Integration Opportunities at Transit Jurisdictional Borders

by

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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.

Daniel Hall

Abstract

The Greater Toronto and Hamilton Area faces numerous transportation challenges now and in the future: congestion, population growth, and an inadequate public transit network. The metropolitan region has also changed in form in past decades, shifting from a monocentric to a polycentric region, further compounding the challenges. Currently, the public transit service is delivered by 9 different agencies comprised of 6 municipal providers, 2 sub-regional providers, and 1 regional provider. A region possessing a multiplicity of agencies suggests an overabundance of jurisdictional borders - borders that can potentially restrict travel across them.

This thesis seeks to determine the impact of the presence or the omission of jurisdictional borders on transit patrons. A comparative approach is employed to investigate the benefits and costs to patrons and agencies through greater integration of specific origin-destination (OD) pairs. The chosen methods selects OD pairs that are known to be transit competitive, possess a high travel demand, and cross a transit-jurisdictional border. The relationship between transportation and land-use is relied upon to select clusters of dense employment or population, called activity centres, where public transit is known to compete well with the private auto. The travel demand between these centres is obtained using the 2006 Transportation Tomorrow Survey and the current optimal transit routing is determined using Google Trip Planner. Three OD pairs are selected that possess the most onerous transfers, a proxy for poor integration. Another three OD pairs are selected that possess seamless or no transfers using a variety of modes. In both

cases, the existing transit routing is compared to an alternate routing to understand the benefits achieved through inter-jurisdictional integration; the first compares existing trips to improved inter-jurisdictional routes while the second compares existing trips to exclusively intra-jurisdictional routes.

Through identification of 40 employment and 29 population activity centres in the region, and the acquiring of travel demand between them, the six case study OD pairs are selected. The three OD pairs investigated, with onerous transfers, are comprised of trips between Brampton-Mississauga, Hamilton-Burlington, and Brampton-Toronto. The remaining inter-jurisdictional case study OD pairs are made up of three different modes: conventional bus, express bus, and regional rail. They comprise trips between Toronto-York Region, Brampton-Mississauga, and Mississauga-Toronto respectively. This study finds that in all cases, the routes with greater integration reduce total travel time and the generalized cost to patrons. Additionally, the penalty due to transferring is reduced through integration implying a current barrier existing at some jurisdictional borders. For the agencies, the cost of delivering the suggested inter-jurisdictional service varies dramatically. The costs are translated into a quantity of additional patrons necessary to justify the operation investment while maintaining the current revenue/cost ratio.

These findings provide insight into the current transit network. Promoting integration throughout the network will help attract new riders as the generalized cost of travel is reduced. Also, when inter-jurisdictional connections are made, such as in the case of the Brampton-Mississauga Zum service, the beneficiaries of that service are widespread and not limited to the corridor in which the service operates.

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Dedication

To my beautiful wife Jess.

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Chapter 1: Introduction

1.1 Background and Research Motivation

Metropolitan areas around the world are expanding in size and population increasingly straining transportation networks. Congestion, rising commute times, and the escalation of carbon emissions are symptoms of this growth and have expedited the need for alternative transportation solutions to the private automobile. A major alternative is public transportation that can help alleviate many of the symptoms of the growing metropolitan areas. However, the current infrastructure and resident behaviour of many North American cities encourages the automobile to be the dominant transportation mode. Improving the public transportation infrastructure and service is of great importance in offering an enticing transportation alternative to residents.

The Greater Toronto Hamilton Area (GTHA) is one of the aforementioned metropolitan areas. It is the most populous metropolitan in Canada with 6.3 million inhabitants and is the economic engine of the country; it accounts for one-fifth of Canada's GDP (OECD, 2010). Its growth has led to significant congestion, longer commute times, and greater carbon emissions. Congestion in the region has hindered residents' quality of life and reduced the productivity of the region. The OECD reports that in 2006 the cost of this congestion to commuters in the GTHA was $3.3 billion and the economic cost was $2.7 billion.

Growth is not the only reason these mobility issues have arisen; the form of the city has also changed. It is no longer a monocentric entity exclusively requiring travel to and from a central business district; residents live and work throughout the region. This has further promoted auto use as the plethora of dispersed origins and destinations make it more difficult for public transportation to serve these trips effectively.

The increasing commute times in the GTHA have motivated the public, and subsequently politicians, to desire changes to the transportation network. As a result, many reports and studies have been conducted for the GTHA to chronicle the current mobility issues and suggest solutions (Canadian Urban Institute, 2011; Dobson et al., 2013; Metrolinx, 2008a; Ministry of Infrastructure Ontario, 2006; OECD, 2010). All of these studies point to the need for better public transportation infrastructure and a more integrated transportation system. In fact, the goal of improving regional transportation led the Ontario government in 2006 to create Metrolinx, an agency whose mandate is to "provide leadership in coordinating the development and implementation of an integrated transportation network that supports … a high quality of life, a sustainable environment, and a strong, prosperous economy" (Ministry of Transportation Ontario, 2006 sec. 5 (1)).

The current issues of significant congestion and shortfalls in public transportation infrastructure are exacerbated by the projected increase in population and jobs in the GTHA. In the Greater Toronto Area alone there are expected to be 2.8 million additional people by 2036, a 44.6% increase from 2011 (Ministry of Finance Ontario, 2012). If the transportation network is underperforming now, what will that mean for the future?

Metrolinx was created to help improve the mobility of the region with the future population and employment demands looming. The Agency is tasked with focusing on regional solutions instead of single municipalities. This is much needed because as development in the region has expanded, the many municipalities comprising the GTHA no longer possess discernable borders between them, only political ones. Possessing no discernable borders is also true for the road and highway infrastructure where drivers experience a seamless transition from one municipality to the next. The same cannot be said for public transportation.

There are nine transit service providers in the GTHA that each has its own service area and funding source. A regional transit provider does exist, GO Transit, and some transit providers do cross their service boundaries; however, for many transit passengers the municipal borders are real barriers that can significantly deter them from choosing to ride transit. A trip requiring the use of multiple transit agencies can cause confusion because of different information provided, can require an additional fare, and can involve an onerous transfer. The focus of this thesis is to identify transit trips requiring onerous transfers as a result of a jurisdictional border and to analyze the potential benefits of a more seamless transit system for those trips.

Public transportation agencies in the GTHA must be prudent with their investments and their operational decisions because of the scarcity of municipal finances. Choosing what areas to service and how often to service them are therefore very important questions. These decisions end up causing real consequences for residents either positively or negatively. Therefore, a transit agency must do its best to match the provision of transit service to the travel demand of the residents who will use the service.

1.2 Research Objectives

The objective of this thesis is to identify shortcomings in the GTHA transit network as it relates to trips made across transit jurisdictional borders. The research purpose is to inform the regional transit authority, Metrolinx, and the local transit agencies of the current ability of the network to provide regional mobility well. Specifically, this thesis identifies onerous transfers that exist between agencies and quantifies the benefits that could be achieved through greater integration between these agencies. The aim is to provide cost-conscious regional transit providers with a tool to identify routes with untapped potential to generate ridership by offering competitive services, as compared to the private auto, across municipal borders.

This thesis uses the relationship of transit competitiveness and density to focus the analysis on dense clusters of employment and population, applying methods utilizing Geographic Information Systems (GIS). The Transportation Tomorrow Survey (TTS) is relied on to estimate the current travel demand between these clusters and therefore exclude connections that have insignificant travel demand. Finally, a comparative approach is undertaken to quantify the benefits to transit patrons and agencies over proposed improvements in the network. Based on the motivations and goals listed above, this thesis aims to address the following research questions:

1) Where are the high travel demand transit origin-destination pairs in the GTHA that cross transit jurisdictional boundaries?
2) Of these high demand trips, which possess onerous transfers?
3) What are the (dis)benefits to patrons and agencies by providing greater inter-agency integration for these trips?
4) What are the benefits to patrons achieved by existing well-integrated inter-jurisdictional service?

1.3 Content of Thesis

This chapter has introduced the motivations and objectives of this thesis. The following chapter summarizes the literature dealing with the relationship between land use and transportation, transportation modelling, and traveller behaviour research. Chapter 3 describes the methods that are applied to obtain the results that are displayed in Chapter 4 along with the analysis of these results. Chapter 5 concludes the thesis by summarizing the study, providing the limitations and recommendations of the findings, and offering ideas for future research.

Chapter 2: Literature Review

Rising congestion, population growth, environmental awareness, and stringent fiscal policies are contributing to a rethinking of urban land use and transportation patterns in cities around the world. Many Canadian metropolitan regions, in response to their current dispersed environment, are opting for a nodal strategy to focus population and employment growth in mixed-use, walkable, and transit-oriented communities and to utilize transit infrastructure effectively (Filion, 2012). This shift in the planning paradigm has given transit a rediscovered value and has contributed to the recognition that improving the transit network and attracting new riders is of key importance.

Current and future transit patrons desire a more seamless transit experience across the metropolitan region requiring more coordination and integration between transit agencies (Rivasplata, Smith, & Iseki, 2012). The focus of this thesis is to identify trip patterns in the GTHA with significant travel demand that currently offer onerous inter-agency transfers and quantify the (dis)benefits of specific integration improvements.

Prior to undertaking this research, it is necessary to understand the theory and methods of other studies that have explored similar questions. This chapter begins by exploring the relationship between land use and transportation and defines the concept of activity centres and the method used to identify them. Next, theory on transfers and transfer penalties are presented followed by an introduction to transport modelling. Different model types, and the current modelling practice of the GTHA are described coupled with the use of generalized cost formulas and their role in mode choice models. Finally, the literature review finishes with a theoretical review of transit integration and examples of its impacts in practice.

2.1 Land Use and Transportation

Understanding where transit competes well with the private auto is important in establishing criteria for selecting trips to analyze in this research. The benefits of improving public transit integration between agencies will have the greatest impact for trips that have high travel demand and where transit is competitive with other modes. Intuitively, density has a positive relationship with higher transit use due to potentially shorter commutes, better transit service, less parking, and greater mix of uses. Frank and Pivo (1994) set out to test this hypothesis by investigating the relationship of land use mix, population density, and employment density to mode choice. The study used 1989 travel data from the Puget Sound region, an area comprising Seattle and Tacoma, and conducted the analysis at the census tract level. They conducted a correlational research design comparing the mode choice of many census tracts with various urban form characteristics. The researchers recognized the strong influence of non-urban form factors on mode choice, such as socioeconomic and demographic characteristics, and controlled for these. The study found three major results:

- The first result confirmed the positive relationship of land use mix, population density, and employment density to increased transit and walking mode share for both work and shopping trips;
- the second result determined that the relationship between employment density and mode choice was non-linear with large decreases in single occupancy vehicle use occurring between 49 and 123 employees/ ha and a significant transit mode share increase above 185 employees/ ha;
- the final compelling result was that tracts with population density greater than 32 residents/ ha had a noticeable shift away from single occupancy vehicle use for shopping trips.

It is important to note that these findings do not prove causality but only relationships. Potential limitations to these findings are their lack of transferability to other regions and to other sizes of analysis zones such as TAZs.

Cervero and Kockelman (1997) also study the relationship between urban form and travel patterns. In their study of the San Francisco Bay Area, they investigated the vehicle miles travelled and the mode choice of 50 neighbourhoods dispersed throughout the region. To do this they tested the statistical significance of 12 characteristics of the neighbourhoods to determine if each was associated with reducing motorized trips while controlling for socio-demographic, household, transportation supply, and distance characteristics. These 12 characteristics were representative of broader themes of density, diversity of land uses, and design (the 3Ds). The results show a modest relationship between the 3Ds and reduced motorized trips. Since the 12 characteristics may co-exist and be interrelated, the study also conducted a factor analysis to attempt to understand how the broader themes of the 3Ds explained the variation. It determined that two variables, walking quality (design) and intensity of land uses (density) explained 18% and 47.6% of the variation respectively. This helps prove the need for improving all 3Ds simultaneously if reducing motorized trips is the goal. Unfortunately, there is very limited available data in the GTHA that possess design characteristics or even diversity of land use for every TAZ; field surveys, as was the case in the Cervero and Kockelman study, are often relied upon to measure design elements. Therefore density is the best available source of data that explains travel patterns well.

Since transit patronage can be influenced heavily by external factors such as gas prices or economic conditions, studying one region at one time can isolate most of these factors. Johnson (2003) investigates a transit planning subregion in the Minneapolis – St. Paul metropolitan area using 2002 data to estimate the elasticities in transit stop patronage due to various land use and socioeconomic factors. The findings show a significant correlation between increased transit patronage and population density at the block group level, a geographic definition that captures a larger area than the immediate block level transit corridor. The study also determines a relationship between land use type and patronage: increased densities of multifamily residential in a larger area (400 m radius) lead to increased transit patronage.

Similarly, Chan and Miranda-Moreno (2013) developed a linear regression model of Montreal to estimate the factors that influence transit patronage at each metro station. Using morning peak period data from 1998 and 2003, the authors estimate that population density at a 500m radius plays the greatest role in positively influencing transit trip production with an elasticity of 74.2%. At the destination side of the trip, the presence of government and institutional land uses followed closely by commercial land uses within a 1000m radius influenced trip attraction the most, with elasticities of 66.7% and 52% respectively.

In contrast to these studies on the positive relationship between density and reduced private vehicle use, Gomez-Ibanez (1991) suggests that because causality cannot be proven due to a plethora of factors that cannot all be controlled for (income, gas prices, etc.) then the relationship is questionable. Additionally, Gordon and Richardson (1991) discuss the paradox that exists due to perceptions of increased congestion while actual travel times have decreased or remained stagnant in the top 20 American metropolitan areas. Their answer for why this phenomenon occurs is the relocation of households or firms. However, their conclusion that employment decentralization has resulted in reduced commute times has been refuted by Cervero and Wu (1998) and by Hamilton and Röell (1982). Gordon and Richardson also highlight the relatively lower commute times in cities of low density compared to high density and conclude that promoting density may not be a good planning intervention. Again, Cervero and Wu challenge this conclusion by proving vehicle miles travelled, an indicator of distance travelled and mode share, is higher in less dense regions. Finally, Ewing and Cervero (2010) further investigate the urban form and travel pattern relationship by conducting a meta-analysis of previous studies completed prior to 2010. They calculate a weighted average of the elasticities of each study to investigate seven urban form criteria (the 7Ds) to determine the relative role of each in explaining travel behaviour. They find that destination accessibility is the criterion most predictive of reduced vehicle miles travelled, while there is only a weak correlation of population and job densities to travel behaviour once all the other urban form factors have been controlled for.

A major limitation to the research determining the impacts of land use on transportation is the issue of residential self-selection; if residents desire to reduce their private auto usage, they will locate near the presence of good transit or greater accessibility. To account for possible self-selection bias, the mode and location choice can be modelled at the same time. Brownstone and Golob (2009) simultaneously model the density choice, vehicle miles travelled, and fuel consumption using a California subset of the 2001 National Household Transportation Survey. Their model determines that density influences vehicle miles travelled but in small ways – a 40% increase in density results in only a 5% reduction in vehicle miles travelled. Similarly, Badoe and Miller (2000) call into question the validity of all studies that try and determine the exclusive impacts of urban form on transportation citing their co-dependant relationship. They argue that an integrated modelling approach is the only proper method to estiamte the influence of urban form on transportation.

For the purposes of this research, the relationship between density and travel behaviour is important to predict where transit is most competitive and where there is a high travel demand. The goal is not to conclude causality of density to mode choice, controlling for all other factors, but rather use the positive relationship between density and transit use to focus the analysis to high-density locations where transit has a high likelihood of competing well with the private auto. Other factors, such as destination accessibility, may be better predictors of mode choice ceteris paribus, but do not include any influence over the total travel demand. Therefore, for this study, density is the best predictor of locations that are transit competitive with high travel demand.

2.1.1 Activity Centres

Cities are constantly evolving in spatial form; the most significant change in the past century has been the shift from monocentric cities to polycentric cities (Ladd & Wheaton, 1991). The GTHA has experienced this change also and is now facing the challenges and opportunities that a polycentric city provides. The economic literature explains this change in terms of utility for both households and firms. As transportation costs declined, employment and population decentralized to maximize their utility (Wheaton, 1979). A household's reduced housing costs and a firm's easier access to export markets on the periphery of a city meant an increase in utility for both parties (White, 1976).

Helsley and Sullivan (1991) expand this analysis outside of the central city to explain agglomerations of employment that they refer to as subcenters. The authors argue that subcenters form because of the tradeoff between production economies of scale and the diseconomies of transportation. Assuming a rational planning environment that focuses on the short-term, their model predicts three stages of sequential development of a city: growth of the central city, exclusive growth of a subcenter, and simultaneous growth of both central city and subcenter. This sequence aligns well with the historical development of the GTHA. The final stage is accurate in describing the current growth as both the downtowns and the suburban subcenters are growing in population and employment.

The literature uses many words to describe agglomerations of employment or population: subcenter, activity centre, or suburban employment centre. These terms can generally be used interchangeably but this thesis will primarily use the term 'activity centres'. Activity centres can be defined as having greater concentrations of employment and/or population than adjacent zones and offer firms or households benefits from their economies of agglomeration. Activity centres in urban areas "exert significant influences on land values, housing prices, and travel patterns" (McDonald, 1987, p. 242).

Public transportation benefits from activity centres' influence on travel patterns as higher densities of employment or residents require higher frequency or higher order transit thus increasing the attractiveness of the system. Clusters of non-residential uses are proven to support increased transit use especially when the total employment is a significant size– above 930,000 square metres in this case (Pushkarev & Zupan, 1982). This study also concludes that an increase in residential density can lead to a greater support of public transit, albeit to a lesser degree than employment density. Similarly, Casello (2007) identifies employment activity centres in the Philadelphia metropolitan area and determines that public transportation competes best against other modes for trips between these centres.

2.1.2 Identifying Activity Centres

The identification of activity centres, or clusters of density, is a method to determine the locations in the GTHA where transit is competitive and where high travel demand exists. The current literature offers two methods for defining an activity centre; both are employment exclusive analyses. The first method defines activity centres as a set of contiguous zones:

- with total employment above a threshold, and
- with each zone's employment density greater than a minimum threshold.

The developers of this method, Giuliano and Small (1991), investigated the Los Angeles metropolitan area using 1980 traffic analysis zone data with thresholds of 10,000 total employees and 24.7 employees per hectare. To capture additional employment centres on the periphery of the city, the authors lowered their total employment threshold to 7,000 employees and defined these as 'outer centres'.

The second method takes a spatial approach to define activity centres. McMillen (2003) predicts employment densities for each analysis zone based on distance from the CBD and a smoothing function that accounts for the employment density of nearby zones. The density prediction equates to a minimum density threshold; however, the threshold is varied for each analysis zone throughout the metropolitan region. Zones with higher than predicted densities are considered candidate zones. In a similar approach to Giuliano and Small, activity centres are then defined as clusters of contiguous candidate zones with total employment greater than 10,000. McMillen's approach is more transferable to other regions, requires less prior knowledge of a region, and is better at identifying higher than adjacent densities than the first method.

Although the lack of transferability and variation across a metropolitan region are shortcomings of the first method, it is more widely used due to its simplicity. Cervero and Wu (1997) use the Giuliano and Small method to identify employment centres in the San Francisco Bay Area in order to study the commute patterns and residential locational choices of employees of those centres. Additionally, Bogart and Ferry (1999) utilized the Giuliano and Small method with slight adjustments in their analysis of Cleveland. The employment density threshold was set at 19.3 employees per hectare while the total employment threshold was maintained at 10,000 employees. Once activity centres were identified in this way, Bogart and Ferry added adjacent zones that were below the minimum employment density in decreasing density as long as the entire cluster maintained a density above the threshold. The purpose of this was to capture zones that possessed similar or additive travel flows adjacent to traditionally identified subcentres but were below the density threshold.

A study by Casello and Smith (2006) has built upon Giuliano and Small and Bogart and Ferry's work in multiple ways. First, this study varies the employment density and total employment thresholds based on location to account for the difference in characteristics of major urban centres, secondary urban centres, and suburban activity centres. Secondly, it only applies the Bogart and Ferry method for the suburban activity centres to avoid ultra-high density zones in the downtown from creating an activity centre that is too large to be meaningful for traffic analysis. This study also adds a minimum employment density of the adjacent zones to avoid adding open space to a centre. Finally, it accounts for the varying trip attraction rate of each type of employment by weighting each employment type when calculating the employment density and total employment. Through clustering the zones above the density threshold, it then applies the total employment criteria: 20,000 for major urban centres, 15,000 for secondary urban centres, and 10,000 for suburban centres. These contiguous zones can be defined as transportation activity centres because they better reflect true transportation flows.

Each of these studies assert that setting the threshold for employment density and total employment is critical to the process. Using methods that are based on the actual data and not on perception helps the study's credibility. As such, Pan and Ma (2006) use a statistical analysis of the range of employment densities in order to determine a proper threshold. They use a simple z-score statistic to select a targeted percentile of zones for further analysis.

