Supply and Demand Based Transit Service Allocation: A Method of Evaluating Transit Network Structure Applied to the Hamilton Street Railway

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A thesis
presented to the University of Waterloo
in fulfilment of the
thesis requirement for the degree of
Master of Arts
in
Planning

Waterloo, Ontario, Canada, 2008

Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

Travel patterns in Canadian urban areas changed during the twentieth century. No longer is urban travel downtown oriented. In all but the smallest Canadian urban areas, travel has evolved into a polycentric pattern. Despite this Canadian public transit networks remain oriented to the older travel patterns because of shortages in planning capacity. The transit literature on performance monitoring focuses on "system" variables rather than "network" variables like how well transit networks match travel patterns. This research develops a method by which transit planners can monitor the performance of transit networks in their communities. Applying this methodology provides recommendations to planners on how to improve transit network structures to better facilitate polycentric urban travel. Future research should compare the network performance of Canadian transit systems.

Keywords: Polycentric travel - transit planning – performance monitoring – transit network structure

Acknowledgments

A keen thank you to Professor Jeffrey M. Casello for tolerating me for so long, facilitating the relationships that made this research possible, and for so much advice throughout the whole process. I have learned a tremendous amount thanks to your expertise, so thank you.

Thanks to the other Professors involved in this process, Professors Woudsma, Seasons, and Hellinga for their contributions towards the finished product.

Thanks to the University of Waterloo and the School of Planning for financial assistance that made this research possible.

Most importantly, Jen, thanks for being so patient.

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Chapter 1. Introduction

1.1: Background & Research Question

The relationship between land use and transportation is a fundamental concept in urban planning (Newman & Kentworthy, 1991; Kelly, 1994; Badoe & Miller, 2000). Over long periods of time, urban transportation systems and land use patterns work together to influence urban form. Canadian cities experienced changes in their urban form during the twentieth century. Starting as early as the late nineteenth century, Canadian cities ceased to exhibit their old patterns of tightly clustered residential and employment development around rail lines or central business districts (also known as downtowns or core areas) (Harris & Lewis, 2001). Residential and employment land uses decentralized while metropolitan areas grew in spatial size and population (Harris & Lewis, 2001). A new pattern of urban form, known (among other titles) as “polycentric” or “multi-nucleic”, in which multiple locations within cities attract development, employment, and population, became the North American norm (Greene, 1980; Schneider, 1981; Erickson & Gentry, 1985; Ladd & Wheaton, 1991; Anas, Arnott, Small, 1998; Harris & Lewis, 2001; Modarres, 2003; Casello, 2007).

The Canadian public embraced the automobile as a solution to urban transportation problems during the development of polycentric urban form. Government policies (especially a low rate of gasoline taxation) also contributed to the growth of automobile use (Pucher, 1988). To facilitate the increase in automobile use much road infrastructure was built. By the twenty-first century, over 70 kilometers of four-lane highway existed in Canada per kilometer of urban rail transit offered (North American Transportation Statistics Database, 2004b). Relative investment in, and attention to, public transit declined, while as Table 1.1 demonstrates, the rate of automobile ownership amongst Canadians grew by a factor greater than 19,000 in the twentieth century. Canadians have not embraced the automobile as much as Americans have, but contemporary automobile ownership is almost four times higher in Canada than Mexico.

Table 1.1: Twentieth Century North American Automobile Ownership Rates

Country	Year	Registered Passenger Automobiles	National Population	Passenger Automobile Ownership Rate (Autos per Hundred Persons)
Canada	1903	178	5,651,000	0.003
Canada	1953	2,527,461	14,845,000	17
Canada	2003	18,560,202	31,676,077	59
United States	1990	186,234,513	248,800,000	75
United States	2004	234,056,848	296,400,000	79
Mexico	1990	6,897,372	81,200,000	8
Mexico	2005	15,543,713	103,300,000	15

(Based on Statistics Canada, 2003; North American Transportation Statistics Database, 2004a; North American Transportation Statistics Database, 2004c; Statistics Canada, 2006a; Instituto Nacional de Estadistica Geografia e Informatica, 2007.)

Closely related to results in Table 1.1, Canadian transit usage declined during the twentieth century. Canadians took over 120 transit trips per capita per year in 1945. Fifty years later that number had declined to approximately one third; Canadians took approximately 40 transit trips per year in 1995 (McKeown, 1997). The automobile shifted great numbers of Canadians from public to private transportation.

Prior to the expansion of automobile travel, public transit networks were oriented towards the pre-World War II downtowns of Canadian cities. Downtown areas were the focus of transit networks because of the high concentration of activities located within them and the fixed linear nature of rail transit (Filion, Bunting, Gertler, 2000; Thompson & Matoff, 2003). Rail transit routes were permanently fixed lines that “radiated” from downtowns to suburbs like the radii of a circle. When motorized buses became the predominant North American transit mode in the 1950s and 60s they offered the ability for routes to change on an ongoing basis, yet routes remained largely identical to previous radial rail routes (Thompson & Matoff, 2003). It is documented later in this thesis that the phenomenon of downtown-anchored radial transit routes in Canadian cities largely remains to this day.

While downtowns have played a major role in Canadian cities since World War II (unlike their U.S. counterparts), other urban growth centres are now equally important in terms of employment, shopping, recreation, and the location of public services (Greene, 1980; Schneider, 1981; Erickson & Gentry, 1985; Ladd & Wheaton, 1991; Anas et al., 1998). Along with the de-concentration of trip-attracting urban land uses like those mentioned above has come a change in urban travel patterns (Casello, 2007). In polycentric cities downtown areas do not attract as many trips as they once did. During the twentieth century Canadian public transit systems failed to respond to the trend of urban decentralization and the corresponding rise in automobile use.

The problem of polycentric urban travel has less impact on the largest of transit systems in cities like Toronto or Vancouver, or the smallest of systems in cities like Sault Saint Marie or Brandon, but the greatest impact is felt in systems in mid-sized cities like Halifax or Hamilton. In these cities where growth occurs at the fringe of the urban area but transit routes remain highly downtown-oriented there exists a potential for inefficiencies. In some cities, transit agencies operate high numbers of conventional buses in corridors oriented towards downtowns when travel volumes may not warrant such high capacities (Schumann, 1997). Schumann (1997) and Vuchic (2005) point out the example of Sacramento, California, which removed 60 buses from downtown and replaced them with just eight LRT[1] ("light rail transit") trains. Making the upgrade to higher capacity, more efficient modes of transit like LRT can free lower capacity vehicles to serve under-serviced growth centres located near the fringes of mid-sized cities. In polycentric cities with dispersed travel patterns there is the potential for inconsistency between travel patterns and radial transit networks.

The fact that planners in mid-sized cities often do not have the capacity to monitor the implementation of their plans amplifies the problem of mismatches between transit networks and travel patterns in such cities (Seasons, 2003a). Specifically relating to transit planning, monitoring the implementation of plans involves monitoring the performance of network design. If planners do not have the ability to evaluate the performance of transit networks as closely as is ideal, then unnoticed mismatches between travel patterns and the structure of transit services can result. If the primary goal of public transit is to facilitate as many trips as possible it is important to actually monitor whether the transit network does so. The potential results of planners in mid-sized cities not having the resources to monitor the impact of plans are mismatches between transit networks and travel patterns in mid-sized cities. Such mismatches in transit service and travel patterns increase the relative cost of using transit, make auto-use a more competitive alternative, and are lost opportunities (Casello, 2007).

In mid-sized cities with growing suburban centres there may be significant benefits to reorienting transit networks to complement travel patterns. Doing so may allow transit systems to increase patronage and revenue, improve rates of efficiency, reduce some social costs, and improve the quality of life (Perl & Pucher, 1995). This thesis examines the relationship between contemporary travel patterns in mid-sized Canadian cities and the supply of transit services

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[1] "LRT" is defined as an electric-propelled rail-based transit system consisting of high-capacity vehicles operated in multi-car trains (Vuchic, 2005).

within such cities. The primary question this thesis investigates is: has the supply of transit services been adapted to reflect the polycentric nature of contemporary urban travel in Canada in order to adequately serve urban residents and attract maximum ridership?

1.2: Outline of Thesis & Statement of Research Problem

In order to investigate this research question, Chapter 2 of this thesis reviews the literature on mid-sized cities, transit network design, performance monitoring in planning practice in general, performance monitoring in transit in particular, and reviews past transit planning studies from the city chosen as a case study. Next, this section reveals patterns in the history of, and reasons for the development of the present network structure employed by the case agency this thesis uses as an example. The literature review critiques existing transit performance monitoring literature because it focuses on "system" variables like cost efficiency and productivity, not "network" variables like the accommodation of travel patterns. The literature on transit performance monitoring fails to provide appropriate means by which to monitor and evaluate the performance of transit networks. Thus, the problem of this thesis is to develop a method by which transit planners can monitor the performance of and evaluate changes to transit network structures. Applying this method to a case study contributes to the goal of evaluating whether contemporary transit services have adapted to reflect the polycentric nature of contemporary urban travel.

Chapter 3 describes the development of a transit network performance monitoring methodology. Two processes are developed to do this. One, called "Downtown Network Structure Tendency Estimation" (DNSTE) is useful for estimating the relative tendency of routes within transit networks to be oriented towards downtown areas compared to other transit networks. This process is useful for a macro level evaluation of network structure, as its results indicate the tendency of a network to feature radial routes. A second, more important and comprehensive method called “Supply and Demand Based Transit Service Allocation” (SDBTSA) is developed which allows for the evaluation of the distribution of transit supply within a network relative to transit demand at a medium scale level. This process does not evaluate the sufficiency of the overall level of supply within a network, rather it seeks to evaluate whether the supply offered between aggregated origins and destinations within a network is balanced adequately with aggregate demand. This process uses data based on transit passenger surveys and transit schedule timetables to quantify the proportion of transit service within a network that does and does not facilitate travel demand patterns. This process is useful for evaluating changes to transit route patterns and network structures. Using the two transit network performance monitoring processes that chapter 3 establishes, chapter 4 of this thesis describes a case study that exemplifies the application and benefits of this new methodology.

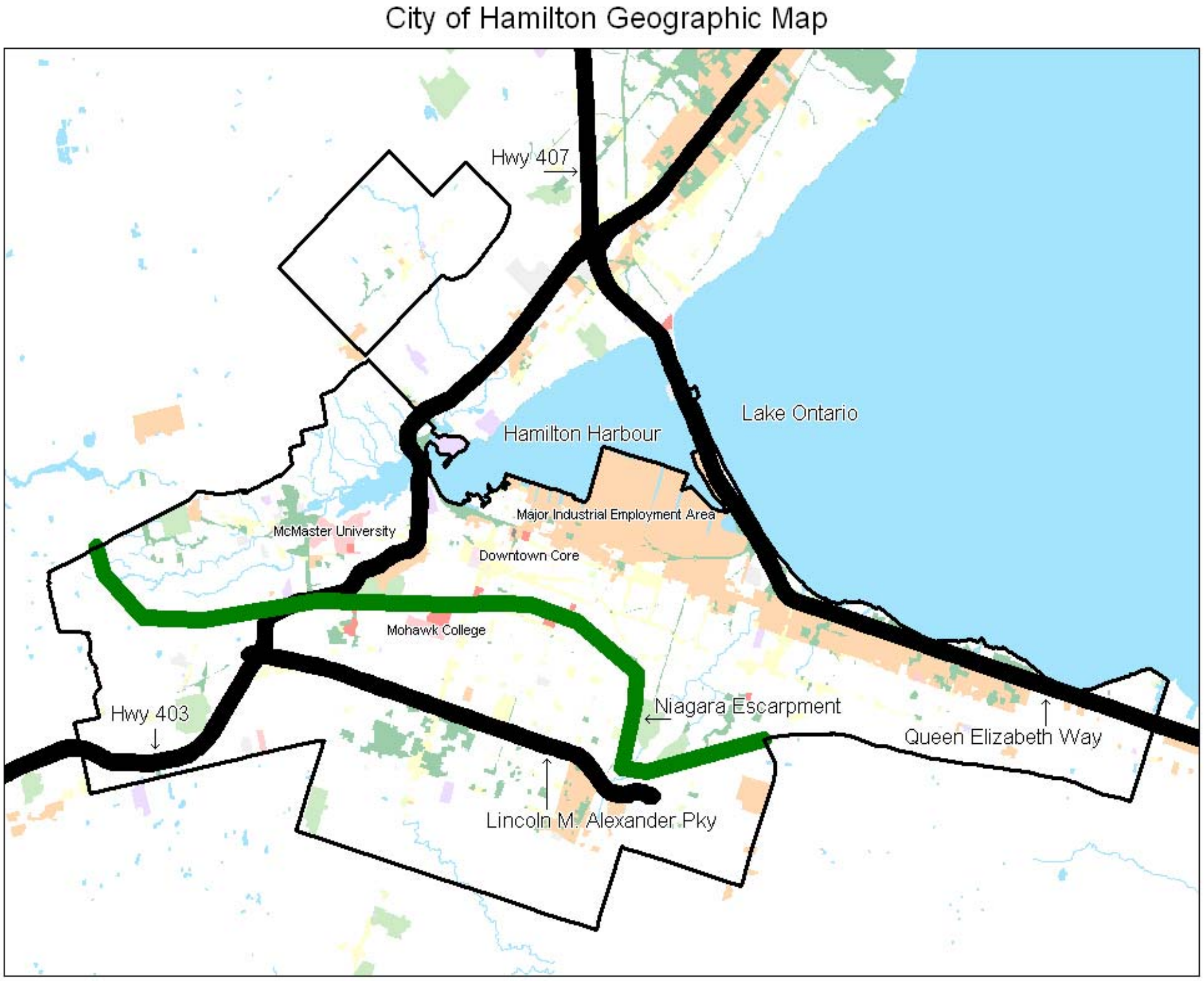
The city of Hamilton, Ontario is chosen as the case study in chapter 4 for a number of reasons. Hamilton faces the spatial, transportation-related, and planning capacity challenges that other mid-sized Canadian cities face. Employment land use patterns are decentralizing. Natural features worsen traffic congestion problems and pose operational problems for conventional transit modes. Anecdotal evidence suggests the transit network experiences inefficiencies. Meetings with Hamilton transit planners indicate an inability by them to perform long-term transit planning studies.

This thesis documents the degree of downtown-orientation normal to Canadian transit networks and evaluates the transit network structure in Hamilton by using the methodology developed in chapter 3. Suggestions for network improvements are made based on the literature on transit network design and the findings from the application of the new methodology. After a discussion of the results of the application of the methodology to the case study, chapter 5 concludes this thesis and makes recommendations for future research on transit network performance monitoring

1.3: Case Study Background

Before continuing with the development of the research problem in chapter 2, this section examines the background of the case city chosen for investigation in chapter 4. The first subject in this examination is the City of Hamilton's unique geography. Located at the southwest corner of Lake Ontario, Hamilton is both a coastal city and a “mountain” city. The Niagara Escarpment (referred to as “the mountain”), which runs from the Niagara Peninsula to the Bruce Peninsula, virtually cuts the city in half (like a river would) because of a large difference in elevation. Located between the escarpment and Lake Ontario is “lower” Hamilton and what is called “the mountain” consists of “upper” Hamilton above the escarpment. A geographical map of Hamilton is presented in Illustration 1.1. The escarpment presents a unique challenge for transportation in Hamilton. The limited number of roads connecting lower and upper Hamilton creates congestion for auto-users. Illustration 1.2 demonstrates the steep slopes that transit vehicles face when crossing the winding roads of the escarpment, and Appendix 1 illustrates how few road connections there are between upper and lower Hamilton.

Illustration 1.1: Geographic Map of Hamilton, Ontario



(Source: author.)

Illustration 1.2: HSR Low-floor Diesel Bus Climbing Niagara Escarpment via Jolley Cut

(Source: author.)

Other unique geographical features exist in Hamilton because of the city's economic base. The City of Hamilton attributes eighty-five thousand jobs located within the city to what it calls the “advanced manufacturing sector” (City of Hamilton, 2006b). Of the top five employers in Hamilton, two are steel manufacturers Dofasco and Stelco (City of Hamilton, 2006c). Dependent upon Hamilton Harbour for raw materials, the steel industry is concentrated in a large portion of lower Hamilton adjacent to Lake Ontario. This is how the nature of Hamilton’s economy further contributes to the city’s unique geography. Also located along Hamilton's coast is the Queen Elizabeth Way (QEW) expressway. Large bridges connect east Hamilton to the

City of Burlington across Hamilton Harbor. Despite being a coastal city, industry and freeways almost entirely buffer Hamilton from Lake Ontario. Illustration 1.1 further illustrates this.

The municipal government of Hamilton has undergone considerable political and organizational change during the last decade. A 2001 municipal amalgamation created a single-tier municipal government called the City of Hamilton from the lower tier municipalities of the former upper tier Regional Municipality of Hamilton-Wentworth (City of Hamilton, 2006a). Six cities and townships have been amalgamated into the borders of the City of Hamilton, which now cover an area of over one thousand one hundred square kilometers (City of Hamilton, 2006a). Political leadership has been in transition during this period. The mayor of the former City of Hamilton lost a re-election bid in 2001 after amalgamation and the next two successors have each only lasted one term. Hamilton's fourth mayor in seven years, Fred Eisenberger, won the 2006 election (City of Hamilton, 2007).

Hamilton Street Railway (HSR) has a mandate to provide transit services in the urban portions of the massive area the City of Hamilton governs. The City currently uses a funding system known as “area rating” for certain services (City of Hamilton – Corporate Services, 2006). Municipal property tax payers pay different rates in different areas of the city in order to assign the costs of area-specific services to those areas of the city. Areas correspond to the pre-amalgamation lower-tier municipalities. Areas of Hamilton subsidize HSR expenses according to the annual kilometers of transit service offered within their respective boundaries. Former City of Hamilton residents pay a higher tax bill and subsidize HSR at a higher rate than suburban residents because of the disparity in service offered within the former City of Hamilton and the former suburban municipalities. In 2006 former City of Hamilton residents paid a 12% higher rate of property taxes than residents of the current City of Hamilton (Based on City of Hamilton

– Corporate Services, 2006) The issue of area rating has become highly contentious, (McGreal, 2007b) with political divisions drawn down geographic lines (McGreal, 2007a).

Despite these geographical and political obstacles, there are opportunities for HSR to attract multiple commuting markets. More of Hamilton's population is concentrated around its downtown core than in the average Canadian city. In 2001, the average distance from the city centre of a home in the Hamilton census metropolitan area was 8.9 km; nationally, the average distance was 14.0 km (Heisz & LaRochelle-Côté, 2005). The percentage of Hamiltonians who live a short distance from their workplace is consistent with the national average, and a higher than average percentage of jobs within the city are accessed by residents (Heisz & LaRochelle-Côté, 2005). It is these groups of commuters in particular to whom more competitive transit opportunities would appeal.

Before considering how HSR can appeal to new markets in the future, it is important to understand first how the system came to be where it stands today. The Hamilton Street Railway Company was exactly that once. Much like many North American transit systems, HSR once offered urban rail routes in a radial pattern originating downtown (Mills, 1971). As transit technologies evolved, the services HSR offered evolved as well. Trolley buses were used on the Barton, Cannon and King routes for decades, all of which were located in the lower city (DeLeuw & Cather, 1972). Diesel and natural gas fueled buses today serve almost all HSR routes. Recently HSR became the first transit service provider in Canada to purchase diesel-electric hybrid articulated vehicles (City of Hamilton – Public Works, 2007). HSR's fleet of public transit vehicles has grown and declined with time. Table 1.2 demonstrates how in 2005 there were fewer vehicles in the fleet and therefore available for service, than there were in 1970. The large decline in fleet size between 1991 and 1999 is discussed later. Table 1.2 reinforces what was mentioned earlier about the decline of investment in, and per capita ridership of, transit systems in Canada.

Table 1.2: HSR Fleet Size by Year

Year	Fleet Size
1970	223
1971	231
1973	263
1991	272
1999	185
2005	204

(Based on various sources.)

The combination of obstacles transit faces in Hamilton results in a number of negative outcomes. Geographic constraints impose restrictions on the potential roads HSR can use, thereby limiting route options. Frequent political change in recent years and the area rating system create volatility and resistance to change. The past decline of fleet size, service cutbacks, and infrequent changes to route patterns lead to various transportation markets that HSR could satisfy being untapped. In recent years ridership gains from modest service improvements have been offset by fare increases. To some extent the environment in which HSR operates contributes to its poor performance compared to provincial and national mode share averages, and the high degree of radiality of its present network structure.

As will be discussed in more detail later, a number of common elements tend to run through past transit studies done in Hamilton. Various reports have agreed that rapid transit is a good idea. Hamilton is of sufficient size and demand for HSR services is high enough to justify some form of improved transit system. Most often, a transit mode featuring rubber tires is suggested for the city. The proposed rapid transit system is often described as having two lines, one that travels along an east to west corridor in the lower city from McMaster University to Eastgate Terminal, and one that runs from downtown to the central mountain. In terms of the present bus network, past reports show that downtown tends to have good service, and other areas are well linked to downtown. Many routes from downtown to the mountain have more capacity than necessary, but those disparities in service levels are justified in past reports. Common themes in the history of HSR are summarized in Table 1.3.

Table 1.3: Themes in HSR History

●Geographic constraints to service patterns
●Area rating system of funding service
●Fleet and ridership decline
●Rapid transit would be good for and work in Hamilton
●Rubber tired rapid transit mode most appropriate
●Two rapid transit lines: a lower city east to west line and a mountain to downtown north to south line
●Most areas of city well connected to downtown by bus network
●Mountain to downtown bus routes over capacity
●Disparities in service levels are justifiable

(Based on various sources.)

The next chapter of this thesis will review the history of transit studies in Hamilton, as well as the literature on mid-sized cities, transit network design, performance monitoring in planning practice in general, and performance monitoring in transit in particular. The literature review will critique existing transit performance monitoring literature because by focusing on “system” variables like cost efficiency and productivity, not “network” variables like the accommodation of travel patterns, the literature fails to provide appropriate means by which to monitor and evaluate the performance of transit networks. Chapter 2 will further explain the problem of this thesis.

Chapter 2. Literature Review

This review moves from the general to the specific. First it examines literature on the place of transit systems in mid-sized Canadian cities, and then it examines the history of transit planning in Hamilton. Afterwards, this review examines literature on transit network design, performance monitoring in planning practice in general and in transit planning in particular. The first subject area for review is that of the place of transit in mid-sized Canadian cities. This section describes the context in which mid-sized Canadian transit systems operate. The second subject is the history of transit planning in Hamilton. This section reveals patterns in HSR history. The third subject area for review is that of transit network design. This part of the literature review informs discussion of the results of a case study of the methodology developed in the next chapter of this thesis. Moreover, knowing what the literature has identified as objectives for network design informs the next section of this literature review. The fourth section of this review is that of performance monitoring. This section determines what present methods of performance monitoring there are for monitoring the performance of transit networks at matching travel patterns.

2.1: Mid-Sized City Transit

The first subject area of this literature review is that of public transit in mid-sized cities. Various studies establish that transit in mid-sized cities is distinct from transit in small and large cities in the United States. Fielding, Brenner & Faust (1985) use cluster analysis to develop “peer groups” of transit systems in the U.S. based on their operating characteristics and several system performance measures. Transit systems in cities with populations of 77,000 to 500,000 are found to combine a set of operating characteristics distinct from groups of systems in cities with smaller and larger populations. Whereas operating speeds tend to be lowest for transit systems in cities with populations over 1,000,000 (fleet sizes ranged from 260 to over 2000), in the peer group of systems from cities with populations of 77,000 to 500,000, transit systems tend to operate at average speeds (20.6 kilometres per hour) and have approximately average fleet sizes (57).

Other studies confirm the uniqueness of mid-sized city transit based on findings about the customers of such systems. Miller (2000) says transit usage is low in mid-size cities compared to other modes. Walking is often a more competitive alternative in such cities.   Gaber, Gaber, Cantarero, & Scholz (1997) survey mid-sized transit providers in Nebraska and find that most systems charge low fares, are patronized highly by elderly and handicapped patrons, and feature a low public awareness level. These are some of the general characteristics that distinguish mid-sized transit systems from others.

There is evidence to suggest transit system size relates to performance. Labrecque (1998) defines “mid-sized” not in terms of population, but fleet size. A transit agency with 150 to 500 vehicles is considered medium. Labrecque defines optimal efficiency as the minimal amount of inputs used to produce the greatest amount of output. For transit, this means the cost of operating the service and the ridership generated. Labrecque finds that small transit agencies can operate as efficiently as large agencies do, but that mid-sized city transit systems are less efficient than small and large systems. Interestingly, Labrecque found that urban density is only marginally related to system performance.

In a comprehensive study of mid-sized city transit in Canada, Andreas (2007) laments the fact that transit gets little academic interest in Canada. Andreas finds that most academic work on transit in Canada compares Canadian transit systems with US systems, or deals with finance, the land-use and transportation link, or reviews transit agencies at a national scope. Andreas finds that from 1976 to 2007 no authors published research specifically about mid-sized city transit in Canada. He suggests the reason for this is that mid-sized city transit is often seen more as a "community service" than as a "viable part of urban transportation system." Mid-sized city transit is similar to small city transit in that respect, but at the same time, mid-sized city transit also has things in common with large city transit. Mid-sized city transit systems feature many routes, must serve low-density areas, and face growth pressures. The central problem facing mid-sized city transit agencies in Canada, Andreas finds, is that they face the same problems as large systems, but cannot produce the same results as large systems because they have much lower ridership and resources.

From case studies of seven mid-sized city transit systems across Canada Andreas (2007) finds some important lessons. One key finding is that many riders of mid-sized city transit systems are "captive." The literature often defines "captive riders" as non-automobile owning transit users (Vandersmissen, Thériault, & Villeneuve, 2004). This is probably an insufficient definition, as not owning an automobile does not force one to be a transit user. Other modes of transportation, like walking and cycling, are alternatives for those without automobiles. Nevertheless, captive riders are transit users who have less transportation choice. Other lessons Andreas learns include the fact that riders of mid-sized city transit want more service, mid-sized city transit systems often lack funding, and mid-sized city transit systems lack public or political support because those two groups do not consider it a key public service. Finally, Andreas also finds that mid-sized city transit systems often face obstacles from geography and urban form. Low-density development patterns, separated land uses, and geographic constraints like hills can limit route options in mid-sized cities.

As Table 2.1 summarizes, some conclusions can be drawn about transit systems in mid-sized cities. They feature unique operating characteristics and customer bases, face pressures due to urban and ridership growth, and enjoy fewer resources than do systems in larger cities. Most importantly, in terms of efficient performance and total ridership transit systems in mid-sized cities provide poorer outcomes than do systems in larger cities. Such systems face a unique set of obstacles that require a unique set of solutions.

Table 2.1: Key Facts about Transit in Mid-Sized Cities

●Distinct characteristics
●Low public awareness and support
●More “captive” riders
●Less efficient performance
●Lower ridership than large cities
●Growth pressures
●Less resources than large cities

(Based on various sources.)

2.2: Past Hamilton Transit Reports & Studies

The second subject area of this literature review is the history of transit studies in Hamilton. Despite declining attention to Canadian transit systems in academic literature, there is an established history of municipal transit studies in Hamilton. Studies range in date from the 1970s to the 2000s and in purpose from annual reports to route planning analyses to detailed rapid transit implementation studies. Table 2.2 lists notable reports and studies completed in the last 37 years.

Table 2.2: Past Hamilton Transit Reports & Studies

Year	Report Title	Main Findings
1970	Hamilton Area Rapid Transit Study: Physical Feasibility Report July 1970	Recommends use of rubber-tired rapid transit mode for Hamilton
1972	Hamilton Area Rapid Transit Study: Phase Two	Ridership decline and need for reorientation of mountain routes
1974	Hamilton-Wentworth Regional Transit Assumption Study	Ownership assumed by Regional Municipality
1981	Final Rapid Transit Report	Provincial funding opportunity for Rapid Transit development
1991	HSR Annual Report	Significant service cutbacks begin
1996	Regional Transportation Review Transit Plan	Two radial rapid transit lines recommended
2000	Business Plan Task Force Report	Area rating system a political obstacle to transit system improvement
2001	Business Plan	Service disparities justified by future growth of city

(Source: author.)

