public and can encourage transit usage.
In the Melbourne transit network the use of signage to convey detailed information is used extensively, particularly because of the more complex operation they run. Information boards that Connex train stations and tram platforms employ are a necessity because of the multi-service platform operation. Platform numbers are always clearly displayed, however, monitors that display the next arriving service and their stopping stations is not as clear because of the small print on the screen. From personal experience, the screens are not easy to interpret because of the amount of reading required to figure out where to go to catch the correct service making it not intuitive to use and confusing for first time users.

Aside from the information boards, the more general signage used at stops and stations in Melbourne are branded by colour association for different modes. Royal blue represents Connex trains, bright green represents Yarra trams and orange represents bus services as seen in Figures 7-8 and 7-9. This method is very useful in communicating the types of connecting modes that are found at each stop and what mode of service to expect at each stop. Prior to this branding, buses in the suburbs did not have signs to designate its stops. This lack of signage was a significant deterrent for passengers and Metlink has taken a step in the right direction through branding which has helped to effectively communicate with passengers the different modes of service as well as where to wait to catch these services.
From these two case study cities, it is clear that the signs at transit stations and stops can be used to communicate a great deal of information to the public. By simple branding, it can also create a consistent feel across the network that helps to unify the service being provided. In Melbourne, the clever use of colour association has intuitively communicated the mode of service that passengers will receive at each stop or station. In Toronto, the simple and consistent red and white signs also effectively communicate the stop and station locations for TTC transit service. The methods used in both these transit systems may be useful considerations for one another as the systems change over time to help the flow of communication with passengers.

7.2.3. Stop/Station Locations
Stop and station location not only affect accessibility to transit but also affect representation on maps, simplicity of routes as well as transferring from one service to another. Therefore, stop and station locations need to be logical and follow some sort of convention because it can impact these other important aspects that can affect transit usage.

In general, the system that the TTC uses is simple. Subway stations are located along three major arterials, Bloor/Danforth Street, Yonge/University/Spadina Avenue, and Sheppard Avenue. Stations are located at selected major intersections and generally use the names of the cross-arterial they are located at as the naming convention. In Melbourne, train stations are named after the suburb they are in and do not follow any particular memorable pattern except that the stations are mostly located near the shopping centre in the suburb. By comparison, TTC station locations are much easier to understand and to remember because they are so closely linked with the road network. Melbourne’s system requires knowledge of the suburb and with so many different suburbs and many more stations; it is more challenging to do. However, because transit in Melbourne is a radial system and transit travel is mostly towards the city centre and back, the core stations in the city centre are named after streets similar to the TTC’s stations making their locations considerably easier to remember.
In Toronto, TTC buses and streetcars follow the same convention as the subway system. Individual routes are primarily along a single arterial and stops are located at the intersection of cross-streets that conveniently allow for the name of the stop to logically correspond with the name of the cross streets. Where stops are located midblock, close landmarks are used to identify the location. This stop location convention also assists transferring to connecting services because most major arterials have transit services that all use the same stopping convention at intersection. This makes the location of catching transit service easier to find even in unfamiliar areas.

In Melbourne, the street layout is not as transit friendly as in Toronto. Melbourne streets are grid like in nature, except that many of the streets terminate at T-intersections every couple of kilometres or turn into smaller local roads with street names that also tend to change along its length. Since buses and trams use the road infrastructure, Melbourne’s street nature is not conducive to simple bus and tram routes because of the more disjointed alignments and naming system that cause more complex routing. The difference between Toronto’s grid street system and Melbourne’s grid street system is illustrated below in a simplified manner in Figure 7-10.

**FIGURE 7-10: TORONTO’S GRID SYSTEM VS. MELBOURNE’S GRID SYSTEM**

The stop locations for the tram and bus routes tend to vary depending on the location. Tram stops for the most part in Melbourne are found at street intersections when enough space is provided for a tram to stop. Buses in Melbourne are a different story because in the suburbs many of the bus stops are not located at intersections even though the stop is named after the cross-street. There is no specific explanation for this stop location except for the fact that guidelines for bus stop locations were not created until 2006 (Bus Stop Guidelines, 2006) and may have been arbitrarily placed before these guidelines were introduced. This arrangement makes transferring from service to service more difficult by needlessly lengthening the walking distance to transfer between services and increasing the chance of missing the connecting service, which can deter transit use.

The location of transit stops also affect how they are represented on maps. The stop location can sometimes needlessly complicate the map’s communication to passengers of where transit services go and where they stop. In
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general, simpler maps are easier to understand making routes easier to remember and to locate stops and stations (HiTrans, 2005). The TTC provides a map that contains all transit services within the area as well as street information. While the TTC map may look complex, the large foldout map provided to passengers gives a complete view of where they can go and where they are. Subway station locations are identified on the map; however, bus stop locations are not. At the very least passengers can assume that every major intersection will have a bus stop, even though it is not shown.

In Melbourne, transit maps are very simplified and are separated by mode. There is one map for the train network, one for the tram network and route maps for bus services. Of these provided maps the best is the tram map that shows where there are connecting train services, as well as the street that the trams travel along, but still does not provide stop location information. For more detailed stop information, individual route maps are available, but still do not provide the road network for reference. Given the complexity and abundance of routes this would be difficult to show all of the transit routes together in one map in Melbourne. However, from the maps provided it is not easy to tell where routes go or where major stops are located and what connecting services are available. Clearly, stop location and its representation on maps is an important consideration because it can affect how well a system can be remembered, understood and used whether it is for routine trips or spontaneous ones as advocated by the HiTrans Best Practice Guide to Network Planning (2005).

7.2.4. Vehicle Interior Design

The interior design of a transit vehicle directly impacts capacity, comfort and accessibility and can also affect passenger attraction. If services are always over crowded with many people standing, the interior design can overcome some of these obstacles or at least assist in reducing these deterrents.