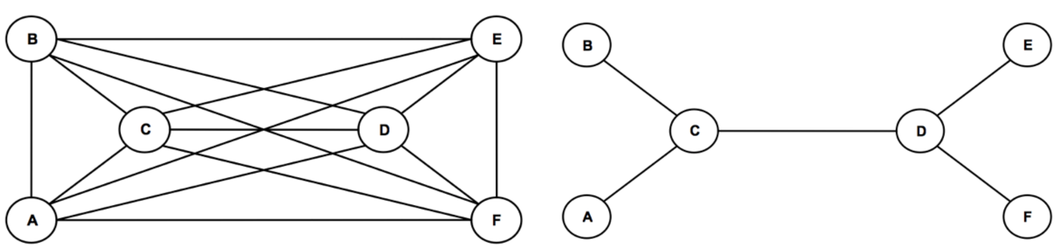
Attempts at identifying clusters of population density are much rarer than of employment density; however, modelling of urban population densities has occurred (Griffith & Wong, 2007; Griffith, 1981). These papers' foci are to build upon other models to accurately predict population density at any given location within a city. Previous attempts to model the population density in a city relied heavily on distance from the central business district; Griffith and Griffith & Wong account for the dispersed peaks in population density caused by subcenters and their effect on the surrounding locations. Unfortunately, the method used does not provide a framework for determining which clusters or peaks of population density should be considered a subcenter.

The literature defines two methods for identifying activity centres, one garnering wider acceptance despite its limitations. Both methods conduct employment exclusive analysis and rely on employment density and total employment of each analysis zone. The goal of identifying activity centres in this thesis is to find the clusters of zones with greater transit competitiveness and increased travel demand.

2.2 Transfers and Transfer Penalties

Across a vast region such as the GTHA there exists a very large number of origins and destinations for everyday travel. Walking, cycling, and auto trips are in most cases flexible enough to provide door-to-door service. Transit trips, however, must rely on fixed routes that cannot offer direct service for all trips - it would be cost-prohibitive and unpractical. Thus, transfers between routes are a necessity that can provide "… different travel routings through the network, shorter headways on some lines, and, generally, better services" (Vuchic, 2005, p. 216). Figure 2:1 below contrasts the number of routes needed in a theoretical six-node network served by the direct service model, 15, to the routes needed in a possible feeder-hub model, 5. This illustrates the benefits of transfers as all nodes are still reached with far fewer routes and with a potentially higher level of service between the hubs C to D.

Figure 2:1 - Six-node network with direct service (left) and with transfer dependant network (right) (Desautels, 2006, p. 19)



Transfers are an important topic in this thesis. A trip pattern with an onerous transfer that crosses a transit jurisdictional border is considered to have poor regional integration. This forms the basis of selecting trip patterns to suggest integration improvements and compare outcomes. In a similar method, cross-border trips with no transfers or seamless transfers indicate well-integrated transit service and are compared to intra-jurisdictional service to quantify the benefits that integration provides.

2.2.1 Transfer Penalty

Although transfers can offer advantages, there are also major disadvantages to transfers that can impose costs that may limit transit competitiveness. These potential deterrents include waiting, walking to the connection, anxiety about making the connection, discomfort due to weather or safety, and the possibility of an additional fare. A summation of these factors is often referred to as the transfer penalty. Guo and Wilson (2004) state that "understanding what affects the transfer penalty can have significant implications for a transit authority, helping to identify which types of system improvement can most cost-effectively improve transfers and thus attract new customers" (p.1). The transfer penalty is important in helping define what an onerous transfer entails and is therefore critical to the process of selecting trip patterns that could benefit from system improvements. Transfer penalties are also critical in calculating user costs of travel for trips that possess a transfer.

The transfer penalty comprises both subjective factors that cannot be explicitly measured, and objective factors such as the wait duration or the amount of the extra fare required. Due to the subjective nature of the penalty, many travel-forecasting models estimate the penalty using a waiting time multiplier. This is often set at twice the wait time (equal to the headway) but other studies have found a more accurate multiplier is three (Liu, Pendyala, & Polzin, 1997). This estimate, however, may be an antiquated and oversimplified understanding of the transfer penalty; Wardman and Hine (2000) conclude that:

> A clear distinction needs to be made between the penalty, transfer time and waiting time elements of interchange. It is not satisfactory to assume that connection time is valued at twice in-vehicle time nor to estimate interchange penalties which include elements of other effects. (p.44)

Table 2:1 - Overall time valuations (relative to in-vehicle time=1.0) (Wardman, 2001, p. 109)

	Mean	S.D.	S.E.	10%	50%	90%	Obs
Walk time	1.66	0.71	0.06	0.90	1.52	2.67	140
Access time	1.81	0.75	0.10	0.88	1.88	2.70	52
Walk and wait time	1.46	0.79	0.10	0.61	1.31	2.43	64
Wait time	1.47	0.52	0.09	0.94	1.33	2.19	34
Adjustment time	0.72	0.64	0.09	0.30	0.50	1.30	56
Headway	0.80	0.46	0.04	0.27	0.70	1.41	145
Search time	1.38	0.52	0.17	0.79	1.22	2.26	10
Late time	7.40	3.86	1.16	1.94	8.00	14.00	11
Delay time	1.48	0.32	0.07	1.04	1.43	2.01	21
Interchange (INTPEN)	17.61	10.93	4.13	3.91	13.52	31.70	8
Interchange (INTFULL)	33.08	22.73	4.64	10.60	28.41	70.47	23
Interchange (INTPREM)	34.59	25.88	6.46	9.5	27.53	66.70	16

This critique of the literature is evidenced by a meta-analysis conducted by Wardman (2001) of British research conducted between 1980 and 1996 on the value of time and service quality measures related to the out of vehicle experience in transit. The results list the relative value of time for an out-of-vehicle section of the journey such as walking, to an equivalent minute of in-vehicle time; refer to Table 2:1 above. The interchanges are separated into three distinctions: INTPEN refers to a pure interchange penalty that accounts for the disutility of making a transfer over and above the actual time spent waiting; INTFULL captures the studies that did not incorporate the actual connection time into the research and therefore INTFULL considers the pure interchange penalty plus the connection time (whether explicitly or implicitly); INTPREM includes the pure interchange penalty plus the premium perception of time spent waiting for the connection as some studies valued the overall travel time at the in-vehicle travel time weighting. The meta-analysis found that a patron's perception of a transfer, excluding the wait time, equalled 17.6 minutes of in-vehicle time. This high number could be explained by the small number of interchange studies available, 23, the large headways present in many of the studies on trains, and the potential inaccuracies of using stated preference data.

In comparison, Guo and Wilson (2004) found that the transfer penalty including the waiting time, for subway transfers in Boston, was perceived to be in the range of 3.5 – 31.8 minutes of in-vehicle time. This study used revealed preference data from on-board travel surveys to find the equivalent walking time of a total transfer penalty. It also tested 12 trip and demographic characteristics but found that none possessed significant explanatory power.

An important conclusion to be made here is that the transfer penalty is dependent on a host of factors that will not be possible to reduce to a single number of equivalent in-vehicle minutes. These studies are sensitive to their applications and do not provide clarity to the type of transfer present. The literature leaves many questions unaddressed such as:

- Does a transit patron view the minutes spent waiting at a subway-to-subway transfer equally as onerous as a bus-to-bus transfer?
- Does a passenger perceive a five-minute transfer in a journey with a one-hour duration the same as in a journey with a twenty-minute duration?

Despite these limitations, the concept of a transfer penalty helps define an onerous transfer and subsequently helps select cross-border trip patterns with onerous or seamless transfers. It also informs the generalized cost calculation that is important in comparing suggested improved routes to existing routes.

2.3 Transport Modelling

Analyzing a complex system such as a transportation network in a metropolitan area can prove to be a difficult task if relying solely on experience or intuition. The sheer volume of interactions that take place between the residents and their environment can lead to very different outcomes than predicted. Transportation models seek to replicate the real world interactions or behaviour of residents by using mathematical formulas and theory based on past research and data (Ortúzar & Willumsen, 2001). These models provide transportation planners and engineers a framework for making informed policy decisions, comparing alternatives, and justifying infrastructure investment. It is important to note that these models are simplified representations of real transportation networks and will not be perfect in their analysis but are calibrated to be as accurate as possible.

As this thesis seeks to analyze the GTHA transportation network, it is important to understand how this type of analysis is typically completed. The modelling literature presents a holistic approach to analyzing changes proposed in the network and is critical when proposing significant infrastructure investment. This thesis does not incorporate a network-wide model; however, it uses the modelling approaches within the network-wide models to inform the calculations of user costs and the potential implications of improved service.

2.3.1 Four-Stage Model

The most commonly used model in transport planning is the four-stage model sometimes called the classic transport model. The four stages are trip generation, distribution, modal choice, and assignment where each stage is a sub-model that must be solved in sequence. The first stage predicts how many trips are generated in each zone; the second stage distributes those trips between destination zones to create a trip matrix; the third stage predicts what mode will be used to make each trip; and the last stage assigns these trip decisions to the transportation network. To calibrate the model for the base year the sub-models are iteratively solved until the model output matches the observed data closely (Ortúzar & Willumsen, 2001, p. 2).

The four-stage model also aggregates individual or household decision making into a geographic area known as a Traffic Analysis Zone (TAZ). This aggregation balances the desire for sufficiently small zones with mathematical tractability. You et al. (1998) describe an efficient method for designing TAZ boundaries that optimize the socioeconomic homogeneity of the zones, the location of boundaries to fall on census borders or physical barriers such as roadways or rivers, and the spatial compactness of the zones. The TAZs in the GTHA are predefined and will be used with the caveat that the zone may not adequately represent all households within it.

The sequential nature of the four-stage model simplifies the problem; however, it does not match real travellers decision making. For example, if the cost of travelling in time or money is too high travellers may decide to change their route, mode, the time of departure, the destination, or the frequency of the trip (Ortúzar & Willumsen, 2001). All of these potential changes may be considered simultaneously, not in sequence, for travellers to maximize their utility. These are some of the significant limitations that four-stage models possess that other models try to accommodate.

2.3.2 Activity-Based Models

The new paradigm shift in transportation modelling is the activity-based models that do not rely on analyzing individual trips but analyze travel based on an individual or household's daily activities (Ben-Akiva & Bowman, 1998). This way the model can adapt more similarly to human behaviour by having the ability to adjust the total number of tours (return trips made for the purpose of an activity), the number of trips per tour, and the time of day of the tour. Besides the theoretical advantages to the activity-based approach, Vovsha and Bradley (2006) confirm its practical advantages over the standard four stage model. When reviewing projects in San Francisco, New York, Columbus, and Montreal they found that this approach produced better forecasts of policy and infrastructure decisions than its out-dated counterpart.

2.3.3 Current Practice

Although the activity-based approach holds obvious advantages over the four-stage model, the latter is still widely used and is the current method used in the GTHA.

> Despite both the criticism of the four-stage approach and the considerable optimism concerning alternate methods, the four-stage process is currently the most practical operational approach to modelling urban travel demand for regional planning agencies within the GTA. (E. Miller, 2001, p. 6)

This research will proceed with the understanding that the current region-wide transportation demand forecasting model is a four-stage model and therefore, due to interactions with the model, must comply with this approach. Due to the ubiquity of the four-stage model, many improvements have been implemented including a more realistic decision-making model at the mode choice stage. The mode choice stage is where the analysis in this thesis focuses its attention using the generalized cost approach.

One of the foundational elements in the mode choice stage is to model decision makers as agents whose goal is to maximize their utility, or in the case of travel, minimize their disutility. A utility calculation from the analyst's point of view is often not sufficient for accurately predicting travel behaviour. This is possible for many reasons such as existing habits, social perception, or comfort. Therefore when trying to understand the effects of a particular change in the transportation network, utility calculations by mode, in isolation, cannot accurately predict behaviour change.

Discrete choice theory helps explain this phenomenon; it allows decision makers to choose a single option out of a set of mutually exclusive options using utility maximization as the goal. It can be witnessed, however, that decision makers with the same socioeconomic characteristics and utility functions may choose different modes. To account for this variability, even across an aggregated zone, a random utility approach is used. This states that although the utility functions calculated from the analyst's point of view suggest the decision makers to choose a certain option, there must be some unobservable attributes that exist that influence each decision maker's own utility function thereby preserving the maximization of utility for all decision makers. The mode choice model is then defined as the probability that a given mode is chosen based on the probability of that mode having the highest utility among the alternatives (Ben-Akiva & Lerman, 1985). This theory helps inform the output from the generalized cost analysis – the analyst cannot predict a traveller's utility function perfectly.

2.3.4 Generalized Cost

Regardless of the simulation or modelling technique utilized, the comparison between a resident's propensity to ride transit versus other modes or choose one travel path over another, in a rational decision-making context, is based on the minimization of their disutility of travel and the availability of each mode. Generalized cost is essentially the measure of this disutility providing a framework to compare modes or paths of travel possessing different time, cost, and journey characteristics. This comparison is important if changes are proposed to the system; it offers the modeller an ability to predict the resulting changes in transit ridership and therefore agency revenue. As previously mentioned, there are many other factors that affect the choice of mode that cannot be represented by a cost or time component; these include but are not limited to car ownership, household structure, type of trip, and qualitative conditions experienced on the journey. These factors are not incorporated explicitly into the generalized cost calculation but affect the perception and value of time. The generalized cost, GC, of each mode or path i, is calculated as shown in Equation 2:1.

Equation 2:1 – Generalized Cost (Casello, Nour, & Hellinga, 2009)

$$GC_{OD}^{i} = (\alpha_1 AT + \alpha_2 WT + \alpha_3 IVTT + TP)\frac{VOT}{60} + Fare$$

Where:

	GC	is the generalized cost from origin to destination using mode i
	α_i	is the relative valuation of time of each cost component
	AT	is the access time including both access and egress to and from the transit service [min]
	WT	is the waiting time at the stop or station [min]
	IVTT	is the in-vehicle travel time [min]
	TP	is the transfer penalty including the wait and walk time [min]
	VOT	is the value of time [$/hour]

Calculating the relative cost of each mode for a given trip allows the probability of residents choosing each mode to be determined.

This research requires a greater understanding of the transfer penalty component of the generalized cost equation, TP. The concept of a transfer penalty is really about quantifying the impedance of a transfer and represents a generalized cost – "including monetary costs, time, paid labour, discomfort, inconvenience, etc." (Iseki & Taylor, 2009, p. 780). As discussed earlier in Section 2.2.1, the transfer penalty can be further divided into three components: the penalty associated with the requirement to transfer, the time to transfer between vehicles, and the time waiting for the connection (Wardman & Hine, 2000). Equation 2:2 shows the breakdown with relative weightings of each component.

Equation 2:2 – Transfer Penalty

$$TP = TP_t + \alpha_4 TT + \alpha_5 WT$$

Where: TP is the transfer penalty including the wait and walk time [min]
α_i is the relative valuation of time of each cost component
TP_t is the relative valuation of the requirement to transfer [min]
TT is the time to transfer between vehicles [min]
WT is the transfer waiting time at the stop or station [min]

The transfer penalty formula defined by Wardman & Hine (2000) is well-defined but is difficult to explore using revealed preference data; a transfer may be perceived as onerous because of its long wait time, its long time walking between vehicles, or its combination of both. Obtaining accurate coefficients for both a transfer walk time and wait time is therefore a challenging proposition.

A widely referenced study by Kittelson & Associates (1999) helps alleviate some of these potential inaccuracies. The study conducts a meta-analysis to provide the relative time valuation coefficients for all aspects of the generalized cost formula including the transfer penalty. The average multipliers of equivalent in-vehicle time found in their analysis are 2.2 for walk time, 2.5 for transfer time, and 2.1 for initial wait time (p.3-20). This study also notes that others have attributed a penalty of the requirement to transfer in addition to the increased value of time while transferring and found it to be in the range of 12-17 minutes. Many agencies, including Metrolinx, use this format to model transfer penalties – a fixed equivalent time penalty plus the premium perception of time while transferring. This assumes a different layout of the transfer penalty equation, removing the time to transfer between vehicles (TT) as a separate variable. The resulting generalized cost formula put forth by Kittelson & Associates is shown in Equation 2:3.

Equation 2:3 – Generalized Cost Formula with Average Time Valuations

$$GC_{OD} = (2.2AT + 2.1WT + 2.5TWT + IVTT + TP_t)\frac{VOT}{60} + Fare$$

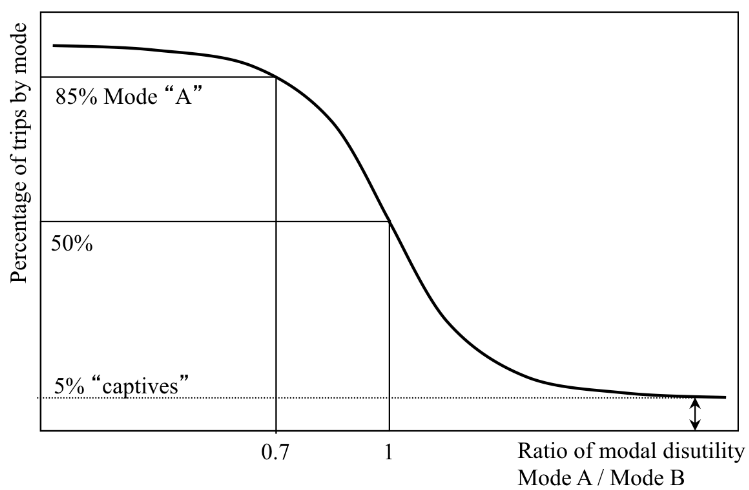
Where:
- GC is the generalized cost from origin to destination using transit
- AT is the access time including both access and egress to and from the transit service [min]
- WT is the waiting time at the stop or station [min]
- TWT is the transfer time; waiting and walking [min]
- IVTT is the in-vehicle travel time [min]
- TP_t is the penalty associated with transferring vehicles; 12-17 [min]
- VOT is the value of time [$/hour]

The equations above try to explain the perceived costs to the traveller of each component of the journey. The Kittelson & Associates (1999) formulation is widely used by agencies and in the literature and is thus the generalized cost formula chosen for use in this thesis. Understanding the ridership and utility effects of a reduction in any component of the transfer penalty or generalized cost through greater integration is an important aim of this research.

2.3.5 Elasticities

If precise generalized costs are unknown for all modes then other methods are required to predict net ridership change as a result of network changes. Since the private auto generalized costs are unavailable for every origin and destination, another method to predict ridership change is needed. Elasticity studies seek to quantify the change in ridership with respect to a change in a given parameter; for example, total travel time or generalized cost. Evans (2004) observes an average ridership elasticity of +0.5 for bus service changes (revenue-vehicle kilometres or revenue-vehicle hours) both in historical results and more recently. Balcombe et al. (2004) find that for buses, ridership elasticities range from -0.4 to -1.7 for generalized cost changes for multiple trip purposes and income levels. A more recent study by Dowling (2005) investigates travel time elasticities using the Portland tour-based travel-forecasting model. Since tour-based models are relatively new, their applicability to other regions is questionable. Despite these limitations the model has intriguing results: it predicts an elasticity of -0.129 for transit ridership and +0.036 for drivers with a change in transit travel time.

Figure 2:2 - Mode Choice Diversion Curve (Vuchic, 2005, p. 495)



Since the suggested integration improvements will take many forms, these various elasticities can be used to help estimate the ridership changes. However, the relationships presented are highly dependent on many external factors especially the current comparison in generalized cost or travel time between transit and the private auto. Figure 2:2 illustrates a mode choice diversion curve comparing the percentage of travellers choosing mode A relative to mode B based on the modal disutility or generalized cost ratio between modes. If only 5% of current users ride transit, for example mode A, the disutility of transit is significantly higher than mode B, or the private auto. For example, if the ratio is currently 2, and an improvement in operations reduces the transit generalized cost by 30%, the ratio will change to 1.4 causing minimal net ridership gains on the order of 5-10%. In contrast, if ridership is currently 50% and a network change leads to that same 30% reduction in transit generalized cost, enormous ridership gains are realized in the order of 35%.

Although elasticity models can be helpful predictors of the ridership effects of an infrastructure change, due to their limitations, a model with very similar circumstances to the proposed change must be used in order to obtain accurate predictions. Since there are no models found studying integration improvements of various modes, elasticity models will not be utilized in this thesis.

2.4 Integration

The desire for seamless travel across a region is increasing as residents' social and economic activities are interspersed throughout. Due to jurisdictional boundaries and the provision of transit service by those individual jurisdictions, many regions offer fragmented service that creates barriers to riding transit. The generalized cost of this barrier is represented as a transfer penalty and can be reduced or nullified through the improvement in regional coordination or integration. Defining what integration is, how to implement it, and what benefits can be realized by implementing it is important to this thesis. NEA Transport has defined regional coordination or integration as:

The organisational process through which elements of the passenger

> transport system (network and infrastructure, tariffs and ticketing, information and marketing etc) are, across modes and operators, brought into closer and more efficient interaction, resulting in an overall positive enhancement to the overall state and quality of the services linked to the individual travel components (NEA Transport Research and Training et al., 2003, p. 5).

To achieve 'efficient interactions' and 'overall positive enhancements to the system' a theoretical framework must be developed to specify what optimal integration is or looks like in practice. NEA et al. review the literature and find a lack of theory on optimal integration of public transportation that factors all costs and benefits. However, the study does provide four approaches to achieving integration:

- the typical 'engineering' perspective that concludes there is an optimal state of integration that is attractive to passengers and is a result of best practices within a well-planned transport network
- the microeconomic theory that focuses on market failures and the interventions required to maximize welfare; it does not concern itself with the process of implementation
- the public management perspective that investigates the implementation of integration through multiple agents (public and private) working in an unchanging institutional context
- the institutional perspective that does not specify an optimal design but finds the barriers to cooperation between institutions and recommends reforms

This theoretical investigation is helpful in understanding the many facets of integration and their role in holistically achieving a more seamless regional transit network.