Major findings from past studies are described below. One early report, titled “Hamilton Area Rapid Transit Study: Physical Feasibility Report July 1970” by DeLeuw Cather Consulting Engineers investigates the physical feasibility of implementing a rapid transit system within the geographical constraints of Hamilton. The report finds at least six feasible route alignments for a rapid transit system linking the Mountain, the CBD, and the industrial area along Barton Street. The report recommends the use of a rubber-tired rapid transit mode for Hamilton because of the better adhesion rubber tires offer during the climbing of slopes like the escarpment (DeLeuw Cather, 1970).

The second phase of the DeLeuw Cather report, completed in 1972, studies the Hamilton bus network and travel patterns within the city. Despite population and employment growth within the city, the report finds that transit ridership declined by nine percent since 1967. The report finds some issues with the planning of transit routes. Though the report finds that most areas of the city were well connected to downtown, route change recommendations are made for industrial and suburban areas. The report found that some portions of mountain routes were underutilized relative to the capacity offered and therefore required a reorientation. The report recommends reorienting the mountain-area network away from a grid-like network towards a network featuring a high-capacity line running from north to south from downtown that receives feeder routes from locations on the mountain (DeLeuw Cather, 1972).

The second phase of the report suggests that limited stop express transit service was not justified in Hamilton at the time. Many trip lengths were under 30 minutes in duration, so travel time savings from limited stop service would be minimal unless right-of-way upgrades were made as well. However, the report suggests that right-of-way upgrades for transit were not justifiable at the time either. The maximum flow of buses in one direction per hour anywhere in the city was 40; the report suggests this number was not high enough to justify dedicating a lane of traffic to the exclusive use of transit. As for travel patterns, the report documents the flow of passengers between areas of the city in 1971 (DeLeuw Cather, 1972).

A report written in 1974, the Hamilton-Wentworth Regional Transit Assumption Study, documents the transfer of HSR ownership from the lower-tier City of Hamilton to the Regional Municipality of Hamilton-Wentworth. The report describes the funding sources, operational efficiency, and service levels of HSR in 1974. Service levels were high, but by this time there had still been no progress on the development of a rapid transit system (Transit Technical Committee, 1974).

After the regional municipality assumed ownership of HSR, another rapid transit study was undertaken. The final report of this project, which was completed in 1981, suggests the city had reached its best opportunity for the implementation of a rapid transit system yet. After studying five different transit modes and 51 possible route alignments, the report recommends the use of ICTS (Intermediate Capacity Transit System) technology to link downtown Hamilton and the mountain. An example of ICTS technology is the Scarborough RT line in Toronto. A Crown Corporation of the Province of Ontario developed ICTS technology as an economic development opportunity. The report suggests ICTS technology is ideal for Hamilton for operational reasons and because of a proposal by the Province of Ontario to fund 90% of the construction and 100% of the operation of the system until it reaches its ridership goals. Hamilton taxpayers would be responsible for $14 each for ten years and operational costs once the system reached its ridership goals (Metro Canada Ltd, 1981).

The report recommends building a system composed of five stations. Stations located at Mohawk Rd and Upper James St, Fennel Ave and Upper James St, and St. Joseph's Hospital would serve the mountain and the escarpment areas, and stations located at King William St and John St N, and King St W and MacNab St would serve downtown (see Appendix 2 for map). The study also describes how the bus network could be redesigned to feed into individual rapid transit stations. The study suggests that the proposed rapid transit system conformed to municipal official plans, economic development plans, and all of the past transit studies about Hamilton. Considering the provincial funding offer, the proposed rapid transit system was a great opportunity for the city. In fact, the authors of the 1981 study surveyed Hamilton residents and found that 61% favoured the implementation of the system (Metro Canada Ltd, 1981). Contemporary Hamilton transit planners suggest the lobbying of a citizens group opposed to the system was particularly important in the abandonment of the plan.

The 1991 HSR Annual Report was not on its own merit an important study. Apart from annual financial details, all the report describes is how HSR was implementing a plan to provide more customer amenities across Hamilton. In 1991 dozens of shelters, benches, and landing pads were installed. What this report is significant for, however, is the documentation of how significant transit service reductions began due to an economic downturn in Hamilton. Not only did the city have trouble with its budget due to the macroeconomic changes happening in Canada, but also HSR operating costs were increasing. Council decided to cut transit expenses in 1991; almost all routes in the HSR network route saw changes or service reductions. This is reflected in the large decline in the size of the HSR fleet after 1991 as shown in Table 1.2 (Hamilton Street Railway, 1991).

The 1996 Hamilton-Wentworth Regional Transportation Review Transit Plan, a more upbeat study, describes an “ideal” higher order transit network. The report indicates an ideal rapid transit network for Hamilton would consist of radial rapid transit lines from downtown to Eastgate Terminal in east Hamilton, Limeridge Mall Terminal on the mountain, and McMaster University in west Hamilton. Appendix 5 provides an illustration of these locations. The plan suggests two BRT lines could be developed along with a restructuring of feeder bus routes. The report suggests that its vision of rapid transit in Hamilton had by then become an old idea, but suggests that the network structure recommended in past reports was still the ideal higher order transit network structure for the city (Delcan Corp, 1996).

After the municipal amalgamation in 2000, the next HSR Business Plan describes how HSR could obtain a more competitive position in the transportation market. The plan suggests HSR should provide more limited stop service, use transit signal priority measures, provide more information sources for customers, allow more fare payment options, implement a program to continually improve stop amenities, and practice better maintenance. The plan says disparities in service levels between different areas of Hamilton are justified because ridership was much higher in some areas than others, but adds that opposition to tax increases in some areas of the city has some role in limiting the amount of service offered there (Hamilton Street Railway, 2000). In other words, the area rating system had become a political obstacle to service improvements in some areas of Hamilton.

The 2001 HSR Business Plan suggests that service levels had not kept up with ridership levels. Modest ridership growth combined with service cutbacks had lead to some parts of the city experiencing passenger overloads and schedule adherence problems. The report describes route adjustments to overcome the operational issues experienced in 2001. For example, the report recommends moving the limited stop express route, known as Beeline, from internal neighbourhood streets to arterial roads, as well as changes to turn some long routes in "short turn" routes where some trips do not serve the entire length of the route. The most notable suggestion in this report, however, is made when the authors suggest excess capacity exists on some mountain to downtown north to south routes and some service from those routes could be redeployed to the east to west routes in the lower city that experience operational issues. The report says, however, that the growth of employment and retail land uses on the mountain justifies the continued over supply of mountain to downtown routes at the expense of lower city routes (Hamilton Street Railway, 2001).

As mentioned earlier, a number of common elements run through past transit studies done in Hamilton. Various reports agree that rapid transit is a good idea. Hamilton is of sufficient size and demand for HSR services is high enough to justify some form of improved transit system. Most often, a transit mode featuring rubber tires is suggested for the city. The proposed rapid transit system is often described as having two lines, one that travels along an east to west corridor in the lower city from McMaster University to Eastgate Terminal, and one that runs from downtown to the central mountain. In terms of the present bus network, past reports show that downtown tends to have good service, and other areas are well linked to downtown. Many routes from downtown to the mountain have more capacity than necessary, but those disparities in service levels are justified in past reports. Table 1.3 summarizes the common elements found in HSR history and past studies.

2.3: Transit Network Design Objectives

The third subject area for review is that of transit network design objectives. A transit network is a set of connected transit routes that are coordinated to efficiently integrate services across a geographic area. This definition implies intentional design. A transit route is the infrastructure and service provided by transit vehicles on a fixed schedule. Routes can follow fixed travel paths or deviate (Vuchic, 2005).

Vuchic (2005) says there are three objectives for transit network design, all of which correspond to the three groups of actors concerned with public transit. In his words, the first objective is to “perform maximum transportation work.” This objective, which implies attracting riders and carrying them from their origin to destination, is the desired objective of customers. A second objective is to “achieve maximum operating efficiency.” This objective, which implies minimizing the cost of providing the required services, is the desired objective of transit service operators. A third objective, to “create positive impacts,” which implies that transit service can create positive “spill-over” effects, composes the desired objective of the community. These three groups of objectives are influenced by the design of the transit network. Determining upon which routes to operate transit vehicles and when to schedule their trips to achieve these outcomes is the problem of transit network design.

There is a rich and decades old research literature on this topic. The field has two important components, literature that focuses on determining the ideal geometric shape of transit networks, and literature that focuses on determining the ideal methods by which to design transit networks. Methods of transit network design range from ad hoc planning to sophisticated computer-based mathematical algorithms designed to “optimize” the flow of passengers through an abstractly represented “network.” A good place to start, however, is with literature discussing ad hoc transit planning.

Dubois, Bel, & Llibre's (1979) ad hoc bus network design method involves three stages: choosing a set of streets for service, choosing a set of bus lines on those streets, and determining optimal frequencies. The frequency of a transit route refers to the number of vehicles passing by a point along the route during a particular time period. At the time of their publishing, Dubois et al. suggested that step two was rarely dealt with in the transit literature because there were no agreed objectives for the evaluation of a route system. However, they do suggest six principles they consider important in network design. Routes should offer direct trips (following the shortest path) between locations when possible, fewer routes are preferable to more (though they suggest no reasons why), routes should travel in direct paths (instead of diverting mid-route to provide access), routes should serve important destinations, and the transit agency should allocate the minimum number of vehicles necessary to each route (to ensure efficiency).

Through detailed case studies of more than a dozen metropolitan areas in Canada, the U.S., and the U.K., Schneider (1981) recommends a number of objectives in designing transit networks. Schneider finds that downtowns have become only one of many key destinations for transit, since cities have become polycentric. In fact, Schneider finds that non-rail transit systems are largely oriented towards downtowns only. In Schneider's words, “few [systems] have been reoriented to providing good service to non-downtown destinations.” Transit systems in Canada, the U.S., and the U.K. have a declining share of the urban transportation market because monocentric systems do not fit the travel patterns within polycentric cities. Schneider recommends a network structure of express service between key centres and downtown, good local service to activity centres, and good “internal circulation service” in high-density areas.

Schumann (1997) makes the link between travel patterns and urban form central to his understanding of transit network design objectives. In his opinion, since contemporary urban form has become polycentric, first with the decentralization of residential land uses and then with the decentralization of employment land uses, individuals have started to travel from the inner city to suburbs and from suburbs to suburbs. Though his article primarily involves the U.S. environment, the lessons are in principle applicable to Canada, since similar forces of decentralization towards polycentricity are at work in Canada. Schumann suggests that CBDs should remain the focus of transit systems in the polycentric city because they are the cultural core of the city, are major employment centres, and feature specialized retail functions, but other major activity centres within the city should have good transit service too. The transit system should connect all trip-attracting land uses like universities, sports centres, employment centres (government, commercial, and medical), interurban transportation connections, airports, and regional shopping centres. Centres of trip-attracting activity, like those listed, should be the centres of “transit villages” which feature a hierarchy of land uses starting with office and retail then featuring a gradient of residential density towards single family homes.

Schumann feels the most important objective when designing the system is to provide “customer-oriented transit.” Agencies should develop services for multiple markets. In other words, services should connect many different destinations, involve easy transfers, and have an integrated fare system. Transit systems should use different modes to match demand when it varies from route to route and hour by hour. When transit agencies practice “customer-oriented transit” in “transit villages” Schumann says it is possible to attract many markets to transit. In effect, having routes that only focus on radial service to and from downtown is not sufficient to attract all the potential transit customers in a polycentric city.

In particular, Schumann says “transit services, coordinated by timed-transfer scheduling, should be arranged in a tiered hierarchy.” Transit agencies should place multimodal regional connections featuring high capacity lines at the top of the hierarchy, then feeding into those should be less popular “primary trunk routes” of the same character as the regional lines, and then “feeders and shuttles” that move passengers from communities and local streets to transit centres should serve the bottom of the hierarchy. Regionally radial lines traveling to the CBD should pass through the CBD to attract more travelers and lower-capacity bus routes should feed rail systems.

A detailed study of objectives for designing individual routes within a network is Penn's (1995) Transit Cooperative Research Program Synthesis of Transit Practice, “Bus Route Evaluation Standards.” One goal of the project was to survey U.S. and Canadian transit agencies to determine what criteria they use in practice to evaluate bus routes. Penn finds there are many standards used for route design, though some are used much more than others. Route design standards include: coverage (geographic access), spacing (distance between routes), limiting deviations and branches (to prevent undue travel time delays), system design considerations (such as whether a route fits a timed transfer system), reduction of duplication, network connectivity (which is the connection between the route and *all* other routes – i.e. can a route make the whole network greater than the sum of its parts), route directness, proximity to trip generators, and bus stop location and spacing. Schedule design standards include: level of service, character of service, number of standees, load factors, headways, and span of service. Penn also finds that transit agencies use economic and productivity standards, service delivery standards, and passenger comfort and safety standards. Interestingly, Penn finds that medium sized systems (defined as having a fleet of 201 to 500 vehicles) had the highest average scores on all of the factors.

In a study of the transit system in Monterrey, Mexico, El-Hifnawi (2002) models before and after scenarios to measure potential gains from introducing “cross town” transit routes. In this study, the goal was to evaluate whether introducing cross town routes that complement radial routes can help facilitate non-downtown oriented travel. Ninety-five of Monterrey's one hundred and fourteen bus routes traveled into or through downtown on one end before a route restructuring in 1993. Rather than expand the fleet to add non-downtown oriented routes Monterrey reoriented service from radial routes to new “cross town” routes that did not travel to downtown. El-Hifnawi measures route-level financial productivity gains and losses, as well as passenger utility benefits, resulting from ridership changes before and after the network restructuring. The results of the evaluation show that after the route restructuring vehicle operating cost remained the same, but users had less travel time cost and saved some fares from eliminating previously necessary transfers. The operating speed of the system increased slightly because congestion decreased because some people switched from auto to bus in the cross-town scenario. The only loses under the cross town route scenario were reduced fare collection due to the eliminating of some transfers, and some increased waiting time for some users of radial routes. Thus, El-Hifnawi recommends the use of non-downtown oriented transit routes to facilitate travel patterns that does not originate or terminate in downtowns.

Thompson & Matoff (2003) explain the difference between radial and multidestinational transit systems in their study. According to them, the typical U.S. transit system features "radial" routes, meaning routes connect the suburbs in lines, but on such systems passengers traveling elsewhere other than downtown require indirect travel. On the other hand, "multidestinational" systems offer travel across metropolitan areas. In their words,

> The concept of the multidestinational approach is that a network is designed of fixed routes that interlock with each other so that passengers can reach most regional destinations with one transfer. Transfers are "timed," meaning that they occur at nodes where several routes converge. Buses and trains on all routes arrive or depart at the same time, two to four times an hour (Thompson & Matoff, 2003).

Another type of network orientation is grid-based service, but Thompson & Matoff focus solely on radial and multidestinational. Thompson & Matoff find that although multidestinational systems carry fewer passengers to downtowns than do radial systems, the overall efficiency, effectiveness, and equity of multidestinational systems is greater than that of radial systems. Based on their review of the literature, Thompson & Matoff conclude that transit routes remained radial in U.S. cities after World War II based on two beliefs. The first is that

CBD centric transit systems can stimulate investment in the CBD, and the second is that there is not enough demand for travel to suburban destinations to justify multidestinational routes

The advantages of multidestinational systems are numerous, Thompson & Matoff say. Radial networks avoid transfers by providing many routes that focus on only one destination (the CBD), but that pattern of service limits the potential for connections between non-downtown destinations. Multidestinational systems try to stimulate ridership to non-downtown locations by creating opportunities for transfers between non-downtown destinations. Of course, this does rely on the premise that in designing a multidestinational system the non-downtown ridership gained is higher than the downtown-oriented ridership lost due to any extra transfers. In their study, Thompson & Matoff (2003) compare the performance of radial and multidestinational type networks using performance data from nine U.S. metropolitan from 1983 to 1998 and control for demographic variables. They conclude that variations in network orientation help explain variation in system performance. Multidestinational systems perform better at passenger miles delivered per capita, passenger miles per vehicle mile, and operating and capital cost per passenger mile.

In a study that geo-correlates employment and transit service in Los Angeles metropolitan area, Modarres (2003) concludes that transit service in that region has not mirrored land use change. The region developed a polycentric pattern of employment land uses, but bus routes operate in radial patterns too often. Good access to transit is only present in radial corridors that travel to and from downtown, whereas employment has spread across the entire metropolitan area. Transit use has been low and declining in Los Angeles since a decentralization of employment accelerated in the 1950s, but transit service in Los Angeles has not changed to match the land use change. Modarres recommends that polycentric metropolitan regions like

Los Angeles should offer a “hierarchical public transit system” and continually monitor their networks for efficiency at connecting people to jobs. Transit agencies should adapt networks to fit the polycentric employment structure with interregional, regional, and local services in a tiered hierarchy. Transit agencies should offer express services between regional centres, compliment them with major routes in other corridors, and local routes that connect residential areas to the closest regional centres, and thereby the entire network.

In a multivariate analysis of dozens of metropolitan areas in the U.S. ranging in size from 500,000 to over 10,000,000 in the years 1990 to 2000, Brown & Thompson (2007) investigate the relative productivity of radial and multidestinational transit networks. Brown & Thompson operationalize their two key variables as follows. They define productivity as the number of passenger miles traveled on the system per vehicle mile provided (also known as “service efficiency,” “passenger load factor”). They characterize “system orientation” by the percentage of routes in a network that pass through a CBD. A higher rate indicates a more radial network structure, whereas a lower rate indicates a more multidestinational network structure. Whereas across the U.S. productivity decreased from 1990 to 2000, Brown & Thompson use a multiple regression analysis to show that those productivity losses were not statistically significantly attributable to multidestinational network structure. In fact, their results show a positive relationship between multidestinational network structure and productivity. If a transit agency modifies its network from having seventy percent of routes travel through the CBD to only twenty percent it is possible to achieve a productivity gain of twenty to thirty percent. Though these results relate to large cities, it remains evidence in defense of multidestinational network structure.

As Table 2.3 summarizes, this review shows that there is considerable agreement about transit network structure. It is important to design transit network structures based on urban form because of the relationship between urban form and travel patterns. Schneider (1981), Schumann (1997), and Modarres (2003) all make this point. When cities have a polycentric urban form it is important to design networks to be multidestinational. Indeed, Schneider (1981), Schumann (1997), El-Hifnawi (2002), Thompson & Matoff (2003), and Modarres (2003) all agree that transit networks in polycentric cities should feature a tiered hierarchy of services serving major destinations including but not limited to downtown ranging from high capacity direct routes between major destinations to feeder routes and local circulation routes as the neighbourhood scale will allow most passengers to arrive at most major destinations with just one transfer. Most importantly, Brown & Thompson (2007) find evidence to suggest that multidestinational network structure better attracts passengers than radial network structure.

Table 2.3: Key Areas of Agreement about Transit Network Structure

●Design network structure based on urban form
●Multidestinational structure superior to monocentric structure in polycentric cities
●Connect key destinations, including but not limited to downtown
●Hierarchy of services
●Multidestinational network structures perform better than radial network structures

(Based on various sources.)

2.4: Performance Monitoring in Planning Practice

The third subject area of this literature review is that of performance monitoring. This section examines the concept of performance monitoring in general, in planning practice, and in transit planning in particular. The performance monitoring literature is vast and detailed. Talen (1996) concludes that performance monitoring is an important part of planning. Planners need to assess the impacts of their plans to justify the existence of the profession and its interventions and to assess their effectiveness. Before monitoring, it is important to determine what it means to be successful, however. Seasons (2003b) agrees with Talen. Seasons concludes that planners need to monitor performance to avoid wasting resources, missing opportunities, and damaging the reputation of the profession. Thus, the goal of performance monitoring – determining effectiveness – is intrinsically important and for the continued justification of the existence of planning.

Contant & Forkenbrock (1986) argue that evaluating if policy changes are effective is key to performance monitoring. They surveyed planners and found this activity to be among the most common performed within the profession. The relevance for transit is also clear in this case. Monitoring changes to routes, fares, service levels and other variables is important to evaluating a network. Contant & Forkenbrock also found that planners are taught plan evaluation methods in planning school. They found that methods taught in planning schools were increasingly converging with the methods needed in planning practice. Yet despite performance monitoring being important to planning and planners having the knowledge necessary for it, there is evidence that planners are often unable to do so.

Seasons (2003b) conducted face-to-face interviews with senior staff from fourteen municipal planning departments in Ontario, Canada and found that staff members are forced to settle for limited monitoring rather than ideal levels because of limits in resources, a lack of means to collect data on the proper indicators, political obstruction, organizational culture, and other reasons. Seasons finds that planners "satisfice." In other words, they make due with the best performance monitoring they can obtain. Patton (1986) agrees and says planners need to quickly perform methods of analysis due to resource constraints. Thus, a conclusion that can be drawn from this literature review is that planners need quick methods of analysis to help them monitor the performance of their activities to planning objectives more closely.

The notion of performance monitoring contains two concepts. The first concept is "performance" and the second is "monitoring." Performance monitoring assumes there are differences between "good" and "bad" performance and that "indicators" can measure these differences (Fielding, 1992). Rossi, Freeman, & Lipsey (1999) define monitoring as "the systematic documentation of aspects of performance that indicate whether or not activities are functioning as intended or according to some appropriate standard." Seasons (2003a) defines "monitoring" as "a continuous evaluation or assessment of activities in policies, programs, processes, or plans. This involves the collection and interpretation of data on a regular basis." These authors define monitoring as an evaluation of activities. Monitoring is done by assessing indicators, Seasons argues:

> Indicators … perform many functions: description, simplification, measurement, trend identification, clarification, communication and instigation … Indicators provide the foundation of information that is monitored on a continual basis to identify trends and patterns, and is then analyzed through a formal process of evaluation (2003a).

Thus, a definition for performance monitoring is the collection of data to identify and measure trends in order to evaluate whether planned activities are functioning as intended to. The relevance of performance monitoring for transit is clear from this definition. Schumman (1997) talks about the need for customer focused transit service. Vuchic (2005) says the customer objective of transit use is to obtain the maximum “transportation work” from the network. Maximum transportation work is achieved when the transit service supplied by the network allows for the closest facilitation of passenger trips from origins to destinations. The most important aspect of performance monitoring for transit should involve determining whether transit systems actually accomplish the goal of moving people from location to location. More precisely, transit network performance monitoring can be defined as the collection of data to identify and measure the flow of passengers within a set of coordinated transit routes in order to evaluate whether the planned provision of service allows for the maximum facilitation of passenger trips.

2.4.1: Public Transit Network Performance Monitoring

The next subject for this review is that of performance monitoring for transit, and for network performance in particular. In their own review of the literature on performance monitoring in bus transit operations, De Borger & Kerstens (2000) say two concepts compose “performance,” namely “efficiency” and “effectiveness.” De Borger & Kerstens say there is disagreement about what the best variable is to measure performance in transit, but there are some areas of agreement about which variables to include. The reason for the disagreement on the best measure of performance is that there is no agreement on what the goal of a transit agency should be. Various authors have suggested public welfare maximization, cost-efficiency, distributive justice, employment provision, or productive output as the ultimate goal of transit agencies. What the literature does agree on, De Borger & Kerstens say, is that the performance monitoring variables that are used should be based on an empirical reflection of transit supply and demand attributes. In fact, De Borger & Kerstens say performance should be evaluated "within the framework of a joint demand-supply equation system."

Fielding, Babitsky, & Brenner (1985) identify seven important indicators for transit performance monitoring in the U.S. They find that U.S. regulations have been effective at ensuring transit agencies report the same indicators, thereby making cross-agency comparisons possible. Fielding et al. perform a number of statistical analyses on the data U.S transit agencies report annually to the Federal Transit Administration (FTA) and find the following variables are most reliable for cross-agency performance comparisons:

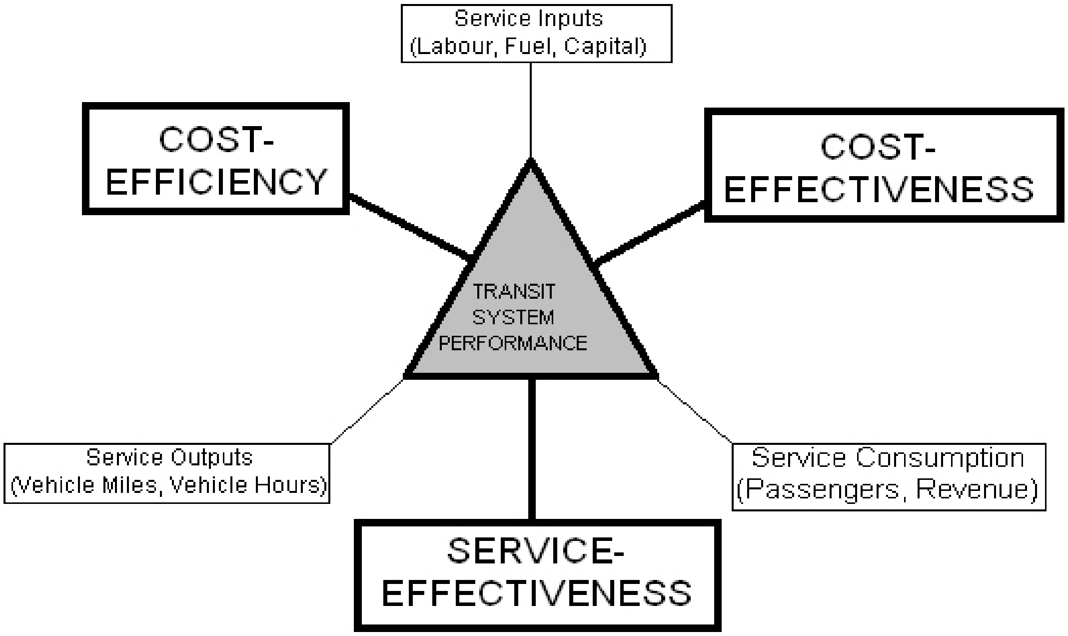
Table 2.4: Cross-Agency Applicable Performance Indicators

Concept Measured	Indicator
●Productive Output	●Revenue Vehicle Hours per Operating Expense
●Service Utilization	●Boardings per Revenue Vehicle Hour
●Revenue Generation	●Operating Revenue per Operating Expense
●Labour Efficiency	●Total Vehicle Hours per Employee
●Vehicle Efficiency	●Total Vehicle Miles per Peak Period Vehicle Required
●Maintenance Efficiency	●Total Vehicle Miles per Maintenance Employee
●Safety	●Total Vehicle Miles per Accident

(Based on Fielding et al, 1985.)

Brown & Thompson (2007) say the FTA encouraged the development of transit performance monitoring in the 1970s and 1980s in order to determine if planners or external factors were responsible for ridership declines. Researchers agreed that three concepts should be involved in transit performance monitoring. Fielding et al. (1985) graphically represent the conceptual relationship between the transit performance indicators developed in the 1970s and 1980s. Their diagram resembles Illustration 2.1:

Illustration 2.1: Transit System Performance Framework



(Based on Fielding et al, 1985).

According to this conceptual framework, transit performance is composed of three factors. Transit systems are most appropriately evaluated in terms of cost efficiency (cost per passenger carried), cost effectiveness (cost per unit of service provided), and service effectiveness (utilization per unit of service provided). From Illustration 2.1 it is apparent how closely related transit efficiency and effectiveness are. However, there is a problem with performance monitoring using indicators of this variety.