The major difference in interior vehicle design is with the trains and this is reflective of the different purposes that this mode serves. In Melbourne, the train system was originally designed as commuter rail (The Victoria Transportation Plan, 2008), which locals commonly refer to as suburban trains, but has developed into a hybrid mode and is more of what Vuchic (2005) would describe as Regional Rapid Transit as already explained in Chapter 4. Because of this hybrid nature, the seating arrangement used here is more of the commuter style with conference seating as seen in Figure 7-11 below. The problem with this design is that as the vehicle approaches the city, trains become progressively more crowded. With such an arrangement of seats, capacity is greatly reduced with very little room to stand or handlebars to hold. While a comfortable ride is important for the larger service area, the interior design is not conducive for the increase in demand as it approaches the city.
In Toronto, trains are used for rail rapid transit, as described by Vuchic or metro/subway systems as they are more commonly referred to. The interior arrangement has less seating and more standing room to accommodate a higher capacity. Because people are not travelling as far or as long, they do not necessarily need to sit to be comfortable. This arrangement can be seen in Figure 7-12. Given the increasing demand for train transit in Melbourne, the interior seating arrangement in Toronto’s subway vehicles may be a good consideration for interior seating arrangement during the peak periods to accommodate the higher volume of passengers to reduce crowding and lessen the aggravation crowding can cause.

### 7.2.5. Fare System

The fare system and cost is also an integral part of transit systems. Both the TTC and Melbourne Transit system have integrated fares meaning that there is no extra cost for transferring to another service to complete one’s trip. Even though both systems have integrated fares, the fare structure is different and has different implications on transit travel.

To make a trip on the TTC, fare in the form of exact cash, tokens, ticket or transit pass, must be paid or shown (in the case of a pass) at the beginning of the trip. Transferring to connecting routes (i.e. routes that use the same stop/station or intersection) are free, but for surface routes, that are not within proof-of-payment free areas, a paper transfer obtained from bus and streetcar drivers or subway stations need to be shown to the driver. The transit fare pays for a one-way continuous journey that may or may not involve transferring to other services. The cost of transit for the TTC is summarized in Table 7-2.
### Table 7-2: 2009 TTC Fares*

<table>
<thead>
<tr>
<th></th>
<th>Adult</th>
<th>Senior/Student</th>
<th>Child</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cash</strong></td>
<td>$2.75</td>
<td>$1.85</td>
<td>70¢</td>
</tr>
<tr>
<td>Single fare purchase</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Tickets &amp; Tokens</strong></td>
<td>5 tokens for $11.25</td>
<td>5 senior/student tickets for $7.50</td>
<td>10 child tickets for $5.00</td>
</tr>
<tr>
<td>10 tokens for $22.50</td>
<td>10 senior/student tickets for $15.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Monthly Metropass</strong></td>
<td>$109.00</td>
<td>$91.25</td>
<td>Not Applicable</td>
</tr>
<tr>
<td><strong>Metropass Discount Plan (MDP)</strong></td>
<td>$100.00</td>
<td>$84.00</td>
<td>Not Applicable</td>
</tr>
<tr>
<td><strong>Weekly Pass</strong></td>
<td>$32.25</td>
<td>$25.50</td>
<td>Not Applicable</td>
</tr>
<tr>
<td><strong>Downtown Express</strong></td>
<td>$2.25 cash, token or Express Sticker</td>
<td>$1.50 cash, Senior/Student Ticket, or Express Sticker</td>
<td>50¢ cash or Child Ticket</td>
</tr>
<tr>
<td><strong>Other Fares</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Day Pass</strong></td>
<td>$9.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>GTA Weekly Pass</strong></td>
<td>$47.00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*source: Fares, TTC website, www.ttc.ca

Individual tickets and tokens are paid per trip and thus can be shared amongst travellers if bulk tickets or tokens are purchased. Passes can also be shared but only after the holder of the pass has completed their TTC trip before someone else can use it. A day pass also doubles as a family pass on weekends where up to one adult and up to five children, two adults and four children or two adults can travel. In order to break even, four TTC trips using tokens must be made on a day pass during a weekday, meaning that more than four trips need to be made to receive any discount on travel. Because the TTC uses a flat fare system, it is often perceived at penalizing short trips, where short trips supplement the cost of long ones on the system because there is no association of cost for the amount of service being used. This perception may be true; however, flat fare systems are much easier to understand with much fewer fare options to consider (Vuchic, 2005). As seen from the ridership records, the TTC seems to be performing well in comparison to Melbourne that uses a graduated system.

Melbourne transit uses an integrated fare system of zonal fare structure. The transit system is divided into a 2-zone system as described earlier in the description of the Melbourne Transit system where zone 1, the inner zone, is similar in size to the City of Toronto. There is also a city saver zone for travel within the city centre that is within zone 1 and is mostly for tourist purposes. Tickets can be purchased in an extensive number of options and must be validated at the first boarding of the trip. The numerous options are listed below in Table 7-3. After the first boarding, tickets are valid for 2 hours from the next full hour after the time of boarding meaning that if the ticket was first validated at 9:01am the ticket is valid for travel until 12:00pm the same day. An unlimited number of boardings can
be made within the time period that the ticket is valid. On trains and trams, validation of tickets are on the honour system because of multi-door boarding, which is different from TTC streetcars where boarding mostly occurs through the front door because drivers still check for proof-of-payment. Boarding of buses still occurs through the front door similar to TTC buses where validation of the ticket using the validator machine is supervised. However, unlike the TTC, tickets can be purchased from the driver and exact change is not required.