Other studies have investigated integration on a practical level and classified the benefits of integration to transit patrons as either direct or indirect. Miller et al. (2005) categorize the direct integration benefits as infrastructure, schedule, information, fare, and special events and emergency conditions; examples of the indirect benefits include joint procurement agreements and data sharing. In an attempt to research the impacts of specific integration practices this study conducted a two-round survey of initially 96 transit agencies in the US. The specific integration practices were categorized and examples were identified for a variety of reasons including but not limited to:

- available data to measure the ridership or cost impacts,
- innovative institutional and funding agreements, and
- cooperation between multiple transit providers

An example in southwest Connecticut observed the impacts of three adjacent bus services developing a single regional service jointly operated by all. A state-funding grant provided the capital to initiate the 'Coastal Link' service but it is believed the service will outlast the higher-level funding subsidy. Patrons have positive feedback citing the system's convenience, the increased job accessibility, and the ability to switch modes from the private auto. From the agencies perspective they have witnessed increased ridership, an admirable farebox recovery of 46%, and the ability to reduce service on other routes (M. Miller et al., 2005).

An additional example of infrastructure integration was reported on in the

Washington Metropolitan Area where local jurisdictions fund both local and regional service and where ridership impacts have been measured. The local bus service coordinated with the regional provider to build and operate a transfer hub that "advanced the level of coordination beyond formal channels into operations" (M. Miller et al., 2005, p. 108). This has increased ridership in the corridor by 14% and satisfied patrons greatly.

In the study's conclusion Miller et al. (2005) compile some recommendations of the agencies that had participated in integration projects. Regardless of the type of project, willingness to cooperate and coordinate amidst the institutional barriers was cited as a prerequisite as well as having an institutional champion to provide guidance. Experience of the agencies in coordinating infrastructure integration projects suggested that formal written agreements prior to implementation is a necessity.

Integration's impacts can be seen historically also. Between the 1950s and 1970s, automobile ownership increased dramatically in both the US and in West Germany causing financial strain for public transit operators. To combat this, cities in West Germany acted within their jurisdiction to provide more coordination of various public transit service through the creation of a Transport Federation (Dunn, 1980). The first such federation was created in Hamburg in the mid-1960s to unite the two main carriers in the city, the federal railway and the main transit carrier operated by the city government. Prior to coordination, transit ridership was down 23% between 1954 and 1968 (Homburger, 1970). After coordination, transit ridership stabilized despite increasing car ownership rates (1980).

Usually in all cases of integration the government plays an important role; Rivasplata, Smith, and Iseki (2012) note that for a successfully integrated system, an autonomous authority must develop region-wide service standards that balance the needs of the patrons and the operators. Their study focused on the transit agency perspective and conducted a nationwide survey to further understand the agencies' experience with regional integration. A key finding is that "one of the principal strategies warranting consideration in many cities is the granting of greater power to metropolitan planning organizations (MPOs) to promote regional transit policies and generate funding opportunities for the implementation of interagency initiatives (Rivasplata et al., 2012, p. 68). The province of Ontario recognized the importance of an MPO for its largest metropolitan region and established the *Metrolinx Act* (Ministry of Transportation Ontario, 2006). The mandate of Metrolinx in the regional context as outlined in this act is "to provide leadership in the co-ordination, planning, financing, development and implementation of an integrated, multi-modal transportation network" (Ministry of Transportation Ontario, 2006 sec. 5.(1)(a)). Through this mandate, Metrolinx can work toward greater integration among agencies and various jurisdictions.

2.5 Chapter Summary

The literature presented provides a basis for the methods and analysis used throughout the remainder of this thesis. The relationship of land use and transportation is explored and relied upon to choose locations that are transit competitive with high travel demand. These locations are referred to as activity centres and their characteristics are described and a method for their identification is presented.

Transfers are often perceived as a barrier to travel and the literature shows a range in how onerous patrons perceive them to be. However, transfers serve an important role in transit networks, especially regionally, and reducing the transfer penalty will become crucial to provide a compelling alternative to the automobile.

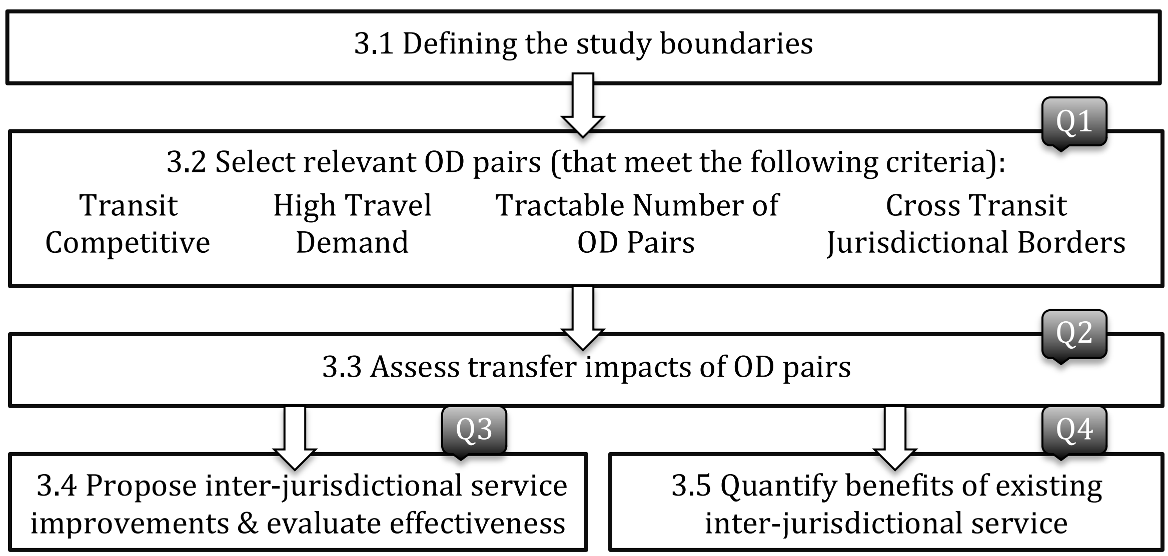
Transportation modelling is introduced on a broad scale to inform the method of comparing network alternatives to existing service. Also, literature on the relationship between transit ridership and service changes is explored both as a generalized cost comparison and as elasticity models. The available data limits how these various methods are utilized in this thesis, however.

Finally, the literature helps define integration and the many ways it is implemented. Past studies are explored that suggest potential benefits of greater integration that can help inform the results and analysis.

Chapter 3: Methods

This chapter describes the framework used to answer the research questions and achieve the research objectives. The goal of understanding the benefits of greater integration through improved transit connections across jurisdictional borders is approached using the methodological overview shown in Figure 3:1. The research questions as described in Section 1.2 are also displayed in the figure.

Figure 3:1 - Methodological Overview



The study boundaries are defined by the available data and the geographic scope of this thesis. Selecting OD pairs that meet the four criteria is accomplished through a process of identifying dense clusters of employment or population, called activity centres, where transit is known to be competitive and where high travel demand is likely to exist. Transit competitiveness is important because improvements in the transit system will make greater impacts in locations where transit is already competitive with the car. Similarly, choosing OD pairs with high travel demand prioritizes the routes that have a high potential for ridership gains. The activity centres identified become the origins and destinations. To further limit the total number of OD pairs to a tractable number exclusively high travel demand OD pairs are focused on. Finally, OD pairs that do not cross a transit jurisdictional border are excluded from the analysis since they do not require any regional integration.

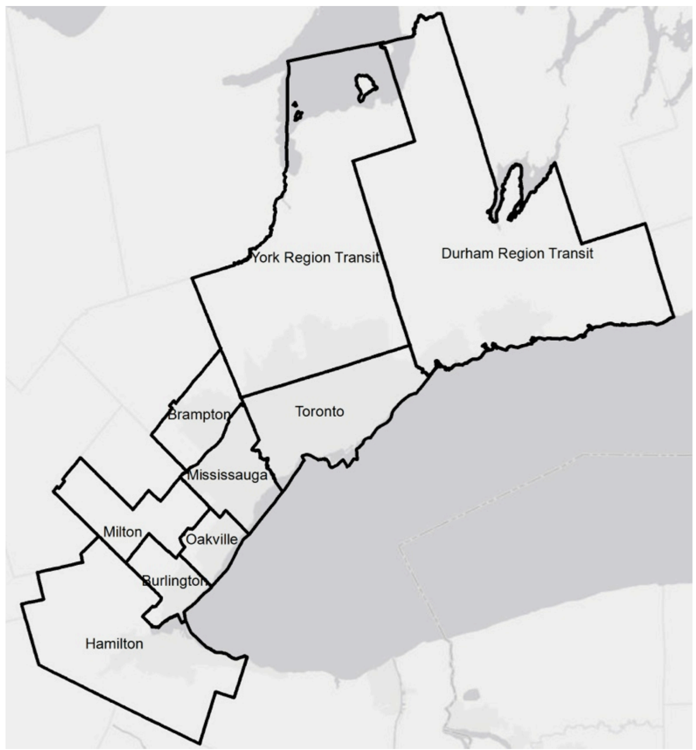
With the relevant OD pairs selected, the existing optimal transit routing is determined and the transfers are analyzed to determine their impact on overall travel cost. OD pairs with high transfer impacts are selected and investigated further to propose service improvements and evaluate the effectiveness of those improvements. Conversely, OD pairs with no or low transfer impacts are also examined to quantify the benefits of existing cross-jurisdictional service.

3.1 Defining the Study Boundaries

3.1.1 Geographic Limits

To investigate the metropolitan area's regional travel patterns, this thesis focuses on the geographical limits of the GTHA. The GTHA in this case comprises the regional municipalities, as defined by the TTS, of Hamilton, Halton, Peel, York, Toronto, and Durham. To further delineate the study area, areas within the GTHA that do not possess a fixed-route transit agency are excluded from the analysis. Transit agency jurisdictional borders are best represented by the Statistics Canada definition of census subdivisions (CSDs) and census divisions (CDs), rather than the regional municipality borders. Therefore, CSD and CD boundaries are used to correlate to the jurisdictional boundaries of the transit agencies; municipal transit agencies with CSDs and regional agencies with CDs. Figure 3:2 below shows the overall study boundaries and the transit agency jurisdictional boundaries; it is worth noting that both York and Durham Region have regional transit agencies that operate in multiple census subdivisions.

Figure 3:2 – GTHA Transit Agency Jurisdictional Boundaries



3.1.2 Level of Disaggregation

The most disaggregate data is selected because of its ability to better highlight peaks in density or in travel demand. The TAZ is a finer scale of zone compared to the census tract and is therefore selected as the level of disaggregation. For instance, within the study boundaries there are 2194 TAZs but only 1210 census tracts (plus two census subdivisions). The average TAZ is 3.51 km^2 while the average census tract is 5.71 km^2. Previous research identifying activity centres in the US has focused on the smallest unit of available data there: the transportation analysis zone (Bogart & Ferry, 1999; Giuliano & Small, 1991; McMillen, 2003). The average area of TAZs in their studies ranged from 0.96 to 7.99 km^2 supporting the use of TAZs in this research. Also, TAZs are defined by both employment and population, whereas census tracts are defined solely by population, and therefore TAZs are better suited for this research as it is not population exclusive. Finally, the data necessary for analysis is available at the TAZ level from the TTS.

3.1.3 Time Period

The TTS data used in this study are the most recent available data, from 2006. The survey is conducted every 5 years; however, the 2011 data are not available at this time.

3.2 Selecting Relevant OD Pairs

Selecting OD pairs for further analysis is a very broad title that encompasses many steps. The end result is to have transit OD pairs that compete well with the private auto, possess a high travel demand, cross a transit jurisdictional border, and are sufficiently limited in quantity to maintain tractability. To achieve this result, the analysis must first identify the transit competitive locations - called activity centres. These centres become the origins and destinations in the analysis, and by limiting the quantity of centres, the number of OD pairs is kept to a tractable total. Finally, all intra-jurisdictional OD pairs are excluded from the analysis and a minimum travel demand for these OD pairs is implemented.

3.2.1 Preparing the Data for Spatial Analysis

Spatial analysis is a critical part of the methods of this thesis. It allows for the determination of zone adjacency in order to define clusters of dense employment and population. It also helps visualize the cluster locations and travel demand in the region, enriching the analysis. To prepare the data for spatial analysis, the 2006 TAZ boundary files are obtained from the University of Toronto data management group and imported into GIS. Boundary files for census subdivisions are obtained from Statistics Canada for 2006 and also imported. The CSDs outside of the study boundaries are deleted and the CSDs within Durham and York Region are grouped respectively to match the transit jurisdictional areas. With the transit agency boundaries defined, TAZs outside these boundaries are selected and removed from the analysis. To allow for analysis by individual transit agency, the transit agency name is appended to every TAZ based on jurisdictional boundaries using the union tool in GIS.

Since identifying activity centres requires the employment and population density of each zone, the total employment and population data of every TAZ is imported into GIS using data obtained from the TTS by 2006 zone of work and zone of household. This tabular information was joined to the spatial TAZ boundaries in GIS based on the TAZ identification number. To finalize the data preparation, employment and population density are calculated by dividing the total employment or population by the TAZ area.

3.2.2 Identifying Activity Centres

There exists a cogent relationship between land use and transportation. As Pushkarev and Zupan (1982) note, transit is well supported by employment clusters and to a lesser extent population clusters. Similarly, Frank and Pivo (1994) estimate that increased employment or population density results in increased transit use. Since dense clusters of employment or population support increased transit use and clusters with a significant total of employment or population possess increased travel demand, identifying these clusters becomes crucial to selecting connections to analyze.

In economics research, clusters of employment are referred to as activity centres and are formed because of the utility that is achieved by relocating households or firms and by agglomerative economies. This thesis will extend the activity centre definition to also include clusters of population. The methods used to identify activity centres is based on the Giuliano and Small (1991) method and the adjustments made to it by Bogart and Ferry (1999) and Casello and Smith (2006). These analyses were employment exclusive, however, the same analysis is used in this thesis for population since the literature review is inconclusive in developing a method for identifying population activity centres and the continuity of methods is beneficial. Furthermore, every trip is comprised of an origin and destination and a prudent analysis will also include the areas of high residential density - a common origin in the morning peak period.

Using the guidance from the literature, and with the goal to find transit competitive and high travel demand locations in a tractable amount, activity centres are identified by the following process:

- Sort TAZs by employment and population density for each jurisdiction;
- Find the natural thresholds at which substantial changes in density occur;
- Select zones with density greater than the threshold;
- Add adjacent zones with continuity of land use while maintaining a cluster density above the threshold;
- Set a total cluster threshold for both employment and population.

The following sub-sections explore this process in further detail.

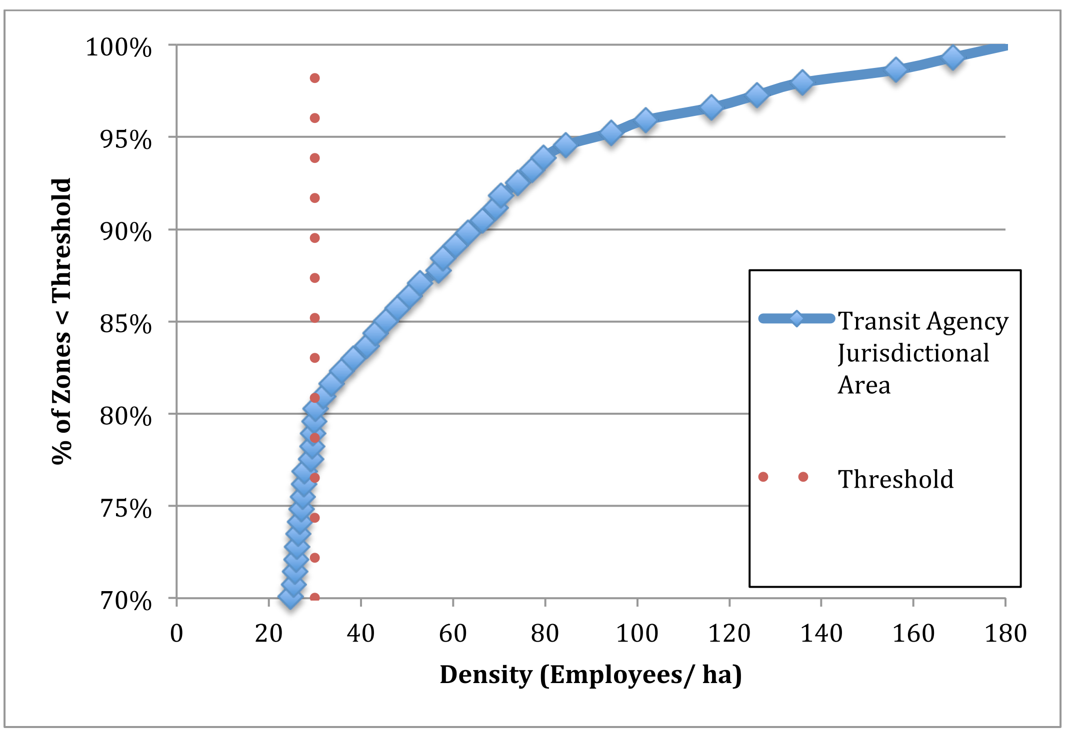
Setting a Density Threshold

The Giuliano and Small (1991) method uses a minimum density threshold as the first step to determining clusters of high density. The goal for the threshold is identifying activity centres that do possess the traits found in the literature – higher than adjacent densities, greater transit patronage, and in the case of employment centres - exhibiting economic agglomerative activities. A second goal for the threshold is to limit the analysis to a tractable number of clusters.

The previous literature cited relies on the author's prior knowledge and experience of what *should* constitute an activity centre in their city to set the density threshold. Giuliano and Small (1991) and Bogart and Ferry (1999) use a constant density threshold across the entire metropolitan region. In contrast, Casello and Smith (2006) employ three different density thresholds for defined areas of major urban, secondary urban, and suburban activity centres. A statistical approach is utilized in Pan and Ma (2006) that does not rely on previous knowledge of a city and sets the threshold based on a specific percentile of zones desired for analysis. This thesis takes a similar approach to Pan and Ma, trying to utilize an empirical method to determine the density thresholds.

The first step in this empirical method is sorting the TAZs by ascending density for every transit jurisdictional area. Next, the cumulative weighting of each zone is calculated as a percentage of the total number of zones to normalize the data across all transit areas. For example, if the transit area has 200 zones, the first zone would have a 0.5% weighting while the tenth zone would have a 5% weighting. The cumulative weighting was plotted against the density to observe the 'natural' thresholds that might exist within each of the jurisdictional boundaries; see Figure 3:3.

Figure 3:3 - Example Employment Density of Sorted Zones



A natural threshold indicates a noticeable change in the densities of the zones. This break point may illustrate different development styles (single-storey retail versus multi-storey offices) on either side of the threshold that may suggest the presence of agglomeration activities and therefore greater transit patronage. The example in Figure 3:3 shows a theoretical linear trend in the cumulative zone densities. However, in real life, trend lines will have to be plotted alongside the curves in order to best approximate the natural thresholds. If multiple natural thresholds exist, the first break point with at least 80% of the zone densities below the threshold in most cases was selected; this limited the analysis to the densest 20% of TAZs.

The cumulative distribution plots were created for every transit jurisdictional area. However, to maintain relevant activity centres, similar transit areas were grouped together to avoid relatively low thresholds that would be found in the remote suburban areas. These low thresholds would indicate the densest zones in a particular jurisdictional area, but when these zones are considered in the metropolitan context they would not indicate a cluster of regional importance. The opposite is true too. If a single threshold were set for the entire metropolitan area, the clusters with higher than adjacent density in the suburban areas would not be captured.

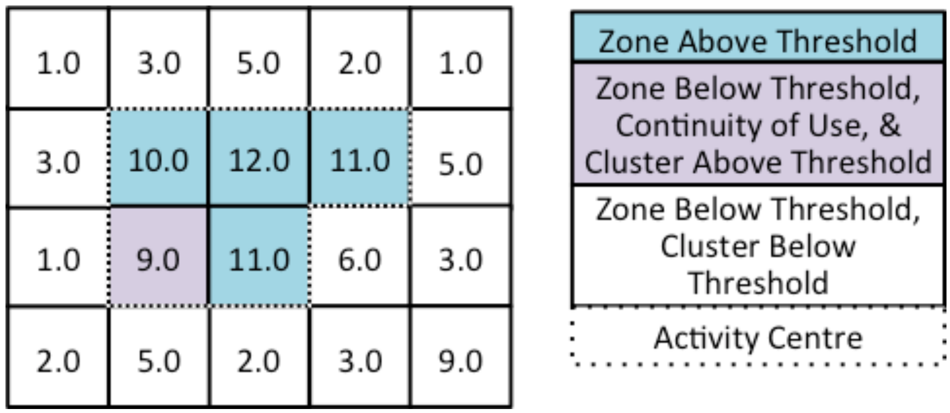
Therefore a balance is required to set an appropriate number of thresholds. Varying the thresholds across the region captures the phenomenon of decreasing density away from the urban cores and allows zones with higher than adjacent densities on the region's periphery to stand out in the analysis. The approach taken mimicked the three defined areas of major urban, secondary urban, and suburban activity centre as put forth by Casello and Smith (2006). The defined areas of Toronto, Mississauga, and Elsewhere are used in this thesis, as described in Section 4.1.1.