While these indicators aptly measure transit system performance *as an organization*, they do not measure transit system performance *as a transportation network*. These measures do a good job of describing the overall quantity of passenger flows relative to inputs, but they do not measure the relationship between passenger flows and the structure of transit supply within the network. Passenger movement (service effectiveness) is measured in direct relation to overall service inputs and service outputs, not the structure of transit supply within the network. Existing transit performance indicators are descriptive statistics that do not explain *why* a route or a system performs how it does. The question that remains unanswered by these indicators is "How well does the transit system perform at moving passengers from origin to destination?" The important aspect of transit system performance which is left out by the *organizational* focus of these previous authors is the evaluation of how well transit networks "fit" travel demand *as networks*. Given the definition of transit network performance monitoring used above, these indicators fall short of fulfilling their goal.

Fielding, Glauthier, & Lave (1978) suggest a simple method of measuring ridership per route to perform this task. If ridership is counted as high on a route then it is considered to "fit" travel patterns. No real criteria for "high" are described by Fielding et al. (1978), however. This method is a simplification at best, and inaccurate at measuring network performance at worst. The authors admit that this method is an abstraction of the ideal way to determine if routes match travel patterns and suggest that transit planners would ideally want to know to where and from where passengers actually flow within the network. Yet, they found that at the time of publishing few transit agencies in the U.S. actually monitored the flow of passengers from origin to destination. If this pattern continued to this day in this country, then it would be consistent with and reinforce what Seasons (2003a, 2003b) says about performance monitoring in municipal planning. If appropriate methods to measure the performance of a transit network at accommodating the flow of passengers do not exist then there is a serious gap in the literature on transit performance monitoring. Developing such a method is thus an important step in enhancing the performance of public transit.

2.5: Conclusions of Literature Review

To summarize, the purpose of this literature review is to research four subject areas. The first subject area for investigation is mid-sized city transit in Canada. The second subject area for investigation is that of the history of transit studies in Hamilton. The third subject area for investigation is that of transit network structure design. The fourth subject area for investigation is that of performance monitoring in public transit. Findings from this literature review suggest some conclusions can be drawn.

The first conclusion that can be drawn is that transit systems in mid-sized Canadian cities face challenges. They have low ridership, low resources, and low planning capacity, yet face pressures to grow and often feature mismatches between network structures and travel patterns. Downtown areas tend to be over serviced by mid-sized transit systems relative to the flow of travelers within mid-sized cities, which is perhaps some of the source of their poor performance relative to systems of other sizes.

A number of common elements tend to run through past transit studies done in Hamilton. Various reports have agreed that rapid transit is a good idea. Hamilton is of sufficient size and demand for HSR services is high enough to justify some form of improved transit system. Most often, a transit mode featuring rubber tires is suggested for the city. The proposed rapid transit system is often described as having two lines, one that travels along an east to west corridor in the lower city from McMaster University to Eastgate Terminal, and one that runs from downtown to the central mountain. In terms of the present bus network, past reports show that downtown tends to have good service, and other areas are well linked to downtown. Many routes from downtown to the mountain have more capacity than necessary, but those disparities in service levels are justified in past reports.

This review finds agreement in the literature that transit networks should be structured based on the urban form of the city they serve. Transit networks should be coordinated to provide multidestinational service when cities feature polycentric urban form and polycentric travel patterns. Areas other than downtowns need to have high quality transit service as well. Yet, existing performance monitoring measures designed for transit planning do not focus on these relationships. Most existing performance monitoring measures focus on assessing "*organizational*" efficiency and effectiveness, rather than assessing "*network*" performance. Thus, another conclusion is that existing transit performance monitoring measures do not provide transit planners with all the tools they need. Transit planners need to judge whether the systems they plan adequately provide the multidestinational services that are necessary in contemporary Canadian cities. How then can the performance of network structures be measured? This thesis now develops a methodology by which transit planners can monitor the performance of transit network structures.

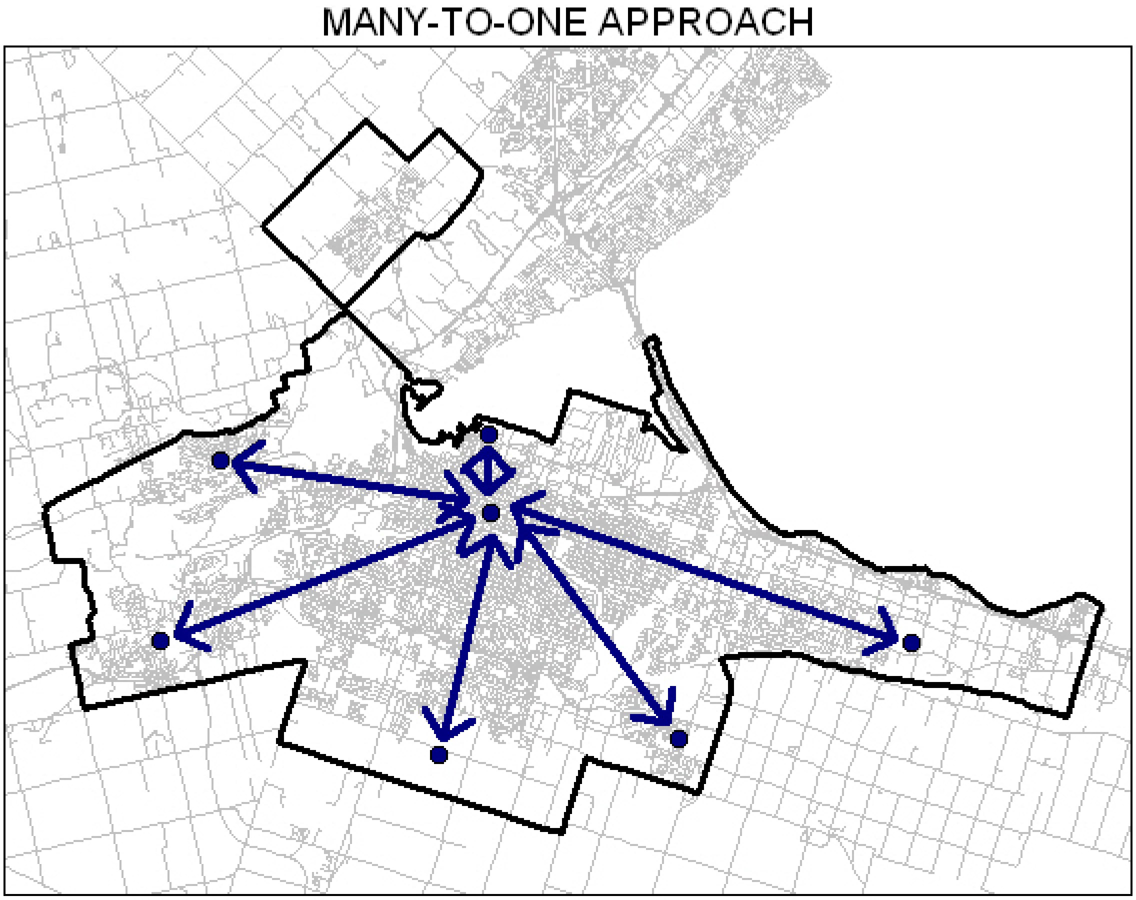
Chapter 3. Methodology

3.1: Methodological Framework

Since the literature on performance monitoring for transit does not provide adequate methods to evaluate the performance of network structures, a new method is developed in this chapter. In their review of the transit performance monitoring literature De Borger & Kerstens (2000) say that transit performance monitoring variables should be based on an empirical reflection of transit supply and demand attributes. They say transit performance should be evaluated “within the framework of a joint demand-supply equation system.” Transit network performance monitoring is defined as the collection of data to identify and measure the flow of passengers within a set of coordinated transit routes in order to evaluate whether the planned provision of service allows for the maximum facilitation of passenger trips.

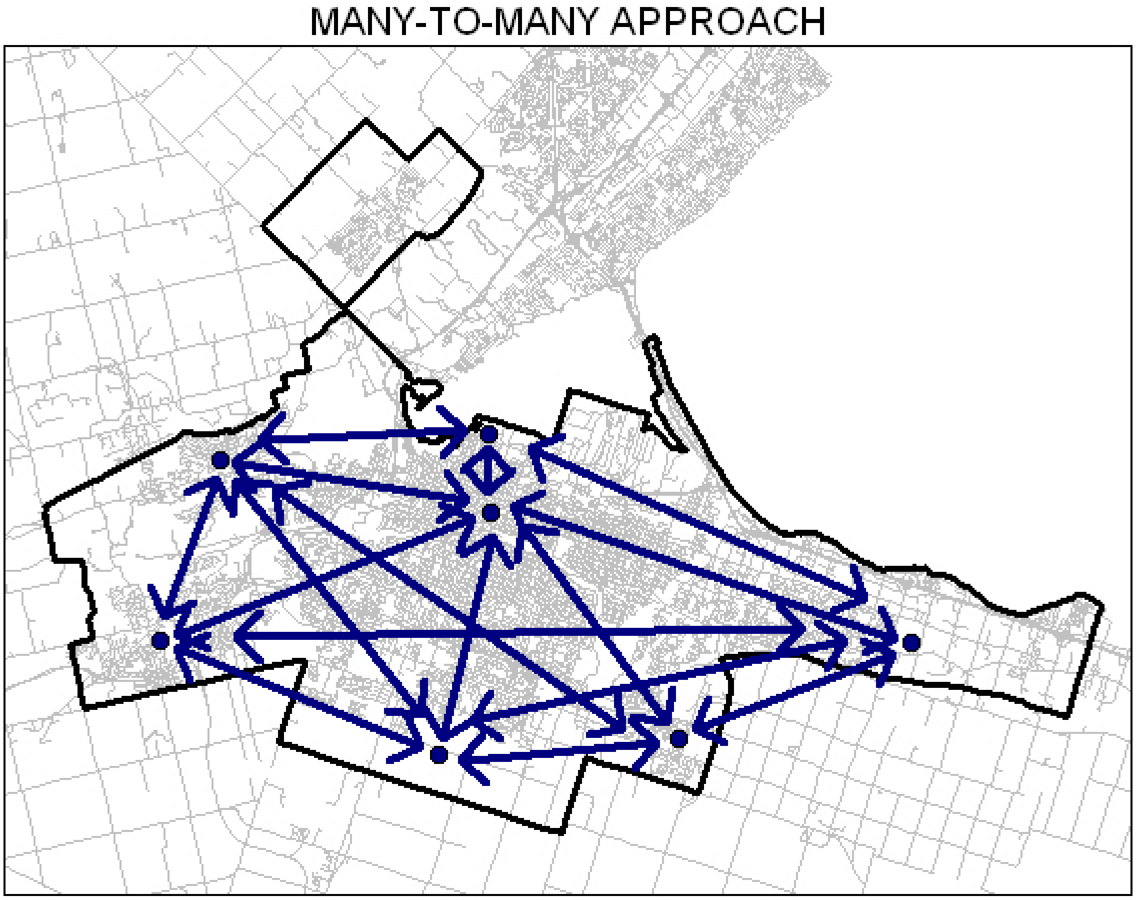
Therefore, the transit network structure performance monitoring methodology developed below considers the relationship between transit services provided by subject agencies and transit services demanded by passengers. Two approaches are used to examine this relationship. The first method, which evaluates travel patterns using a “many-to-one” approach, is titled Downtown Network Structure Tendency Estimation, or “DNSTE”. The transit network design objectives literature agrees that the relative radial or multidestinational structure of a transit network is an important variable in network performance, therefore this method determines the tendency of Canadian transit networks to be structured towards downtown areas by comparing the number of routes within a network that pass through downtown areas to the total number of routes in a network. This method is useful for revealing a baseline rate of network downtown orientation tendency. The second and more important method, which evaluates transit network structure performance using a "many-to-many" approach, is titled Supply and Demand Based Transit Service Allocation, or "SDBTSA". Illustrations 3.1 and 3.2 demonstrate the approaches to network evaluation used in these two methods, and Illustration 3.3 demonstrates the conceptual framework used to guide the collection and analysis of data in the SDBTSA process.

Illustration 3.1: Many-to-one Approach



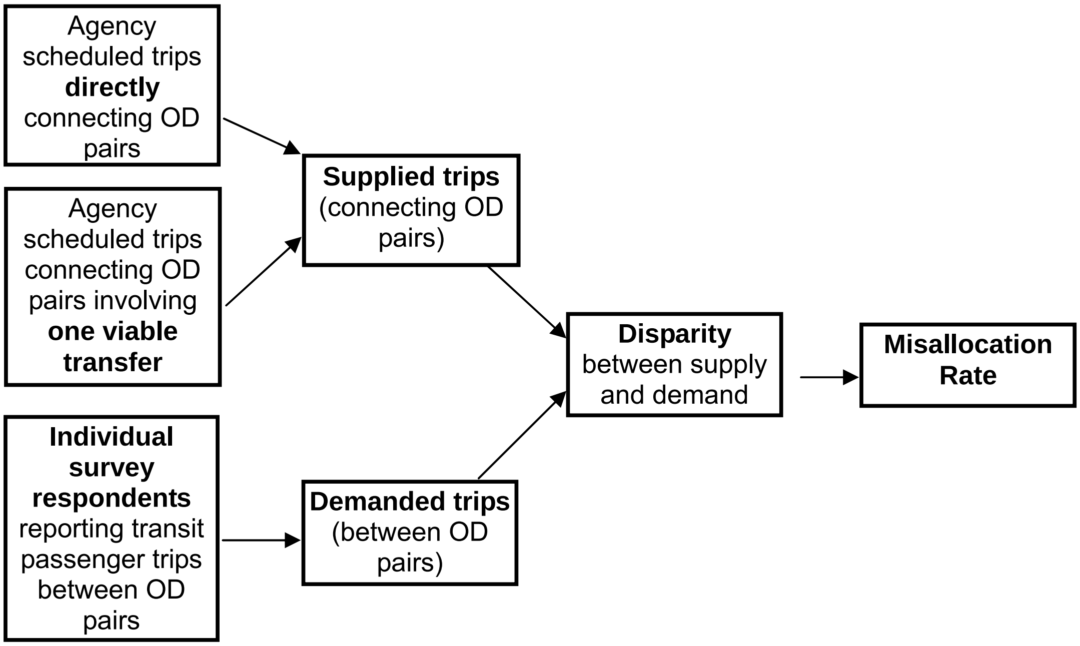
(Source: author.)

Illustration 3.2: Many-to-many Approach



(Source: author.)

Illustration 3.3: Methodological Framework for Supply and Demand Based Transit Service Allocation (SDBTSA)



(Source: author.)

The SDBTSA process compares the number of trips supplied by a subject transit agency to the number of trips demanded by passengers within the service area of the subject agency. Results of this process indicate whether the distribution of transit supply is balanced relative to the distribution of passenger demand within a network. This process reveals two important results. First, this process reveals geographic patterns of disparity between travel patterns and transit service supply, and second, this process reveals an overall rate of network structure performance. This process does not evaluate the sufficiency of the overall level of capacity within a network, rather it seeks to evaluate whether the supply offered between aggregated origins and destinations within a network is balanced adequately with aggregate demand. This process quantifies the proportion of transit service within a network that does and does not facilitate travel demand patterns. This process is useful for evaluating changes to transit route patterns and network structures.

There exist a variety of network evaluation methodologies in the literature, however none were found that directly compare transit supply and demand. Existing methodologies consider route specific design elements such as the directness of a route, network scale geometric alignments such as route spacing and length, multi-modal competitive user cost, and even equity impacts (Penn, 1995; Thompson, 1998; Vuchic, 2005; Casello, 2007). The literature says the relationship between transit supply and demand is a key factor in performance; therefore methods that consider this relationship need be developed to appropriately evaluate transit network structure.

3.2: Downtown Network Structure Tendency Estimation (DNSTE)

It was established earlier in this thesis that downtowns were once the focus of transit networks because of the concentration of activities located within central areas and the fixed linear nature of rail transit. If downtowns are served by a proportionately high number of routes within a network this indicates a high degree of radiality. It was also established earlier in this thesis that radial transit routes limit the ability of transit users to travel to non-downtown locations (unless they originate in the downtown). Radial transit networks are less compatible with contemporary polycentric travel patterns than multidestinational networks. Therefore, one way to evaluate how well a transit network facilitates polycentric travel patterns is to establish a radiality benchmark and compare the performance of a subject network to that benchmark.

In order to establish such a benchmark, the first method developed in this chapter, DNSTE, involves performing a survey of Canadian transit networks. In order to obtain representative results it is necessary to include as many systems in the survey as possible. Agencies should be selected for the survey from as many provinces and as many sizes of cities as possible to ensure that the final results are representative of all of Canada. One place to obtain a list of Canadian transit systems from which to populate the survey is the website of the Canadian Urban Transit Association (CUTA). While it is desirable to include as many transit agencies as possible in the survey, reasons to exclude some transit agencies include the absence of a public website or route map which clearly distinguishes routes. Moreover, transit systems which do not have the resources to provide a public website often provide only the most minimal service, which provides further justification to exclude them from the survey.

Other reasons to exclude transit systems from the survey can include the following. Systems with few routes may be excluded because the level of coordination required to construct a network of few routes is minimal and the size of the urban area served by such systems is likely far too small to ever justify or apply a multidestinational transit network. It is also reasonable to exclude transit systems of a solely commuter-regional nature, like GO Transit, because they do not provide the same type of service most transit systems do or have limited hours of operation. If transit agencies do not provide the necessary data to complete the survey it is logical to exclude them as well.

Collecting data for the DNSTE process involves a number of steps. The first of the three variables collected is the total number of routes within each system in the survey. The second variable to investigate is the location of downtowns within the urban area served by a subject transit agency. It is important to consistently define and identify downtown locations to ensure valid results. Gad and Matthew (2000) define downtowns as “areas with concentrations of businesses and institutions offering high-order goods and services in highly accessible places” (p. 250). Seasons (2003a) cites others when he says downtowns are the symbolic and functional heart of cities. Seasons says downtowns contain the primary business district and receive much public investment. Robertson (1999) notes that downtowns are both where the community gathers for collective events and the location of the oldest and most recognizable buildings in a city. Robertson emphasizes that being a centre of community heritage is vital to the definition of what is a downtown. Taken together, what these authors emphasize is that a downtown location is a highly accessible functional and symbolic centre of a city because it is a key centre of business and community heritage.

There are numerous methods of identifying downtowns based on the above definition. One simple method involves using the preset definition a municipality may provide. Gad and Matthew (2000) say municipalities often identify their central areas themselves with formal boundaries. A downtown can also be identified by the location of a high amount of transportation infrastructure. Bus and rail stations, as well as urban transit terminals can be used to identify a location as part of a downtown because they indicate accessibility. Closely related to accessibility is land value, and therefore the height of buildings. Downtowns can often be identified by the location of the tallest and most densely organized buildings in a city. Sometimes key buildings become reputable on their own and can themselves be used as indicators of a downtown location, like the CN Tower in Toronto or the Harbour Centre in Vancouver. Functional features like city halls, stock exchanges, food terminals, and farmers markets also identify downtown locations. Heritage locations like the oldest building or street can identify downtowns as well.

Gad and Matthew say “suburban downtowns” can have similar features as “central downtowns” but are relatively limited in size. Therefore some transit system can serve multiple downtown locations and all of these can be included in the survey. Regardless, the surveyor will have to use some subjective judgment in identifying downtown locations because of the varying mandates of transit systems and the varying geographies of Canadian cities. What is considered a downtown can depend on the particular city and any knowledge the surveyor has of particular cities can be useful in this survey. While multiple methods can be used to identify downtowns within the survey the consistent application of each method is important.

Once downtown locations are established for each transit system in the survey, the surveyor can investigate the third variable in the survey. In their 2007 article measuring the relative performance of radial and multidestinational transit networks Brown and Thompson suggest that the most desirable approach to indicating the degree of downtown orientation of a transit network is to calculate the proportion of vehicle miles traveled on each route which serves a downtown relative to the vehicle miles traveled by the entire system. This method could be expressed as follows:

$$DNST = \frac{\sum L_d}{\sum L_t}$$

DNST = Downtown Network Structure Tendency

L = length of route in kilometers

d = length of downtown portion of route in kilometers

t = total length of route in kilometers

Brown and Thompson (2007) suggest time and financial constraints can justify using a more simple method. In this thesis the purpose of developing the DNSTE process is to estimate the relative tendency of routes within transit networks to be radially oriented towards downtown areas compared to other transit networks. In other words, the purpose is simply to evaluate network structure from a macro level. This further justifies the use of a more simple method.

The next simplest method is to use the number of routes that travel to a downtown as an indicator of radiality. If the required data is possessed, GIS software can be used to analyze and summarize the results. Line-based data representing route paths and polygon data representing downtown boundaries can be used to isolate routes that serve downtowns. However, because of the wide variety and number of cities studied in this process, other methods will likely need to be employed as well. One such method is visual inspection. For each route on a transit system map, the surveyor can track the path of vehicles through the city via visual inspection. If a route enters the area considered downtown then those are instances of a route serving a downtown. Even if a route serves other activity centres elsewhere in a city, if it enters the area considered downtown then it is an instance of a route serving a downtown. There is a basis in the literature to justify the use of visual inspection of maps to identify when routes serve downtowns. In their 2007 article measuring the relative performance of radial and multidestinational transit networks Brown and Thompson use this method. The method that is used in this thesis can be expressed as follows (alternatively, the results of this method can be displayed in the example DNSTE table in Appendix 3):

$$DNST = \frac{R_d}{R_t}$$

DNST = Downtown Network Structure Tendency

R = Number of routes

d = downtown routes

t = complete network of routes

The value of the DNTSE score is to compare the degree of radiality different transit networks feature to each other and an average. The sum of the number of routes that serve downtowns in all surveyed systems divided by the sum of the total number of routes in all surveyed systems represents the percentage of surveyed transit routes that serve downtowns. A lower degree of radiality indicates a more multidestinational network structure, and possibly therefore a network more consistent with contemporary travel patterns, and therefore higher performing. Contrarily, if employment is heavily concentrated in a downtown and resultantly so are travel patterns then a high degree of network radiality is not undesirable. Statistics Canada publishes reports indicating the proportion of employment located within downtowns. If one determined that employment and travel patterns are concentrated in a downtown then this process could confirm that a transit network structure matches travel patterns in its respective city. However, in a city with a polycentric employment and travel patterns then to properly evaluate the network structure one must use not only the many-to-one approach but also a many-to-many approach. It is important to distinguish between transit networks of similar peer groups in this analysis for the above reasons. Calculating DNSTE rates for “small”, “medium”, and “large” systems allows for the comparison of systems in cities with similar land use patterns. At any rate, DNSTE establishes what the baseline rate of downtown orientation is for a set of transit networks.

3.3: Supply and Demand Based Transit Service Allocation (SDBTSA)

SDBTSA is the second, and more important method developed in this chapter, which evaluates transit network structure performance. Illustration 3.3 demonstrates the conceptual framework used to guide the collection and analysis of data in this process. This method compares the number of trips supplied by a subject transit agency to the number of trips demanded by passengers within the agency's service area to determine where disparities between travel patterns and transit service supply exist. This process does not evaluate the sufficiency of the overall level of capacity within a network, rather it seeks to evaluate whether the supply offered between aggregated origins and destinations within a network is balanced adequately with aggregate demand. This process evaluates the physical structure of transit supply within a network.

3.3.1: Study Area Disaggregation

The first step in SDBTRA is to disaggregate the study area into origin and destination zones. Something important to consider when choosing the number of zones to disaggregate the study area into is the concept of the “activity centre” (Casello & Smith, 2006). An activity centre is generally recognized in the literature as a high concentration of activities located outside traditional core areas of cities. This is precisely the type of development that occurs in polycentric metropolitan areas. Something the literature has had a difficult time agreeing on, however, is a precise definition of what land uses and level of transportation demand constitute an activity centre.

In their 2006 article, Casello and Smith identify a problem with the conventional definition of an activity centre. They argue that while the literature typically uses high concentrations of employment as an indicator of activity, what is more relevant for transportation analyses is to disaggregate employment types when developing activity centre definitions because of the varying trip-attracting attributes of different employment types. Casello and Smith (2006) do agree that high concentrations of aggregate employment are important indicators of activity in transportation analyses, however. Therefore, it is important to consider employment concentrations when designing the zonal system used in SDBTSA.

The goal of dividing the study area is to create enough geographic zones to provide a medium level of detail while at the same time capturing distinctions between important activity centres. The number of zones should depend on the size of the subject city. Larger cities, in terms of population and area, require more zones to maintain the same level of detail, especially since they likely contain a greater number of activity centres. Municipal boundaries may include rural areas, and travel data may contain trips originating in locations external to a study area, such travel patterns contribute little to overall demand and can be segregated into a rural/external zone. That said, the following approximations may be used to determine the number of zones needed:

Table 3.1: Zones by Study Area Size

Urban Study Area	Level of Detail	Number of Zones	Size of Zones
250 km^2	Low	5-10	25 – 50 km^2
250 km^2	Medium	10-15	16 – 25 km^2
250 km^2	High	15-20	12 – 16 km^2
100 km^2	Low	5-10	10 – 20 km^2
100 km^2	Medium	10-15	6 – 10 km^2
100 km^2	High	15-20	5 – 6 km^2

(Source: author.)

Table 3.2: Zones by City Population

Population of City	Level of Detail	Number of Zones	Size of Zones
500 000 persons	Low	5-10	50 000 – 100 000 persons
500 000 persons	Medium	10-15	33 000 – 50 000 persons
500 000 persons	High	15-20	25 000 – 33 000 persons
250 000 persons	Low	5-10	25 000 – 50 000 persons
250 000 persons	Medium	10-15	16 000 – 25 000 persons
250 000 persons	High	15-20	12 000 – 16 000 persons

(Source: author.)

The next step is to determine the boundaries of the zones used in SDBTSA. The activity centre literature identifies numerous methods of establishing zonal boundaries based on combinations of aggregated low level TAZ boundaries using employment concentration criteria (Casello, 2007). Considerations other than employment concentration to use when defining zonal boundaries include barriers to travel within the city, such as geographic features, political boundaries, institutional boundaries, or physical features like large works of infrastructure or even large buildings. For example, if the study area contains a major river, then since this feature naturally limits movement it is a logical choice for a zonal boundary. If the study area municipality self-defines political boundaries that separate neighbourhoods, wards, or districts, then these are appropriate boundaries as well. If the SDBTSA analysis is done using data with an existing aggregated geographic data structure then such boundaries are also logical as choices.

3.3.2: Time Period

After establishing a geographic data structure, the next step in SDBTSA is to choose a time period for the study. The relationship between transit service and travel demand is most sensitive during the peak hour of demand, in other words the hour when more individuals attempt to use the service than any other time. The peak hour is the time when supply is most constricted relative to demand, and therefore when the performance of the network is most critical. It is possible to use daily flows of transit users, but for the reasons mentioned above the peak hour is preferable.

3.3.3: Quantify Transit Demand

The next step in SDBTSA is to quantify transit demand and aggregate it into the disaggregated study zones during the chosen time period. Transit user trip data can be obtained from a computer generated regional transportation model or from a transit user survey. To collect data that measures the flow of passengers within the subject network by survey involves obtaining information on a variety of passenger-related variables. Trip flows include the location at which passengers start their trips (origins), the location at which they end their trips (destinations), and the times at which they travel. Passenger trips are the basic unit of demand for movement within a transit network and therefore form the basic variable to represent demand for transit service. When performing a survey the researcher often collects data on other variables (like age, gender, etc.) at the same time because of the relationships between those variables and transportation demand. When the data which quantifies transit demand is aggregated into the disaggregated study zones during the chosen time period it represents the origin and destination points of passenger trips, and is called "Origin-Destination" (or "OD") data. Typically OD data is displayed in tables (or "matrices") that resemble the example in Table 3.3, or it can be represented as follows:

Table 3.3: Example Origin-Destination Table (Matrix)

# represents # passenger trips demanded between zones	Destination Zone			
Origin Zone	Zone A	Zone B	Zone C	TOTAL ORIGINATING
Zone A	5	0	10	15
Zone B	0	15	5	20
Zone C	10	5	10	25
TOTAL DESTINED	15	20	25	60

(Source: author.)

$$\sum D_{(a_{1,} b_1 ; a_{2,} b_2 ; etc)}$$

D = trips demanded by transit passengers

a = origin location

b = destination location

There exist a variety of survey methods by which to obtain OD data. On board transit vehicles, one can manually distribute self-reported surveys to individual passengers, or perform automatic data collection of passenger boarding and alighting locations via smart card technology. Off line surveys can be conducted any number of ways including by phone, mail, and e-mail (Schaller, 2006). The use of web-based survey techniques presents a new opportunity for transit agencies to conduct surveys in a more cost-effective manner (Spitz, Niles, & Adler, 2006). The choice of a data collection method depends on local circumstances, resources, skills, preference, and experience. In fact, the use of a regional transportation model or existing survey data to provide transit OD data saves considerable time.