**TABLE 7-3: 2009 METLINK FARES**

<table>
<thead>
<tr>
<th>Zone</th>
<th>City saver</th>
</tr>
</thead>
<tbody>
<tr>
<td>City Saver</td>
<td></td>
</tr>
<tr>
<td>Full</td>
<td>2.80</td>
</tr>
<tr>
<td>Concession</td>
<td>1.60</td>
</tr>
<tr>
<td>Zones</td>
<td>1</td>
</tr>
<tr>
<td>2 hour</td>
<td>Full</td>
</tr>
<tr>
<td></td>
<td>Concession</td>
</tr>
<tr>
<td>Daily</td>
<td>Full</td>
</tr>
<tr>
<td></td>
<td>Concession</td>
</tr>
<tr>
<td>Off-Peak Daily</td>
<td>Full</td>
</tr>
<tr>
<td>(first travel after 9am on Weekdays)</td>
<td>Concession</td>
</tr>
<tr>
<td>Sunday Saver</td>
<td>Full</td>
</tr>
<tr>
<td>Senior Daily</td>
<td>Concession</td>
</tr>
</tbody>
</table>

**Value Metcards**

<table>
<thead>
<tr>
<th>Zone</th>
<th>City Saver</th>
</tr>
</thead>
<tbody>
<tr>
<td>City Saver x 10</td>
<td></td>
</tr>
<tr>
<td>Full</td>
<td></td>
</tr>
<tr>
<td>Concession</td>
<td></td>
</tr>
<tr>
<td>Zone</td>
<td>1</td>
</tr>
<tr>
<td>10x2 hour; 5x daily; weekly</td>
<td>Full</td>
</tr>
<tr>
<td></td>
<td>Concession</td>
</tr>
<tr>
<td>Monthly</td>
<td>Full</td>
</tr>
<tr>
<td></td>
<td>Concession</td>
</tr>
<tr>
<td>Yearly</td>
<td>Full</td>
</tr>
<tr>
<td>5x weekend daily</td>
<td>Full</td>
</tr>
<tr>
<td>5x senior</td>
<td>Concession</td>
</tr>
<tr>
<td>10 x early bird</td>
<td>free</td>
</tr>
</tbody>
</table>

* Source: www.metlinkmelbourne.com.au

Clearly from Table 7-3 above, Metlink offers many more fare options making it much more complicated to understand and purchase appropriate tickets. One major difference is the cost discrepancy between the 2-hour ticket and the daily. In the TTC system, a minimum of 5 trips need to be made to make the day pass a better value. In Melbourne,
The daily ticket costs the same as two 2-hour tickets. This daily ticketing method can encourage transit use because people who only planned for 2 transit trips may have a tendency to make extra transit trips because there is no extra cost for making more trips than necessary. Another incentive is that during the evening, any ticket validated after 6pm (meaning any time after 5pm because of whole hour rounding) is valid till 3am the next day, which also encourages transit use and likely compensates for lower frequency of service into the evening hours. Cheaper weekend rates and off-peak rates also try to provide passengers with a discount during times when service is less frequent and does somewhat compensate for this disadvantage.

In terms of cost, Melbourne transit is more expensive than the TTC by pure magnitude comparison not accounting for currency exchange, which is in fluctuation. However, by allowing for at least 2 hours of travel, depending on the time of validation, the fare in Melbourne provides the opportunity for passengers to complete short trips without the need for paying another fare, thus overcoming that shortfall of the TTC because Metlink fares are time oriented not trip oriented. However, in the suburbs where the frequency of transit service is low, what seems like a short trip by distance may be much longer in terms of time due to the poor frequency. Another major difference between the two fare systems is that because of the way tickets are issued, value Metcards cannot be shared amongst passengers travelling together. In Toronto, 5 tokens can be purchased and used by 5 people at the same time, in Melbourne a 5x-daily ticket can only be used by one person because only 1 ticket is issued that has the 5 fares recorded in the magnetic strip and cannot be back passed. While there are many features of the various Metlink fares that help to compensate for lesser frequency during weekends and certain hours and more inconvenient transferring that may take more time to complete, the complexity of the number of fare options can be in itself a deterrent causing patrons to not know what they should buy to get the best value. This can often leave patrons feeling cheated for the service they receive if the fare purchase was not the best value for their travel purposes.

One clear advantage of the fare system in Melbourne is the fare media used. By using the magnetic strip and validation machines, boarding of trams can be done through any door. This method is common practice in Europe where electronic fare media have become the norm. Even though there are issues with fare evasion because of the honour system, overall it can speed operations through shorter boarding times. The TTC is still behind the times on this matter, however modifying the fare system is on the agenda for future improvements, which provides a good opportunity to learn from other systems already using this method to learn from the challenges they have experienced and the best approach to overcome them.

7.3. Future Direction

The direction for the future of transit provides interesting insight into what the transit planners see as the areas of improvement. Both of the case study cities have recently released transportation plans which outline the goals and direction for the coming years. The plans incorporate many aspects of transportation such as freight movement, active transportation and of most importance to this study, public transport. The following sections give brief
summaries of the future plans for the GTA and MMA as they pertain to public transit developments followed by a comparison of their directions and explore what they can learn from one another’s experience.

7.3.1. GTA’s “The Big Move” & Transit City Plan Highlights

The newly established Metrolinx agency, formerly known as the Greater Toronto Transportation Authority (GTAA), recently published in 2008 the final regional transportation plan for the Greater Toronto and Hamilton Area (GTHA) known as “The Big Move”. Since the GTHA is not a monocentric urban area like the MMA, the transportation plan seeks to tackle many of the issues brought on by the polycentric design and separate local government transit agencies that run transit services in their respective governing areas. According to the plan there are ten major strategies to address the challenges of congestion, population growth, car-dependence and lack of investment. Out of the ten strategies, the two strategies that advocate for “building a comprehensive regional rapid transit network” and “implementing an integrated transit fare system” are the focus of this study because of their importance on the development and direction of public transit (The Big Move, 2008). The TTC’s Transit City Plan fits into the creation of the regional rapid transit network, where some of the routes from that plan are on the priority list for completion in the next 15 years. Details on the rest of the plan can be found on the Metrolinx website (http://www.metrolinx.com/thebigmove/default.aspx) and details on the Transit City Plan can be found on the TTC website (http://www3.ttc.ca/About_the_TTC/Projects_and_initiatives/Transit_city/index.jsp).