Implementing Thresholds and Adding Pertinent Zones

All zones possessing densities below the threshold are temporarily removed from the analysis while every cluster of zones or standalone zone with density above the threshold is highlighted in the GIS software. Applying the density threshold in this way does not decipher between land use continuity nor does it understand the zone's contribution to the cluster. Therefore, to achieve more accurate activity centre definitions, adjacent zones with densities below the threshold but with land uses that act in continuity with the originally selected zones are analyzed to determine if they should be appended to the cluster.

The zones with continuity of use are appended using the Bogart and Ferry (1999) method: adjacent zones are added to the cluster in order of decreasing density while maintaining a cluster density above the initial density threshold. Figure 3:4 provides an example of this method, showing a cluster of zones with density above the threshold and adjacent zones below the threshold. One adjacent zone with a continuity of use is added to the cluster while many are excluded based on the resulting cluster's density in relation to the threshold. Once the cluster is substantial in size, possessing eight or more zones, the adjacent zones are no longer investigated to eliminate the possibility of clusters becoming too large for meaningful analysis. Eight zones is selected to limit the size of the cluster while allowing for enough total employment or population to be selected as an activity centre.

Figure 3:4 - Adding Pertinent Zones by Zone Density if Threshold = 10.0



Additional considerations are observed in specific circumstances: Very large clusters of zones are divided into multiple sections along natural or logical borders – rivers or freeways for example – in order to best reflect the agglomeration activities or the likely travel patterns. Also, clusters adjacent to transit jurisdictional borders are closely investigated to determine if zones in a different jurisdictional area have a continuity of use with the cluster in question. If so, the zones are added to the cluster while maintaining a density greater than the threshold of the initial cluster. This does illustrate the limitation in defining thresholds by jurisdictional area: abrupt changes in density thresholds occur at the borders rather than a smooth density function across the entire region.

In the GIS software, adjacent zones selected for appending to the clusters are added to the cluster layer using copy and paste functions within edit mode. After adding all pertinent adjacent zones or separating clusters as necessary, the clusters are named and their internal zone boundaries eliminated to create one feature for each cluster. This is achieved using the dissolve tool in GIS; the total population, employment, and area of the individual zones are summed while eliminating the internal boundaries so that the total area and total employment or population is a defined characteristic of each cluster.

Applying the Total Cluster Criteria

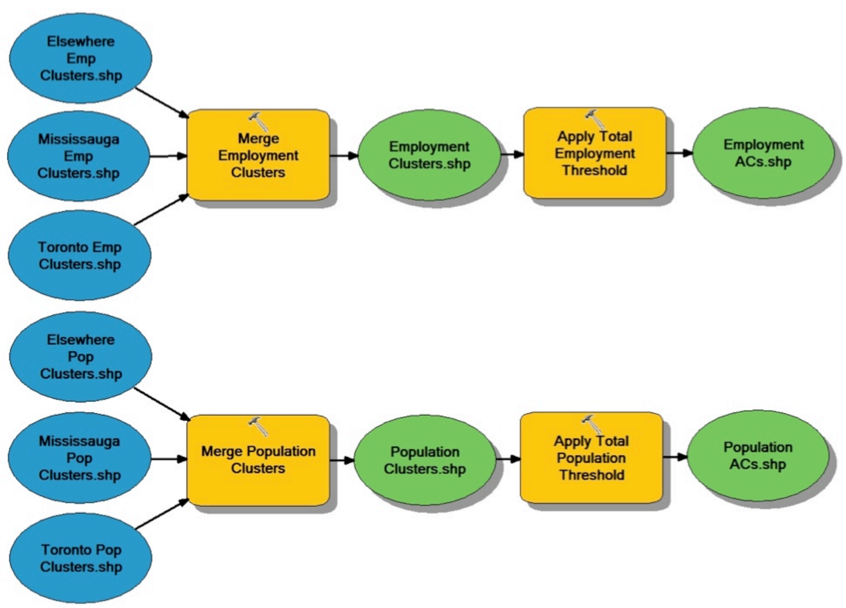
The next step in identifying activity centres following the Giuliano and Small (1991) method is to set a total employment or population threshold. By setting a total threshold, the analysis eliminates any dense clusters that do not possess significant enough totals to achieve the manifestations that define an activity centre. For employment, similar to Giuliano and Small and Casello and Smith (2006), if the cluster has greater than 10,000 employees it becomes an activity centre.

Using the employment definition to identify destinations has its limitations. It under-represents places such as universities and colleges because the measurement of jobs does not account for students attending these institutions, as only the faculty and staff are recorded. Similarly, retail destinations are measured in terms of jobs only, and not customers, when identifying employment activity centres. However, the retail limitation will have a lesser impact on trip demand between 6-9 am and both students and shoppers will be captured in the population analysis.

To identify population activity centres there is no precedent for setting a total population threshold. To accomplish this, all clusters or standalone zones that met the density threshold were used as a starting point. Guiding the decision is the desire to have a tractable number of population activity centres that are representative of the region and have enough total residents to warrant increased transit use. Section 4.1.3 documents the process of determining a 20,000 resident threshold.

The GIS method of applying the total thresholds is shown in the flowchart below in Figure 3:5, starting with the three regions of density thresholds for both employment and population and finishing with the defined activity centres. First, the various layers, each possessing a different threshold, are merged. After merging, only the clusters with total employment or population above the defined threshold are selected and carried forward in the analysis. This concluded the identification of activity centres and both population and employment centres are ready for further analysis.

Figure 3:5 – ArcGIS Method to Apply Total Employment and Population Threshold



3.2.3 Creating a Trip Matrix

Defining activity centres is a proxy for limiting the region-wide analysis to the most relevant clusters for transit use. This focuses the analysis on where transit demand and its competitiveness with the car are high. To understand the current barriers to riding transit across jurisdictional borders, the analysis is conducted at the trip level. A matrix of origins and destinations (population activity centres and employment activity centres) is created and populated with TTS trip demand data for all modes for the peak morning period between 6 and 9 am. The 2006 TTS trip data are acquired through the Internet data retrieval system operated by the Data Management Group at the University of Toronto. Using trip demand data that included all modes is chosen instead of using exclusively transit demand because the transit demand might only reveal OD pairs currently well served by transit and might dismiss OD pairs with high total travel demand where transit is currently failing.

This matrix is expanded to include the travel between destinations (employment activity centres) because public transit has been known to compete well against other modes for these trips (Casello, 2007). A sample scaled-down matrix showing the total trip demand between activity centres is shown in Table 3:1; the full matrix is shown in Appendix G.

Table 3:1 - GTHA Morning Peak Sample Trip Matrix

		Destinations			
		Employment Activity Centres			
Origins	Population Activity Centres				
	Employment Activity Centres	-			
			-		
				-	
					-

The TTS data are compiled at the zonal level and includes only trip demand between TAZs. Therefore, to obtain the total trip demand between activity centres the trip demand between each origin zone and destination zone has to be aggregated; refer to Table 3:2.

Table 3:2 - Sample Aggregation of TAZs for Activity Centre OD Pair - Total Trip Demand = 265

	Destination Activity Centre				
Origin Activity Centre	TAZ #	5175	5196	5198	5203
	5110	5	20	10	0
	5130	10	15	5	20
	5135	5	10	10	15
	5143	25	15	10	15
	5082	5	10	20	0
	5074	5	10	15	10

3.2.4 Eliminating OD Pairs Within a Single Jurisdiction

This research is concerned specifically with improving regional integration and is not interested in trips made within one transit agency's jurisdiction. As a result, the trips linking the activity centres from the same transit jurisdictional boundaries are removed from the analysis.

The first step in accomplishing this was to categorize all the activity centres into their respective transit agencies. If activity centres had zones in more than one agency's jurisdiction, the jurisdiction with the original cluster is chosen. Once the centres are categorized by jurisdiction, a check could be performed on every OD pair to determine if the origin is in the same jurisdiction as the destination. A visual basic script is written, shown in Appendix E, that completes the following steps:

- Selects an OD pair
- Extracts the origin name from the OD name
- Determines the transit jurisdiction of the origin

- Extracts the destination name from the OD name
- Determines the transit jurisdiction of the destination
- If the jurisdictions match, the script deletes the OD name and associated travel demand and then skips to the next OD pair
- If the jurisdictions are different, the data is retained and the script skips to the next OD pair

3.2.5 Applying a Minimum Travel Demand

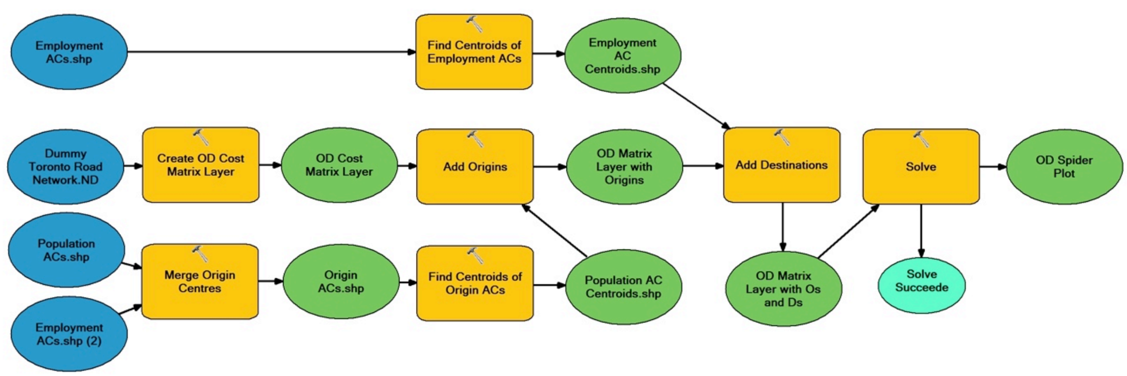
With only the OD pairs crossing transit agency borders remaining, the next filtering method used is travel demand. Since the travel demand values obtained are for all modes over a three-hour morning peak period, OD pairs without “significant” demand do not justify further analysis. In this case I computed significant demand as follows: to support a bus service running on 15-minute headways, with 15 passengers on each bus, 180 total passengers would be required for the morning peak period. At a substantial mode share of 50% this would translate into a travel demand of 360, a very conservative estimate that will only exclude the very low demand OD pairs.

After applying this last criterion, the OD pairs still remaining in the analysis are investigated further to understand the current optimal transit routing and the transfer impacts associated with it. A visualization of the trip demand is also completed to provide greater insight into where high-demand, cross-border trips exist spatially.

3.2.6 Visualization

Although the visualization of the results is not required to address the research questions, it enriches the discussion of this topic. To visualize the travel demand documented in the activity centre matrix geographically, a spider plot technique is used. The spider plot, also referred to as desire lines, produces a connecting line between the centroids of all activity centres with the ability to assign a value to the line, such as travel demand. The method to create the spider plot is documented in ArcGIS Model Builder and is shown to connect all population and employment centres to employment centres, see Figure 3:6.

Figure 3:6 – ArcGIS Spider Plot Workflow



To achieve the output of connecting all activity centres with weighted lines, the ArcGIS network analyst add-in is used requiring the use of a 'dummy' road network. Once the activity centres have been identified and their centroids found, the origins (Os) and destinations (Ds) are inputs into the network analyst tool to produce an OD matrix layer. Once that is complete, a simple solve with no distance or cost restrictions produces the desired output of lines connecting the activity centres. The solve tool names each line by the origin and destination of the activity centres it connects.

With lines connecting all the activity centres, the trip matrix needs to be joined to the attribute table in GIS to visualize the trip demand of each connection. The spreadsheet possessing the trip matrix of exclusively cross-border OD pairs is converted from the matrix grid into a simple two-column list, see example in Figure 3:7. The first column is the name of the activity centre origin and destination and the second column is the total morning peak travel demand between them. This is completed to match the GIS nomenclature for each desire line and is achieved by creating a visual basic script within Excel to automate the conversion; refer to Appendix F for full code.

Figure 3:7 - Sample Matrix to List Conversion

	Origin A	Origin B	Origin C
Destination A	OADA	OBDA	OCDA
Destination B	OADB	OBDB	OCDB
Destination C	OADC	OBDC	OCDC

OD Pair	
Origin A – Destination A	OADA
Origin A – Destination B	OADB
Origin A – Destination C	OADC
Origin B – Destination A	OBDA
Origin B – Destination B	OBDB
Origin B – Destination C	OBDC
Origin C – Destination A	OCDA
Origin C – Destination B	OCDB
Origin C – Destination C	OCDC

To finish the process, a join function is conducted in GIS to append the converted spreadsheet to the original attribute table based on the matching OD pair name. The travel demand could now be visualized spatially with line widths and colours corresponding to the travel demand between activity centres.

3.3 Identifying Onerous Transfers

The OD pairs that cross jurisdictional borders, are located in transit competitive corridors, and possess high travel demand are analyzed to understand the current best transit routing and the impacts of crossing jurisdictions. To obtain the current optimal transit routing, the OD pairs are inputted into Google Trip Planner to determine available transit routing. The weekday schedule is used and the arrival time is set to 9:00am. If more then one trip is available, the trip that allowed the latest departure time is used for the analysis. Many of the trip characteristics are recorded to facilitate the definition of an onerous transfer: departure time, transfer duration, service providers, route identification, and total travel time. In addition to this information, headway information for each route is also obtained since headway can strongly influence the transfer penalty, especially when reliability is considered.

As noted in the literature review, the cost of transfers can be measured in many ways and their impacts experienced in various capacities. Time is the easiest metric by which to measure a transfer. However, perceived time is equally important. Cost is another common metric; however, for the purposes of comparing transfers, costs related to fares are excluded from the analysis. Finally, the total travel demand can also influence a transfer's impact because of the transfer penalty being experienced by more people.

There are also factors that affect these metrics such as: headway; schedule adherence or reliability; transfer facilities and infrastructure; and the total trip length. It is possible to obtain information for some of these factors - headway and total trip length - while other factors present data challenges such as the presence of transfer infrastructure or the schedule adherence.

Table 3:3 - Transfer Metrics for Analysis

Transfer Metrics	Units	Description
Total Transfer Time	Minutes	A simple summation of the total time spent transferring; helps quantify the total delay
Transfer Penalty (TP)	Minutes	A Metrolinx standard that is calculated as 10 minutes plus half the headway for each transfer. This includes reliability and time factors plus a transfer penalty for each transfer.
Transfer Percentage	%	Calculated by dividing total transfer time by total travel time. Relativizes the transfer in relation to the total trip.
Demand Weighted Transfer (DWT)	Hours	Calculated as the total trip demand multiplied by the average mode share (16.5% in 2006, (Metrolinx, 2008)) and by the total transfer time in hours

The methods proceed with the available information and quantify transfer metrics as listed in Table 3:3 for every OD pair. The goal in selecting these four metrics is to try and capture the many ways a transfer impacts riders while including but minimizing the weight given to the subjective nature of riders' time perceptions. For example, total transfer time simply indicates the transfer duration while the transfer penalty incorporates a traveller's perception of time and reliability impacts. The transfer percentage metric tries to account for the length of the transfer relative to the length of the trip while the demand weighted transfer aggregates the waiting time across all passengers whom potentially use that connection.

For each of the four metrics, every OD pair is relativized to the other pairs by dividing that pair's penalty by the maximum penalty in that criterion. The OD pairs with the highest average percentage of all four criteria are analyzed. By using this approach, many of the impacts a transfer can have on traveller behaviour are considered. Sample calculations for the last three metrics and the comparative approach are shown below:

Equation 3:1 - Transfer Penalty Formula (Metrolinx)

$$TP = 10 + 0.5 * headway \text{ (min)}$$

Equation 3:2 - Transfer Percentage Formula

$$Transfer\ \% = total\ transfer\ time / total\ travel\ time$$

Equation 3:3 – Total Disbenefit/ Demand Weighted Transfer Formula

$$DWT = region\ mode\ share\ (\%) * trip\ volume * total\ transfer\ time\ (h)$$

Equation 3:4 – Relative Penalty Percentage

$$Relative\ Percentage = Penalty_{OD} / Penalty_{Max}$$

3.4 Quantifying Benefits of Integrated Service

Three OD pairs with the most onerous transfers are selected and operational improvements to reduce the transfer penalty or total travel time are suggested. The selected OD pairs are referred to as case studies to help differentiate from the other OD pairs. Suggestions for improvement include incorporating many operational strategies including new routes, increased frequency, or a change in type of service. Improvements for trips between activity centres with onerous transfers can provide benefits or costs to the transit patron and the transit agency.

3.4.1 Patron Costs & Benefits

On the patron side, benefits can be experienced in time savings, a reduction of the total transfer penalty, or through a reduction in generalized cost. The generalized cost formula is a good summation of the perceived and actual cost of travel as well as the change in transfer times. It also provides an easy comparison tool between existing service and proposals suggested to improve service. The Kittelson & Associates (1999) formula is used, as in Section 2.3.4 with a value of time of $16 per hour and a perceived transfer penalty of 10 minutes per transfer to align with Metrolinx standards.

3.4.2 Agency Costs & Benefits

To adequately investigate proposals for additional service, the implications of that service on the transit provider need to be understood in conjunction with the effects on the transit patrons. Will the new service generate more ridership and subsequently more revenue? Does the new service require more revenue vehicle hours and therefore incur more costs?

The two main impacts of greater integration and more service – revenue and costs – are explored below. First, there is potentially more revenue received due to increased ridership. Unfortunately, due to the dissimilarity of the selected OD pairs with available elasticity models, an accurate change in ridership cannot be predicted. Despite this shortcoming, the net ridership needed to justify the investment can be calculated using the cost of service delivery and operating parameters of the agency; refer to Equation 3:5 below.

Equation 3:5 - Required Ridership Equation

$$Ridership\ Needed = \frac{Expenses * R/C}{Rev/Boarding}$$

Where:	Expenses	are the cost for the agency to deliver the service [$]
	R/C	is the revenue: cost ratio on an annual basis for the entire system
	Rev/Boarding	is the average revenue received by the agency per boarding [$]

The second impact to the agency is the cost or expense to deliver the improved service and is much simpler to calculate. Using the Canadian Urban Transit Fact Book from 2010, the various operating parameters such as cost per revenue vehicle hour and revenue per boarding are presented for all the different transit agencies. Using these average values for service delivery, each case study's suggestions will be analyzed to determine their additional service requirements in cost and the net ridership (revenue) needed to warrant the improvements.

3.5 Quantifying Benefits of Existing Inter-Jurisdictional Service

Approaching the problem of quantifying the benefits due to integration has two logical extensions. The first, described in the previous section, investigates places that could benefit from greater integration and compare the existing service with the proposed better-integrated service. The second approach analyzes currently well-integrated service and attempts to compare this service to cross border trips made using only intra-jurisdictional service. However, comparing current service to less-integrated local service is problematic due to the inability for the service delivery to match the demand or the travel patterns when regional routes are removed from the network. Despite this shortcoming, the comparison to local-only service can still illuminate the significant benefits of integrated regional service.

To measure the benefits of existing regional service the comparative case has to be defined. The 'local-only' solution removes all cross-jurisdiction service without a terminus near the jurisdictional border; patrons are routed to their destination using exclusively intra-jurisdictional service. Since the removed service would mean higher demand for the local routes, the frequency of local routes in the same corridor as regional routes are increased to match the total frequency of the local plus regional routes. For example, if the regional route offered 6 vehicles/ hour and the local route offered 4 vehicles/ hour, the comparative case would possess a local route with a frequency of 10 vehicles/ hour.

The analysis of patron or agency costs and benefits follows the same analysis techniques as in the previous case studies. Three additional OD pairs, of currently well-integrated connections, are selected for further analysis. These pairs had low or no transfer impacts and are chosen by type of service in order to have a variety in the analysis. The case studies possess different types of current regional service: express bus, standard bus service with a transfer, and regional rail.

Similarly to the case studies where improvements are suggested, the costs and benefits to patrons and agencies are calculated. This is completed using generalized cost formulas, as shown in Section 2.3.4, and operating cost calculations as described in Section 3.4.2.

3.6 Chapter Summary

The methods described are rooted in the literature and use a combination of previous studies to inform it. First, study boundaries are defined to limit the scope of the thesis to the GTHA using 2006 data. Next, OD pairs are selected for further analysis based on their transit competitiveness, high travel demand, and cross jurisdictional reach, and are limited to a tractable number. The relationship between land use and transportation is relied on to identify activity centres, dense clusters of population or employment, where transit is competitive and high travel demand exists. Activity centres represent the origins and destinations in the trip analysis, and are limited in quantity to maintain their definition as higher than adjacent clusters and to keep the OD pair analysis tractable. The selected OD pairs are then analyzed to understand their transfer impacts. Three OD pairs with the greatest impediments due to transfers, and three OD pairs with low or no impediments due to transfers are chosen as case study pairs. The case studies with the highest transfer penalties are analyzed thoroughly to suggest regional improvements and quantify the benefits of these integration techniques while the case studies with low transfer penalties are analyzed to quantify the current benefits achieved through well-integrated connections.