3.3.4: Quantify Transit Supply

The next step in SDBTSA is to quantify the transit supply in the selected time period that connects the disaggregate OD zones to each other. This step of the SDBTSA process involves the collection of data used to operationalize the concept of "transit supply." A number of indicators can perform the task of representing transit supply, but a case is made for the use of one particular indicator in this process. Transit supply consists of three attributes: the distance traveled by, capacity of, and service frequency of the vehicles supplying the service. Different indicators measure each of those three attributes. The number of vehicle kilometers traveled in service on a route measures the distance traveled by a route. Capacity is measured by the number of seats and amount of standing space offered by vehicles on a route per unit of time. The number of vehicles passing along the route per hour measures frequency. The most detailed indicator of transit supply is a conglomerate indicator, “seat kilometers per hour,” that measures all three dimensions of transit supply. A seat kilometer consists of the distance traveled by the route multiplied by the frequency of service multiplied by the capacity of each vehicle serving the route.

It would seem desirable to use this indicator for the purpose of analyzing network structure, but a case can be made for a different one. When an agency uses a common vehicle size it is sufficient to use frequency of service as an indicator of transit supply because it captures both service frequency and capacity. This is a logical assumption because most transit agencies almost universally use a common vehicle size and the differences between seat configurations of conventional transit vehicles are small.

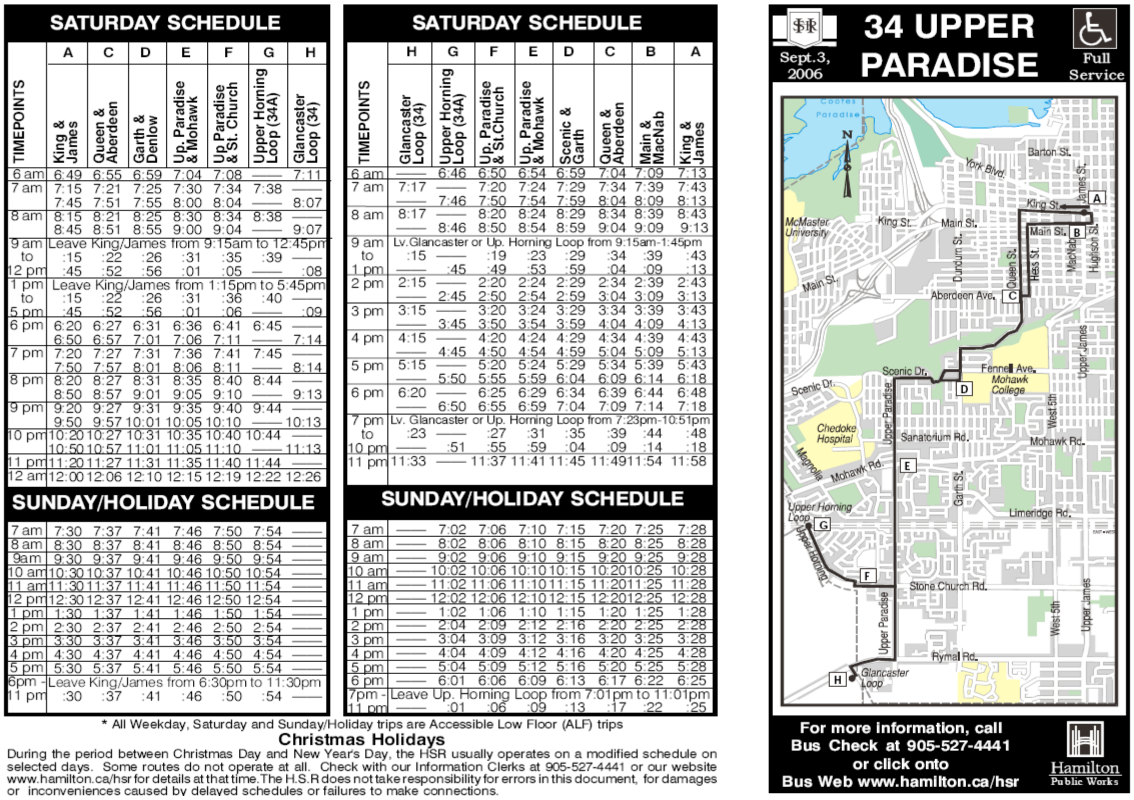
The distances traveled by individual routes within the zonal boundaries established earlier in this process may be significant in this analysis depending on the size of the zone. The concept of “Service coverage” implies that transit routes only truly serve areas located within the walking catchment area of stops along such routes. When zones are sufficiently small it may be assumed that if a route travels within a zone it services the whole zone. Naturally, a route must make a stop for passenger boarding and alighting in a zone to be considered viable. Further criteria can be used to define trip “viability” for “indirect” trips that travel between OD pairs that require passengers to transfer.

The literature suggests that transit users perceive a dis-utility to transferring routes, and that networks should be designed to minimize transfers for major passenger flows (Kittelson et al., 2003). Therefore, it is logical to limit the number of potential transfer points within the network to locations where transfers are convenient in time and space. The method used in this thesis make the following assumptions. It is assumed that only one point per zone exists where the subject agency intentionally coordinates service and offers amenities. These locations need not necessarily be transit terminals.

If the transfer time between routes is less than half the headway of the connecting route, the transfer is viable. For example, if the headway of route B is 10 minutes and route A arrives 7 minutes before route B departs, those two routes do not combine in that instance to provide a “viable” supplied trip within the network. It would be possible for passengers to transfer between them, but the combination of those two routes is not part of the “intentionally” supplied transit network. However, if route A arrives 3 minutes before route B departs, it is considered a viable transfer, and therefore an intentionally supplied trip within the network.

Data used to indicate the supply of transit services within a network are available from transit agency public schedule timetables. Typically these timetables are available in hard copy or via the Internet. An example timetable is displayed in Illustration 3.4. When all viable trips between zones have been identified, adding the sums of these to another OD table with the same design as the ones used in the transit demand step of this process allows for comparative analysis.

Illustration 3.4: Example Schedule Timetable



SATURDAY SCHEDULE

	A	C	D	E	F	G	H
TIMEPOINTS	King & James	Queen & Aberdeen	Garth & Denlow	Up. Paradise & Mohawk	Up Paradise & St. Church	Upper Horning Loop (34A)	Glancaster Loop (34)
6 am	6:49	6:55	6:59	7:04	7:08	——	7:11
7 am	7:15	7:21	7:25	7:30	7:34	7:38	——
	7:45	7:51	7:55	8:00	8:04	——	8:07
8 am	8:15	8:21	8:25	8:30	8:34	8:38	——
	8:45	8:51	8:55	9:00	9:04	——	9:07
9 am	Leave King/James from 9:15am to 12:45pm						
to	:15	:22	:26	:31	:35	:39	——
12 pm	:45	:52	:56	:01	:05	——	:08
1 pm	Leave King/James from 1:15pm to 5:45pm						
to	:15	:22	:26	:31	:36	:40	——
5 pm	:45	:52	:56	:01	:06	——	:09
6 pm	6:20	6:27	6:31	6:36	6:41	6:45	——
	6:50	6:57	7:01	7:06	7:11	——	7:14
7 pm	7:20	7:27	7:31	7:36	7:41	7:45	——
	7:50	7:57	8:01	8:06	8:11	——	8:14
8 pm	8:20	8:27	8:31	8:35	8:40	8:44	——
	8:50	8:57	9:01	9:05	9:10	——	9:13
9 pm	9:20	9:27	9:31	9:35	9:40	9:44	——
	9:50	9:57	10:01	10:05	10:10	——	10:13
10 pm	10:20	10:27	10:31	10:35	10:40	10:44	——
	10:50	10:57	11:01	11:05	11:10	——	11:13
11 pm	11:20	11:27	11:31	11:35	11:40	11:44	——
12 am	12:00	12:06	12:10	12:15	12:19	12:22	12:26

SUNDAY/HOLIDAY SCHEDULE

7 am	7:30	7:37	7:41	7:46	7:50	7:54	——
8 am	8:30	8:37	8:41	8:46	8:50	8:54	——
9am	9:30	9:37	9:41	9:46	9:50	9:54	——
10 am	10:30	10:37	10:41	10:46	10:50	10:54	——
11 am	11:30	11:37	11:41	11:46	11:50	11:54	——
12 pm	12:30	12:37	12:41	12:46	12:50	12:54	——
1 pm	1:30	1:37	1:41	1:46	1:50	1:54	——
2 pm	2:30	2:37	2:41	2:46	2:50	2:54	——
3 pm	3:30	3:37	3:41	3:46	3:50	3:54	——
4 pm	4:30	4:37	4:41	4:46	4:50	4:54	——
5 pm	5:30	5:37	5:41	5:46	5:50	5:54	——
6pm -	Leave King/James from 6:30pm to 11:30pm						
11 pm	:30	:37	:41	:46	:50	:54	——

SATURDAY SCHEDULE

	H	G	F	E	D	C	B	A
TIMEPOINTS	Glancaster Loop (34)	Upper Horning Loop (34A)	Up. Paradise & St.Church	Up. Paradise & Mohawk	Scenic & Garth	Queen & Aberdeen	Main & MacNab	King & James
6 am	——	6:46	6:50	6:54	6:59	7:04	7:09	7:13
7 am	7:17	——	7:20	7:24	7:29	7:34	7:39	7:43
	——	7:46	7:50	7:54	7:59	8:04	8:09	8:13
8 am	8:17	——	8:20	8:24	8:29	8:34	8:39	8:43
	——	8:46	8:50	8:54	8:59	9:04	9:09	9:13
9 am	Lv.Glancaster or Up. Horning Loop from 9:15am-1:45pm							
to	:15	——	:19	:23	:29	:34	:39	:43
1 pm	——	:45	:49	:53	:59	:04	:09	:13
2 pm	2:15	——	2:20	2:24	2:29	2:34	2:39	2:43
	——	2:45	2:50	2:54	2:59	3:04	3:09	3:13
3 pm	3:15	——	3:20	3:24	3:29	3:34	3:39	3:43
	——	3:45	3:50	3:54	3:59	4:04	4:09	4:13
4 pm	4:15	——	4:20	4:24	4:29	4:34	4:39	4:43
	——	4:45	4:50	4:54	4:59	5:04	5:09	5:13
5 pm	5:15	——	5:20	5:24	5:29	5:34	5:39	5:43
	——	5:50	5:55	5:59	6:04	6:09	6:14	6:18
6 pm	6:20	——	6:25	6:29	6:34	6:39	6:44	6:48
	——	6:50	6:55	6:59	7:04	7:09	7:14	7:18
7 pm	Lv. Glancaster or Up. Horning Loop from 7:23pm-10:51pm							
to	:23	——	:27	:31	:35	:39	:44	:48
10 pm	——	:51	:55	:59	:04	:09	:14	:18
11 pm	11:33	——	11:37	11:41	11:45	11:49	11:54	11:58

SUNDAY/HOLIDAY SCHEDULE

7 am	——	7:02	7:06	7:10	7:15	7:20	7:25	7:28
8 am	——	8:02	8:06	8:10	8:15	8:20	8:25	8:28
9 am	——	9:02	9:06	9:10	9:15	9:20	9:25	9:28
10 am	——	10:02	10:06	10:10	10:15	10:20	10:25	10:28
11 am	——	11:02	11:06	11:10	11:15	11:20	11:25	11:28
12 pm	——	12:02	12:06	12:10	12:15	12:20	12:25	12:28
1 pm	——	1:02	1:06	1:10	1:15	1:20	1:25	1:28
2 pm	——	2:04	2:09	2:12	2:16	2:20	2:25	2:28
3 pm	——	3:04	3:09	3:12	3:16	3:20	3:25	3:28
4 pm	——	4:04	4:09	4:12	4:16	4:20	4:25	4:28
5 pm	——	5:04	5:09	5:12	5:16	5:20	5:25	5:28
6 pm	——	6:01	6:06	6:09	6:13	6:17	6:22	6:25
7pm -	Leave Up. Horning Loop from 7:01pm to 11:01pm							
11 pm	——	:01	:06	:09	:13	:17	:22	:25

* All Weekday, Saturday and Sunday/Holiday trips are Accessible Low Floor (ALF) trips

Christmas Holidays

During the period between Christmas Day and New Year's Day, the HSR usually operates on a modified schedule on selected days. Some routes do not operate at all. Check with our Information Clerks at 905-527-4441 or our website www.hamilton.ca/hsr for details at that time.The H.S.R does not take responsibility for errors in this document, for damages or inconveniences caused by delayed schedules or failures to make connections.

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(Source: HSR website.)

3.3.5: Defining Disparity

The final step in SDBTSA is to compute the disparities between transit demand and transit supply. Raw numbers of supplied and demanded trips between OD pairs cannot be compared directly because they are in different units of measurement. Demand values are measured in individual passenger trips, whereas supply values are measured in transit vehicle trips. Transit vehicle trips contain space for many individual passengers. One way to make the supply and demand data comparable is to convert the values of each to proportions of total demand and total supply. One method of analyzing and displaying supply and demand data is by the example tables in Appendix 4. Supply and demand data for individual OD pairs can also be mathematically represented as follows:

$$\text{Disparity }(o,d) = \left[\frac{S\,(o,d)}{\sum_o \sum_d S_{od}} - \frac{D\,(o,d)}{\sum_o \sum_d D_{od}} \right] \text{X } 100$$

Assuming there is a limited supply of transit trips to be offered within the network, the sum of the absolute value of the number of trips disparity that exist for each OD pair divided by two (because modifying the route pattern of one trip to reallocate service from one OD pair to another equilibrates two OD pairs) divided by the total number of supplied trips indicates how well the network performs at matching overall supply (service in network) and demand (passenger travel patterns). This figure represents a “misallocation” rate that measures how well balanced transit supply and demand are within a network, and can be represented by the following formula:

$$\text{Misallocation Rate} = \frac{|\sum \text{Disparity }(o,d)|/2}{\sum_o \sum_d S_{od}}$$

The performance monitoring literature tells us that the purpose of collecting this data is to identify or measure a trend. The misallocation rate can be used to indicate performance at transit network design. Moreover, as changes to the network structure are made, changes to the misallocation rate can be tracked. Since the misallocation rate is a quantity, degrees of changes are evident. The misallocation rate represents a percentage of service within the network that does not optimally facilitate the existing travel patterns. In other words, the misallocation rate represents the number of supplied trips that do not facilitate the optimum number of passenger trips demanded within the network. The misallocation rate indicates the quantity by which the planned transit services do or do not match travel patterns.

Moreover, recommendations for network changes are evident based on individual OD pair disparities. Making changes to the supplied number of trips on individual routes connecting each zone can reduce the misallocation rate and improve the performance of the network at facilitating travel. Justifications for individual route changes are evident based on the individual zonal disparities. Recommendations for changes in land use that can influence transit demand are also evident from the disparity rates of individual OD pairs. Furthermore, the misallocation rate figure provides a way to compare network structure performance between transit systems. If the same methodology is applied to another system then relative misallocation rates are comparable. This methodology is therefore a viable means of setting a network performance benchmark. The evaluation step in performance monitoring is fulfilled this way: the lower the misallocation rate, the better the performance.

The following chapter of this thesis provides an example of the application of the SDBTSA method justified by the application of the DNSTE method. These methods are applied to the case of Hamilton to determine the performance rate of the HSR network structure.

Chapter 4. HSR Case Study

4.1: Case Study Justification & Demographic Profile

As mentioned earlier, this chapter describes a case study that exemplifies the application and benefits of the methodology developed in chapter 3. The Hamilton Street Railway (HSR) is chosen as a test case for a number of reasons. Firstly, it was suggested earlier that Canadian mid-sized cities can experience mismatches between travel patterns and transit networks. The SDBTSA method designed in chapter 3 evaluates this concept; therefore the transit system of a mid-sized Canadian city is used as a case. Seasons (2003a) defines a mid-sized Canadian city as having a population of between fifty thousand and five hundred thousand. Similarly, Henderson (1997) defines U.S. mid-sized cities as one with a population of 100 000 to 500 000 people. With 2006 census results indicating a municipal population of just over 504 000 people, the City of Hamilton is on the upper bound of mid-sized cities (Statistics Canada, 2007).

Furthermore, HSR shares some of the characteristics of mid-sized city transit systems described in chapter 2. With transit representing a modal share of eight percent of journey to work trips in 2001, Hamilton under performs at attracting ridership compared to the Ontario (13 percent) and Canadian (10 percent) averages (Statistics Canada, 2006b). While the Ontario average remained steady in 2006, HSR’s modal share increased to 9% that year (Statistics Canada, 2007). In addition, HSR receives a lower level of funding than do larger transit systems in Ontario. HSR received $141 per capita for maintenance and capital expenditures in 2004 whereas the Toronto Transit Commission received $554 and Ottawa-Carelton Transpo received $431 per capita in their respective municipalities (Tomalty et al., 2007).

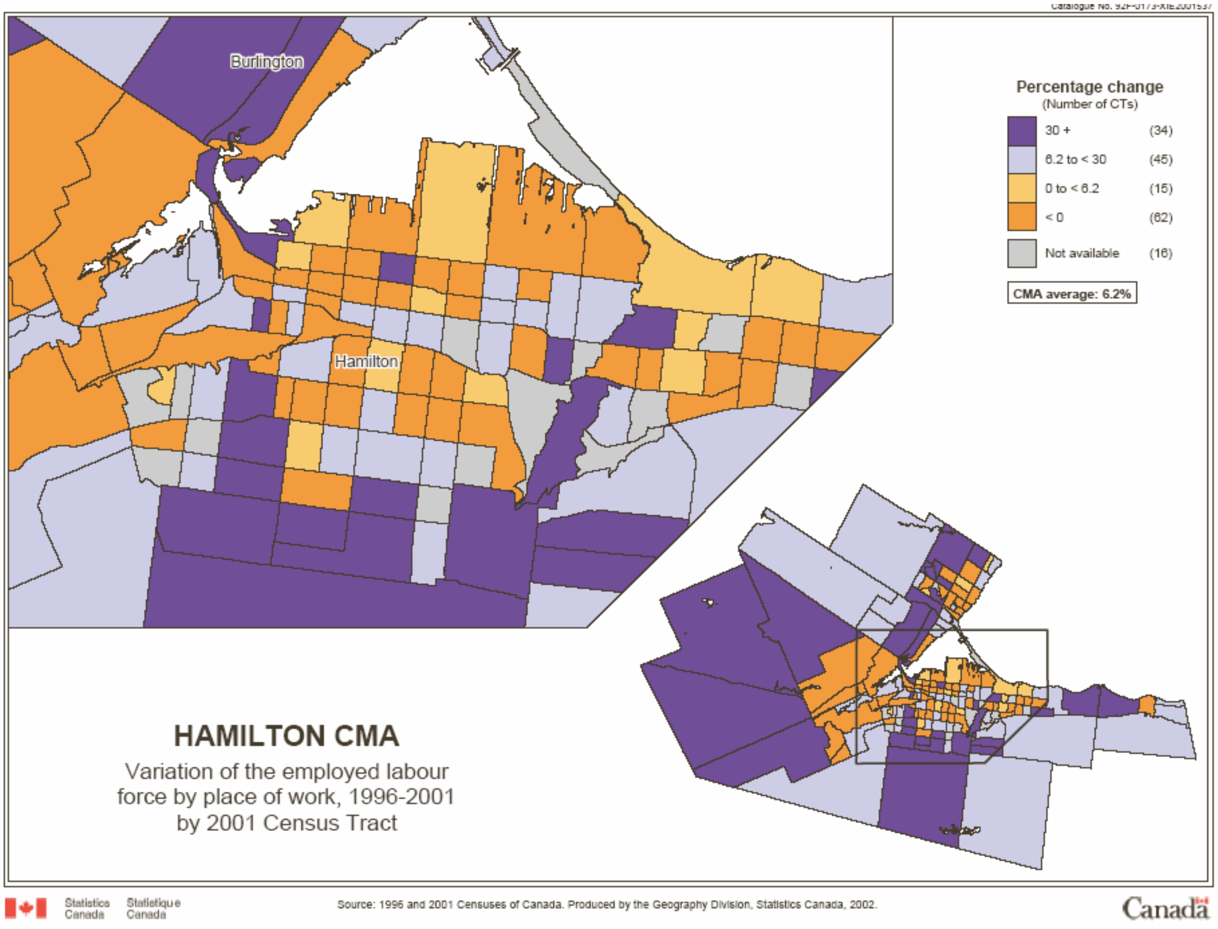
When maintenance and capital expenditures on transit are compared to similar expenditures for roads the disparity in funding for HSR is even greater. HSR spends on maintenance and capital expenditures only 56% of what the City of Hamilton spends on road maintenance and capital expenditures. In its 2007 Ontario Community Sustainability Report, the Pembina Institute, an environmental policy research group, ranks Hamilton 11th out of 27 Ontario municipalities on the transit to road expenditures ratio (Tomalty et al., 2007). Hamilton places behind smaller municipalities like Sarnia, Barrie, Thunder Bay, North Bay, Peterborough and Guelph.

HSR also faces considerable growth pressures like other mid-sized city transit systems. Whereas many routes in older portions of the city like the Core Area, Central Hamilton and West Hamilton regularly experience passenger overloads, much of the city's growth occurs at the fringes of the developed area. Illustration 4.1 demonstrates that much of the employment growth in the City of Hamilton between 1996 and 2001 occurred at the fringe of the metropolitan area. Census tracts with the highest above average rates of employment growth between 1996 and 2001 tend to be located in the southern area of the city. On the other hand, employment density is highest in the Core Area, followed by West Hamilton. That said, West Hamilton and Central Hamilton combine to feature a higher number of jobs than the core area, and so does a combination of the three main mountain zones. These figures are described in Table 4.1.

Table 4.1: Description of Hamilton Origin and Destination Zones

Zones	Total Number of Jobs in 2001	Proportion of Total Jobs	Job Density (jobs/km^2)	Approximate Area (km^2)
Ancaster	5194	3%	144	36
Central Hamilton	34235	20%	1141	30
Central Mountain	12366	7%	589	21
Core Area	27335	16%	2734	10
Dundas	5725	3%	249	23
East Hamilton	21105	12%	879	24
East Mountain	12120	7%	466	26
Stoney Creek	7055	4%	588	12
Stoney Creek Mountain	1125	1%	94	12
Waterdown	NA	NA	NA	36
West Hamilton	34055	20%	2003	17
West Mountain	10105	6%	439	23
Urban Study Area	170 420	100%	631	270
Rural	N/A	N/A	NA	869
Total City of Hamilton	170 420	100%	NA	1139

Illustration 4.1: Variation of the Employed Labour Force by Place of Work, 1996-2001 by Census Tract



(Source: http://geodepot.statcan.ca/Diss/Maps/ThematicMaps/cma_e.cfm?name=Hamilton.)

With scarce resources to distribute, HSR has a difficult task of balancing service between older and newer areas of the city. Growth pressures are exacerbated by the pattern of vehicle ownership and income distribution within the city. As illustrated in Table 4.2, the Core Area has the lowest rate of vehicle ownership per household in the city at 64%. Central Hamilton and West Hamilton are the only other areas of the city with a lower than average vehicle ownership.

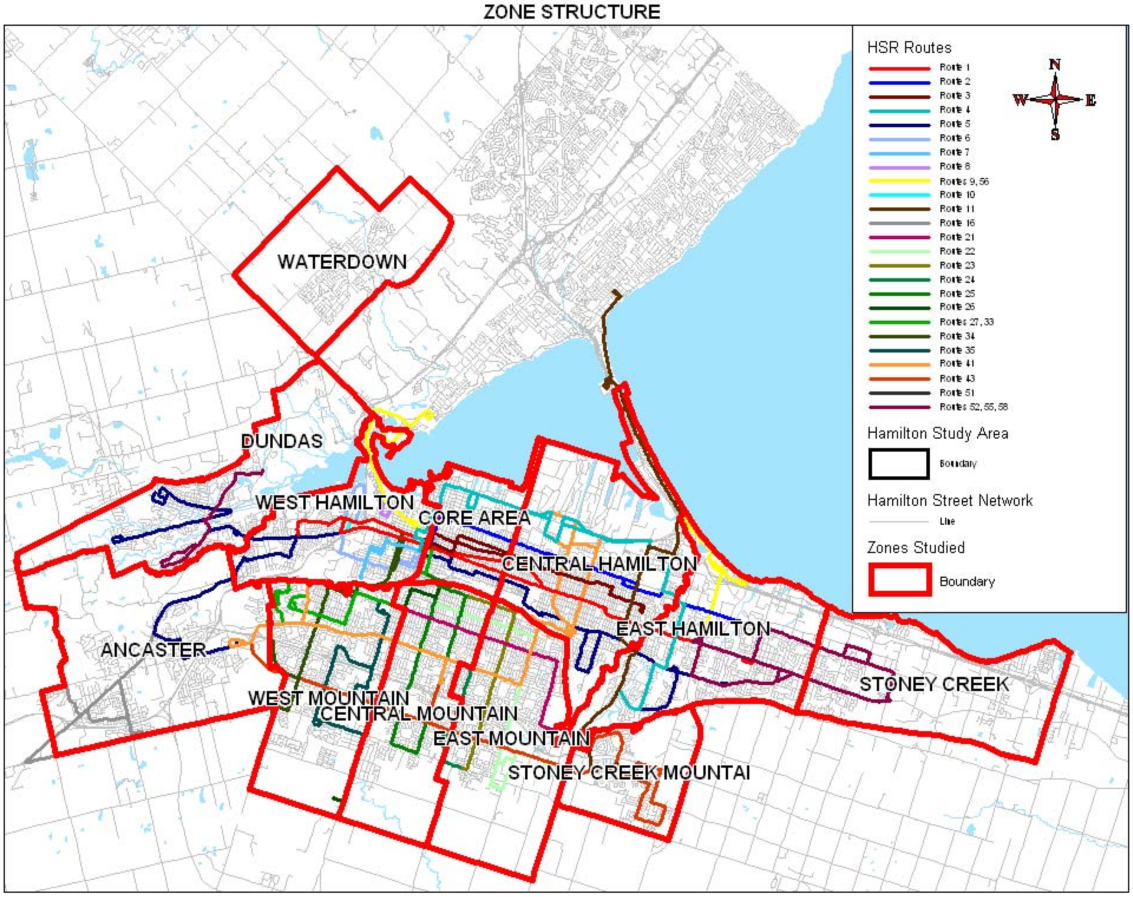
These areas of the city have the highest transit ridership and regularly experience passenger overloads. The Core Area, Central Hamilton, and West Hamilton zones each feature an average household income below the municipal average. This means these zones are the most likely to have transit-dependent inhabitants. It is no coincidence that these are the busiest zones in the HSR network since they are most likely to have high captive ridership. Illustration 4.2 presents a map of the zonal boundaries used to define Hamilton in this thesis. These patterns of vehicle ownership and income distribution make it difficult for HSR to justify favoring newer parts of the city experiencing development when adding service.