In the GTHA, cross boarder travel in the GTHA by transit is time consuming, expensive and inefficient because of the separate operation of local transit systems, the largest and most successful being the TTC. This plan emphasizes that the future direction of transit in this area is a regional transit network. The major highlights of this strategy in the plan include the following (The Big Move, 2008):

- Expansion of GO-rail services – express rail from Hamilton to Oshawa and improvement of other regular services;
- Rapid transit lines in downtown Hamilton area, Halton and Peel;
- Subway expansion into York region;
- Eglinton, Finch and Sheppard LRT from the TTC Transit City plan ; and
- Establishment of a rail link between Union station and Pearson Airport

In the “Places to Grow” Provincial Growth plan for the Greater Golden Horseshoe, there were 17 major urban growth centres that were identified as focuses for development (The Big Move, 2008). The expansion of GO-rail service, rapid transit and the TTC subway will connect these 17 major growth centres by higher quality transit services and more regional type services similar to Melbourne’s approach to transit. These extensions and improvements are anticipated to be completed within 15 years of the issue of the plan, meaning that these projects should be underway and completed by 2021. The Transit City plan also fits within this 15 year timeline as proposed by the TTC. Three of the proposed seven lines of the new LRT network have been selected as part of the priorities for the first 15 year scheduled plan. As a whole, the Transit City plan seeks to supplement the existing TTC network with the upgrade of
the bus routes existing on these seven routes, with new light rail lines similar to the extensive tram lines Melbourne has to provide intermediate quality transit to suburban areas in the City of Toronto. Eglinton Crosstown, Etobicoke-Finch West and Sheppard East routes have been approved in “The Big Move” Plan moving the TTC’s network to have a larger share of the streetcar/light rail (LRT) mode. The other major project within this first 15 year timeline is the connection of Pearson Airport to Union station with new rail service. Presently, the only transit service to the airport is bus service. The new LRT lines purposed by Transit City will provide two new connections to the airport along with a third rail service that will provide a direct connection to Union station creating a link between these two hubs.

In its efforts to unify GTHA transit, transit fare integration is the other major endeavour that “The Big Move” has plans for. Even though there may not be much demand for cross boundary transit travel, this lack of demand is partly influenced by the lack of collaboration between transit agencies. In the GTHA there are ten different public transit government agencies that are separately owned and operated. Fares are not integrated within the GTHA, meaning that if transferring from one service to another that is operated by different transit agencies, riders will have to pay two different fares, one per transit agency of the service. This arrangement is confusing for passengers, expensive and inconvenient. The Big Move’s strategy plans introduce both an integrated fare and new electronic fare medium to be used for paying transit fares. This approach to fare collection will allow passengers to travel with various transit agency services without the worry of carrying the correct tickets or fares for the corresponding transit agencies because all systems will use the one unifying fare system. Already in the testing process since 2007, the Presto card will hopefully allow for both the new integrated fare and electronic fare payment to be rolled out in 2012 at the same time (The Big Move, 2008). This fare integration will likely encourage those who may have considered transit in the past but were deterred by multiple fare costs to reconsider this option again and increase their usage of transit.

7.3.2. The Victoria Transportation Plan Highlights

The Victoria Transportation Plan, released at the end of 2008, is the document that outlines the direction for the future of the state of Victoria. Unlike Ontario, Melbourne is the only major urban centre in Victoria, which is responsible for much of the economic activity in the state. Even though the plan is called the Victoria Transportation Plan, the MMA is a major focus. According to the plan (2008) there are six major areas of focus, however for the purposes of this review only the areas on “shaping Victoria – Linking jobs, services and homes” and “creating a Metro system – practical steps to increase the frequency and reliability of trains and trams” are the focus of this study because they relate to the development and direction of the public transit in the Melbourne area. Timelines for these projects anticipate procurement and construction to commence in 2012 for expected completion dates by 2018. Details on the rest of the plan can be found on the Department of Transport Victoria’s website (http://www4.transport.vic.gov.au/vtp/).
The MMA is generally regarded as an urban area with a strong central core. As pointed out in the plan (2008), having only one central core places large demand and stress on the transportation infrastructure particularly in the peak periods. To better utilize the current infrastructure and focus growth as well as the addition of new transport links, which include a cycling network, roads and transit, more housing along tram and rail lines, the plan identifies six “designated Central Activities Districts (CAD).” These are key parts to the development of public transit as Transit-Oriented Development advocates, where increasing the density and encouraging compact urban environments have been shown to improve the use of public transit and to be more sustainable from long term perspective (New Urbanism, 2008). CADs are not a new concept where polycentric urban designs are used elsewhere such as the city of Toronto and the GTA. Cities that are less dense than older European ones have taken for granted the luxury of space. A polycentric city design is useful in providing guidance for concentrating expanding developments, both business and residential, in certain areas to curb random sprawl and to help bring jobs closer to home.

The other major transit oriented component of this plan is a clear outline of projects and investments that seek to relieve congestion on transit vehicles and on the road and improve service in the existing transit system and recognize the need for creating a metro system. This portion of the Transport Plan (2008) highlights several key projects and they are:

- Investment in new train and tram rolling stock;
- New Electronic Fare payment media – Myki;
- Construction of a new underground rail tunnel for a new metro line;
- New and upgrading of suburban rail stations for better walkways and drop off areas;
- Operational changes in the suburban rail network to better utilize capacity and increasing service long congested lines; and
- Integration of bus timetables with train services

The projects and initiatives are practical and necessary upgrades. Of the projects, the most ambitious project is the building of a new metro line that will run north through the city centre and provide more transfer opportunities for transit users. The project reveals that this transport plan is taking a much more focused approach to complement its already regional transit system. Also, this plan recognizes that the existing suburban rail has very complex operations, which often suffer from delays that propagate throughout the system because of the line integration. To address this issue the plan advocates that a simpler, more frequent and higher capacity service is the future direction for rail transit in the MMA. Metro rail will be different from what Melburnians are used to with heavy rail. The plan (2008) stipulates that this line will run with much higher frequency and simple operations with key station upgrades for the new service.

Along with these new transit initiatives, a new electronic fare medium that is similar to Presto in the GTA, branded as Myki, is already in the testing phase with complete implementation by 2010. This new fare medium is similar to the
trend in London with the Oyster card and Hong Kong with the Octopus card. This transit ticketing system will be used across Victoria and will allow for electronic top-up making paying for transit easier.