Chapter 4: Results

The following chapter presents the outcomes of applying the methods to the study area. The breakdown of sections caters to the results and is thus slightly different from the methods. The activity centre analysis is exhibited first followed by a comparison to mobility hubs, a term used by Metrolinx to describe clusters of employment or population, near current or proposed rapid transit, where development is encouraged. Next, the trip analysis looks at the connections between activity centres and the process of refining these OD pairs by the desired criteria. The remaining OD pairs are then filtered based on the transfers present in their optimal transit routing. Finally, three OD pairs with particularly onerous transfers and three OD pairs with seamless or no transfers are selected and analyzed to determine the benefits of greater integration.

4.1 Activity Centres

Metropolitan regions are complex in nature and their diversity of land uses dispersed throughout the region cause an equally dispersed travel demand. In the GTHA, downtown Toronto still remains the employment and population hub for the region. However, regional subcentres are also growing in importance and in size. Identifying these activity centres methodically will provide a foundation for a regional analysis on the impacts regional integration can have on public transit trips. Figure 4:1 and Figure 4:2 below visualize the employment and population densities respectively and the variability observed across the entire metropolitan area.

Figure 4:1 - 2006 GTHA Employment Density (Jobs Per Hectare)

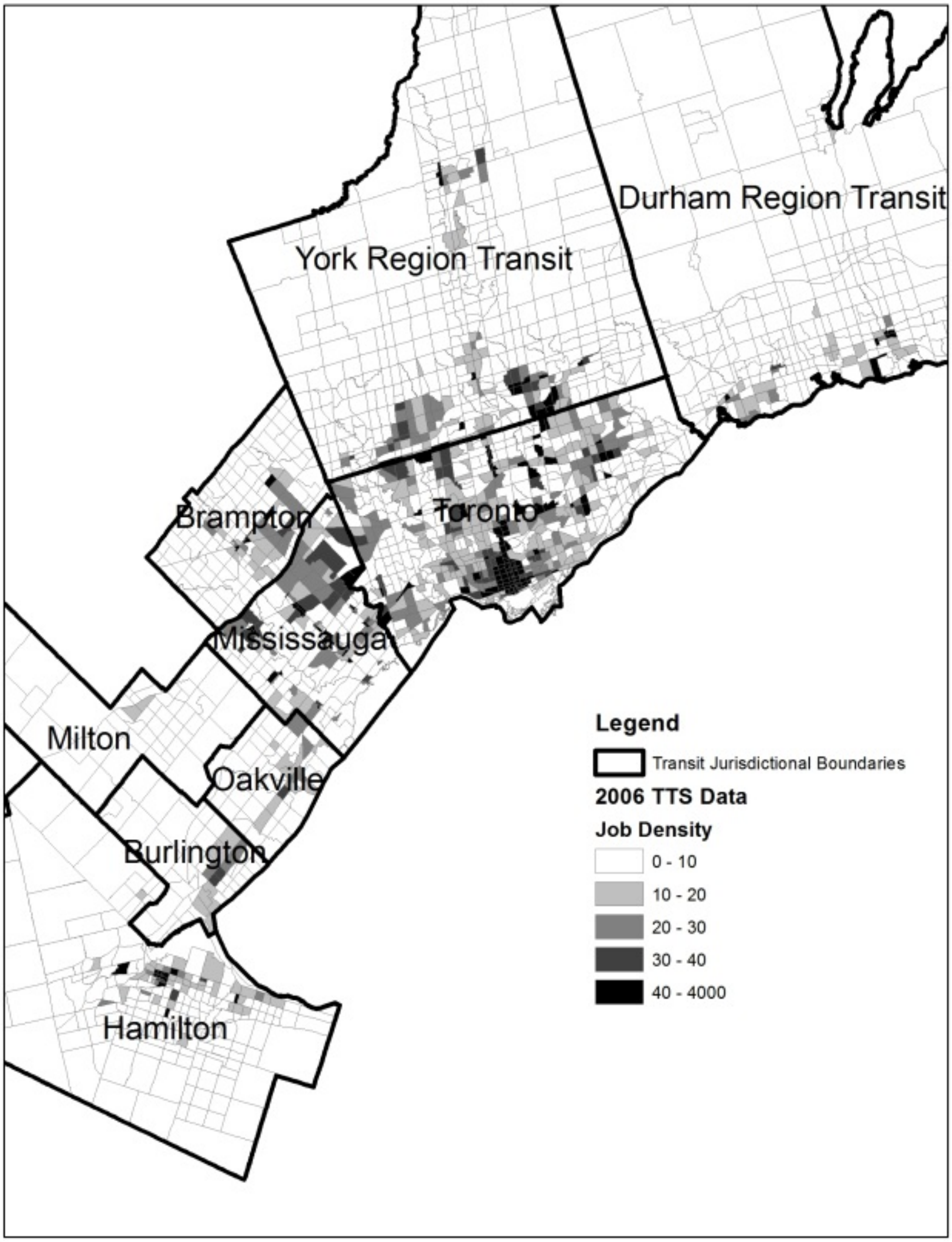
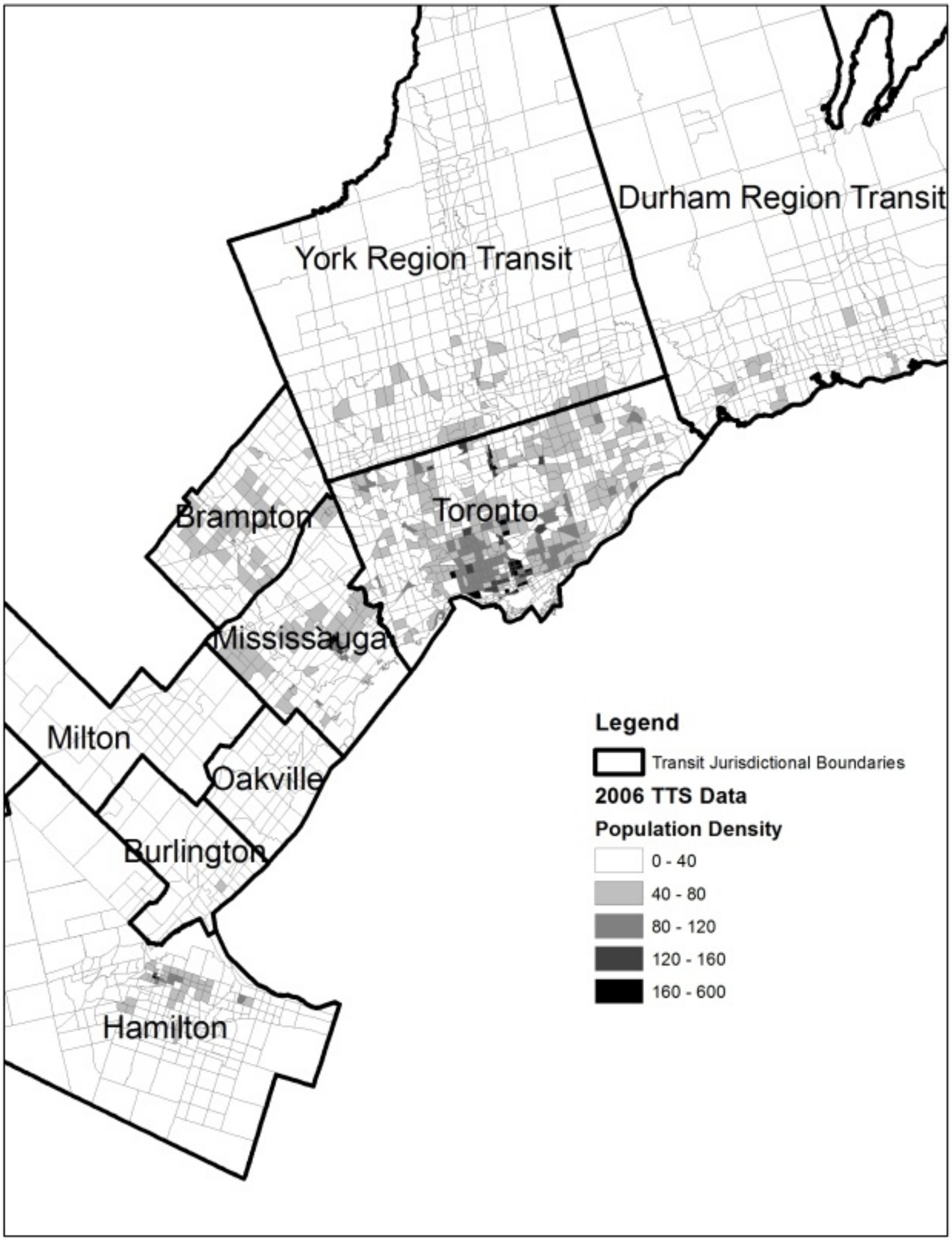


Figure 4:2 - 2006 GTHA Population Density (Residents Per Hectare)

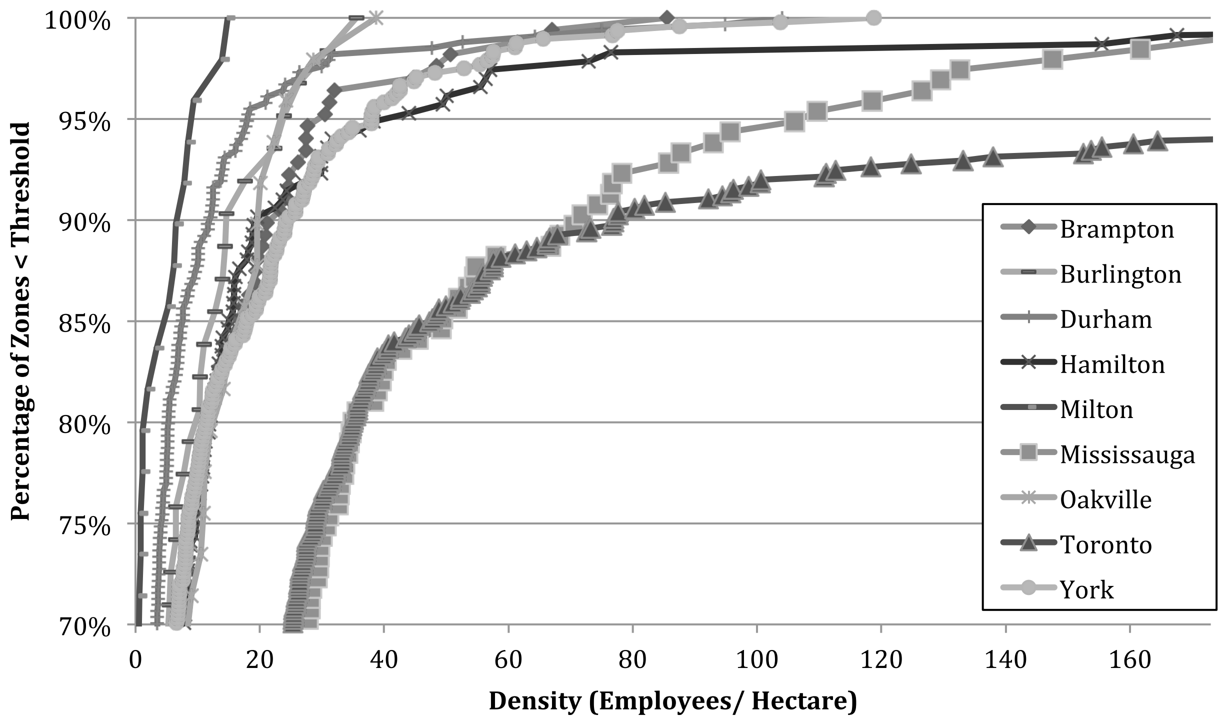


4.1.1 Determining a Density Threshold

The goal of determining a density threshold is to capture zones with higher than adjacent densities that are regionally significant. As seen in the above density figures, if only one threshold is used for the entire metropolitan area, Toronto will possess a disproportionate number of the activity centres. Alternatively, if there are too many thresholds, clusters in very low-density areas may be considered activity centres but do not possess regional significance.

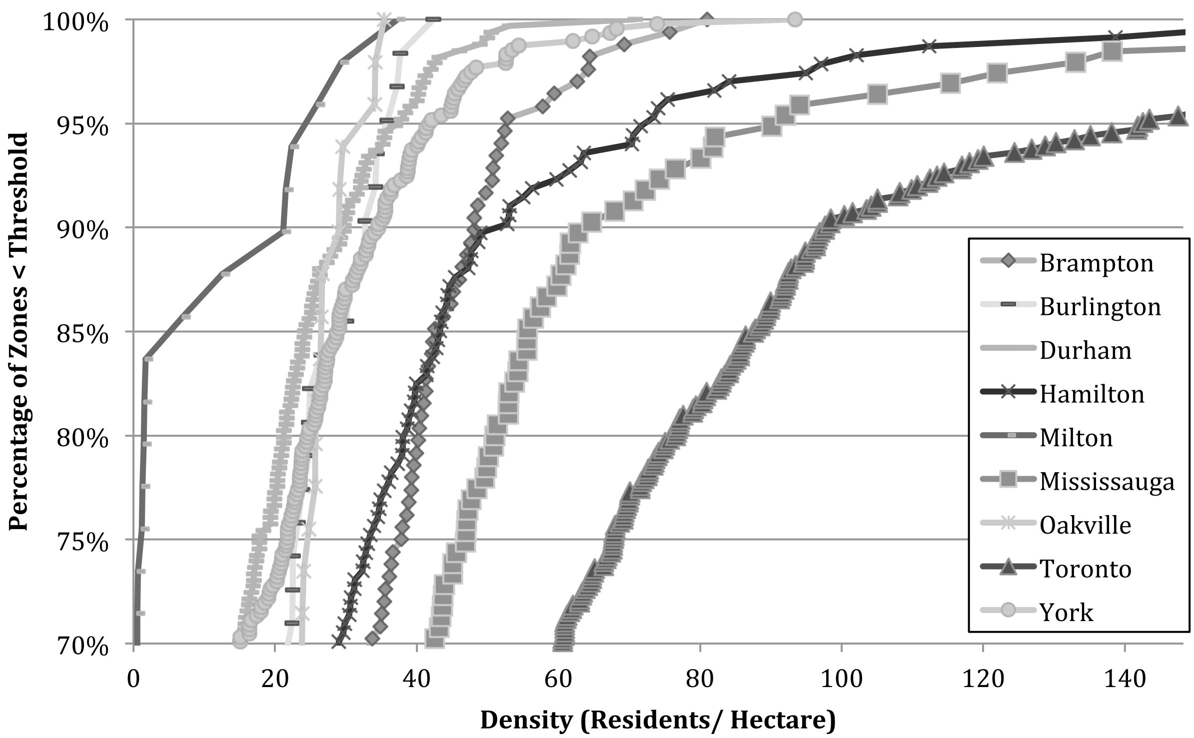
A separate analysis was conducted to define thresholds for both employment and population. For each analysis, the data was sorted first by transit jurisdictional area and then by density in increasing order. Each TAZ's share of the total number of zones in each respective transit area was found so the cumulative zonal density could be plotted, as shown in Figure 4:3 and Figure 4:4. The cumulative approach is used to isolate the densest zones from the remaining zones.

Figure 4:3 - GTHA Employment Density of TAZs by Transit Jurisdictional Area



The density figures illustrate the stark differences in development densities that are apparent between urban and suburban settings. For example in Figure 4:3, employment in Toronto and Mississauga is distributed vastly different from the other municipalities. Around 30% of TAZs in Toronto and Mississauga have an employment density greater than 25 employees/ha (~10 emp./acre) whereas only 10% of zones meet this density threshold in York Region and Hamilton. Percentages are even smaller in the remaining areas. This accentuates the more segregated nature of land uses in the suburban context where employment lands are focused and not dispersed geographically. Also, Figure 4:3 shows how similar the employment density distribution is for the least dense 90% of zones in every region outside of Toronto and Mississauga. These similarities suggest that all regions outside Toronto and Mississauga can be grouped together with one threshold to highlight the densest clusters in this area while excluding clusters that lack regional significance.

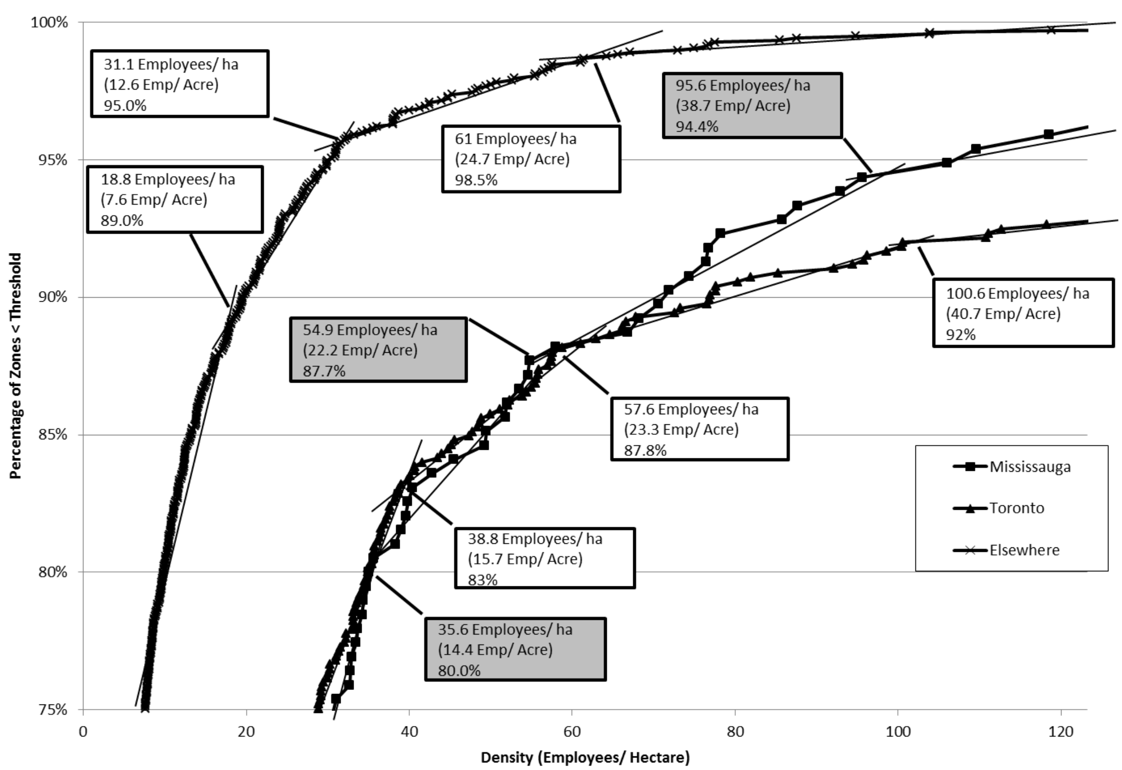
Figure 4:4 - GTHA Population Density of TAZs by Transit Jurisdictional Area



Similar to the employment distribution, the population distribution of TAZs is different between transit jurisdictional areas. Figure 4:4 illustrates the discrepancy between high density Toronto and lower density areas like Milton and Oakville. Despite the wider range of population densities outside Toronto and Mississauga compared with the employment analysis, to maintain consistency, all regions not in Toronto and Mississauga were grouped into one. Combining the transit jurisdictional areas in this way will exclude some low-density areas from the analysis entirely and capture a disproportionate number of zones in the more dense areas. However, this is desired since the low-density development patterns are too dispersed for transit to serve well and the more densely populated areas still possess higher than adjacent densities.

The analysis from nine separate transit jurisdictional areas was reduced to three: the seven areas outside Toronto and Mississauga were grouped into one area that will be referred to as 'Elsewhere'. The initial data making up the entire Elsewhere region was combined and sorted to re-plot the data as shown in Figure 4:5 and Figure 4:6. The next step in determining a threshold was to plot trend lines along the curve to observe if there were natural thresholds present in the data. The goal of using the natural thresholds was to choose cut-offs where a different type of development existed, such as multi-storey office compared to single-storey retail.

Figure 4:5 - GTHA Employment Density Thresholds



Only the thresholds that eliminated at least 80% of the least dense zones in each grouping were considered. In the case of the Elsewhere group, the change in density is very gradual due to the large quantity of zones and the similarity in the development typology throughout these areas. The first apparent change in density gradient above 80% is not until the selected threshold at 89%. Although, on a percentage basis this captures fewer zones compared to Toronto and Mississauga, relatively it captures a high number of zones, and the absolute density threshold is still far lower than the other two areas (see Table 4:1). Toronto and Mississauga both had clearer thresholds due to a lower quantity of zones, a greater variety in development patterns, and a higher ratio of jobs to residents. The first threshold eliminating greater than or equal to 80% of the zones in Mississauga occurred at 80% while in Toronto this occurred at 83%.