Table 4.2: Hamilton Household Vehicle Ownership and Average Income by Area of City

Area of Hamilton	Percentage of Households Owning At Least One Vehicle	Average Household Income, 2001
Ancaster	98%	$112,474
Core Area	64%	$55,383
Central Hamilton	84%	$62,192
Central Mountain	88%	$41,667
Dundas	93%	$86,169
East Hamilton	87%	$60,147
East Mountain	89%	$63,028
Stoney Creek	99%	$88,614
Stoney Creek Mountain	99%	$79,014
Waterdown	99%	NA
West Hamilton	71%	$60,637
West Mountain	93%	$69,291
Hamilton Average	85%	$63,504

(Source: Data Management Group, 2003a; Statistics Canada, 2006b.)

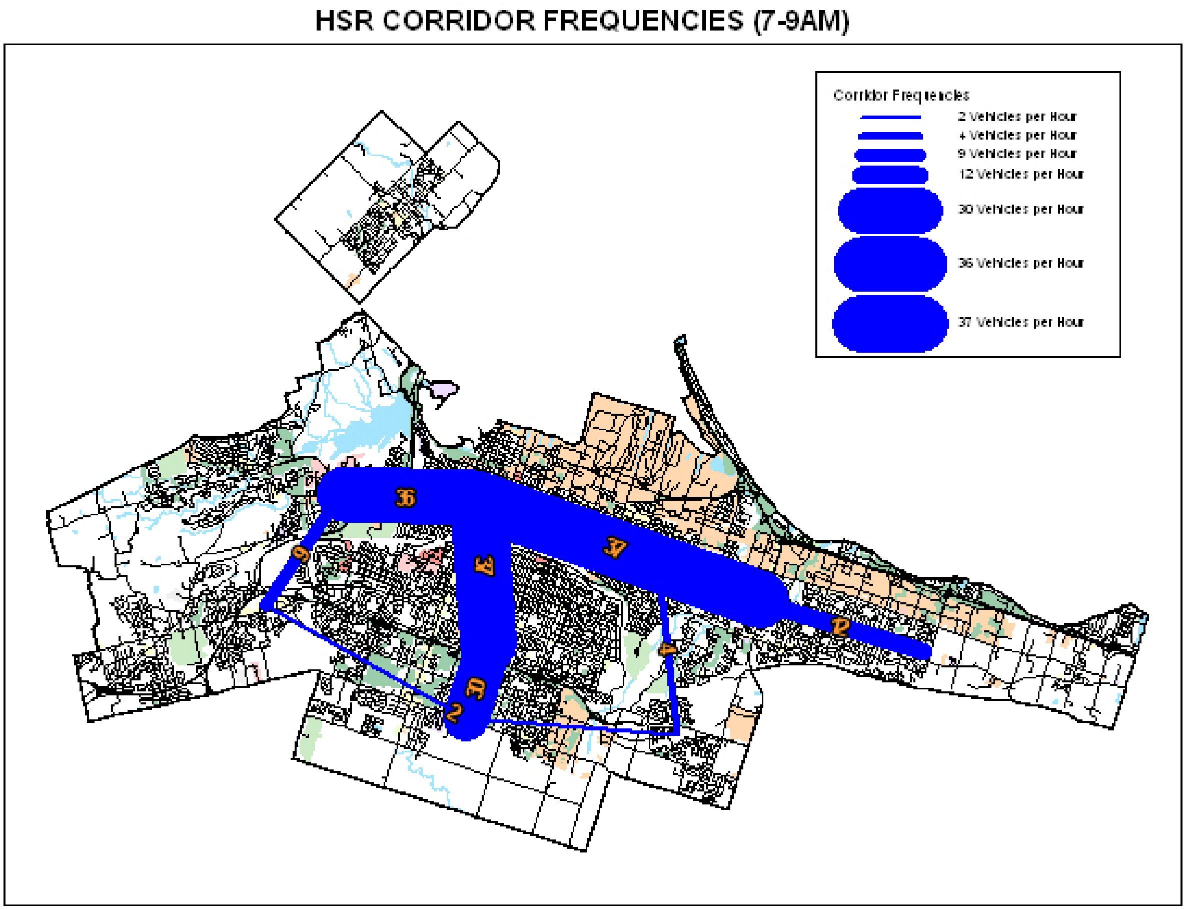
Illustration 4.2: City of Hamilton Study Area Zonal Boundaries



(Source: author.)

Furthermore, preliminary evidence suggests there are indeed mismatches between the HSR network structure and travel patterns in Hamilton, thus necessitating an evaluation. Travel by all modes within Hamilton has developed into a polycentric pattern. Only nine percent of daily origins and destinations within Hamilton travel to or from the Core Area (Based on Data Management Group, 2003a.). In fact, six other centres each generate and attract more travel than does the Core Area. Dozens of transit units serve downtown Hamilton per hour during the AM peak period, while few serve suburban growth centres. Illustration 4.3 demonstrates some of the potential mismatches in the Hamilton transit network. The potential for mismatches between a transit network that concentrates so heavily on the Core Area and travel patterns that are diffuse throughout the city is apparent.

Illustration 4.3: HSR 7:00 AM – 9:00 AM Corridor Frequencies



(Based on Fall 2006 HSR pocket timetables.)

Another reason to choose HSR as a test case for the methods developed in chapter 3 is that anecdotal evidence suggests HSR has limited resources for long term planning. In face-to-face meetings regarding this study, Hamilton transit planners indicated they do not have the resources to perform long term planning. This is consistent with what Seasons (2003a) says about the capacity of planners in mid-sized cities. Applying SDBTSA and DNSTE to the Hamilton case can help provide HSR transit planners with information they need for future service planning.

4.2: Downtown Network Structure Tendency Estimation (DNSTE) Results

The application of the DNSTE process developed in chapter 3 to a group of Canadian transit systems, and specifically to the case of Hamilton, is described below. A survey in 2006 included 40 Canadian transit systems[2]. CUTA membership includes over 90 conventional transit systems in Canada. Many of these systems serve small communities and therefore are very small. Such systems were not included in the survey to avoid biasing the results towards an over-indication of radial routes. Systems included in the survey do range from small to very large, Fredericton and Vancouver being examples respectively. Of the 40 surveyed systems, seven provinces are represented, with Quebec being the most notable exception. Peer groups of transit systems were defined for small cities (population below 50,000), mid-sized cities (population between 50,000 and 500,000), and large cities (population over 500,000).

During the survey, downtowns were identified in a number of ways. The primary method of identification was visual inspection of online and hard copy route maps and air photos via Google Earth. Downtowns were identified by road patterns that indicated the location of the oldest part of a city, the location of CBDs, and the location of the tallest buildings. Some of the

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[2] For Edmonton and Calgary only the number of stations serving downtown per LRT line is considered due to poor route maps.

surveyed systems were considered to travel to more than one downtown, especially regional transit systems like in Durham Region and Waterloo Region. Routes were inspected for passage through downtowns solely by visually inspecting route maps.

$$DNST = \frac{R_d}{R_t}$$

The result of the DNSTE survey (formula shown above) is that across the survey 44% of transit routes serve downtowns in their respective cities. In small cities, the surveyed average was 100%, in mid-sized cities the surveyed average was 59%, and in large cities the surveyed average was 32%. These results are described in detail in Table 4.3. These results set a benchmark that is useful for comparing the degree of radiality different transit systems feature. Results show that only in approximately one third of the surveyed systems do fewer than 50% of routes serve downtowns. In the mid-sized peer group only in eight of twenty-eight systems do fewer than 50% of routes serve downtowns. No surveyed transit system in the Greater Toronto Area (GTA) apart from HSR features a figure of greater than 37%. The result for HSR was 64%, which is 20% above the national average and 5% above its peer group average. The results of the DNSTE process suggest the HSR network features a more monocentric network orientation than is average to Canadian transit systems and a slightly more monocentric orientation than is average to peer group systems. When the number of routes in each network is correlated with downtown network structure tendency rates there results a negative relationship with a correlation coefficient of -0.5. When Census 2006 service area populations are correlated with downtown network structure tendency rates there results a negative relationship with a correlation coefficient of -0.54.

Table 4.3: Tendency of Canadian Transit Routes to be Structured Towards Downtowns

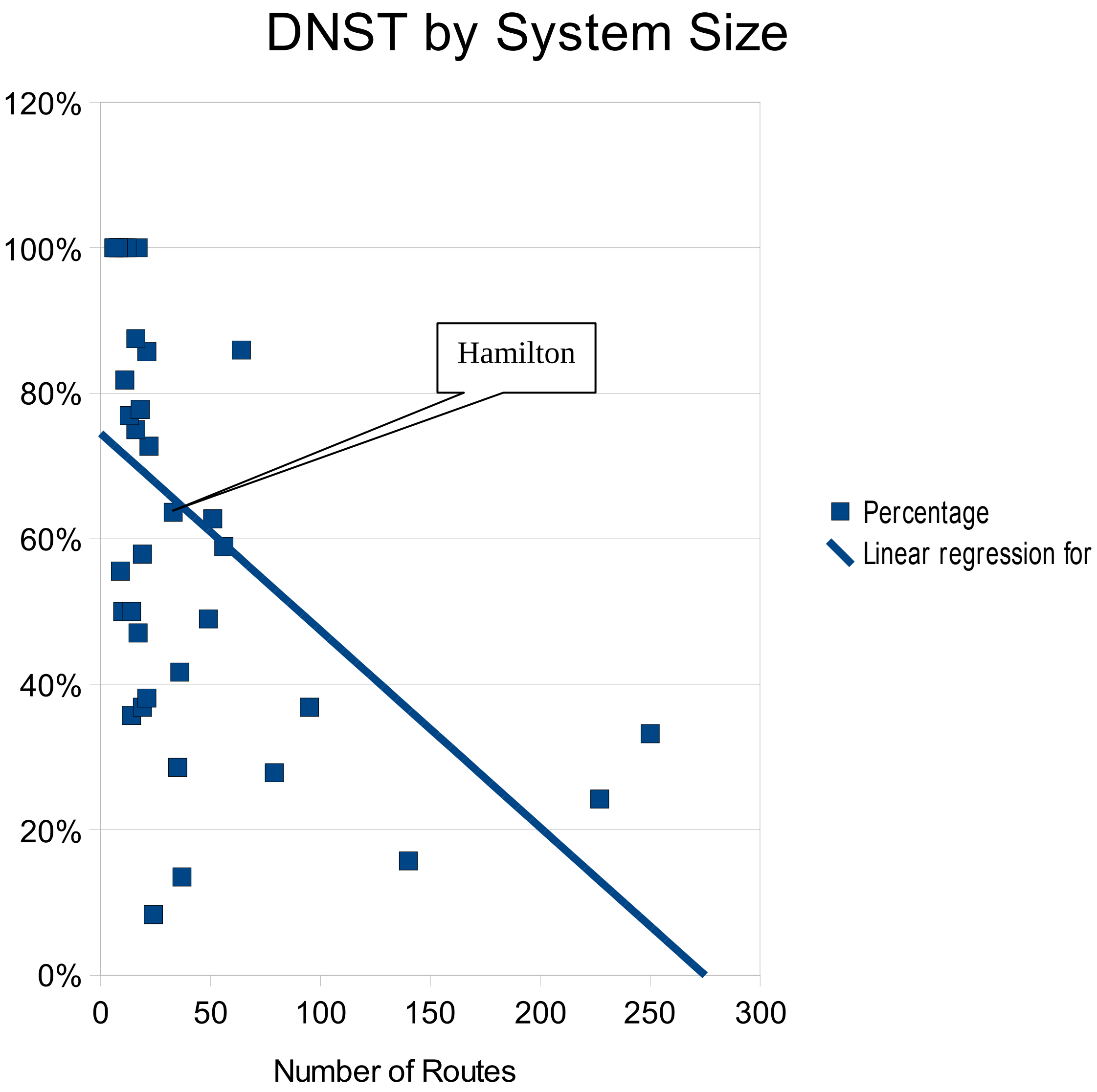
System	Total # Routes	# Routes Traveling to Downtown	Percentage	Service Area Population (2006)
		Population Under 50,000		
Woodstock	6	6	100%	33,269
Belleville	8	8	100%	46,029
Brandon	8	8	100%	48,256
Welland	8	8	100%	48,402
Peer Group	30	30	100%	
		Population 50,000 – 500, 000		
North Bay	8	8	100%	52,771
Medicine Hat	9	5	56%	68,822
Peterborough	11	11	100%	71,446
Sault Saint Marie	12	12	100%	74,566
Niagara	14	7	50%	78,815
Fredericton	6	6	100%	85,688
Brantford	9	9	100%	86,417
Kamloops	16	12	75%	92,882
Lethbridge	17	8	47%	95,196
Barrie	21	18	86%	103,710
Guelph	18	14	78%	106,170
Kingston	13	10	77%	114,195
Moncton	19	11	58%	126,424
St. Catharine's	22	16	73%	129,170
Abbotsford	11	9	82%	159,020
Kelowna	21	8	38%	162,276
Burlington	14	5	36%	164,415
Oakville	24	2	8%	165,613
St. John's	19	7	37%	181,113
Regina	16	14	88%	194,971
Windsor	16	14	88%	209,218
Saskatoon	17	17	100%	233,923

Victoria	49	24	49%	330,088
London	36	15	42%	352,395
Halifax	51	32	63%	372,858
Brampton	37	5	14%	433,806
Waterloo Region	56	33	59%	478,121
Hamilton	33	21	64%	504,559
Peer Group	595	353	59%	
		Population Over 500,000		
Durham Region	95	35	37%	561,258
Mississauga	79	22	28%	668,549
Winnipeg	64	55	86%	694,668
Ottawa	250	83	33%	812,129
Edmonton	10	5	50%	1,034,945
Calgary	35	10	29%	1,079,310
Vancouver	227	55	24%	2,116,581
Toronto	140	22	16%	2,503,281
Peer Group	900	287	32%	
TOTAL	1525	670	44%	-

(Based on various sources.)

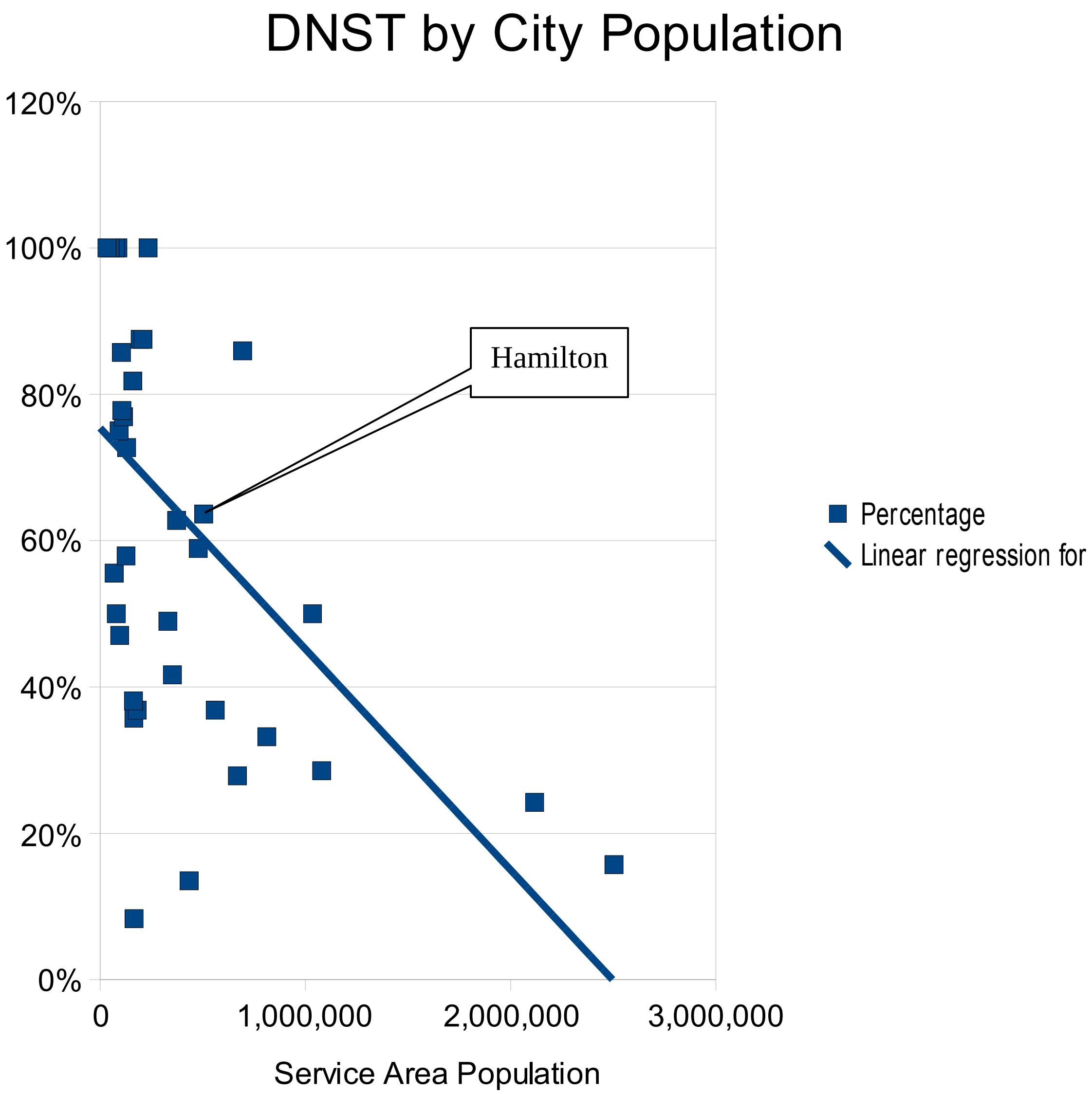
These correlation coefficient scores indicate a strong relationship between system size and network structure. Illustrations 4.4 and 4.5 describe these relationships. As Canadian transit networks grow, they tend to become more multidestinational in structure. HSR runs slightly contrary to this trend. Across the survey, routes increasingly serve destinations outside downtowns as system sizes grow; however with almost half of all transit routes in Canada traveling to downtowns, the phenomenon of downtown-oriented radial transit routes largely remains to this day.

Illustration 4.4: DNST by System Size



(Source: author.)

Illustration 4.5: DNST by City Population



(Source: author.)

These results suggest a need for further investigation. The HSR network features a less multidestinational structure than the Canadian average, and also slightly less multidestinational structure than its peer group average, possibly indicating that it is less compatible with contemporary travel patterns than the Canadian average. That 64% of HSR routes travel to downtown Hamilton is especially significant considering how only 9% of daily origins and destinations by all modes within Hamilton travel to or from downtown. However, to properly analyze the relationship between transit service and travel demand in Hamilton one must investigate the structure of supply within the network, not just the structure of routes. Though many routes may travel downtown, if more service is provided on routes that do not travel downtown than the structure of routes may be more compatible with travel patterns than it appears. Though the DNSTE process establishes an important benchmark for evaluating the structure of a transit network, it does not explain why the HSR network is more heavily downtown oriented than Canadian transit routes are on average, or whether this is a good or bad thing. The following section presents the results of the application of the SDBTSA method to Hamilton.

4.3: Supply and Demand Based Transit Service Allocation (SDBTSA) Results

The following section describes the application of the SDBTSA method developed in chapter 3 to the case of HSR. The application of this method evaluates the present HSR network structure. The performance of the present network structure at facilitating travel patterns is discussed. The results of this method indicate whether the present primarily radial transit network structure or a multidestinational network structure is more appropriate. The benefits of applying this methodology are demonstrated by the results presented below.

This method compares the number of schedule departure trips supplied by HSR to the number of trips demanded by passengers within Hamilton to determine where disparities between transit service and travel patterns exist. Data that measures the flow of passengers within the HSR network were obtained from the Transportation Tomorrow Survey (TTS) (Data Management Group, 2007). A suitable alternative to the TTS survey is the results of a regional transit model or the results of an OD survey performed by the researcher. The TTS survey is among the largest consecutive travel behaviour surveys ever completed. The 2001 survey was completed in the fall of 2001 for residents of the City of Hamilton. The survey sampled the study area population in the Greater Toronto Area of 2.51 million people at a rate of 5.5%. Random households from across the study area were selected from Bell Canada telephone listings and contacted up to eight times in order to obtain a response. Households were first contacted by mail to raise awareness of the survey and later by telephone for official responses. Respondents were asked to respond about the most recent weekday on which they traveled, with effort made to control for an over-representation of Friday trips (Data Management Group, 2003b).

Data were validated by comparing results to a variety of sources. Data were compared to the results of previous TTS surveys, the 2001 Census of Canada, traffic cordon counts, transit ridership data, and post-secondary school enrollment. There are a number of limitations to the data that are relevant for this study. Due to the method of contacting respondents by telephone, certain populations are mis-represented in the data. Those with unlisted telephone numbers, no home phone, or only cellular phones are under-represented. Those with multiple home phone numbers listed with Bell Canada are over-represented. In particular, the 18-27 age group is under-represented because many members of that age group do not have a home phone, and those who do may not have them set up when the survey was completed due to it being near the beginning of a school term.

Variables collected by the TTS survey include household data, demographic data, and trip-related data. Responses for each individual within the household were usually contributed by only one person during telephone interviews. Trip-related transit data include the location of trip origins and destinations, as well as trip purpose, time, the sequence of routes used, and methods of access and egress to and from transit vehicles. Passenger trips are the basic unit of demand for movement within a transit network and this survey did indeed measure passenger trips (Data Management Group, 2003c).

Once converted to table format, the data were agglomerated from their original micro level into geographic zones according to the criteria established in chapter 3. Using GIS software the study area was divided into 13 zones, including a rural external zone, because that number fit the appropriate boundaries within the study area but maintained the level of necessary detail described in chapter 3. Zonal boundaries were chosen based on geographical constraints, the former lower tier municipal boundaries of Hamilton because of their approximation of the area rating boundaries, and major roads that separate neighbourhoods. To some extent the zonal boundaries were also limited by the underlying GIS structure of the TTS data. The zonal boundaries used in this study are demonstrated in Illustration 4.2 and their spatial and activity related characteristics are defined in Table 4.1. The Core Area represents 16% of employment while Central Hamilton and West Hamilton each represent 20% of employment; this pattern of employment distribution can be described as polycentric.

The relationship between transit service and travel demand is most sensitive during the peak hour of demand. Unfortunately the TTS data represents full day travel patterns. To convert the data from full day values to peak hour values a conversion factor based on HSR load data was used. The load data was collected in the autumn of 2005 on a single day across the entire service day by visual observation of vehicles at cordon points near the core area. Vehicle loads were summed by hourly intervals (i.e. 8:00 AM to 9:00 AM, 8:15 AM to 9:15 AM, 8:30 AM to 9:30 AM) for the whole day to determine which hourly interval featured the highest volume of demand. The hour with the largest volume of demand was determined to be 3:15 PM to 4:15 PM. This peak hour was confirmed with HSR planners (HSR staff, personal communication, October 3rd, 2007). The peak hour was determined to represent approximately 10.2% of total daily demand, so the full day TTS OD data was reduced to that factor to represent peak hour travel patterns. Though this assumes travel patterns in Hamilton are the same regardless of time of day, it results in the closest possible approximation of peak hour travel patterns given the limits of the data available. Peak hour transit travel patterns are represented in Table 4.4.

Table 4.4: HSR Passenger Demand OD Table

Peak Hour Total Transit Passenger Trips Demanded	Destination Zone													
Origin Zone	Ancaster	Core Area	Central Hamilton	Central Mountain	Dundas	East Hamilton	East Mountain	Rural	Stoney Creek	Stoney Creek Mountain	Waterdown	West Hamilton	West Mountain	Total Result
Ancaster	0	0	0	2	0	2	5	0	0	0	0	25	2	35
Core Area	2	252	249	88	8	76	51	0	3	0	0	250	95	1074
Central Hamilton	2	247	134	43	3	125	26	2	4	2	0	140	47	774
Central Mountain	3	77	35	193	2	17	115	2	2	8	0	105	87	646
Dundas	2	11	0	4	16	2	2	2	0	0	0	23	3	65
East Hamilton	0	77	148	10	0	141	7	0	22	4	0	62	13	485
East Mountain	7	58	28	95	2	12	118	0	2	4	0	84	41	451
Rural	0	0	2	2	2	0	0	4	0	0	0	0	0	10
Stoney Creek	0	9	5	2	0	18	4	0	2	2	0	11	0	53
Stoney Creek Mountain	0	0	2	10	0	4	6	0	0	2	0	6	2	33
Waterdown	0	0	0	0	0	0	0	0	0	0	0	0	2	2
West Hamilton	27	234	143	108	29	76	83	0	8	6	0	592	127	1433
West Mountain	2	95	51	93	7	13	39	0	0	2	4	134	127	566
Total Result	44	1058	798	650	69	486	455	10	42	31	4	1434	547	5627

(Source: Based on Data Management Group, 2003a).

To represent transit supply the number of scheduled trips offered by HSR that travel through and within the zones described in Illustration 4.2 were used. The criteria developed in chapter 3 to distinguish “viable” supply was used. The number of potential transfer points within the network was limited to no more than one point per zone. These locations included Dundas and Main St in Dundas, McMaster University in West Hamilton, Meadowlands Power Centre Terminal in Ancaster, Limeridge Mall Terminal in Central Mountain, Valley Park Loop in Stoney Creek Mountain, Eastgate Mall Terminal in East Hamilton, and the McNabb Terminal / Gore Park area of the Core Area zone. These points are illustrated in Appendix 5.

Data used to indicate the supply of HSR trips were available from the agency's public schedule timetables. These timetables were obtained from the HSR website during the Fall 2006 scheduled period. The five-year duration between the TTS survey and the schedule period used in this analysis to represent supply could be significant if major route changes happened during that period. An example HSR timetable is displayed in Illustration 3.2. When all viable trips between zones were identified, their sums were added to another OD table with the same design as the ones used to represent transit demand. These results are presented in Table 4.5. Further steps, which are described in chapter 3, were taken to completely analyze the data. The resultant disparities between supplied service and demanded service, which are calculated by the following formula, are illustrated in Table 4.6.

$$\text{Disparity (o,d)} = \left[\frac{S\,(o,d)}{\sum_o \sum_d S_{od}} - \frac{D\,(o,d)}{\sum_o \sum_d D_{od}} \right] \text{X } 100$$

The following is an example calculation of the number of trips disparity for and OD pair. Table 4.4 shows that the Core Area to Central Hamilton OD pair has a passenger demand of 249 trips during the peak hour. This represents 4.425% of total passenger demand (249 / 5627). Table 4.5 shows that this OD pair has a service supply of 38 trips during the peak hour. This represents 3.008% of total transit supply (38 / 1263). When passenger demand for this OD pair is subtracted from service supply, there is a resultant shortage of 1.416% of total supplied trips. Converted back from proportion to the raw number of trips, this represents a shortage of 18 scheduled trip departures between the Core Area and Central Hamilton (-1.416 * 1263 = 17.884).

Another table shown below, Table 4.6, contains the number of trips that each proportion of service disparity represents. Geographically concentrated patterns of service disparity are evident. Ancaster, the Core Area, and East Hamilton receive a large surplus of trips, whereas Central Hamilton, West Hamilton, and West Mountain receive a large shortage of trips. Significant service disparities exist for numerous individual OD pairs. The OD pair featuring the greatest individual surplus of service is within the Core Area. The OD pair featuring the greatest individual shortage of service is within West Hamilton. The network performance rate, which is indicated by the misallocation rate described in chapter 3, for the HSR network is 30.81%. A graphical illustration of the cumulative patterns of disparity these results show is illustrated in Illustration 4.3 following the results tables. Lines on Illustration refer to interzonal disparities whereas points refer to intrazonal disparities. The width of the line describes the extent of the disparity, whereas the colour indicates the direction, with green lines representing a surplus and red lines representing a shortage.

Similarly, Table 4.7 represents demand by all modes of transportation within Hamilton in the peak hour. Table 4.8 represents the disparities the SDBTSA method calculates between demand by all modes and the HSR network of transit supply. These results are discussed in the following chapter.