7.4. Completing the Network

The above summary highlights of the regional plans from the two case study areas revealed a strange case of complement where what Toronto and the GTHA already have is what Melbourne and the MMA want to progress towards and vice versa. In the GTHA’s case, the plan is to move forward with a wider regional and suburban transit that will connect all of the urban growth centres together, meanwhile this has always been the approach taken by Melbourne’s suburban rail network until now. The Melbourne transit has also already integrated transit fare throughout their extensively reaching transit system, something which the GTHA is finally incorporating into their future plans. The TTC has also decided to expand their transit network by upgrading several of their well used bus routes into streetcar/light rail lines, which will form a network comparable in size to the very extensive tram network in Melbourne. Meanwhile, Melbourne’s monocentric approach to planning has redirected their planning approach to become polycentric. This planning approach is already in practice in City of Toronto one that has been reinforced by the Growth strategy put forth by the Province of Ontario. Melbourne is still focused on improving their rail network but has decided that the best option for expansion is the addition of a simple and high-frequency metro line that will connect with all modes of transit in a convenient manner, which is very similar to the approach that the TTC has taken with their subway lines.

The plans for the future transit development in Toronto and Melbourne are complementary to one another’s existing system and provide excellent case study cities for what challenges and possible solutions can be anticipated from one another’s experience. While the planning bodies may not always consider one another as case study examples, the TTC has compared their streetcar operations to the tram operations in Melbourne when studying St. Clair Avenue for streetcar upgrades (On track Consulting, 2004). Certainly the design and past experience from each case study area can offer valuable insight into what issues can be avoided and what best practice design guidelines are better to follow.

7.5. Summary

As seen from the discussed areas, there are many things that the TTC and Melbourne transit/Metlink can learn from one another regarding different approaches to overcoming the disadvantages that both systems have. Design aspects ranging from standards and guidelines, stop/station design to signs and fare structure can all assist in reducing deficiencies or inconveniences inherent in the network structure. Based on the patronage results comparison between Melbourne and Toronto, it seems that “simple” methods are still better as advocated by the HiTrans Best Practice Guide to Network Planning (2005). Since these two cities are currently facing many of the same challenges of auto-dependence, rising transit ridership, increased congestion on transportation infrastructure
etc. the future direction of transit in these two cities are strangely complementary and can learn from one another’s designs to better anticipate the challenges to come.
8. Conclusion
The main objective of this study was to quantitatively explore the connection between network structure and network effect and its impact on transit usage as seen through the real-world experience of the Toronto and Melbourne transit systems. This objective was motivated by previous studies, such as that done by Mees (1997; 2000) that have examined Toronto and Melbourne and that have qualitatively concluded that it is the TTC’s network structure and resulting network effect that gives the TTC the leading edge in terms of ridership performance. In this study, the analysis of ridership/capita and mode split show that Toronto’s TTC performed better during the periods of 1999/2001 and 2006 examined. However, past travel behaviour research has indicated that there are many socio-economic, demographic, trip and other design factors that can also influence transit patronage. Therefore, this study provided a complete comparison all of these factors to systematically deduce the key explanatory differences for transit usage performance between these two case study cities.

Several compromises had to be made for this study because of data limitations and differences within the organization and structure of the transit networks themselves. The most recent available travel survey data for the MMA is the 1999 Victoria Activity Travel Survey. Since no data exist in the GTA for 1999, the closest available year, 2001, was used for comparison of these factors. The 2006 Australian census data does contain some travel behaviour information regarding journey to work, therefore this data was also included and used for comparison with the 2006 journey to work Transportation Tomorrow Survey data to give some reference to transit performance data for parts of the study that used more recent data. There is also a large difference in transit area coverage between the two case study cities. Melbourne’s transit system is much more extensive than the TTC, which is partially due to the different ways transit is owned and operated in the GTA in comparison to the MMA. Due to of the size difference, the study area for Melbourne that was deemed most comparable with the TTC coverage area of the City of Toronto was the collection of LGAs covered by the tram network. The majority of the network analysis comparison between Toronto’s transit and Melbourne’s transit was between the TTC network and Melbourne tram network because of ridership data limitations. However, the comparison between grid and radial networks was still feasible because of the distinctly radial tram network in Melbourne.

Through the analysis of the various socio-economic, demographic and trip factors using the 1999/2001 data available for the two study areas the following differences were noted as being part of the explanation for the TTC’s better performance.

- **Higher population & residential density particularly in the city centre of Toronto than in Melbourne** (3940 person/km²-Toronto VS. 2420 persons/km²-Melbourne) - This result is partially due to the much higher share of high rise apartments in the City of Toronto making the city more compact and better served by transit.
• Higher vehicle ownership in the Melbourne Study Area than in the Toronto Study Area (1.4 vehicles/HH – Melbourne VS. 1.1 vehicles/HH -Toronto) – This suggests a higher dependence on private vehicles as a mode of transportation. The main mode split difference occurs with work trips being more auto dependent in Melbourne.

• Higher part-time employment share in the Melbourne Study Area than in the Toronto Study Area (20% - Melbourne VS. 10% -Toronto) – Taking public transit to and from part time work can be more difficult due to travel hours that are more likely to take place during off-peak periods and less frequent transit service during that time making transit a less attractive option.

• Dominance of work trips in the Toronto Study Area compared to a much smaller proportion of work trips in Melbourne Study Area (35.6% - Toronto VS 16.1% - Melbourne) – Work trips are better captured by transit because they are routine trips usually from the same origin to the same destination with a large portion often oriented to the CBD as shown through the origin-destination analysis in Section 5.3.5.

• Higher midday travel in the Melbourne Study Area compared to the Toronto Study Area – Off-peak hours often have less frequent service than peak hours making transit less attractive during this time of day.

To investigate the relationship between network structure and network effect, four different network supply and demand indicator pairs were used. These four indicator pairs are:

1. Connectivity & Transfer rate
2. Theoretical Directness of Service & Observed Directness
3. Revenue Service Kilometres & Passenger Kilometres
4. Area Coverage & Population Coverage

Both networks, as indicated from the first two network indicator pairs’ results, generate some proportion of evidence of each network effect, transferring and directness. However, the first two network indicator pairs also showed that each network structure does indeed generate different types of dominating network effects. The dominant network effect evidence in grid systems is transferring, making the demand for and operation of individual lines much more interdependent. Radial networks, on the other hand, are dominated by direct trips, which is a type of network effect generated by demand or concentrations of travel, particularly towards the CBD and is a partial reflection of the increased number of available direct trips in radial networks. The last two network indicator pairs did not provide any additional explanation of the network structure-network effect relationship, except to say that both networks provide similar passenger/service kilometres and area coverage.