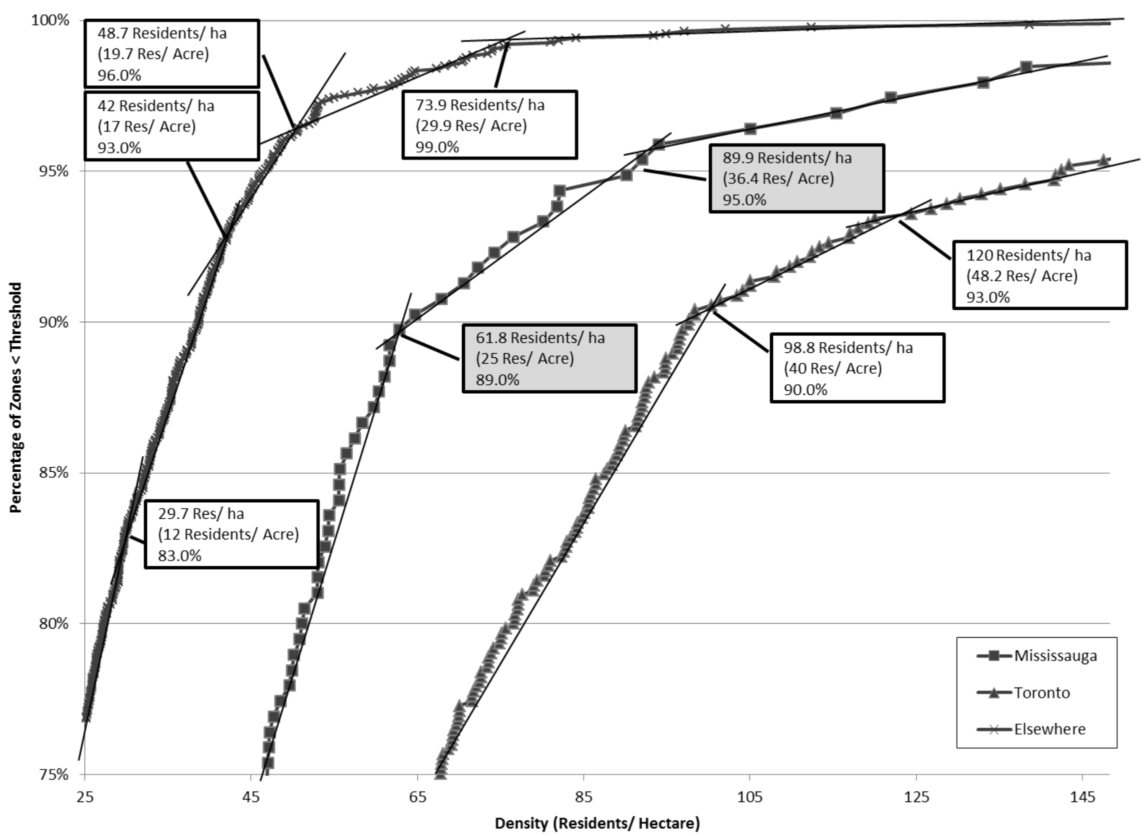
Table 4:1 - 2006 TTS Employment Statistics of Transit Groupings

Transit Grouping	Percentage of TAZs Above Threshold	Total Quantity of TAZs Above Threshold	Density Threshold (Jobs/ha)	Jobs to Residents Ratio
Mississauga	20%	39	35.6	0.60
Toronto	17%	106	38.8	0.55
Elsewhere	11%	147	18.8	0.41

The population analysis of the three areas showed very distinct cumulative density plots for each area; see Figure 4:6. Similarly to the employment analysis, the Elsewhere area does not have distinct changes in density gradients due to the high quantity of zones and the similarity in development typology throughout the area. The first threshold over 80% found in the Elsewhere area, at 83%, is too slight a change and highlights clusters that are too large in area, ceasing to represent higher than adjacent zones. The next threshold at 93% is better suited to select the higher than adjacent clusters and to retain a sizable percentage of zones (7%).

In contrast, Toronto and Mississauga both show a sharp change in densities at their respective thresholds. The gradient of zone density of the densest 10% of zones in Toronto is steep indicating a different development typology such as semi-detached houses or high-rises. In Mississauga a similar pattern emerges at the 89% threshold; a different type of development occurs causing a steep gradient in zone density. These sharp apparent changes in zone density provide confidence that selecting the natural thresholds present in the data is achieving the desired output: clusters of higher than adjacent density.

Figure 4:6 - GTHA Population Density Thresholds



An important differentiation must be made between residential unit density and resident density. Residential unit density refers to the physical built form whereas resident density refers strictly to the total number of people per given area.

This distinction is important since in the same development type, for example single-detached homes, the total number of residents could vary greatly. This variation in residents per unit could be due to demographic or cultural influences where families are larger or multiple families live together; or it could arise due to the presence of rental or accessory units in locations where rental demand is high. Since the total number of residents is more indicative of travel demand than the total number of residential units, resident density is utilized.

4.1.2 Appending Adjacent Zones

The threshold analysis selected all TAZs with employment or population densities higher than the designated threshold. In many cases, zones adjacent to these selected zones act in continuity with them and therefore are important to the transportation analysis. Adjacent zones with continuous land uses are added in decreasing density while maintaining a cluster density above the threshold. All single zones or clusters above the density threshold are analyzed; one example cluster is shown below in Figure 4:7 for illustrative purposes.

The employment activity centre illustrated in Figure 4:7, named Burlington Mall, falls within the 'Elsewhere' region possessing a minimum employment density threshold of 18.8 employees/ha. Five zones, A-E, are initially selected in the threshold analysis, while zones F-H are added based on their continuity of land use (refer to satellite imagery in Figure 4:8) while maintaining a cluster density above the threshold. Table 4:2 lists the cumulative job density of the cluster after adding each zone. The analysis stops when the next zone added results in a cluster density below the threshold.

Figure 4:7 - Burlington Mall Activity Centre, Showing Initial Cluster. TAZ ID (Emp/ha)

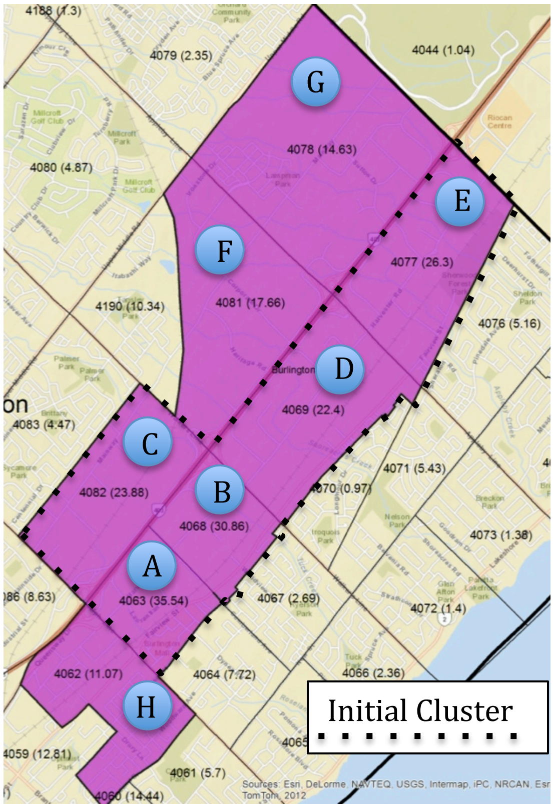


Table 4:2 - Burlington Mall Activity Centre with Adjacent Zones

Map Label	Job Density (emp/ha)	Cumulative Job Density	Cumulative Employment
A	35.54	35.54	4002
B	30.86	33.19	7507
C	23.88	28.78	12368
D	22.40	26.50	17731
E	26.30	26.45	23674
F	17.66	24.38	28543
G	14.63	21.81	34670
H	11.07	20.76	36590

Figure 4:8 - Burlington Mall Satellite Imagery (Google Maps, 2013)

4.1.3 Setting a Total Population Cluster Threshold

Activities centres possess higher than adjacent densities but also require a critical mass of either total employees or residents to achieve the agglomeration effects such as increased transit patronage. For identifying employment activity centres, the past literature was used to set the cluster threshold of 10,000 employees (Bogart & Ferry, 1999; Giuliano & Small, 1991; McMillen, 2003). For the population analysis, there was no literature that identified population centres in this way so a threshold had to be established from the data.

The goal of setting a cluster threshold was to highlight clusters with enough population to witness the defined manifestations of activity centres such as increased transit patronage, while capturing clusters distributed throughout the metropolitan area, and achieving a tractable number of activity centres. After the various density thresholds were applied and relevant adjacent zones had been added, a table was created to investigate how different total population thresholds would influence the quantity and dispersion of activity centres, see Table 4:3. A threshold of 20,000 was selected because it is large enough population to impact transportation analysis, it resulted in a tractable number of activity centres, 29, and it captured a similar percentage of clusters from each of the three regions.

Table 4:3 - Population Cluster Analysis to Determine Total Threshold

Population Threshold	Toronto		Mississauga		Elsewhere		Total		Std. Dev. Of Total %
	Clusters	% of Total	Clusters	% of Total	Clusters	% of Total	Clusters	% of Total	
0	17	100%	10	100%	27	100%	54	100%	0.00
5000	15	88%	4	40%	23	85%	42	78%	0.22
10000	12	71%	4	40%	20	74%	36	67%	0.15
15000	11	65%	4	40%	18	67%	33	61%	0.12
20000	10	59%	4	40%	15	56%	29	54%	0.08
25000	10	59%	2	20%	15	56%	27	50%	0.18
30000	10	59%	0	0%	11	41%	21	39%	0.25
35000	9	53%	0	0%	7	26%	16	30%	0.22
40000	7	41%	0	0%	6	22%	13	24%	0.17

A summary of the density and total thresholds used to identify both employment and population activity centres in all three regions is shown below in Table 4:4.

Table 4:4 - Activity Centre Thresholds

Region	Employees/ ha	% of TAZs < Threshold	Total Employment	Residents/ ha	% of TAZs < Threshold	Total Residents
Toronto	38.8	83%		98.8	90%	
Mississauga	35.6	80%	10,000	61.8	89%	20,000
Elsewhere	18.8	89%		42	93%	

4.1.4 Employment Activity Centres

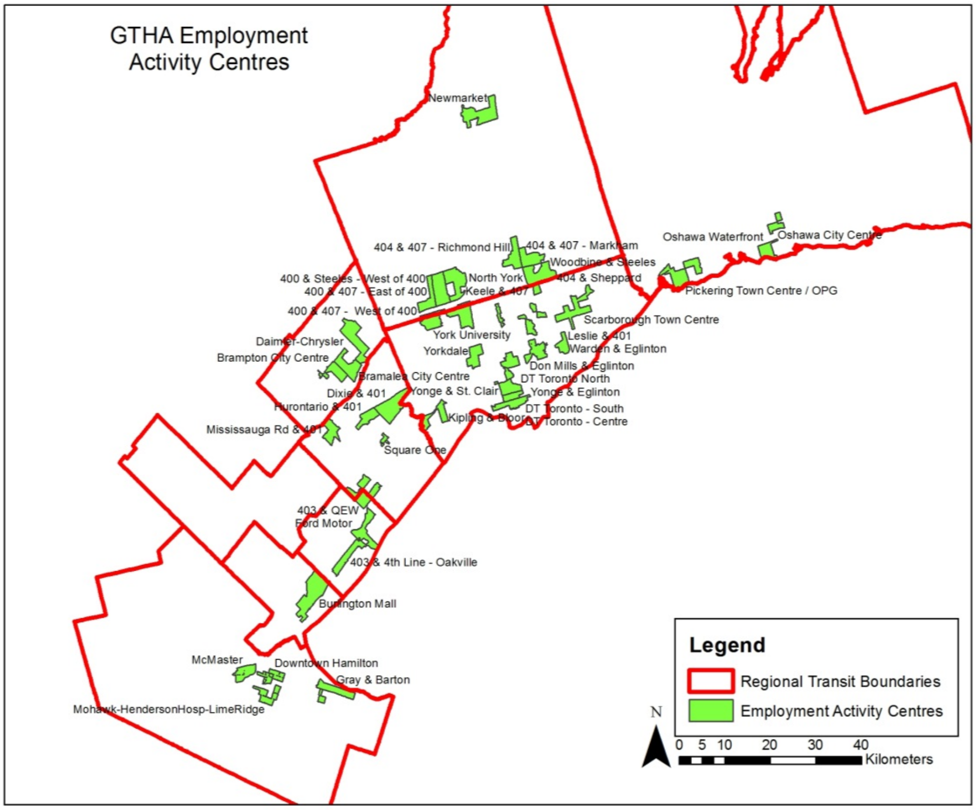
Applying the density threshold, adding the relevant adjacent zones, and applying the total threshold resulted in 40 employment activity centres; refer to Appendix A for the full list or to the summary in Table 4:5. For a full list of TAZs that make up each activity centre, refer to Appendix D. These activity centres make up 48% of the total employment in the metropolitan area while accounting for only 3.9% of the land area. This provides evidence that the activity centre analysis captures a substantial portion of the total employment. The largest cluster, Downtown Toronto, is comprised of three activity centres and possesses 15.1% of all employment in the metropolitan area and 31.6% of all activity centre employment. Appendix A also shows the correlation between activity centres and Metrolinx defined mobility hubs. The major discrepancies exist where activity centres are not located near current or proposed rapid transit or where commercial use is currently the exclusive or dominant land use.

The employment centres are also well dispersed spatially as every transit jurisdictional area, except Milton, possesses at least one activity centre; see Figure 4:9 below. The centres are comprised of 333 TAZs representing 15.2% of all zones which compares well with the 14.3% and 12.3% of TAZs represented in Bogart and Ferry (1999) and Casello and Smith's (2006) research, respectively.

Table 4:5 - Employment Activity Centre Summary

Region	Number of ACs	Total Employment	Total Hectares	Employment Density [emp/ ha]	Total TAZs	Average TAZs/ AC
Toronto	14	722352	7425.69	97.28	127	9.07
Elsewhere	22	518085	19797.47	26.17	175	7.95
Mississauga	4	114884	2573.00	44.65	31	7.75
AC TOTALS	40	1355321	29796.16	45.49	333	8.33
TOTALS	-	2824452	770351.15	3.67	2194	
AC %		48.0%	3.9%		15.2%	

Figure 4:9 - GTHA Employment ACs



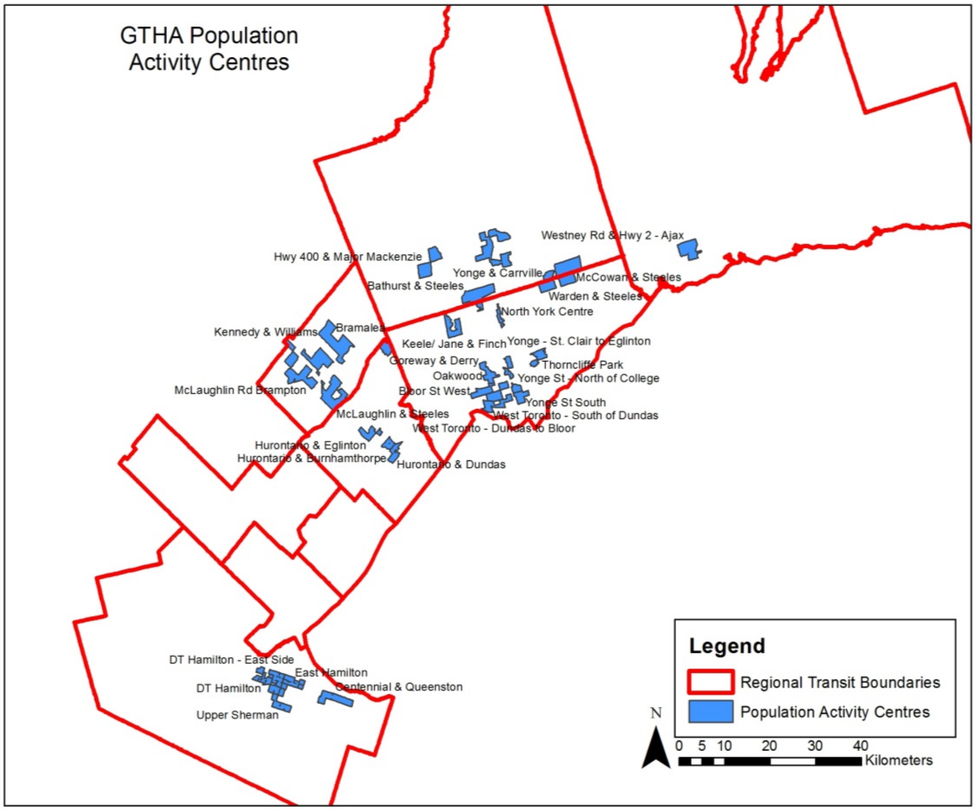
Suburban activity centres, located outside of the urban cores of Toronto and Hamilton, are predominantly employment-only lands that were designed for manufacturing uses and located near the 400-series highways. Some activity centre examples include Burlington Mall, 404 & 407, 400 & 407, and 400 & Steeles. One of the greatest challenges for these employment clusters is the lack of good transit options. Dobson et al. (2013) state that about half a million jobs are housed in these business parks with no higher order transit and no plans for improving transit in the future.

Employment activity centres also represent universities and colleges; however, schools in general are under-represented since the measurement of jobs does not include students. This may have less influence during the peak morning period but is still a limitation of the analysis.

4.1.5 Population Activity Centres

Conducting the threshold analysis exclusively for population in the GTHA yielded 29 population activity centres documented in Appendix B and summarized in Table 4:6. Identifying these centres accounted for only 21.1% of all residents in 2.3% of the land area. This lower percentage of total residents, compared with 48.0% of all employment, is due partly to a density threshold that only captured the top 7-11% of all TAZs and partly to the dispersed nature of much of the housing developments in the region. Similarly to the employment analysis, however, is the prevalence of the densest centres near Downtown Toronto. Although the densities are high in urban centres, the activity centres with the highest total population are found in suburban settings where residential-only land uses are uninterrupted for very large areas. A comparison to mobility hub locations is also made, and exhibits a strong correlation in Toronto but a weak correlation elsewhere. This is potentially a result of the density thresholds being too low and capturing clusters not suitable for Metrolinx' mobility hub definitions. Also, the weak correlation may exist because current housing is far away from any current or future rapid transit lines.

Figure 4:10 - GTHA Population ACs



The population activity centres are less dispersed than the employment centres; see Figure 4:10. Transit jurisdictions such as Oakville, Burlington, and Milton have resident densities that are too low to be transit-supportive and thus have no population activity centres. This can be explained by the lower household density and lower household size relative to other jurisdictions such as Brampton and Mississauga that have many population centres; refer to Table 4:7 for a summary of these values from the 2006 Statistics Canada Census.

Table 4:6 - Population Activity Centre (AC) Summary

Region	Number of ACs	Total Population	Total Hectares	Population Density [Ppl/ ha]	Total TAZs	Average TAZs/ ACs
Toronto	10	458515	3596.71	127.48	70	7.00
Elsewhere	15	662129	13004.31	50.92	115	7.67
Mississauga	4	96227	1254.58	76.70	22	5.50
AC TOTALS	29	1216871	17855.60	68.15	137	4.72
TOTALS		5764963	770351.15	7.48	2194	
AC %		21.1%	2.3%		6.2%	

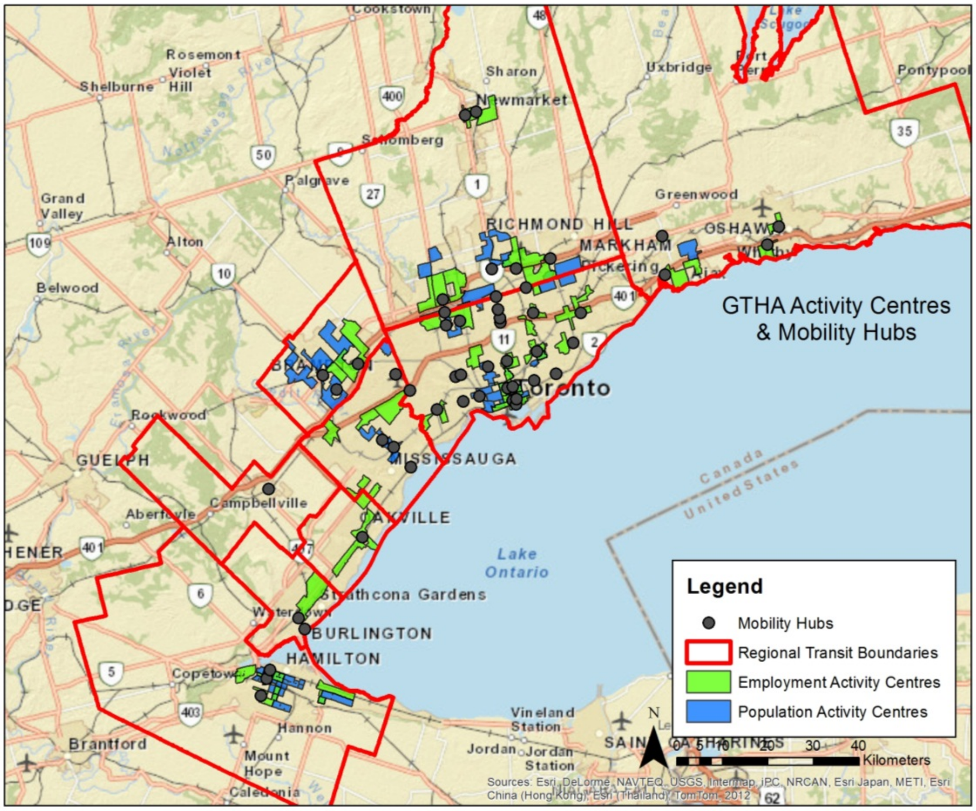
Table 4:7 - 2006 Household Characteristics

Municipality	Oakville	Burlington	Milton	Brampton	Mississauga
Household Density [per km2]	424.6	351.8	51.6	490.4	775.5
Household Size	2.9	2.6	2.9	3.4	3.1

4.2 Mobility Hubs

The relationship between high-density clusters of employment or population and transit supportiveness is understood by many institutional organizations including Metrolinx. As a provincial agency, Metrolinx is tasked with improving mobility within the GTHA region. As part of their Big Move Regional Transportation Plan, Metrolinx identified 51 mobility hubs that are significant origins, destinations, or transfer points in the regional transportation system. The vision for these hubs and their surrounding areas is to be well-connected places to live, work, and play; places that are accessible to transit and contain within themselves a variety of uses. Therefore, mobility hubs present an interesting comparison with activity centres - where do the definitions differ, where are they the same?