Table 4.5: HSR Service Supply OD Table

Peak Hour Total Transit Passenger Trips Demanded	Destination Zone													
Origin Zone	Ancaster	Core Area	Central Hamilton	Central Mountain	Dundas	East Hamilton	East Mountain	Rural	Stoney Creek	Stoney Creek Mountain	Waterdown	West Hamilton	West Mountain	Total Result
Ancaster	9	3	5	4	2	3	4	0	0	2	0	3	4	39
Core Area	3	86	38	28	2	34	16	0	3	0	0	36	12	258
Central Hamilton	5	38	44	2	2	36	2	0	3	2	0	22	2	158
Central Mountain	4	28	2	34	4	20	20	0	0	2	0	39	4	157
Dundas	0	2	2	4	4	2	4	0	0	0	0	2	4	24
East Hamilton	3	34	36	28	2	36	2	0	3	2	0	26	30	202
East Mountain	4	16	2	20	4	2	24	0	0	4	0	39	4	119
Rural	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stoney Creek	0	3	3	0	0	3	0	0	4	0	0	3	0	16
Stoney Creek Mountain	2	0	2	2	0	2	4	0	0	4	0	2	2	20
Waterdown	0	0	0	0	0	0	0	0	0	0	0	0	0	0
West Hamilton	3	36	22	28	2	26	16	0	3	2	0	36	4	178
West Mountain	4	12	2	4	4	30	4	0	0	2	0	4	26	92
Total Result	37	258	158	154	26	194	96	0	16	20	0	212	92	1263

(Source: Based on HSR scheduled timetables, 2006.)

Table 4.6: SDBTSA Disparity Results for Transit Demand Only

Peak Hour Total Transit Passenger Trips Demanded	Destination Zone													
Origin Zone	Ancaster	Core Area	Central Hamilton	Central Mountain	Dundas	East Hamilton	East Mountain	Rural	Stoney Creek	Stoney Creek Mountain	Waterdown	West Hamilton	West Mountain	Total Result
Ancaster	9	3	5	4	2	3	3	0	0	2	0	-3	4	31
Core Area	3	30	-18	8	0	17	5	0	2	0	0	-20	-9	17
Central Hamilton	5	-17	14	-8	1	8	-4	0	2	2	0	-9	-9	-16
Central Mountain	3	11	-6	-9	3	16	-6	0	0	0	0	15	-16	12
Dundas	0	0	2	3	0	2	4	-1	0	0	0	-3	3	9
East Hamilton	3	17	3	26	2	4	0	0	-2	1	0	12	27	93
East Mountain	2	3	-4	-1	4	-1	-2	0	0	3	0	20	-5	18
Rural	0	0	0	0	-1	0	0	-1	0	0	0	0	0	-2
Stoney Creek	0	1	2	0	0	-1	-1	0	4	0	0	0	0	4
Stoney Creek Mountain	2	0	2	0	0	1	3	0	0	4	0	1	2	13
Waterdown	0	0	0	0	0	0	0	0	0	0	0	0	0	0
West Hamilton	-3	-16	-10	4	-4	9	-3	0	1	1	0	-97	-24	-144
West Mountain	4	-9	-9	-17	2	27	-5	0	0	2	-1	-26	-3	-35
Total Result	27	21	-21	8	11	85	-6	-2	7	13	-1	-110	-31	0

(Source: author.)

Table 4.7: Demand by all Modes Within Hamilton OD Table

	Destination Zone													
Origin Zone	Ancaster	Core Area	Central Hamilton	Central Mountain	Dundas	East Hamilton	East Mountain	Rural	Stoney Creek	Stoney Creek Mountain	Waterdown	West Hamilton	West Mountain	Total Result
Ancaster	1918	191	150	334	205	108	165	458	22	39	16	517	475	4599
Core Area	186	2235	1334	680	214	658	566	179	134	102	51	1347	613	8298
Central Hamilton	162	1359	4740	533	120	1789	558	273	305	202	29	733	483	11286
Central Mountain	348	684	512	3592	126	421	1663	297	83	212	49	720	1692	10400
Dundas	192	187	118	127	2144	81	74	418	20	6	65	768	127	4327
East Hamilton	108	646	1783	414	74	5201	371	268	909	333	24	455	272	10858
East Mountain	172	575	599	1672	71	358	3522	247	85	177	15	510	599	8602
Rural	452	193	286	344	411	244	214	1483	45	136	351	349	266	4775
Stoney Creek	27	138	324	87	15	893	69	48	716	47	2	124	73	2561
Stoney Creek Mountain	28	97	198	202	2	315	172	140	48	681	0	126	100	2107
Waterdown	22	43	32	38	71	24	15	373	4	2	859	92	46	1620
West Hamilton	501	1362	741	733	738	481	490	344	128	125	92	4730	766	11231
West Mountain	480	639	530	1625	121	274	636	268	59	102	50	759	3153	8694
Total Result	4596	8348	11347	10382	4313	10847	8515	4795	2557	2162	1603	11230	8664	89359

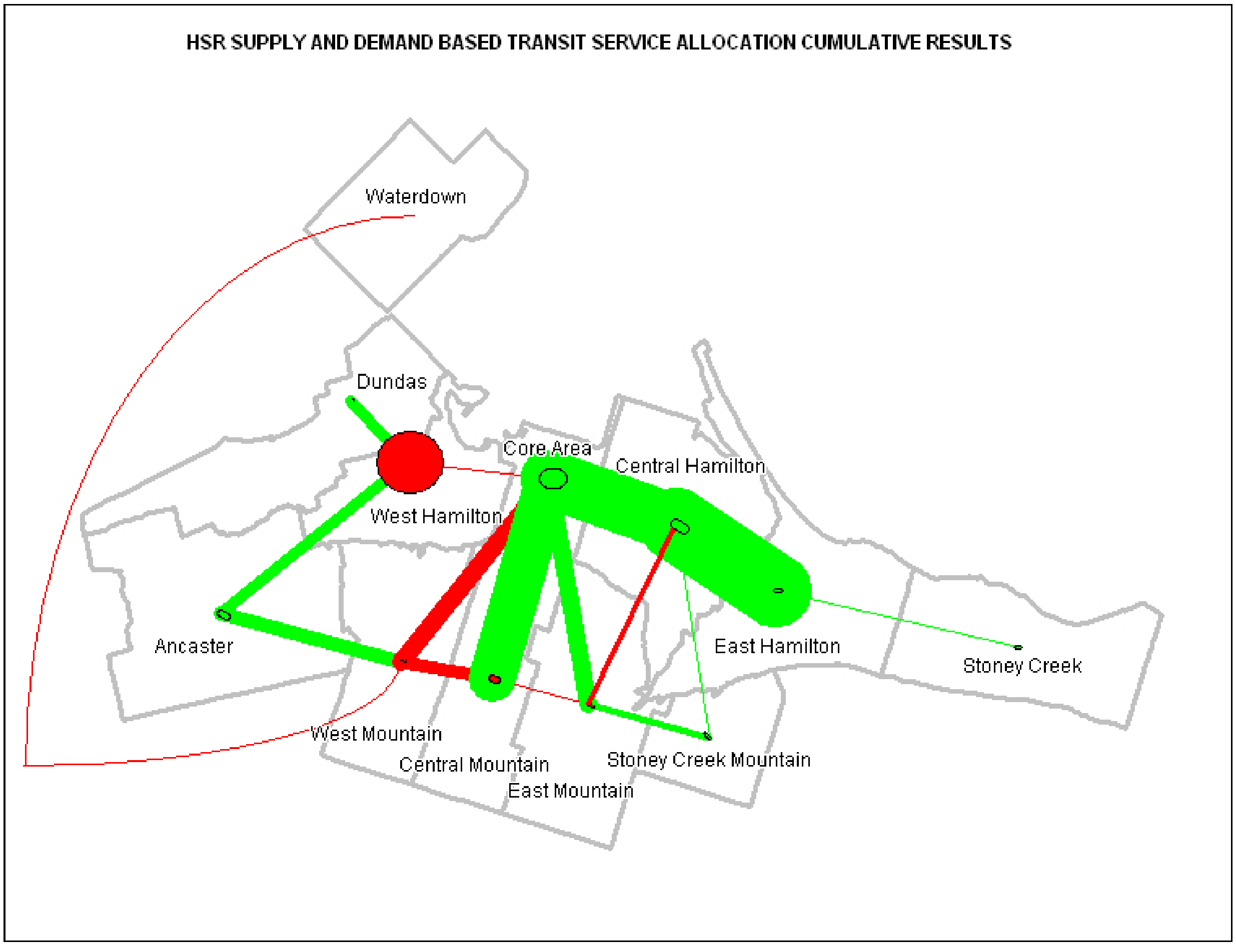
(Source: Based on Data Management Group, 2003a).

Table 4.8: SDBTSA Disparity Results for All Modes

	Destination Zone													
Origin Zone	Ancaster	Core Area	Central Hamilton	Central Mountain	Dundas	East Hamilton	East Mountain	Rural	Stoney Creek	Stoney Creek Mountain	Waterdown	West Hamilton	West Mountain	Total Result
Ancaster	-18	0	3	-1	-1	1	2	-6	0	1	0	-4	-3	-26
Core Area	0	54	19	18	-1	25	8	-3	1	-1	-1	17	3	141
Central Hamilton	3	19	-23	-6	0	11	-6	-4	-1	-1	0	12	-5	-2
Central Mountain	-1	18	-5	-17	2	14	-4	-4	-1	-1	-1	29	-20	10
Dundas	-3	-1	0	2	-26	1	3	-6	0	0	-1	-9	2	-37
East Hamilton	1	25	11	22	1	-38	-3	-4	-10	-3	0	20	26	49
East Mountain	2	8	-6	-4	3	-3	-26	-3	-1	1	0	32	-4	-3
Rural	-6	-3	-4	-5	-6	-3	-3	-21	-1	-2	-5	-5	-4	-67
Stoney Creek	0	1	-2	-1	0	-10	-1	-1	-6	-1	0	1	-1	-20
Stoney Creek Mountain	2	-1	-1	-1	0	-2	2	-2	-1	-6	0	0	1	-10
Waterdown	0	-1	0	-1	-1	0	0	-5	0	0	-12	-1	-1	-23
West Hamilton	-4	17	12	18	-8	19	9	-5	1	0	-1	-31	-7	19
West Mountain	-3	3	-5	-19	2	26	-5	-4	-1	1	-1	-7	-19	-31
Total Result	-28	140	-2	7	-35	41	-24	-68	-20	-11	-23	53	-30	0

(Source: author.)

Illustration 4.6: Graphical Illustration of Transit Only SDBTSA Results for HSR



(Source: author.)

Chapter 5: Conclusion

5.1: Discussion of Results and Recommendations

Despite weaknesses in present performance, Hamilton has ambitious plans for the future of HSR. Plans developed in recent years for a higher order transit network share themes in common with past plans, but also make an important improvement over them. Present plans, as identified in the 2007 Transportation Master Plan involve the implementation of multiple BRT lines. As has typically been suggested, one line is planned to operate from McMaster University to the Eastgate Mall Terminal, and another from downtown to the mountain via James and Upper James streets. As a precursor to BRT, HSR is presently re-marketing the route 10 Beeline service as “BLine”, and it will soon begin operating another limited stop express service on Upper James Street to be called ALine.

The important improvement the 2007 Transportation Master Plan makes, however, is to link the two traditionally planned radial BRT routes with more BRT routes elsewhere in the city in order to create a multidestinational BRT network. One recommended route is planned to serve the southern portion of the mountain via the Linc expressway, and other potential future routes are suggested for Barton Street, Fennel Ave, Upper Wentworth St, Rymal Road, and to connect McMaster University to Ancaster as well as to connect Stoney Creek Mountain to Eastgate Mall Terminal. The plan suggests these BRT routes can help put HSR in a competitive position in the transportation market in order to fulfill the goal of 100 transit rides per capita by the year 2020 (City of Hamilton, 2008).

Given these ambitious plans for a multidestinational BRT network it seems counterintuitive for HSR to maintain a primarily radial transit network. The present primarily radial network and the multidestinational BRT network described in the 2007 Transportation Master Plan present two different visions of transportation in Hamilton. The 2007 Transportation Master Plan vision has been officially endorsed, so continuing with the present network seems contrary to the endorsed vision. Unless there is a strong reason to continue with a primarily radial transit network, such as if the present network performed well at facilitating present travel patterns within the City, then it would seem more compatible with future plans to develop a more multidestinational network structure now. Contrarily, if the present network performs well at facilitating travel patterns then perhaps the new vision of a multidestinational BRT network is questionable.

In either case, there seem to be tension between the two visions that necessitates an evaluation of the performance of the present HSR network structure. The SDBTSA method developed in chapter 3 provides the necessary means to achieve this objective. The results of this process indicate how well the present HSR network structure facilitates travel patterns within Hamilton. If the results of the SDBTSA method suggest there are few disparities between the services offered and present travel patterns then the present radial, downtown-oriented network structure does not need improvement, and the vision of a multidestinational network presented in the 2007 Transportation Master Plan may be questionable for the needs of present riders. Contrarily, if the results suggest there are disparities in the network, especially in the downtown area, then the present network does not perform well at facilitating travel, does need improvement, and a more multidestinational network structure would be more appropriate for the needs of present riders.

The application of the SDBTSA process described in chapter 4, and results shown in

Table 4.6 and subsequent illustrations complete the process of evaluating the HSR network structure. These results suggest that approximately one third of HSR services offered during the peak hour of demand could be reallocated to different OD pairs to better facilitate transit demand during that period. If a goal of public transit is to perform efficiently and effectively, as the literature suggests it should be, then this suggests there may be problems with the structure of the HSR transit network. Specific disparities in transit supply and demand in Hamilton are discussed below. Illustrations of disparities related to individual zones are present in Appendices 6-16. Disparities calculated from TTS data for total travel demand by all modes and HSR transit service supply are also discussed below.

The results show that the Ancaster zone is oversupplied with transit service by almost three quarters (27 of 37 destined trips - 73%). While Ancaster is supplied with more service than other zones at the periphery of Hamilton, and receives a large surplus number of trips, it still receives very little of the total amount of service supplied during the peak hour (37 of 1263 destined trips – 3%). Therefore the oversupply of service in Ancaster cannot be related to a saturation of supply, especially considering the Ancaster zone covers 13.3% of the urban study area (see Table 4.3). The OD pair with the largest individual oversupply of transit service in Ancaster is Ancaster to Ancaster. This indicates that a problem with the pattern of routes within Ancaster results in that zone's poor performance, and that a redesign of service within Ancaster could better facilitate transit use.

The results also show that the Core Area is oversupplied with transit trips. These results are consistent with findings about the above average degree of radiality of the HSR network, anecdotal evidence about the storage of vehicles in the core area during dwell time, and what the literature says about polycentric urban travel and transit networks which have not been adapted to facilitate such travel patterns (Table 4.3; Schneider, 1981; Schumann, 1997; Modarres, 2003). In this case the overall surplus is much smaller than in Ancaster, at approximately 8% (21 of 258 destined trips), but the surplus of trips is the largest for any individual OD pair. The Core Area to Core Area OD pair receives 30 more trips in the peak hour than demand warrants. No present routes serve the Core Area only, so reducing service on such routes is not a solution to this oversupply. To reduce travel by vehicles within the Core Area, vehicles need to be removed from it. It was noted earlier that the use of high capacity vehicles to serve urban cores can free lower capacity vehicles for service elsewhere within transit networks (Schumann, 1997; Vuchic, 2005). One solution to the oversupply of the Core Area is to end routes that travel to the Core Area from other zones before they reach the Core Area in order to feed passengers into a high capacity route that circulates throughout the core to distribute passengers. This solution could also help solve under-supply service disparities for other OD pairs. This solution could also help solve problems related to the physical limitations of dwelling so many vehicles in the core are that Hamilton experiences. This solution could reduce the complication of and area required by the transfer area in the core.

The results of this analysis also show shortages of service between the Core Area and Central Hamilton and West Hamilton, as well as a surplus of service between the Core Area and East Hamilton. One solution involves reallocating service to present routes that connect the Core Area to West Hamilton and Central Hamilton from routes that serve East Hamilton by using “short turn” trips that end in Central Hamilton on routes that travel from the Core Area to East Hamilton. Another solution involves redesigning routes that travel from the Core Area to Central Hamilton to focus on a new terminal located in Central Hamilton. This terminal could be used as a location upon which to focus the increased service that the Core Are to Central Hamilton OD pair requires and as a location for conveniently and more efficiently connecting the Core Area to East Hamilton. In either scenario the vehicles saved by the implementation of a high capacity circulation service in the Core Area could also be applied to resolve service shortages.

Not only do the results show that the East Hamilton zone is oversupplied from zones in the lower city, but they also show an oversupply of trips to and from mountain zones. In particular connections to the West Mountain and Central Mountain zones are oversupplied. Present routes are not structured to offer direct trips between these zones, the trips available between them and East Hamilton result from the scheduling of indirect trips requiring transfers in the Core Area. Some of the connections between these zones could be rescheduled so that trips from the mountain better connect to other lower city routes in the core, especially routes that serve West Mountain and West Hamilton since there is a significant shortage of service between these zones.

The connection between West Hamilton and West Mountain represents a significant service disparity. This OD pair is short by 26 trips destined for West Hamilton. While this only represents 2% of the total trips supplied by the network it represents approximately a quarter of the shortage of trips destined for West Hamilton (26 of 110 destined trips). As was mentioned above, adjusting the schedules of present routes to better connect the West Mountain and West Hamilton zones at the expense of the East Hamilton zone could solve some of the disparity between these zones and better facilitate transit use. Another solution, which relates to what the literature says about direct connections between zones being desirable in a multidestinational network, involves the creation of direct routes between the West Mountain and West Hamilton zones that do not travel through the Core Area (Schneider, 1981; Schumann, 1997; El-Hifnawi, 2002; Modarres, 2003; Thompson & Matoff, 2003). Rather than create new routes that overlap existing service, this could involve the creation of diametrical routes which provide a single vehicle trip through the core by combining two pre-existing routes.

Also located within West Hamilton is the most significant shortage of trips for any individual OD pair. Results show that the West Hamilton to West Hamilton OD pair receives 97 trips less during the peak hour than it requires for the supply of transit service to balance with demand for transit use within that zone. These trips are short trips, with many of them likely originating at or destined for McMaster University. For such trips a short haul, shuttle like service that makes many stops, travels throughout the entire zone, and is centered upon serving McMaster University could help solve the disparity (Schneider, 1981; Schumann, 1997; El-Hifnawi, 2002; Modarres, 2003; Thompson & Matoff, 2003).

Past transit studies in Hamilton have historically suggested that routes which travel from downtown to the mountain are oversupplied with service relative to demand. Route level load data collected by HSR in 2005 confirms this. For the most part, these results confirm this pattern as well. OD pairs in both directions between each of the Ancaster, Central Mountain, and East Mountain zones and the Core Area are provided with a surplus of service relative to demand. The results indicate that supply and demand for the Core Area to Stoney Creek Mountain OD pair is in equilibrium, and the only shortage OD pair with a shortage is the Core Area to West Mountain pair. These results suggest that what past Hamilton transit studies have suggested about mountain to downtown routes has not been heeded and perhaps relate to the statement in post amalgamation reports that service disparities are justifiable. Though such disparities may be politically justifiable they do not contribute towards the maximum possible performance of the HSR network. One possible solution is to reduce the duplication of service crossing the Niagara Escarpment by locating a terminal at peak of the mountain and providing a high capacity route that travels from there to the Core Area. Routes on the mountain could be realigned to focus on feeding the high capacity route rather than traveling into the core. This would reduce the number of trips traveling between the Core Area and mountain zones, and would also contribute towards reducing the surplus of service in the Core Area zone itself.

Examples of differences in disparities between transit demand and transit supply and total demand and transit supply are now discussed. The Ancaster to Ancaster disparity moves from a large surplus to a large shortage when travel by all modes is considered. This indicates that total travel volumes in the area are much higher than transit volumes, which further reinforces the need for improvement to the structure of routes in Ancaster. The Core Area to Core Area disparity moves from a large surplus to an even larger surplus when travel by all modes is considered. This indicates that total travel volume to the Core Area is a smaller percentage of total travel than transit travel volume is to the Core Area. This further supports the conclusion that HSR service is overly oriented towards downtown Hamilton. The West Mountain to West Hamilton OD pair results in an even greater shortage of transit supply when total travel demand is considered. This indicates that transit use is proportionately low for this OD pair, possibly resulting from the lack of direct routes between these two zones. In short, differences in disparities between transit demand and transit supply and total demand and transit supply reinforce and confirm what results indicate about possible problems with the structure of the HSR network.

The literature says downtown anchored radial transit routes can limit travel options for transit users. When taken together, the results of the DNSTE and SDBTSA methods indicate that a great proportion of HSR service travels to downtown Hamilton, which may be incompatible with Hamilton travel patterns. A more multidestinational network structure would be useful for

Hamilton. This suggests that the vision of a multidimensional transit network demonstrated in Hamilton's new Transportation Master Plan is more compatible with present transit user needs than the present network structure is, and that present transit users could benefit from

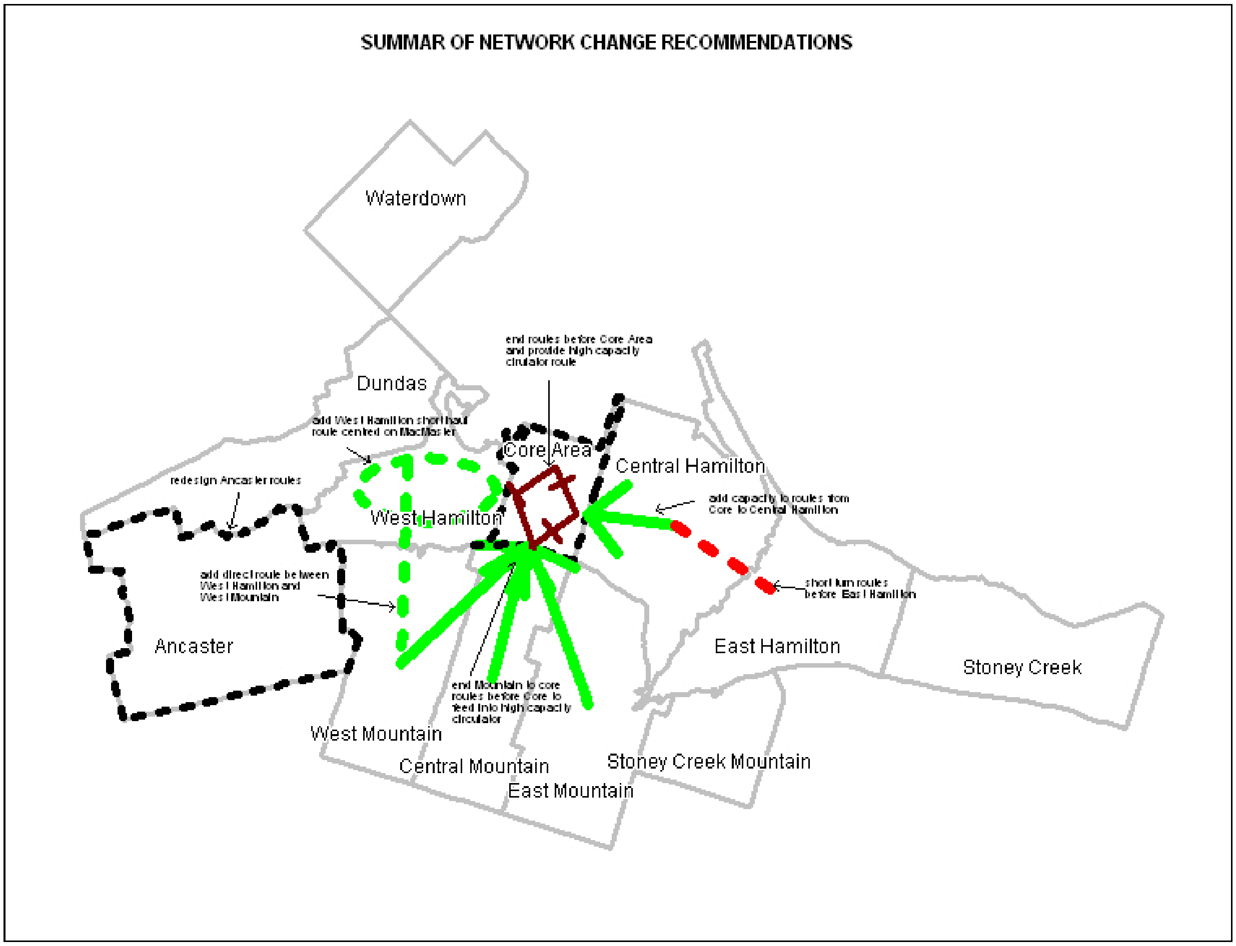
The identified mismatches between transit service and travel patterns in Hamilton likely relate to the shortages of planning capacity the literature suggests midsized Canadian, and specifically Ontario, cities experience. These mismatches also relate to the lack of appropriate means in the literature by which to monitor the long-term performance of the HSR network structure. With the development of the two methods presented in chapter 3 of this thesis and applied to Hamilton in chapter 4, perhaps in some small way some of the mismatches in Hamilton can now be overcome. Table 5.1 presents a summary of the recommended transit service reallocations for Hamilton described above as, and Illustration 5.1 provides a map of those recommendations.

Table 5.1: Summary of Network Change Recommendations

● redesign Ancaster area routes
● end Lower City routes that travel to Core Area before reaching there, feed passengers into high capacity downtown circulation route
● short turn route from Core Area to East Hamilton and reallocate service to connections between Core Area and Central Hamilton and West Hamilton
● adjust schedule to better connect mountain to Core routes with Core to West Hamilton routes rather than Core to East Hamilton routes
● provide new route(s) directly connecting West Mountain and West Hamilton
● provide McMaster-based West Hamilton shuttle route
● end Mountain routes that travel to Core Area before reaching there, feed passengers into high capacity downtown circulation route

(Source: author.)

Illustration 5.1: Summary of Network Change Recommendations



(Source: author.)

5.2: Future Research

To the extent that these results show the high tendency of Canadian transit routes to travel to downtowns, they answer the primary research question of this thesis. Yet, the results from the case study of Hamilton do not necessarily reflect the reality of the rest of Canadian transit networks. Since Hamilton provides a more radial network than many Canadian cities do, and it features significant disparities, these results cannot reflect all of Canada. Therefore, there is a need for more research that applies the SDBTSA method to truly learn if Canadian transit systems have been adapted to reflect the polycentric nature of contemporary urban travel in Canada. Along with the comparison of the tendency of Canadian transit systems to be structured towards downtowns, research needs to be completed to compare the misallocation rates of Canadian transit networks to determine their overall and relative performance rates. Moreover, a long term program that continued research based on the application of the SDBTSA method would actually represent the *monitoring* of Canadian transit networks rather than the evaluation of one network, as was done in this thesis.

There are numerous opportunities for future research to improve the SDBTSA method. Future research could investigate ways to apply this methodology to multimodal transit networks featuring vehicles of varying capacities. Future research could investigate the use of GIS software to define the zonal boundaries used in other applications of the SDBTSA method based on more rigorous definitions of transportation activity related variables. Further research could also investigate the use of advanced data measurement techniques like the integration of smart card and automatic passenger counting technology into the transit demand data collection step in the SDBTSA method. Moreover, the use of advanced scheduling software could improve the transit supply data collection step in the SDBTSA method.