The last network analysis comparison to investigate network structure and network effect in this study was a service frequency comparison based on the assumption that supply reflects demand. This comparison revealed that the TTC had higher frequency of service in 2008 than Melbourne’s transit system when compared by mode and overall. TTC also has a larger distribution of higher frequency service, which is consistent with the theory that states that grid systems need higher frequency to provide attractive transit service. Higher frequency is known to be a major factor
in attracting ridership and better transit mode split and is reflected in the better transit mode split in Toronto for work trips in 2006 than Melbourne. Both radial and grid networks benefit from higher frequency services. However, grid networks can possibly reap a higher benefit because of the higher degree of dependency that the different lines have on one another due to the larger necessity for transferring. Radial systems, particularly ones with integrated lines may reach frequency congestion before grid systems do because of these shared sections where propagation of vehicle delay throughout the system is more prominent, resulting in less benefit for high frequency service on radial systems in comparison with grid systems.

The last phase of this study was to examine other parts of network design that can minimize inconveniences cause by particular network structures as well as a brief examination of the future plans of transit to identify areas that the cities can learn from another. The TTC service planning and monitoring approach, crowding standards, station design and stop location were of better practice than that of Melbourne’s transit system. However, Melbourne was found to have better practices in terms of their reliability monitoring by setting high standards, online journey planner, regional coverage and integrated transit fare system. The shortfalls of transit in these two systems lead to the future plans of the two case studies and appear to be complementary to one another. The GTHA is moving towards a more regional transit approach with more light rail transit influence and integrated fares and MMA becoming more local with a new metro line and simplifying the operations of their network. The experience of these two cities can both lend valuable insight to one another into the planning and design of these new investments since the future direction transit in these two areas are rooted in one another’s past.

Overall, the network analysis provided quantitative proof that grid and radial systems both generate network effects but of different types. The findings here show that the network effect in conjunction with other various socio-economic, demographic, trip and other design factors contribute to the better transit usage performance in Toronto, but it is not solely attributed to the network effect alone. Service level comparison revealed one possible quantitative way of measuring network effects on similar terms, even though the dominant type of network effect generated by varying network structures may be different. However, the service level comparison makes the assumption that supply is reflective of demand, which may not always be the case. One major weakness in this study is that it still does not directly measure the additional ridership and/or additional passenger utility generated by the network effect with respect to the structure of a system. However, this weakness opens up the possibility for future work in this area that could lead to a better understanding of the network effect in the context of public transit, as outlined in the next section.

8.1. Future Work

This study focused primarily on the positive side of the network effect phenomenon, looking at transfer rates, directness and frequency. However, the negative side can also provide much insight into the network effect as well. A possible area of future work is to focus on these negative aspects instead, such as crowding and congestion levels.
and what Vuchic (2005) calls the coefficient of flow variation along different routes. Theoretically, radial systems would have a lower tolerance for network congestion because all routes head towards one area producing high coefficients of flow variation. It would be interesting to examine whether the different network structures manage or handle congestion in different ways.

Another possible area of future work is to investigate the transfer penalty of different systems. This would provide good insight into the network effect phenomenon because it is a quantitative comparison of the utility of transferring within certain transit networks. The transfer penalty or the additional time added to a trip due to the need of transferring from one service to another would capture the overall network and could be related to other system aspects such as service frequency, reliability, connectivity and design of connection points as well. Since not much is known about the passenger behaviour of transferring, this would also allow additional opportunity for research and further understanding of this behaviour.

Similar to the type of work done in this study, further work can be done to expand this study’s process to include many other cities and look at many other grid and radial networks. While this process is data intensive, it provides an opportunity to apply a multivariate regression analysis and the use of variables, like the ones investigated in this study, to apply statistical significance to the network structure’s influence on ridership. Incorporating the network effect could also be done in this type of analysis through the use of a dummy variable. In contrast, future research using micro-level data or route level data to investigate the network effect may also provide valuable insight into this area, by looking at the boardings and alightings difference at stops along feeder-trunk services and interlines services.

Time did not permit this study to fully investigate or analyze transit’s main competition, the car/road network. However this could be an interesting area of possible future work. Investigating the areas related to roads and cars, such as the kilometres of highway, parking provisions and vehicle congestion levels, could bring a more complete perspective in the comparison of these two case study cities.

Additional comparative work on Toronto and Melbourne can also be done in areas other than the network effect, such as operational efficiencies, franchising and procurement. Research in this area can help to identify whether profit seeking private operators affect the amount of service delivered in comparison to public operating entities. Also, Melbourne has just recently undergone its second franchising of its train and tram network and it would be an interesting case study to examine the benefits and costs of contracting services and to see what Melbourne has learned from their first contracting process and if it was addressed in their second. From this study, it recognizes that the learning opportunity from one another’s experience and approaches are extensive and that while Toronto may have some advantages over Melbourne with respect to certain areas of public transit, Melbourne also has other
advantages. Overall, benchmarking comparisons are an important area of research and aid in establishing best practice and trends within the transit industry.
References