Figure 4:11 - GTHA Activity Centres & Mobility Hubs



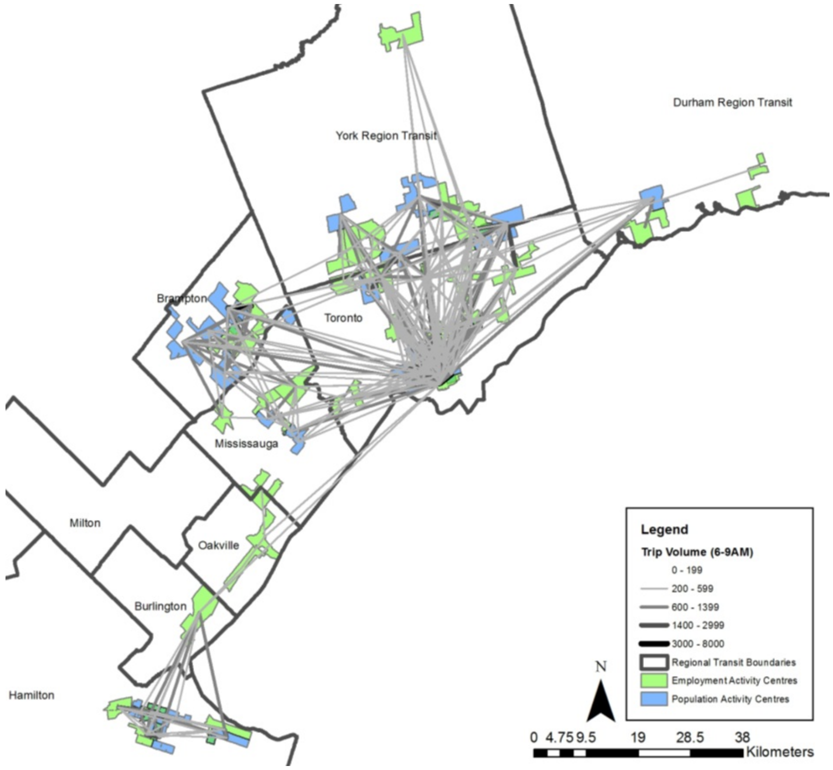
Although both mobility hubs and activity centres are defined using similar factors such as population, employment, and transit-supportiveness, there are fundamental differences based on time. Mobility hubs focus on what could be and leverage the current or future rapid transit network while activity centres are a snapshot of where people presently live and work. Despite their differences, it is evident in Figure 4:11 that the two concepts match well; the discrepancies exist mainly where current activity centres are not located near current or future rapid transit. The activity centres that are and are not represented by a mobility hub are identified in Appendix A and Appendix B. Similarly, Appendix C lists all mobility hubs and their corresponding activity centres if applicable.

4.3 Trip Analysis

Travel between activity centres is the next stage of the analysis. These flows represent trips where transit can be competitive with the private auto and where significant demand exists to warrant investment. To visualize these connections and their relative demand, the desire lines method in GIS is used along with the data output from the TTS. Figure 4:12 below shows all the trips taken during the morning peak, 6-9am, from the population and employment activity centres to the employment activity centres, that have a minimum volume of 200 people. As expected, the travel flows to downtown Toronto are quite high relative to other trips taken. Less intuitive, but quite obvious, are the many trips taken between Hamilton and Burlington, forming a type of sub-region. Other employment areas around the periphery also act as strong trip attractors including those in north Mississauga and in the south of York Region.

Another intuitive result is the relatively large number of trips taken from population to employment centres compared with trips from employment to employment centres: 262,015 and 120,053 trips respectively. Since the data is from the morning peak, this confirms the segregated nature of many of the employment zones since most people start their morning trip from their place of residence.

Figure 4:12 - GTHA Peak AM Trip Flow Between Activity Centres



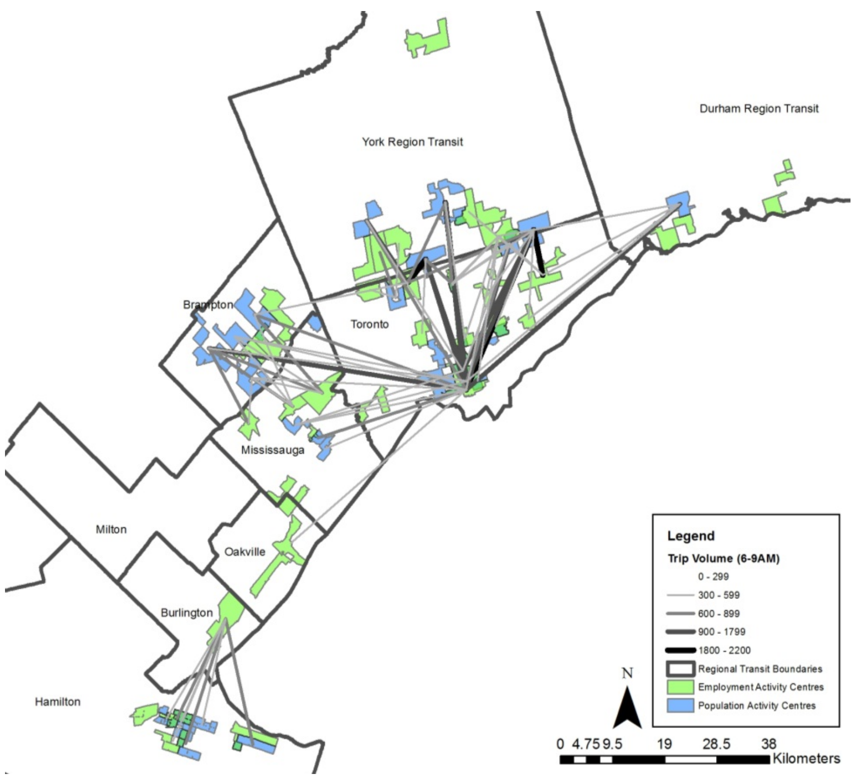
To focus the analysis toward the research questions regarding regional integration, all of the OD pairs that did not cross a transit jurisdictional border are removed from the analysis. Consequently, many of the highest trip volume OD pairs are removed such as the flows within downtown Toronto. Considering the total trips taken in the morning peak in the GTHA, the cross-border trips between activity centres represent only a small fraction of the total, 3.63%. However, of the total trips taken between activity centres, 29.75% of them cross a border; refer to Table 4:8 for a summary. A larger percentage of the trips between activity centres cross a border (29.75%) than the total cross border trips (22.77%) due to the varied definition of activity centres by location and the lower density thresholds established for periphery areas.

Table 4:8 - Trip Summary

Total Trips – GTHA 6-9am	3133922
Total Cross-Border Trips – GTHA 6-9am	713656
Total Trips Between ACs – 6-9am	382068
Total Cross-Border Trips Between ACs – 6-9am	113670
Percentage of Total Trips that Cross a Border	22.77%
Percentage of Total Trips ACs Comprise	12.19%
Percentage of Total Trips Cross-Border ACs Comprise	3.63%
Percentage of AC Trips that Cross a Border	29.75%

The visualization of exclusively cross border trips in Figure 4:13 clearly shows the dominance of downtown Toronto in attracting trips, as well as the significance of short trips between adjacent jurisdictions. This figure shows all the OD pairs with at least 300 trips made in the three-hour morning peak. Most of these trips taken, if by transit, will require a transfer since they are regional trips.

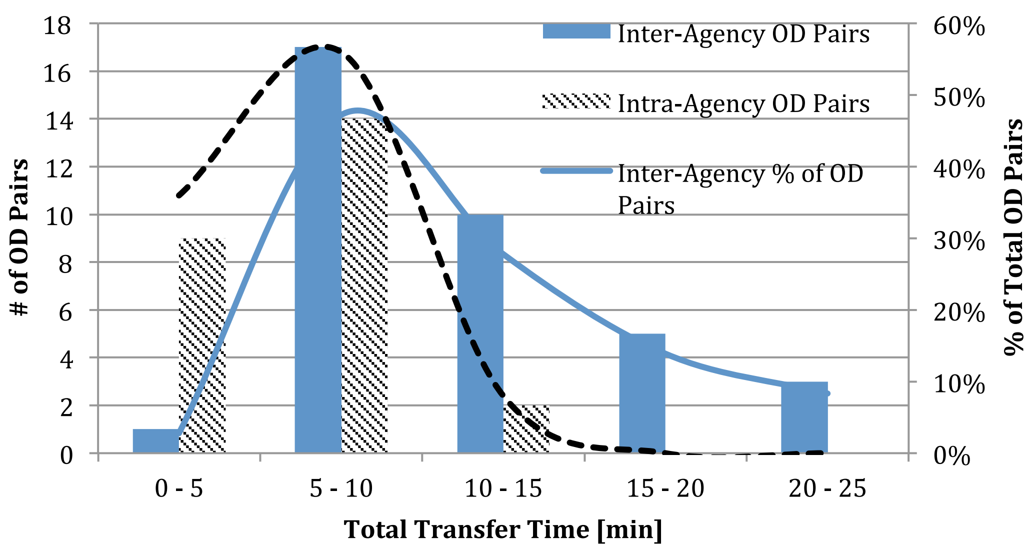
Figure 4:13 - GTHA Peak AM Cross-Border Trip Flow Between Activity Centres



Using the travel demand cut-off established in the methods, 120 trips per hour, 61 high demand OD pairs are investigated further using Google trip planner to identify the best transit routing for each trip.

To understand the benefits of cross-jurisdictional service, the optimal transit routing for OD pairs that are served by multiple transit agencies are compared to transit routing served by single agencies. Inter-agency trips made up 36 of the 61 OD pairs while intra-agency trips accounted for the remaining 25. This comparison of total transfer time, shown below in Figure 4:14, reveals a much greater percentage of OD pairs with a total transfer time of 10 minutes or less for intra-agency trips. Greater coordination between routes within an agency is suggested by this data; however, the finding is not conclusive due to variables such as frequency of service, or distance travelled not being controlled for. Despite these conditions, longer transfer times are likely when using multiple transit agencies for a trip in the GTHA compared to single agency trips.

Figure 4:14 - Total Transfer Times of Inter-Agency or Intra-Agency Transfers for Regional OD Pairs



4.4 Onerous Transfers

The method for calculating the four transfer metrics and relativizing each OD pair accordingly is carried out for all of the 61 high demand OD pairs. The three OD pairs with the highest average penalty are selected to be case studies and are listed in Table 4:9 and Table 4:10 below. Three additional OD pairs are selected that serve multiple jurisdictions but do not require an inter-agency transfer to complete the trip. They are selected based on the variety with which they provide regional service: local service extending into an adjacent jurisdiction, regional rail, and regional express bus. To understand the benefits of integration, the first three case study OD pairs are compared to improved regional connections while the last three OD pairs are compared to local service that does not cross borders. See Appendix H for the calculation of transfer metrics for all cross-jurisdiction OD pairs.

Table 4:9 - Transfer Metrics of Case Study OD Pairs

Origin Activity Centre - Destination Activity Centre	Trip Volume [6-9am]	Transit Routing	Travel Time [min]	Total Transfer Time [min]	Transfer Penalty [min]	Demand Weighted Transfer [h]	Transfer % of Travel Time
Centennial & Queenston - Burlington Mall	617	HSR Route 2 to GO Route 12 to BurT Route 81	82	24	60	40.72	29.3%
McLaughlin Rd Brampton - Dixie & 401	869	BT Route 4 to BT Route 502 to MT Route 35	80	24	28.25	57.35	30.0%
Kennedy & Williams - DT Toronto - Centre	441	BT Route 29 to BT Route 502 to Brampton GO Station to TTC Subway	90	25	48.25	30.32	27.8%
Keele/ Jane & Finch - Keele & 407	373	TTC Route 36 to TTC Route 107 (Extra Fare Req'd North of Steeles)	43	7	14.5	7.18	16.3%
Hurontario & Burnhamthorpe - DT Toronto - South	666	Walk to Cooksville GO Station	61	-	-	-	-
McLaughlin & Steeles - Hurontario & 401	418	BT Route 502	34	-	-	-	-

Table 4:10 – Average Transfer Penalty of Most Onerous OD Pairs

Origin Activity Centre - Destination Activity Centre	Transfer Time [% of Max]	Transfer Penalty [% of Max]	Demand [% of Max]	Transfer % [% of Max]	Average Penalty
Centennial & Queenston - Burlington Mall	96%	100%	71%	98%	91%
McLaughlin Rd Brampton - Dixie & 401	96%	47%	100%	100%	86%
Kennedy & Williams - DT Toronto - Centre	100%	80%	53%	93%	81%

Formulas for calculating the transfer metrics are described in Section 3.3 while sample calculations for the first case study are listed below:

Equation 4:1 - Transfer Penalty Sample Calculation (Metrolinx)

$$TP = [10 + (0.5 * 50)] + [10 + (0.5 * 30)] = 60$$

Equation 4:2 – Total Disbenefit/ Demand Weighted Transfer Sample Calculation

$$DWT = 16.5\% * 617 * \left(\frac{24}{60}\right) = 40.72$$

Equation 4:3 - Transfer Percentage Sample Calculation

$$Transfer\ \% = 24/82 = 29.3\%$$

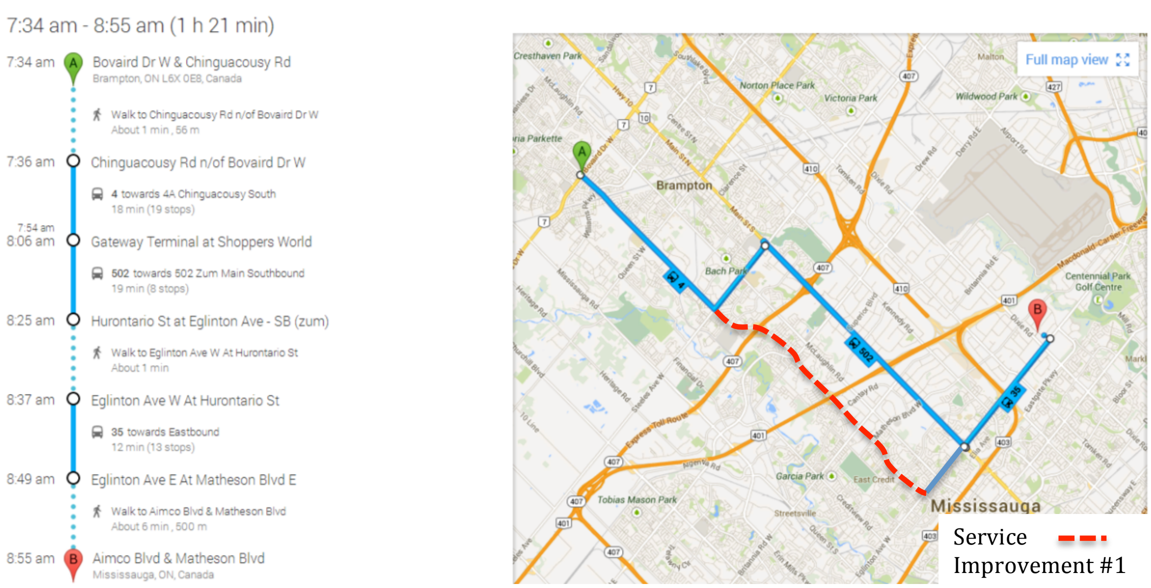
4.5 Candidate Interregional Routes

The OD pairs with onerous transfers are analyzed further. Hypothetical improvements are introduced into the network to compare their performance with the best current transit routing option; these improvements are limited to operational characteristics such as new service or greater scheduling coordination. Transfer metrics similar to the prioritization method are used to compare the more integrated trip with the existing trip. Also, to understand the effects of a well-integrated network further, OD pairs that currently have regional service available are compared to the best intra-jurisdiction transit options.

4.5.1 McLaughlin Road, Brampton to Dixie & 401, Mississauga

This OD pair connects a population activity centre in Brampton with an employment activity centre in Mississauga; it has a trip volume of 869 in the morning peak. The existing optimal routing for a 9:00am arrival time is shown below in Figure 4:15. Brampton Transit Route 4 runs southeast along Chinguacousy Road then northeast along Steeles where it connects with the 502 Zum. The Zum, a regional express bus service, runs southeast along Main Street in Brampton and Hurontario Street in Mississauga to Eglinton Avenue where it connects with Miway Route 35. Route 35 heads northeast on Eglinton for the remainder of the trip.

Figure 4:15 - McLaughlin Rd to Dixie & 401 Transit Routing (Google Maps, 2013)



Service Improvements

Two service improvements are proposed separately to understand the effects of each. The first proposal is to extend the Brampton Transit Route 4 southeast along Chinguacousy Road and Mississauga's Mavis Road into Mississauga, see Figure 4:15. It would finish the route as Miway Route 61 that currently runs along Mavis. This service could be reciprocal between both agencies and provides another north-south connection between the two cities. Integrating these routes would remove a transfer from this OD pair leaving one transfer required at Mavis Road and Eglinton Ave.

The second improvement would be the proposed LRT on Main Street in Brampton and Hurontario in Mississauga that would replace the current Zum service and be faster and run more frequently. To evaluate the LRT, its operating characteristics are obtained from a Metrolinx report prepared by Steer Davies Gleave (2010). A summary of the outcomes of each improvement is shown below in Table 4:11.

Table 4:11 - McLaughlin Rd to Dixie & 401 Alternatives Summary

Trip Description	Total Travel Time [min]	No. of Transfers	Total Transfer Time [min]	Transfer % of Travel Time	Transfer Penalty [min]	Total Disbenefit to Riders [h]
Existing	80	2	24	30%	28.25	57.4
Mavis Extension	71	1	10	14%	13.75	23.9
LRT	60	2	5	8%	25.25	11.9

Both suggestions show noticeable reductions in the transfer penalty. Upgrading from an express bus to an LRT is the best option to improve this trip, however, this option is much more expensive than reconfiguring bus routes. Two transfers are still required for the LRT trip but due to its high frequency and higher speed, the trip is completed faster and with less total minutes waiting for a transfer. The first improvement reduces the transfer component of the trip by a substantial margin, but the operating speed of the local bus would be slower than the Zum express bus, reducing the benefits slightly.

To further express the benefits to patrons of these proposed improvements, a generalized cost calculation is used for each transit routing. The Kittelson & Associates (1999) formula is used, as described in Section 2.3.4, to calculate the generalized cost including a 10-minute base penalty per transfer and a value of time of $16/ hour. A sample calculation is provided below in Equation 4:4 illustrating the current base case: 7 minutes of walking to and from the transit system, zero minutes waiting at the stop, 12 minutes of transferring for two transfers, 49 minutes of in-vehicle time, two ten-minute transfer penalties, a value of time of $16, and a fare of $3.50.

The service improvements show significant savings per passenger in the order of $11 - $13 per trip; refer to Table 4:12. Assuming a transit mode share that is equal to the region-wide share (16.5%) and the current travel demand (869), the total cost savings could be in the range of $3,000 to $3,700 daily.

Table 4:12 - McLaughlin Road to Dixie & 401 Generalized Costs

Routing Description	Perceived Total Travel Time [min]	Fare	Generalized Cost	Total Cost Savings
Current	144.4	$3.50	$42.01	-
Mavis Ext.	104.4	$3.50	$31.34	$3,058.88
LRT	95.9	$3.50	$29.07	$3,708.89

Equation 4:4 – Generalized Cost Sample Calculation

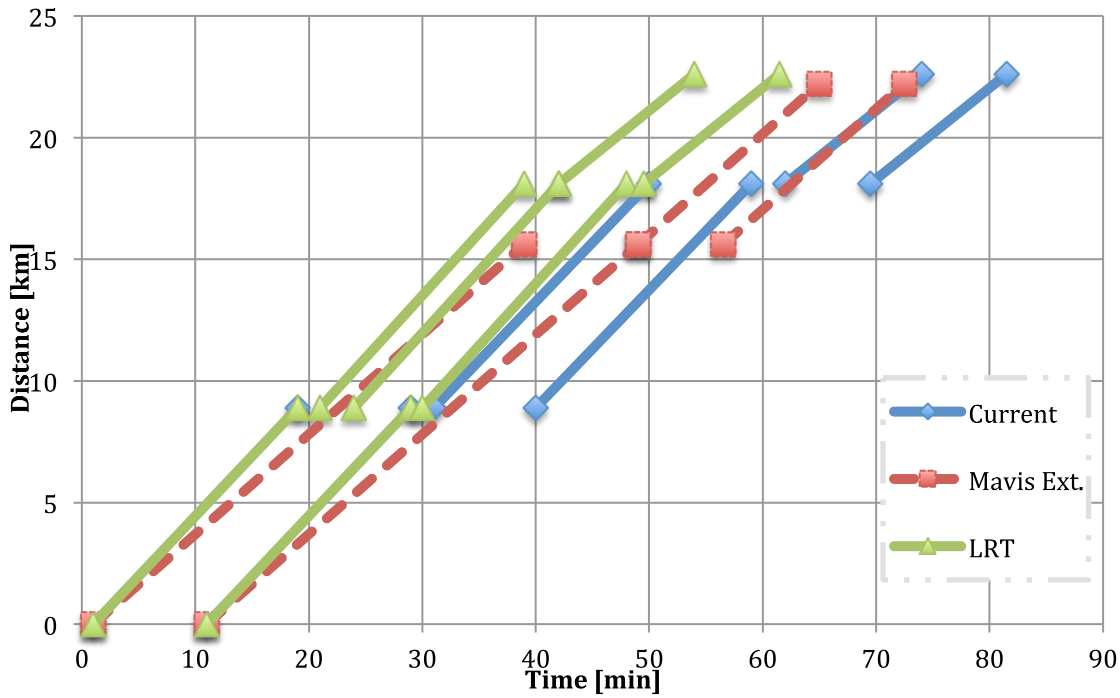
$$GC_{OD} = (2.2(1+6) + 2.1(0) + 2.5(12+12) + (18+19+12) + 20)\frac{\$16}{60} + \$3.50$$
$$= \$42.01$$

Reliability

Reliability is an important factor to consider whenever transfers are involved. If the transfer time is short, and the headways of the connecting routes are large, there is potential for a very large time penalty for missed connections. This can also cause anxiety for the patron during the route or cause them to take an earlier scheduled route thereby further extending their travel time (Casello, Nour, & Hellinga, 2009).