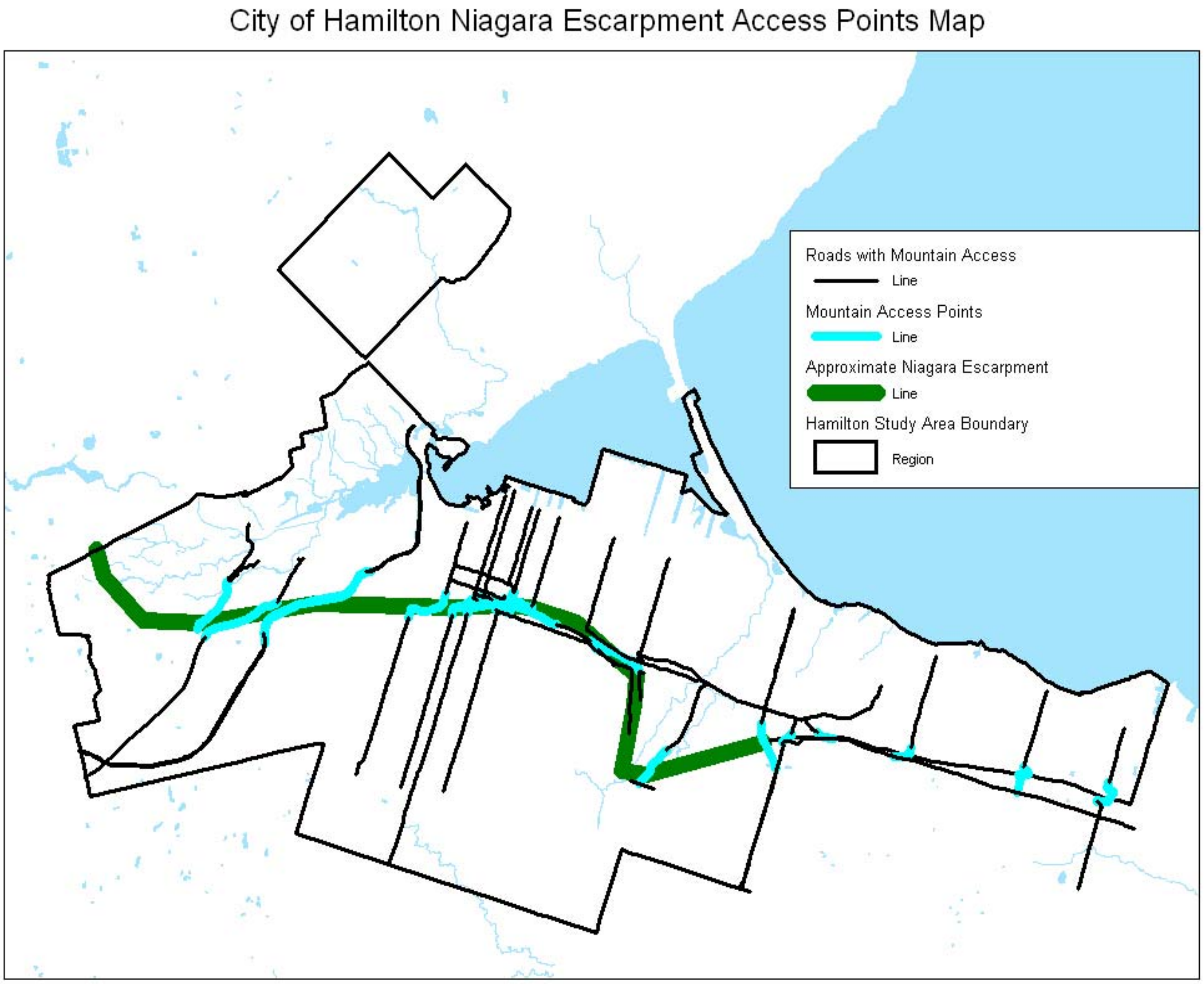
This thesis has accomplished the goal of developing a method of evaluating and monitoring transit network structure, the benefits of that method have been demonstrated by its provision of recommendations based on literature on transit network design, and this thesis has helped HSR planners by providing them with data to help with their planning.

List of Appendices

Appendices

Appendix 1

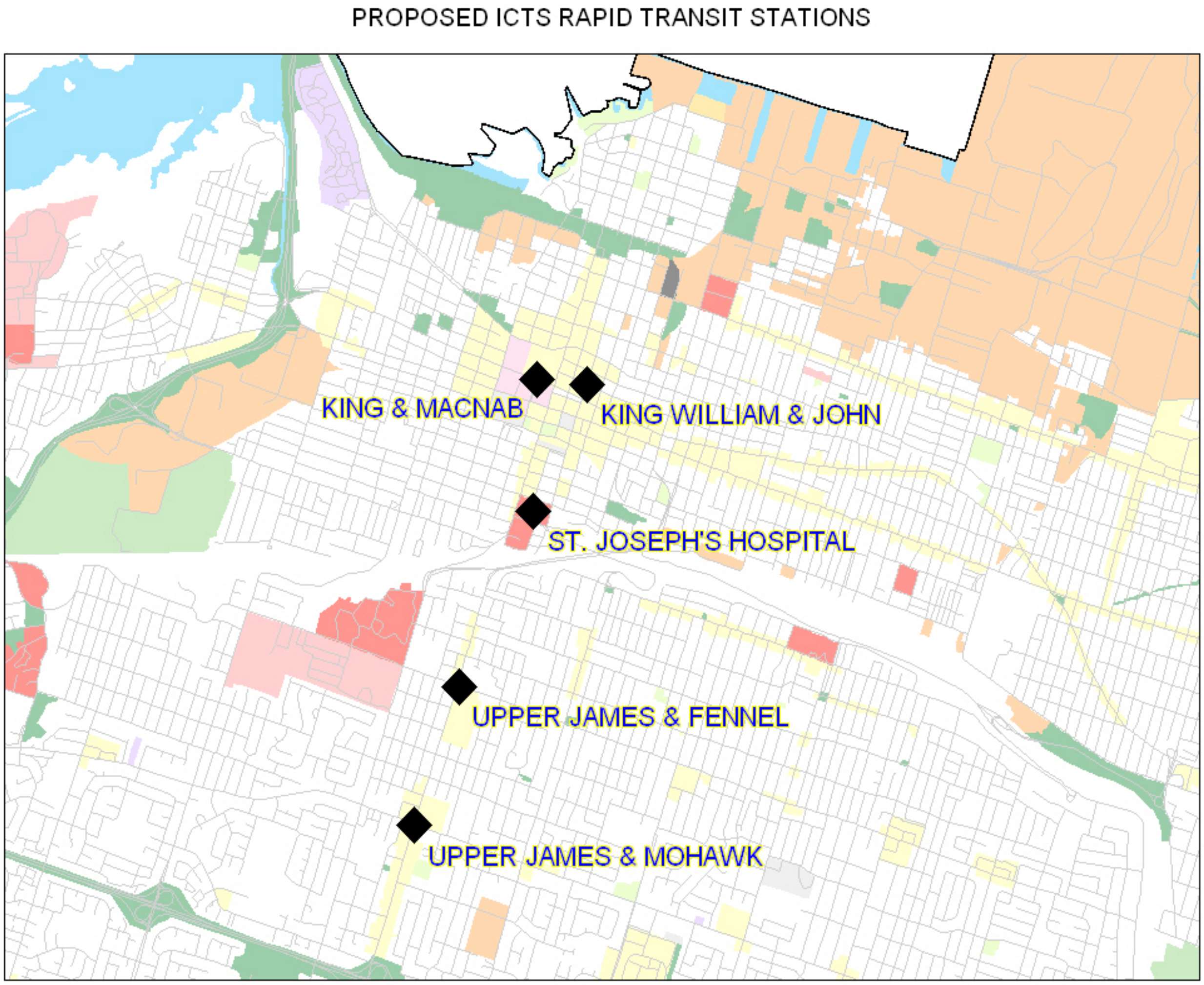
Niagara Escarpment Crossings in Hamilton, Ontario



(Source: author.)

Appendix 2

Proposed ICTS Rapid Transit Stations



(Source: author.)

Appendix 3

Example DNSTE Table

System	Total # Routes	# Routes Traveling to Downtown	Percentage
City A	5	5	100%
City B	10	8	80%
City C	50	30	60%
City D	100	60	60%
Total	165	103	62%

(Source: author.)

Appendix 4

Tabular Method of Displaying Transit Supply and Transit Demand Data

Using supply and demand tables with data consisting of the proportion of total supply and demand corresponding to each OD pair allows for the creation of a “Percentage Disparity Table.” Such a table contains the preliminary results of this methodology. The following five tables contain examples as described above.

Example Demand OD Table

# represents # passenger trips demanded between zones	Destination Zone			
Origin Zone	Zone A	Zone B	Zone C	TOTAL ORIGINATING
Zone A	5	0	10	15
Zone B	0	15	5	20
Zone C	10	5	10	25
TOTAL DESTINED	15	20	25	60

(Source: author.)

Example Supply OD Table

# represents # scheduled vehicles trips supplied between zones	Destination Zone			
Origin Zone	Zone A	Zone B	Zone C	TOTAL ORIGINATING
Zone A	10	0	20	30
Zone B	0	40	0	40
Zone C	20	0	10	30
TOTAL DESTINED	30	40	30	100

(Source: author.)

Example Demand Proportion OD Table

% represents % passenger trips demanded between zones	Destination Zone			
Origin Zone	Zone A	Zone B	Zone C	TOTAL ORIGINATING
Zone A	8.3%	0%	16.7%	25%
Zone B	0%	25%	8.3%	33.3%
Zone C	16.7%	8.3%	16.7%	41.7%
TOTAL DESTINED	25%	33.3%	41.7%	100%

(Source: author.)

Example Supply Proportion OD Table

% represents % scheduled vehicles trips supplied between zones	Destination Zone			
Origin Zone	Zone A	Zone B	Zone C	TOTAL ORIGINATING
Zone A	10%	0%	20%	30%
Zone B	0%	40%	0%	40%
Zone C	20%	0%	10%	30%
TOTAL DESTINED	30%	40%	30%	100%

(Source: author.)

Example Percentage Disparity Table

% represents % disparity between supplied and demanded service	Destination Zone			
Origin Zone	Zone A	Zone B	Zone C	TOTAL ORIGINATING
Zone A	1.7%	0%	3.3%	5%
Zone B	0%	15%	-8.3%	6.7%
Zone C	3.3%	-8.3%	-6.7%	-11.7%
TOTAL DESTINED	5%	6.7%	-11.7%	0%

(Source: author.)

The results in each cell of the Example Percentage Disparity Table represent the proportions of disparity in travel patterns and transit service for each individual OD pair in the example transit network. These results are not inherently useful, since they represent mere proportions. The final example results in trip value are displayed in the following table. Geographically concentrated patterns of service disparity become evident from such a table.

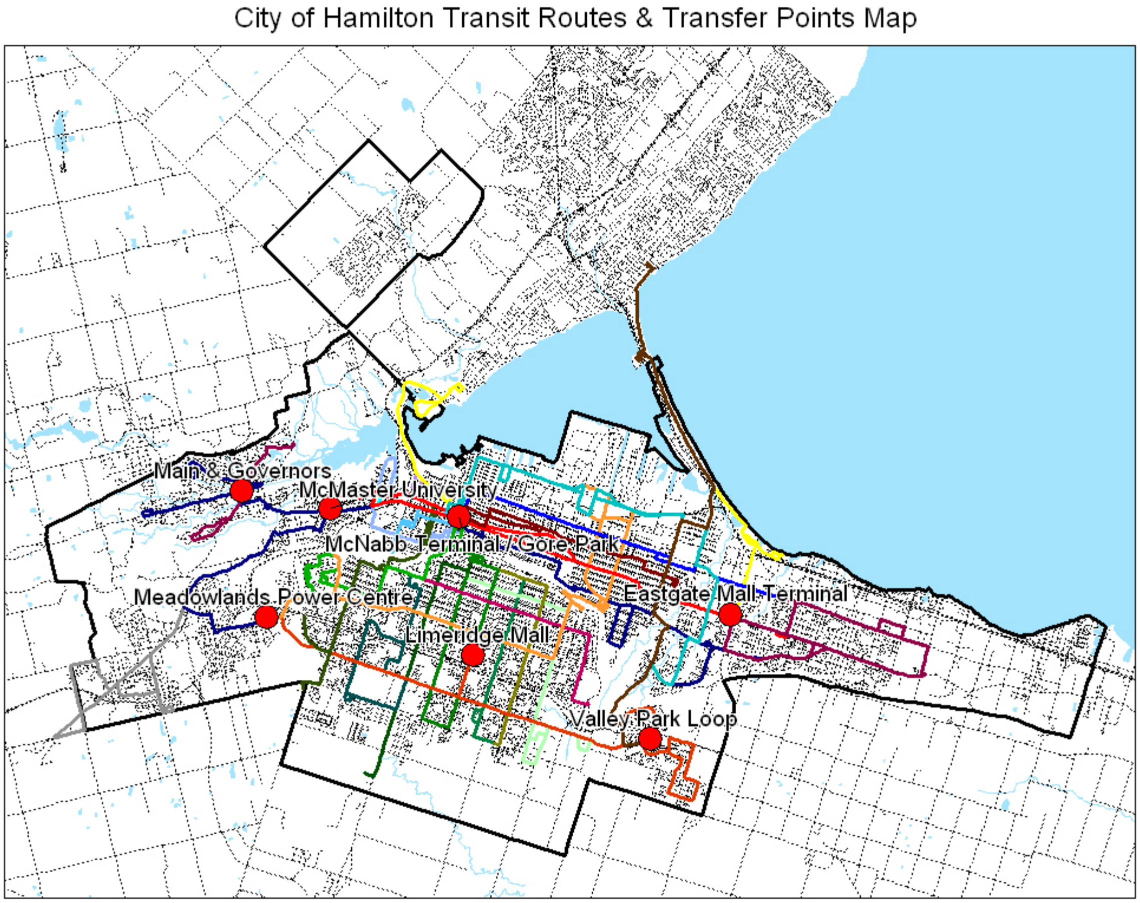
Example Trip Value Disparity Table

# represents # trips disparity between supplied and demanded service	Destination Zone			
Origin Zone	Zone A	Zone B	Zone C	TOTAL ORIGINATING
Zone A	1.7	0	3.3	5
Zone B	0	15	-8.3	6.7
Zone C	3.3	-8.3	-6.7	-11.7
TOTAL DESTINED	5	6.7	-11.7	0

(Source: author.)

Appendix 5

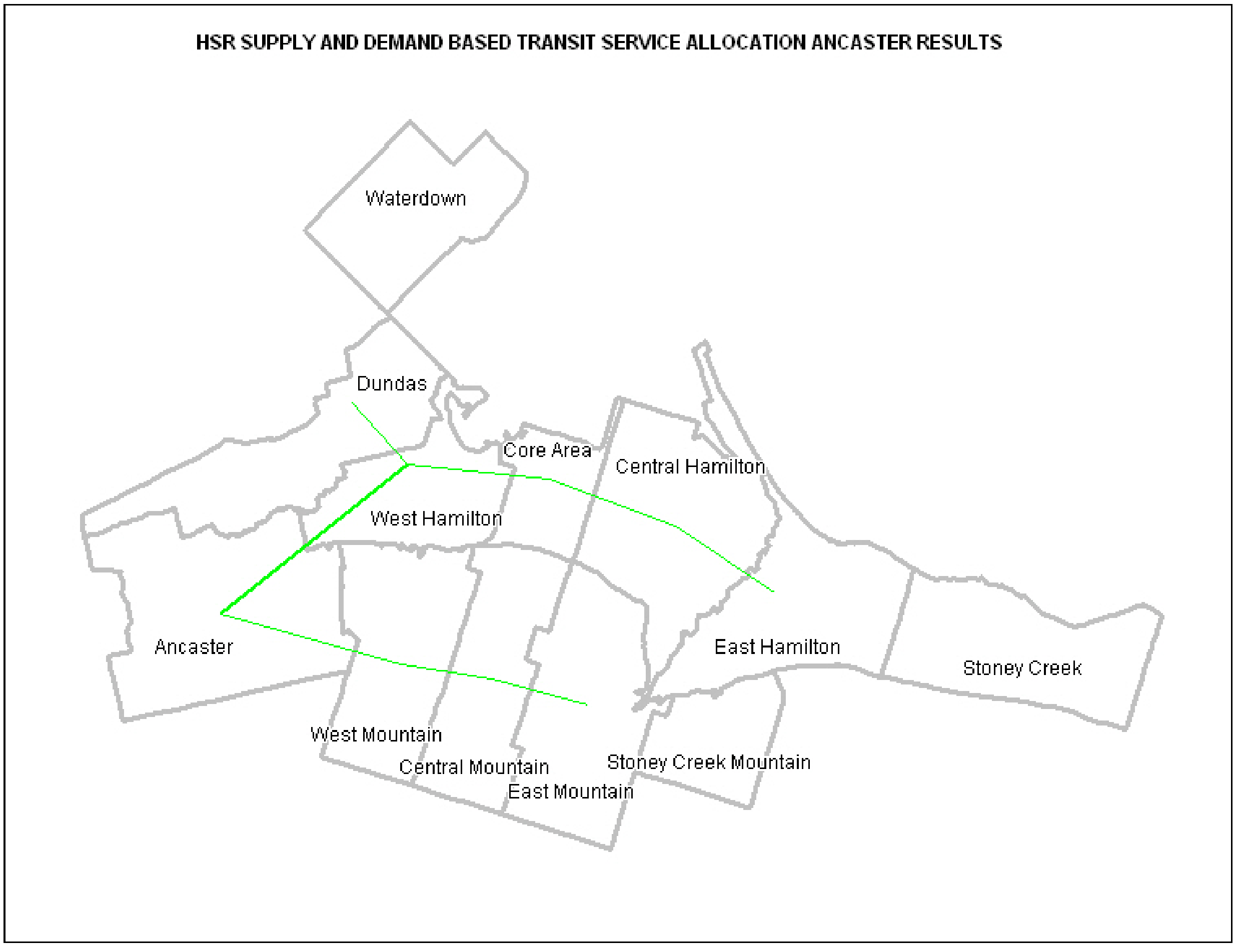
City of Hamilton Transit Routes & Transfer Points



(Source: author.)

Appendix 6

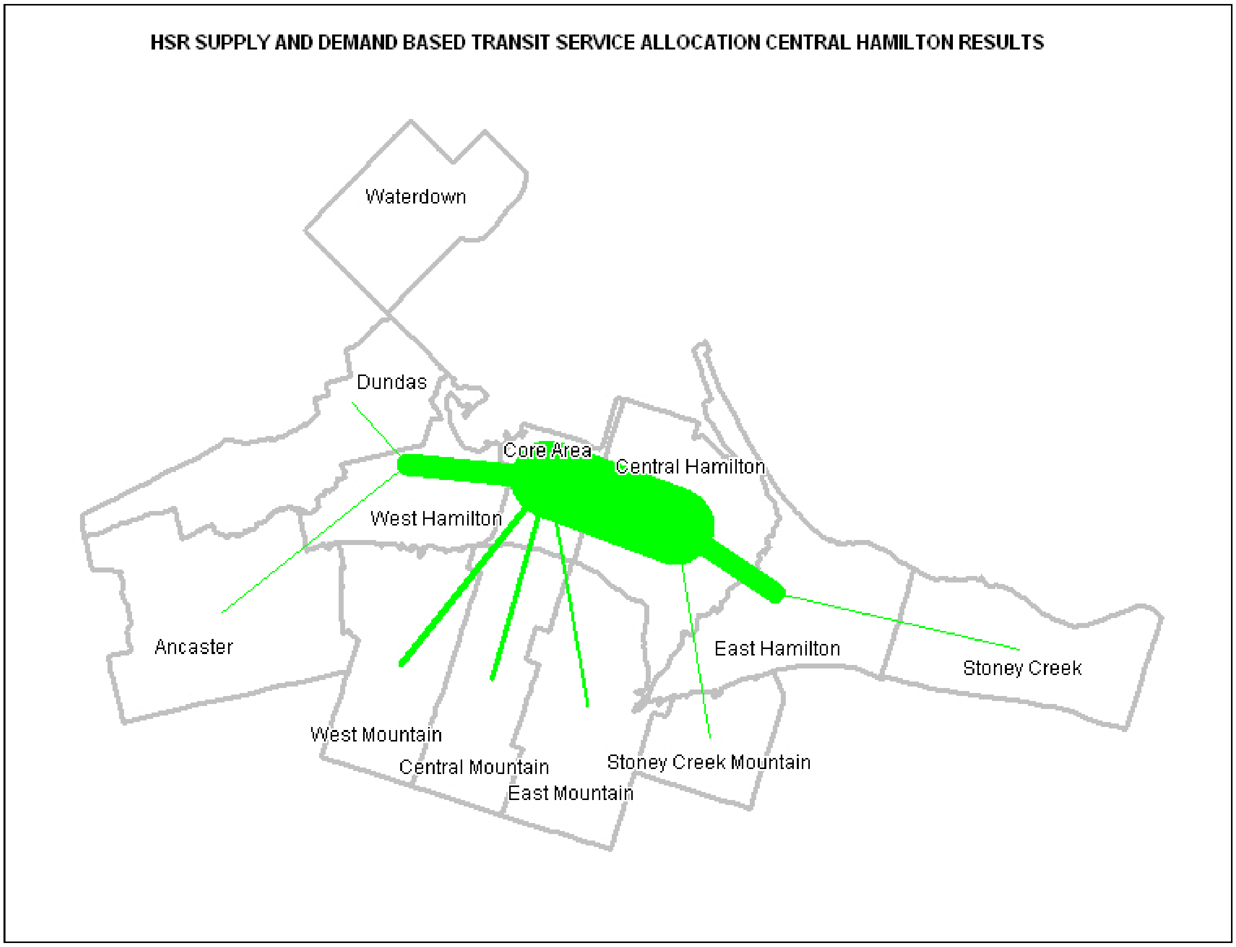
Graphical Illustration of Ancaster-related Disparity



(Source: author.)

Appendix 7

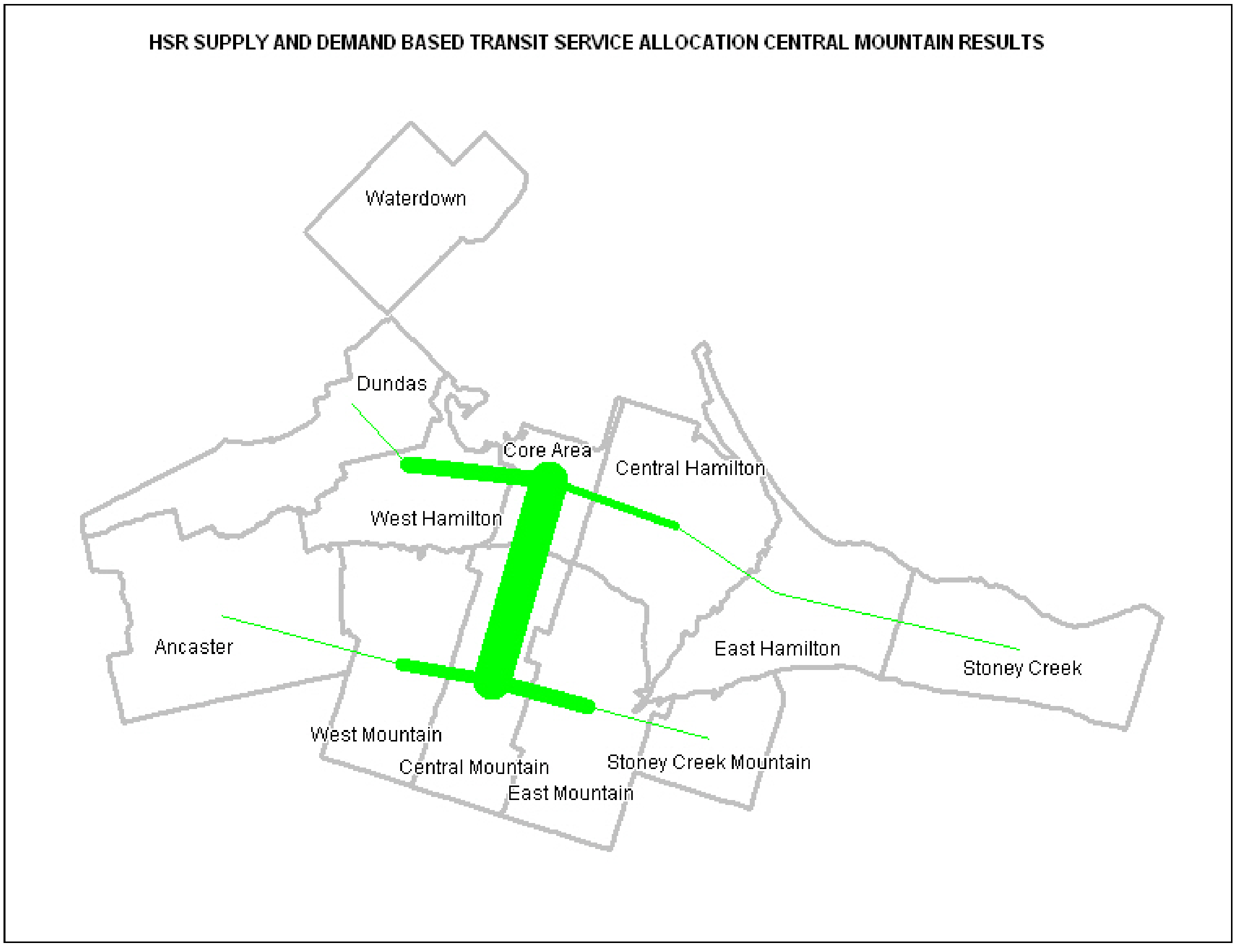
Graphical Illustration of Central Hamilton-related Disparity



(Source: author.)

Appendix 8

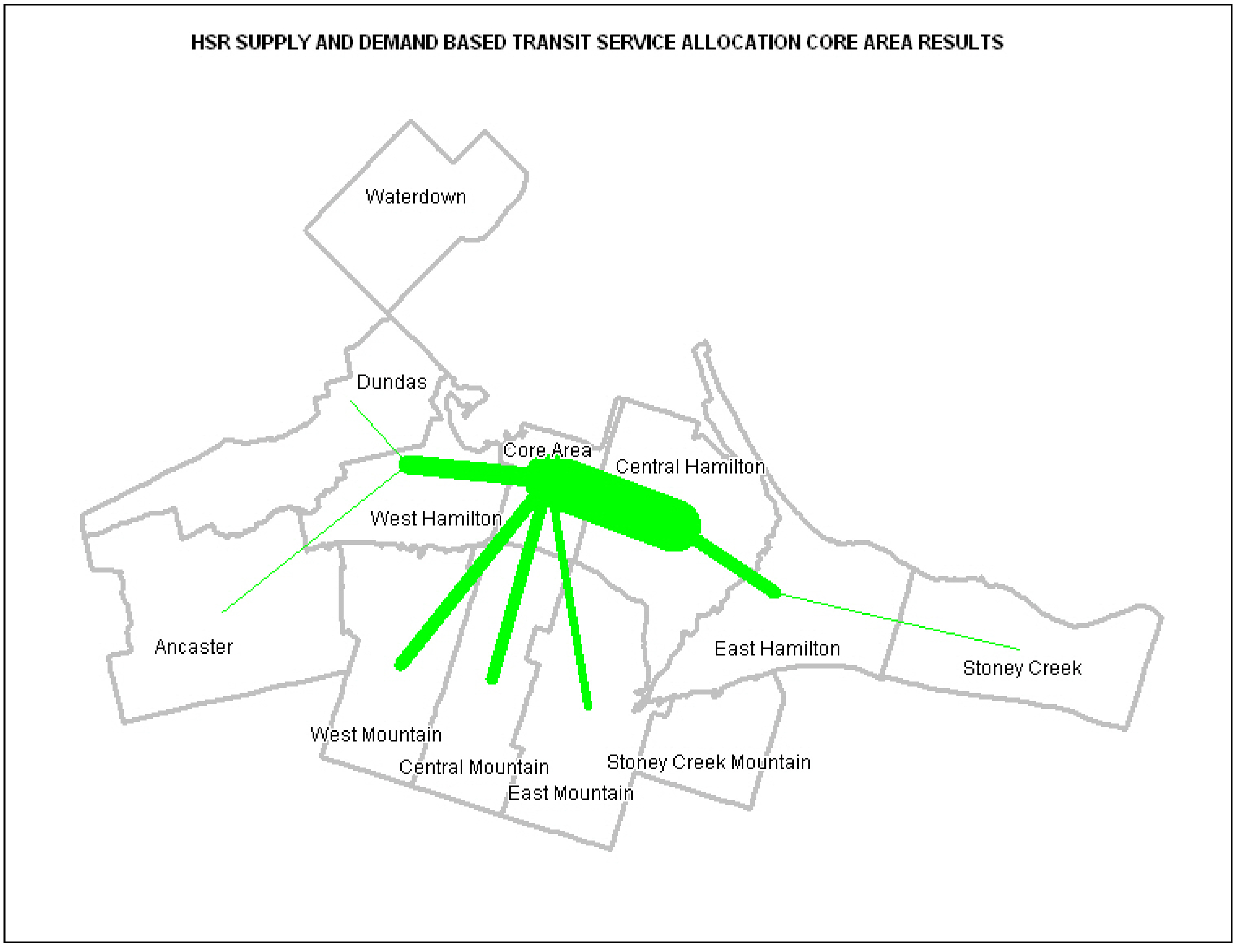
Graphical Illustration of Central Mountain-related Disparity



(Source: author.)