Network Structure and Network Effect – Toronto & Melbourne Experience


123


Network Structure and Network Effect – Toronto & Melbourne Experience


## Appendix A – Network Operational Data

<table>
<thead>
<tr>
<th>Toronto</th>
<th>2006</th>
</tr>
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<tr>
<td>Number of Routes</td>
<td>Number of Routes</td>
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<td>Bus Routes</td>
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<td>Streetcar Routes</td>
<td>11</td>
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<td>Scarborough RT lines</td>
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<tr>
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<th>Length (km)</th>
<th># of Stations or stops</th>
<th>Average Station/stop Spacing (m)</th>
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<td>Total streetcar routes-round Trip route Length including branches and shared roadway (track length)</td>
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<td>6</td>
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<td>Streetcar/Tram</td>
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<td>Subway</td>
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<td>Streetcar Vehicles (CLRV+ALRV)</td>
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<td>Heavy rail cars</td>
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<td>Scarborough Rail Transit Vehicles</td>
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Source: CUTA Factbook – 2006 Operating Data
Source: Service Summary, TTC Report Nov. 2008
Source: Service hours, TTC website, www.ttc.ca
Source: Operating Statistics, 2006, TTC
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<th>2007</th>
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<td><strong>Number of Routes</strong></td>
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<td>Tram Network length (does not double count overlap)</td>
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<tr>
<td>Total Tram Line Length (double counts overlap)</td>
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<td><strong># of shared trams stations (counting each direction separate)</strong></td>
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Source: Public transit Information, Department of Transport Victoria.
Source: Melbourne transit GIS data, Monash University
Appendix B – Patronage Trends

Source: TTC operating Data 2000-2008

### Appendix C – Network Indicator Sample Calculations

**Degree of Connectivity – Node Consolidation**

The following bi-directional nodes and node consolidation was done for all Melbourne tram, TTC streetcar and bus routes for the entire route length a part of the study areas. Non-bidirectional stops were eliminated from the stop list resulting in equal number of inbound and outbound stops.

Example: 57 Midland Ave. portion between Finch Ave. and Sheppard Ave

**Stop Sequence**

<table>
<thead>
<tr>
<th>Outbound</th>
<th>Inbound</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. MIDLAND</td>
<td>1. MIDLAND</td>
</tr>
<tr>
<td>SHEPPARD AVE E</td>
<td>FINCH AVE E</td>
</tr>
<tr>
<td>2. MIDLAND</td>
<td>MIDLAND</td>
</tr>
<tr>
<td>RURAL</td>
<td>MIDB</td>
</tr>
<tr>
<td>3. MIDLAND</td>
<td>LOCKIE</td>
</tr>
<tr>
<td>4. MIDLAND</td>
<td>MIDLAND</td>
</tr>
<tr>
<td>MONTGOMERY</td>
<td>任務</td>
</tr>
<tr>
<td>5. MIDLAND</td>
<td>MIDLAND</td>
</tr>
<tr>
<td>HAVENDALE</td>
<td>LOCKIE</td>
</tr>
<tr>
<td>6. MIDLAND</td>
<td>MIDLAND</td>
</tr>
<tr>
<td>STUBBSWOOD</td>
<td>MONTGOMERY</td>
</tr>
<tr>
<td>7. MIDLAND</td>
<td>MIDLAND</td>
</tr>
<tr>
<td>HUNTINGWOOD</td>
<td>LOCKIE</td>
</tr>
<tr>
<td>8. MIDLAND</td>
<td>MIDLAND</td>
</tr>
<tr>
<td>BOARHILL</td>
<td>RURAL</td>
</tr>
<tr>
<td>9. MIDLAND</td>
<td>MIDLAND</td>
</tr>
<tr>
<td>FINCH AVE E</td>
<td>SHEPPARD AVE E</td>
</tr>
</tbody>
</table>

For the example section:

# of bi-directional nodes, $N = 9$

# of net bi-directional nodes, $N_{\text{net}} = 6$

# of consolidated nodes = 3

(These are nodes that overlap with other routes and need to be consolidated so that they are not double counted)

Once done for all routes, the total net number of nodes in the network is the sum of all net bi-directional nodes plus the number of consolidated nodes.
Degree of Connectivity – Link Count

Example: 57 Midland Ave. portion between Finch Ave. and Sheppard Ave Con’t.

The number of links is counted between the bi-directional nodes on each route.

If there is overlap of routes along certain links, the overlapped link must share the same \( i \)th stop and \( i+1 \)th stop before it the link count is reduced to account for the overlap.

This example section does not contain any overlap.

For Example section:

\# of net links = 8

Once done for all routes, the total net number of links in the network is the sum of all net links plus the number of links that are shared among multiple routes.
**Theoretical Directness** – Direct trips calculation (OD = Origin Destination paths)

The following calculations are done for both Melbourne tram and TTC networks, only sample calculations are shown here for TTC network.

Example: 57 Midland Ave. Full Route

- # of bi-directional nodes, $N = 35$
- # of direct paths on this route, $OD_d = \frac{1}{2} (N \times (N-1))$: $OD_{57\text{ Midland}} = \frac{1}{2} (35 \times 34) = 595$

For each route $OD_d$ is calculated

For TTC network:

From Degree of connectivity – Node Consolidation, the net number of node, $N_{\text{Net}} = 3047$

Therefore:

Total number of OD paths in system, $OD$:

$$OD = \frac{1}{2} (N_{\text{Net}} \times (N_{\text{Net}} - 1)) = 1/2 \times (3047 \times 3046) = 4,640,581 \text{ paths}$$

Total number of OD direct paths in system, $OD_d$:

$$OD_d = 81,684 \text{ paths (but includes overlapping lines)}$$

To reduce the double count along the overlapped sections, these links were identified in Degree of connectivity – Link Count and the multiple counts of these paths were removed.

$$OD_{\text{Net, direct}} = 77,790 \text{ paths}$$

Theoretical Directness, $\delta$:

$$\delta = \frac{77,790}{4,640,581} = 0.017 \approx 2\%$$
Passenger Kilometres – Melbourne tram only

Average Online tram distance travelled = 3.61 km
(straight line distance per tram boarding from 1999 VATS)

1999 Estimated annual tram boardings = 135,000,000 passenger boardings
(Source: Transport Demand Information Atlas for Victoria, Volume 1: Melbourne, 2008)

Passenger Kilometres = Average online distance x annual passenger boardings
Passenger Kilometres = 3.61 x 135,000,000 = 487,350,000 passenger-km
Appendix D – TTC Service Level Quantification Sample Calculations

The following sample calculation is the method used for all of the TTC routes. The Frequency count is for one-direction, but is the average # of runs between the two directions because the time of first/last service is the average of both directions.