Appendix 9

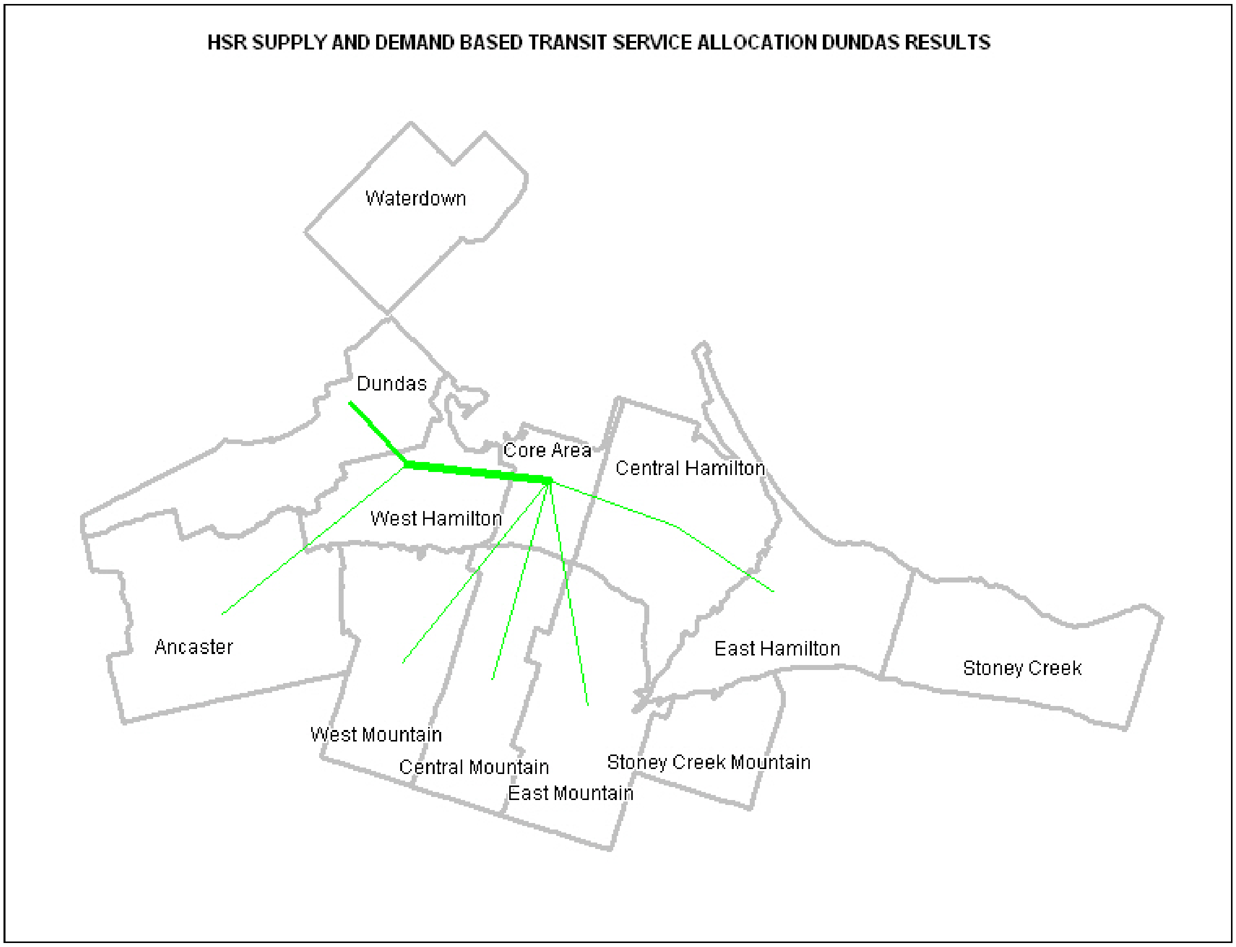
Graphical Illustration of Core Area-related Disparity



(Source: author.)

Appendix 10

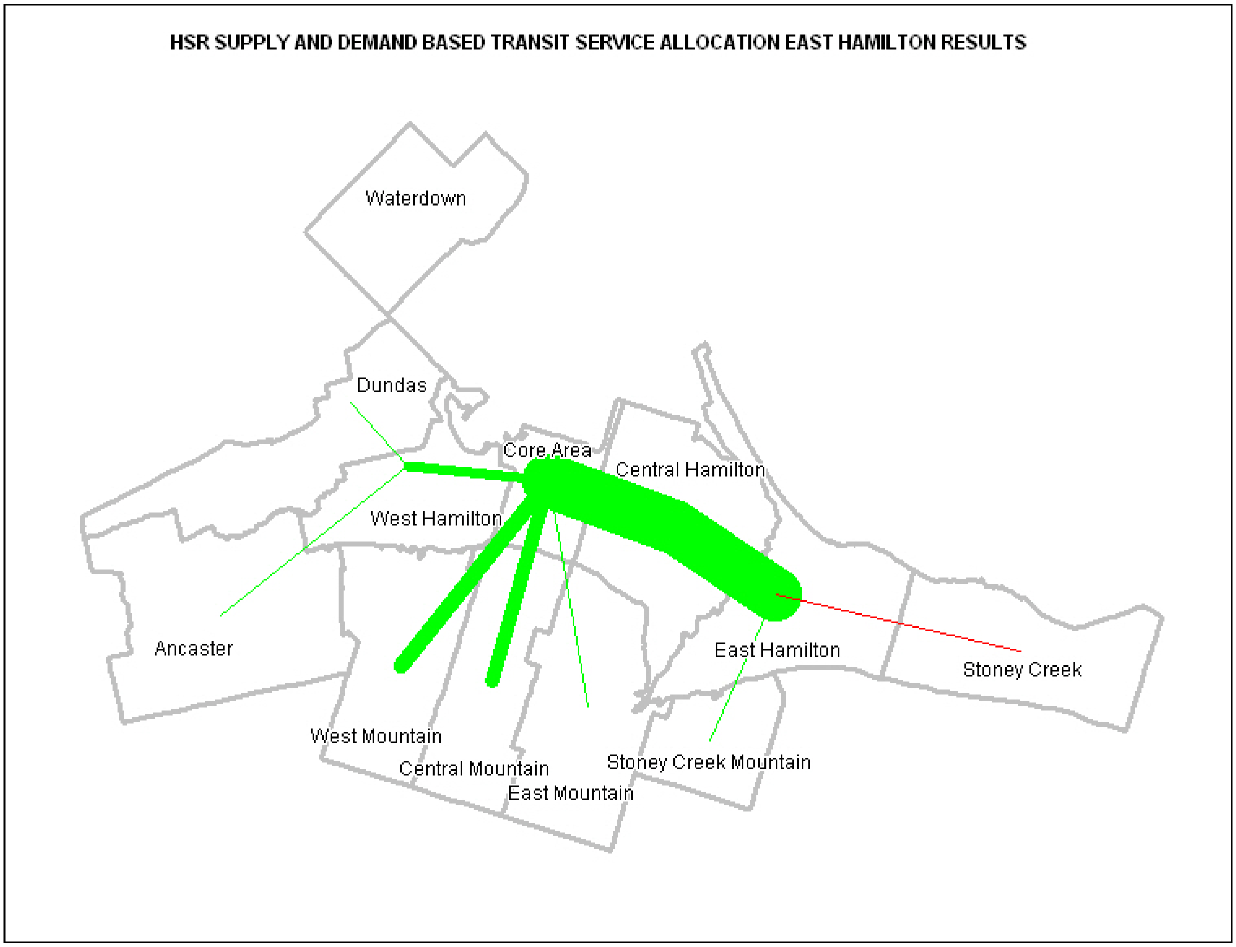
Graphical Illustration of Dundas-related Disparity



(Source: author.)

Appendix 11

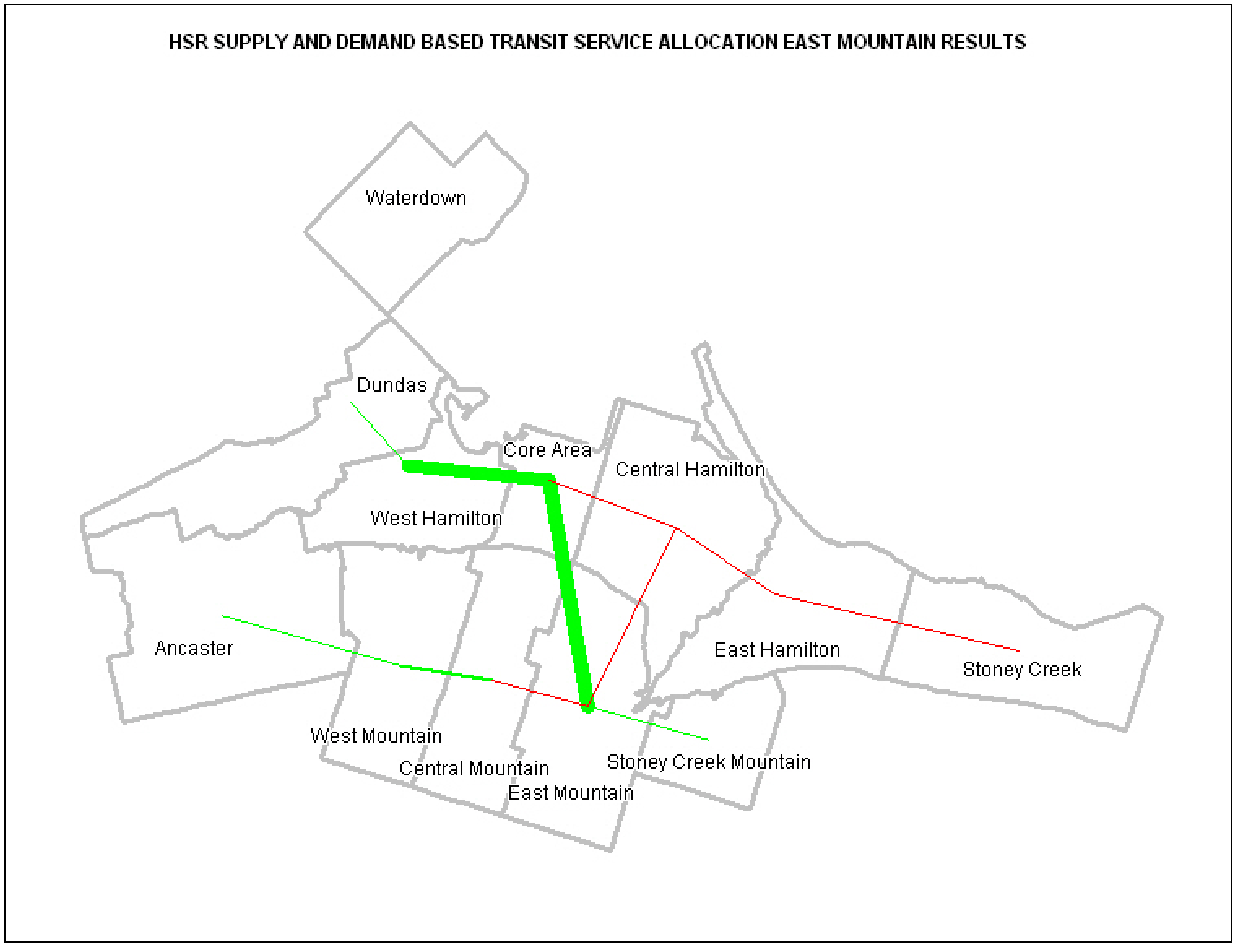
Graphical Illustration of East Hamilton-related Disparity



(Source: author.)

Appendix 12

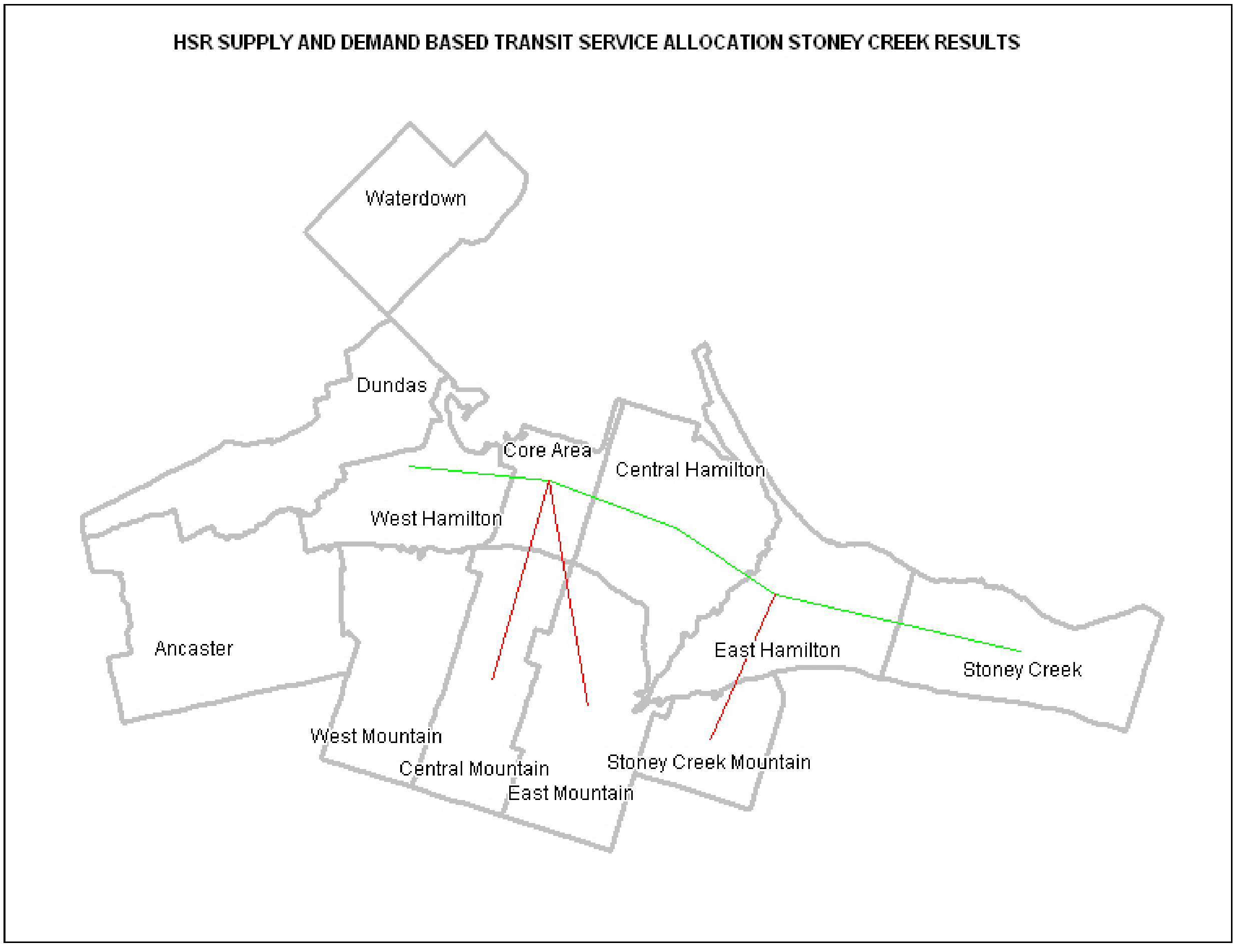
Graphical Illustration of East Mountain-related Disparity



(Source: author.)

Appendix 13

Graphical Illustration of Stoney Creek-related Disparity



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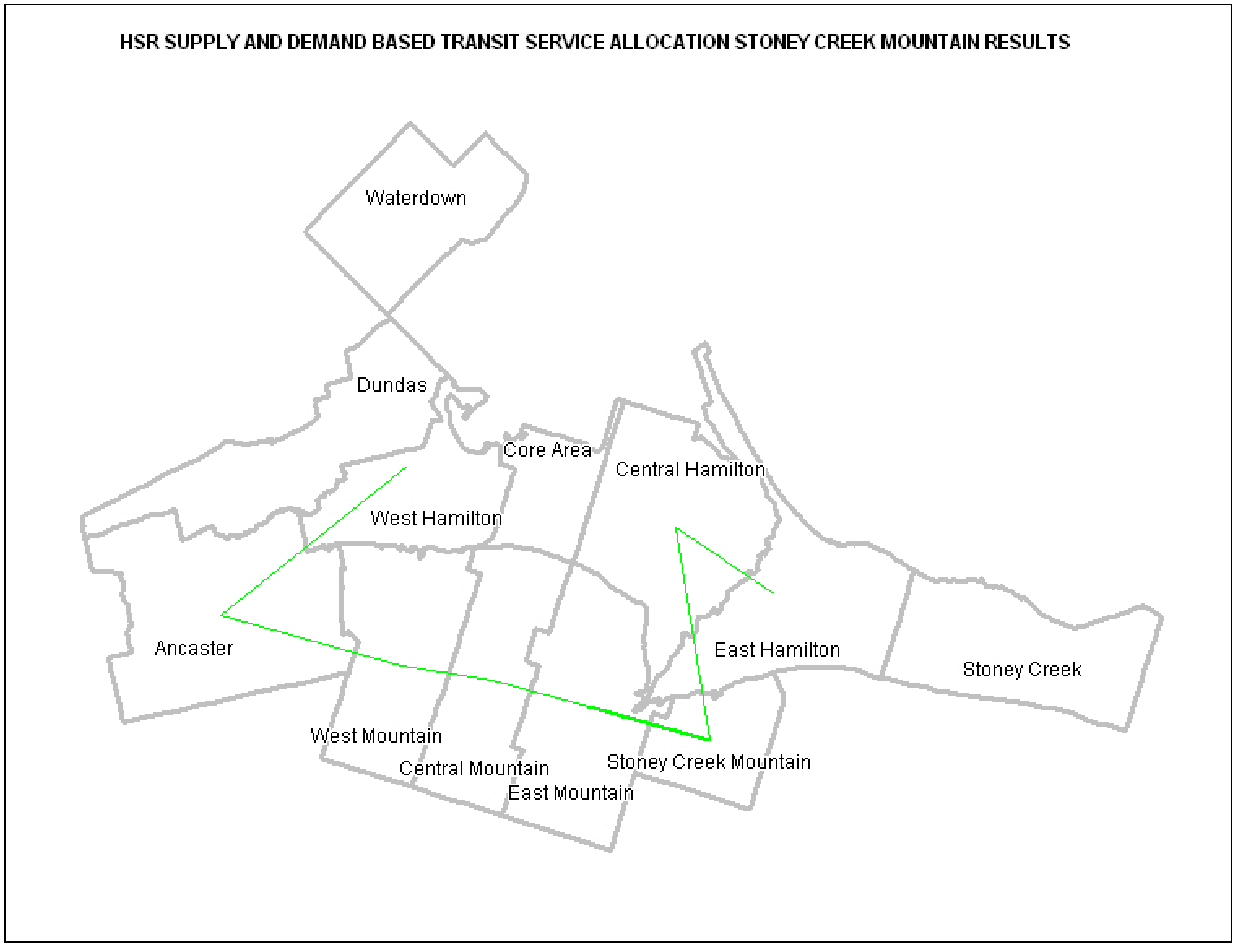
Appendix 14

Graphical Illustration of Stoney Creek Mountain-related Disparity



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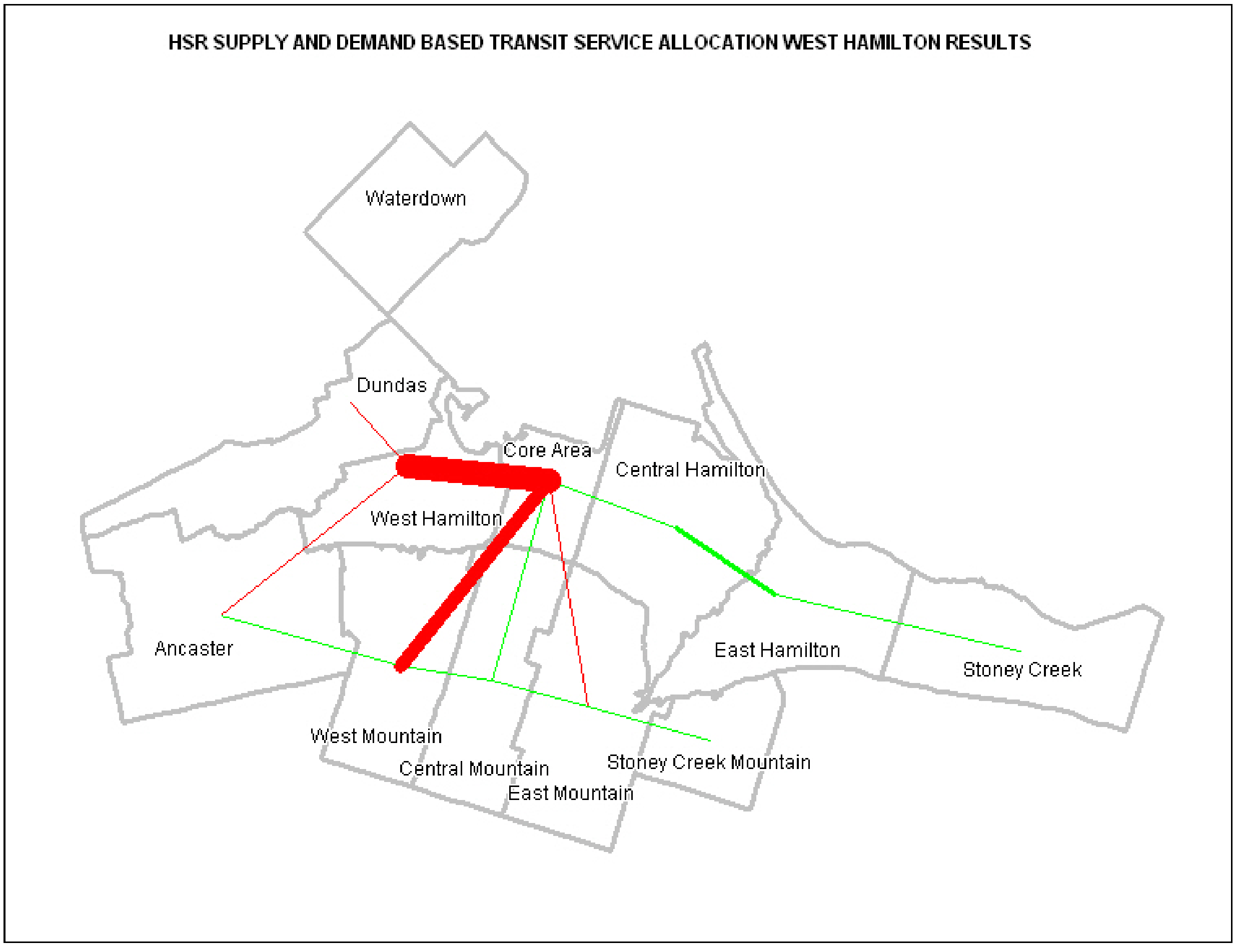
Appendix 15

Graphical Illustration of West Hamilton-related Disparity



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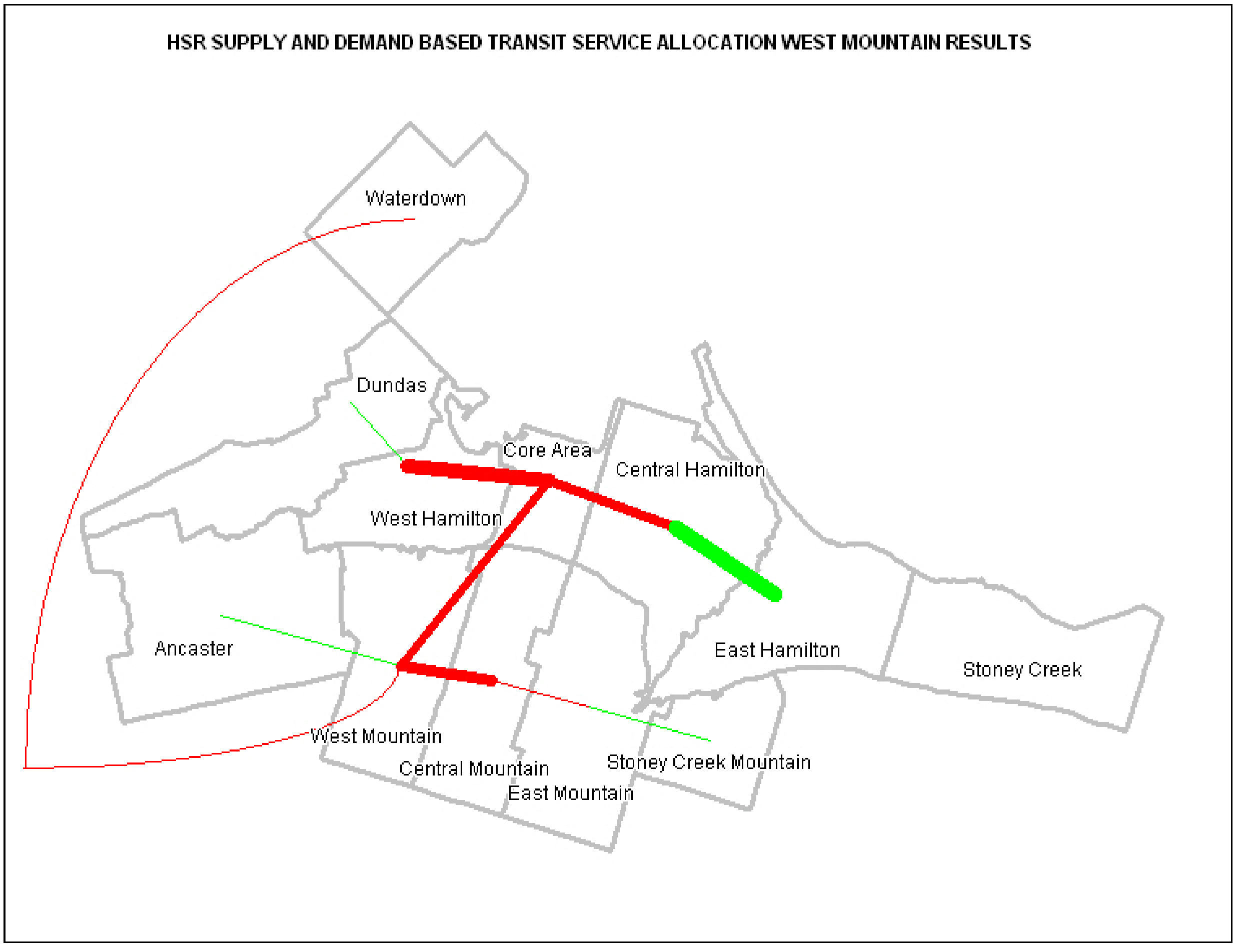
Appendix 16

Graphical Illustration of West Mountain-related Disparity



(Source: author.)

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