Example: Weekday service Bloor-Danforth Subway

First run Westbound: 5:46 am
First Run Eastbound: 5:41 am  Average first run time: 5:43 am
Last run Westbound: 1:31 am
Last run Eastbound: 1:31 am  Average last run time: 1:31 am

Information given by the TTC Service Summary (Nov. 2008 to Jan. 2009) document:

<table>
<thead>
<tr>
<th>Route Name</th>
<th>Average Speed (km/hr)</th>
<th>Cycle Time (minutes)</th>
<th>Number of Transit Units</th>
<th>Minutes</th>
<th>Second</th>
<th>Headway (minutes)</th>
<th>Hour of first/last morning or evening service</th>
<th>Minutes of first or last service</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bloor-Danforth Subway</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monday to Friday</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak</td>
<td>6am - 9am</td>
<td>32.2</td>
<td>101</td>
<td>42</td>
<td>2</td>
<td>24</td>
<td>2.4</td>
<td>5</td>
</tr>
<tr>
<td>Midday</td>
<td>9am - 3pm</td>
<td>30.8</td>
<td>102</td>
<td>22</td>
<td>4</td>
<td>39</td>
<td>4.65</td>
<td></td>
</tr>
<tr>
<td>Peak</td>
<td>3pm - 7pm</td>
<td>31.4</td>
<td>100</td>
<td>39</td>
<td>2</td>
<td>34</td>
<td>2.57</td>
<td></td>
</tr>
<tr>
<td>early Evening</td>
<td>7pm - 10pm</td>
<td>32.2</td>
<td>98</td>
<td>24</td>
<td>4</td>
<td>4</td>
<td>4.17</td>
<td></td>
</tr>
<tr>
<td>late Evening</td>
<td>10pm to 1am</td>
<td>32.4</td>
<td>97</td>
<td>20</td>
<td>4</td>
<td>52</td>
<td>4.87</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The following is calculated:

<table>
<thead>
<tr>
<th>Route Name</th>
<th>Hours of service during Time period</th>
<th># of runs in the time period</th>
<th>Total number daily number of runs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bloor-Danforth Subway</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monday to Friday</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak</td>
<td>6am - 9am</td>
<td>(3.28 x 60)/2.4 = 82</td>
<td>341</td>
</tr>
<tr>
<td></td>
<td>9 – (5+ 43/60) = 3.28 hrs</td>
<td>(rounded down because of longer headway in next period)</td>
<td></td>
</tr>
<tr>
<td>Midday</td>
<td>9am - 3pm</td>
<td>(6 x 60)/4.65 = 78</td>
<td>135</td>
</tr>
<tr>
<td></td>
<td>15 – 9 = 6 hrs</td>
<td>(rounded up because of shorter headway in next period)</td>
<td></td>
</tr>
</tbody>
</table>
### Network Structure and Network Effect – Toronto & Melbourne Experience

<table>
<thead>
<tr>
<th>Period</th>
<th>Time</th>
<th>Service Frequency</th>
<th>Calculation</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak</td>
<td>3pm - 7pm</td>
<td>7 – 3 = 4 hrs</td>
<td>(4 x 60)/2.57 = 93 (rounded down because of longer headway in next period)</td>
<td></td>
</tr>
<tr>
<td>Early Evening</td>
<td>7pm - 10pm</td>
<td>10 – 7 = 3 hrs</td>
<td>(3 x 60)/4.17 = 44 (rounded down because of longer headway in next period)</td>
<td></td>
</tr>
<tr>
<td>Late Evening</td>
<td>10pm to 1am</td>
<td>(12+1+31/60) – 10 = 3.52hrs</td>
<td>(3.52 x 60)/4.87 = 44 (rounded up because of last service)</td>
<td></td>
</tr>
</tbody>
</table>

When the number of runs is applied to the stop sequence, it is important to note that the terminals get double the number of runs because they are the turn around point and the station platforms have the same station ID number. Therefore the service frequency for the day per stop is shown below for the Bloor-Danforth Subway line.

<table>
<thead>
<tr>
<th>Stop List (Westbound)</th>
<th>Frequency Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kennedy</td>
<td>682</td>
</tr>
<tr>
<td>Warden</td>
<td>341</td>
</tr>
<tr>
<td>Victoria Park</td>
<td>341</td>
</tr>
<tr>
<td>Main St.</td>
<td>341</td>
</tr>
<tr>
<td>Woodbine</td>
<td>341</td>
</tr>
<tr>
<td>Coxwell</td>
<td>341</td>
</tr>
<tr>
<td>Greenwood</td>
<td>341</td>
</tr>
<tr>
<td>Donlands</td>
<td>341</td>
</tr>
<tr>
<td>Pape</td>
<td>341</td>
</tr>
<tr>
<td>Chester</td>
<td>341</td>
</tr>
<tr>
<td>Broadview</td>
<td>341</td>
</tr>
<tr>
<td>Castle Frank</td>
<td>341</td>
</tr>
<tr>
<td>Sherbourne</td>
<td>341</td>
</tr>
<tr>
<td>Bloor-Yonge</td>
<td>341</td>
</tr>
<tr>
<td>Bay</td>
<td>341</td>
</tr>
<tr>
<td>St. George</td>
<td>341</td>
</tr>
<tr>
<td>Spadina</td>
<td>341</td>
</tr>
<tr>
<td>Bathurst,</td>
<td>341</td>
</tr>
</tbody>
</table>
Appendix E – Service Level Quantification Figures - Large Scale

Legend
Average Weekday TTC Service
Monday to Friday
- 100 and less
- 101 - 200
- 201 - 300
- 301 and more
- rapid transit polyline

Average Weekday TTC Service Frequency
Legend

Average Weekday MetSA Transit Service

Monday to Friday
- 100 and less
- 101 - 200
- 201 - 300
- 301 and more

suburb_rail_MELB_LGAs_polyline

Average Weekday Melbourne Transit Service Frequency
Saturday TTC Service Frequency
Legend

Saturday MetSA Transit Service

Saturday
- 100 and less
- 101 - 200
- 201 - 300
- 301 and more

suburban_rail_MELB_LOAs_polyline

Saturday Melbourne Transit Service Frequency
Sunday TTC Service Frequency
Sunday Melbourne Transit Service Frequency