The three different routing options are compared in Figure 4:16 below. The chart shows the total travel time on the x-axis versus the distance travelled on the y-axis. Parallel lines are one headway apart and exhibit the penalty associated with missing the scheduled vehicle. Both the base case and the Mavis extension routings schedule large transfer times between routes so the likelihood of missing a connection is low. The presence of an LRT, with very short headways and higher reliability, reduces the transfer time and the potential penalties substantially. It is apparent that in the LRT case, even with missing the first and second connection, the total travel time is still less than either of the other two options when all the connections are made.

Figure 4:16 - Reliability Comparison of the Three Routing Options

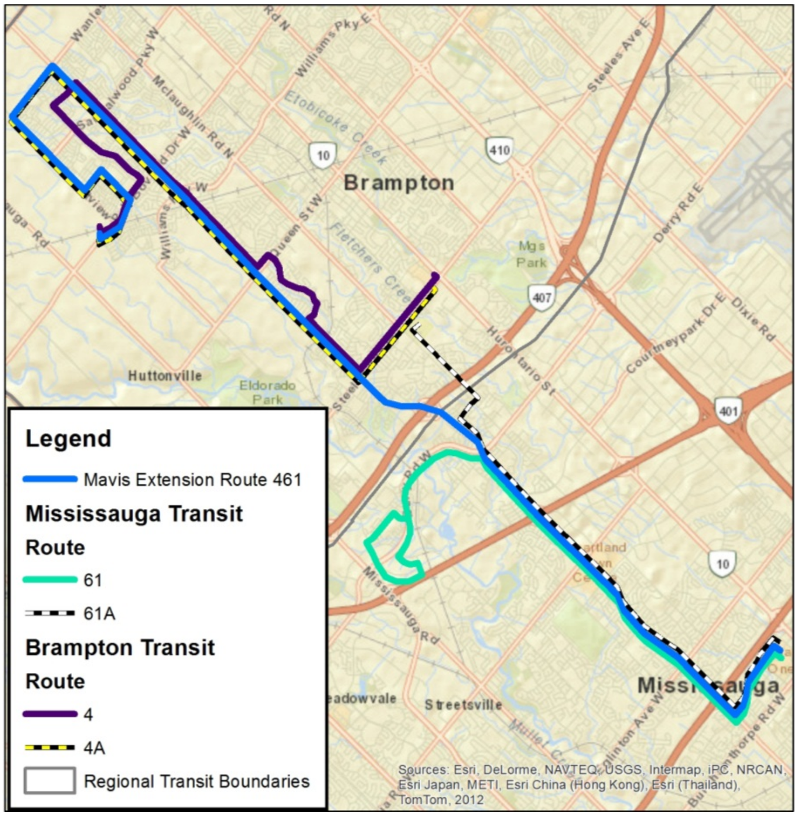


Agency Costs & Benefits

Calculating the relative cost of service provision between the proposed service and the existing service is possible for the Mavis extension as it shares the same mode as the current bus service; however, insufficient data exists to compare LRT operating costs and potential ridership with current bus service.

The Mavis extension or route 461, supplants routes 4 and 4A in Brampton and routes 61 and 61A in Mississauga; see Figure 4:17. It spans a total distance of 27.9 km and connects the Mount Pleasant GO Station in Brampton with the Mississauga City Centre. There are branches of the existing routes that are not served by the new route but these areas retain service from other existing routes.

Figure 4:17 - Proposed and Current Transit Routing for Chinguacousy & Mavis Road



Since the current routes had different service schedules and headways, a new schedule would be required for route 461. In the peak periods, the headways of routes 4 and 61 are 10 and 12 minutes respectively and in the off-peak they vary from 20 to 30 minutes. The new schedule for the Mavis extension is proposed in Table 4:13 and replicates the existing routes' on and off-peak hours.

Table 4:13 - New Mavis Extension Route 461 Service For Each Direction (North/South)

Off-Peak Hours	Off-Peak Headway (min)	Peak Hours	Peak Headway (min)	Daytime Hours	Daytime Headway (min)	Runs
7	20	7	10	6	15	87

Off-Peak (4-6am, 7pm-12am); Peak (6-9am, 3-7pm); Daytime (9am-3pm)

To compare the cost impacts of this new route compared to the current routes, details such as operating times, total number of runs, and cost to deliver a revenue vehicle hour were obtained from a combination of online schedules and the 2010 Canadian Urban Transit Fact Book; refer to Table 4:14.

Table 4:14 - 2010 Mississauga and Brampton Transit Operating Characteristics

Agency	Rev-Veh-Hrs	Boardings	Oper-Rev	Oper-Exp	Revenue/ Cost (R/C)	Rev/ Boarding	Exp/ Veh-Hrs
Miway	1,207,979	30,589,359	$62,809,668	$134,638,294	0.47	$2.05	$111.46
Brampton	696,420	13,843,278	$29,993,183	$69,145,641	0.43	$2.17	$99.29
Weighted					0.45	$2.12	$104.00

Table 4:15 – New Mavis Extension Route 461 Costs Compared to Current Routes

Route	Operating Distance [km]	Operating Time [min]	All-Day Runs	Peak AM Runs	All-Day Rev-Veh-Hrs	Peak AM Rev-Veh-Hrs	Expenses/ Veh-Hr	All-Day Cost	Peak AM Cost
4	17	39	110	20	71.50	13.00	$99.29	$7,099.04	$1,290.73
4A	18.2	39	47	18	30.55	11.70	$99.29	$3,033.23	$1,161.66
61	15	35	77	14	44.92	8.17	$111.46	$5,006.30	$910.24
61A	12.8	36	64	13	38.40	7.77	$111.46	$4,279.97	$865.65
Total	-	-	298	65	185.37	40.63	-	$19,418.53	$4,228.28
461 New	27.9	68	174	36	197.20	40.80	$104.00	$20,508.47	$4,243.13

The operating characteristics of each route are summarized above in Table 4:15. The proposed service does incur an extra daily weekday cost of approximately $1090 and a daily peak AM cost of $15 mostly due to increased frequency in the off-peak hours.

A weighted average is used for the new route to define the relative cost and revenues of service delivery in both Brampton and Mississauga; the weighting is based on distance in each jurisdiction and is shown in Table 4:14. To maintain the existing weighted R/C ratio the new route would require 230 additional daily riders to justify the additional service, see sample calculation in Equation 4:5 based on Equation 3:5. In the peak period, since the cost difference is so small, only 3 more riders are needed to justify the realignment.

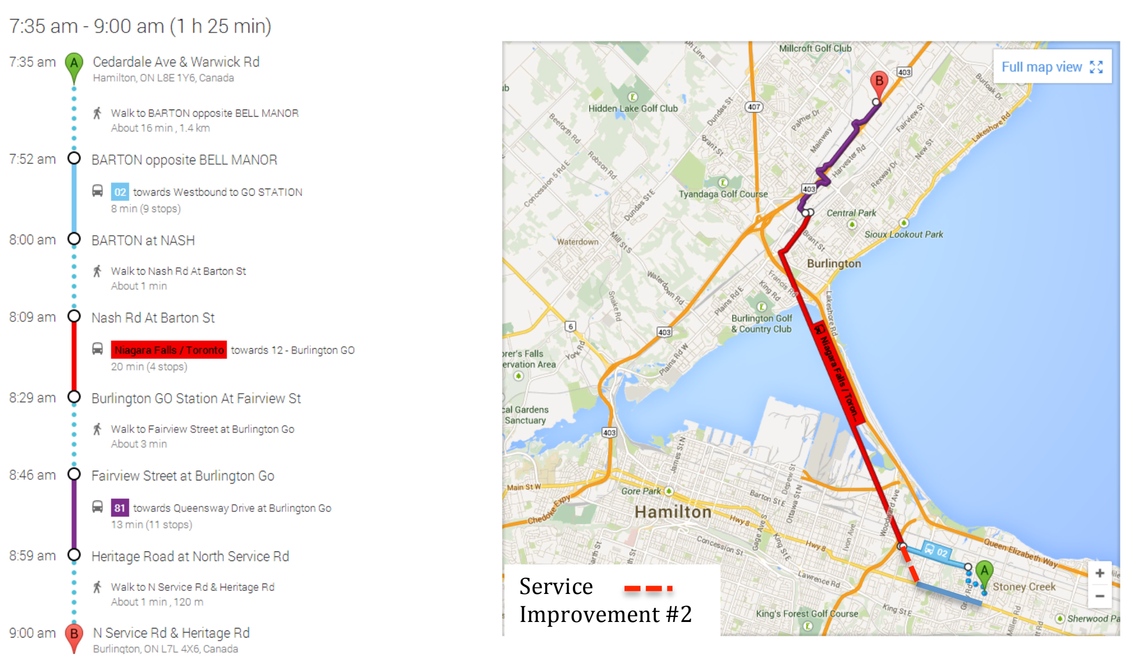
Equation 4:5 - Ridership Sample Calculation

$$Ridership\ Needed = \frac{\$1090 * 0.45}{\$2.12} = 230$$

4.5.2 Centennial & Queenston, Hamilton to Burlington Mall, Burlington

This case study occurs between Hamilton and Burlington and is comprised of east Hamilton residents travelling to Burlington's commercial parks for employment. The existing optimal routing for a 9:00am arrival time is shown below in Figure 4:18. A long walk accesses Hamilton Street Railway (HSR) Route 2, which travels west along Barton Street to connect with GO Transit Route 12 at Nash Road. The GO bus heads directly to the Burlington GO Station connecting with Burlington Transit Route 81 that completes the trip.

Figure 4:18 - Centennial & Queenston to Burlington Mall Transit Routing (Google Maps, 2013)



The current routing has a high transfer penalty due to the lack of schedule coordination between agencies and the low frequency of service. To counteract this, the first improvement proposes a reduction in headways of the Burlington Transit service from 30 minutes to 15 during peak periods. The second proposal increases coordination between GO Transit and HSR by moving the GO stop in Hamilton from Barton Street at Nash Road to Eastgate Square, which is a terminal and transfer location. This small change reduces access time (walk time) to the HSR network because more HSR routes stop at Eastgate Square. A summary of the outcomes of each improvement is shown in Table 4:16.

Table 4:16 – Centennial & Queenston to Burlington Mall Alternatives Summary

Trip Description	Total Travel Time [min]	No. of Transfers	Total Transfer Time [min]	Transfer % of Travel Time	Metrolinx Transfer Penalty [min]	Total Disbenefit to Riders [h]
Existing	82	2	24	29%	60	40.7
Reduce Headway	67	2	10	15%	52.5	17.0
Improve Coordination	75	2	28	37%	60	47.5

This example provides evidence that small changes can have large effects. A doubling of the frequency of service in Burlington would remove 15 minutes of total travel and transfer time. The second improvement of relocating the GO stop location reduces the total travel time by 8.5%. The total transfer time remains high because of the lack of coordination in the schedules; however, a reduction in travel time is still an improvement.

The benefits of each improvement can be quantified monetarily through the generalized cost formula. In Table 4:17 the proposed improvements show generalized cost savings of approximately $5 to 11. Based on the total travel demand, if transit ridership is able to meet the region-wide average mode share, then the total cost savings are in the $1000 to $2200 range.

Table 4:17 - Centennial & Queenston to Burlington Mall Generalized Costs

Routing Description	Perceived Total Travel Time [min]	Fare	Generalized Cost	Total Cost Savings
Current	163.4	$8.00	$51.57	-
Red. Headway	123.4	$8.00	$40.91	$2,171.84
Imp. Coord.	145.2	$8.00	$46.72	$988.19

Agency Costs & Benefits

To understand the cost impacts on the agencies providing the service improvements, the necessary route characteristics and agency operating characteristics are obtained – see Table 4:18.

Table 4:18 - GO and Burlington Transit 2010 Operating Characteristics

Agency	Rev-Veh-Hrs	Boardings	Oper-Rev	Oper-Exp	Revenue/ Cost (R/C)	Rev/ Boarding	Exp/ Veh-Hrs
GO Transit	1,067,374	57,098,000	$325,793,944	$435,056,005	0.75	$5.71	$407.59
Burlington Transit	144,706	1,960,205	$4,581,716	$12,514,263	0.37	$2.34	$86.48

The first proposal of doubling the frequency of service in the peak periods for Route 81 in Burlington shows substantial cost impacts of approximately $888 daily; refer to Table 4:19. Using 2010 figures, Burlington Transit has an average revenue per boarding of $2.34 and a revenue-to-cost ratio of 0.37. To meet the same R/C ratio, a total of 139 boardings are required daily or 82 in the peak AM period. The current peak AM period total trip demand is 617 meaning an additional 13% of people would have to choose transit to justify the change.

The second proposal is a small change in pick-up location for the Stoney Creek stop along GO Route 12. An average additional distance of 1.6km is required to move the stop to Eastgate Square. The GO cost of service delivery per vehicle hour is grossly inflated due to the inclusion of their train data; a GO bus averaging speeds over 60km/hr should have an even lower cost per hour than a conventional urban bus system. If Table 4:19 is updated to use the Burlington Transit expense rate, the change in daily cost is $83.60 and in peak AM period cost is $14.41. Using GO Transit's 2010 R/C ratio of 0.75 and their revenue per boarding of $5.71, an additional 52 riders are needed daily and 9 in the peak AM period to justify this change.

Table 4:19 - Proposed Improvements Agency Costs

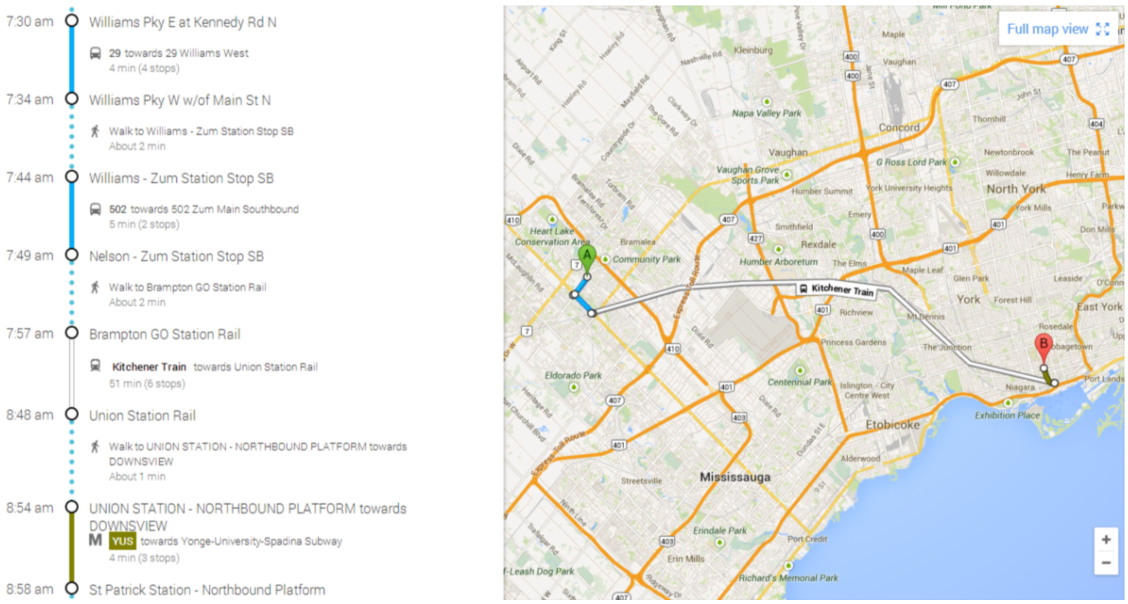
Route	Operating Distance [km]	Operating Time [min]	All-Day Runs	Peak AM Runs	All-Day Rev-Veh-Hrs	Peak AM Rev-Veh-Hrs	Expenses/ Veh-Hr	All-Day Cost	Peak AM Cost
81	15.6	28	27	15	12.60	7.00	$86.48	$1,089.66	$605.36
81 - Additional	15.6	28	49	28	22.87	13.07	$86.48	$1,977.52	$1,130.01
Difference			22	13	10.27	6.07		$887.87	$524.65
GO 12	84.4	80	29	5	38.67	6.67	$407.59	$15,760.33	$2,717.30
GO 12 Relocated	86	82	29	5	39.63	6.83	$407.59	$16,154.34	$2,785.23
Difference	1.6	2			0.97	0.17		$394.01	$67.93

4.5.3 Kennedy & Williams, Brampton to Downtown Toronto Centre

The OD pair from Brampton to Toronto, with a trip volume of 441 in the peak morning period, involves three transfers while still using the regional GO Transit service; refer to Figure 4:19. The first two components of the trip are needed to access the GO train – Brampton transit route 29 to the 502 Zum. The GO train then takes patrons to downtown Toronto where a transfer to the TTC subway is needed to arrive at the destination.

For the distance of this trip, there are no good routing alternatives that could improve upon the GO service. Thus, the improvements suggested are simply increases in speed to the GO line or increases in frequency to the Zum corridor to see the effects of better infrastructure. The first improvement is currently under construction: track improvements on the GO line between the airport and downtown. The second improvement is the increased frequency of the Zum service that will pair well with the potential addition of the LRT south of the GO station.

Figure 4:19 - Kennedy & Williams to DT Toronto - Centre Transit Routing (Google Maps, 2013)



The first improvement reduces travel time by 8 minutes based on the travel time of the new air-rail link (Metrolinx, 2012). The second improvement reduces total travel time and transfer time due to a more aligned schedule made possible by the reduced headway of the Zum service, from 9 minutes to 5 minutes. Table 4:20 summarizes the results of these improvements and shows a noticeable benefit in the increased Zum frequency case. The large benefit is achieved because a subsequent bus can be taken for the first leg of the journey, Brampton Route 29, and this reduces the large waiting time experienced at the GO station. Reliability of the routes becomes more significant when transfer time is reduced because of the increased possibility of missing the connection. This reality can sometimes cause patrons to forego the benefits of reduced transfer times if the probability of missing the connection is high.

Table 4:20 – Kennedy & Williams to Downtown Toronto Centre Alternatives Summary

Trip Description	Total Travel Time [min]	No. of Transfers	Total Transfer Time [min]	Transfer % of Travel Time	Transfer Penalty [min]	Total Disbenefit to Riders [h]
Existing	90	3	25	28%	48.25	30.3
Increase Speed	82	3	24	29%	48.25	29.1
Reduce Headway	73	3	9	12%	46.25	10.9

Travel time savings and reduced transfer impacts are important outcomes but how do the improvements compare financially? Using the generalized cost approach, as shown in Table 4:21, the increase in speed of the routing only reduces the cost by approximately $2 while the increased frequency of the Zum service reduces the cost by $10 or almost 25%. As an extension of this, if 16.5% of people chose transit for this OD pair, the aggregated savings would be almost $1500 daily.

Table 4:21 - Kennedy & Williams to Downtown Toronto Centre Generalized Costs

Routing Description	Perceived Total Travel Time [min]	Fare	Generalized Cost	Total Cost Savings
Current	158.4	$11.40	$53.64	-
Inc. Speed	150.4	$11.40	$51.51	$310.46
Red. Headway	120.9	$11.40	$43.64	$1,455.30

Agency Cost and Benefits

There are significant travel time savings with the proposed options but an understanding of the cost to deliver this service is required. The operating revenues and expenses of the agencies involved from 2010 are shown in Table 4:22 below.

Table 4:22 – 2010 GO and Brampton Transit Operating Characteristics

Agency	Rev-Veh-Hrs	Boardings	Oper-Rev	Oper-Exp	Revenue/ Cost (R/C)	Rev/ Boarding	Exp/ Veh-Hrs
GO Transit	1,067,374	57,098,000	$325,793,944	$435,056,005	0.75	$5.71	$407.59
Brampton	696,420	13,843,278	$29,993,183	$69,145,641	0.43	$2.17	$99.29

The first proposal to increase speed along the GO Train corridor through track improvements is primarily a capital cost and actually reduces operating costs. As displayed in Table 4:23, the eight-minute time savings equates to approximately $761 of daily savings for train operations. This is in addition to the generalized cost savings for patrons.

The second proposal of decreasing the headway of the 502 Zum line from 9 minutes to 5 minutes during peak periods has substantial cost implications. This increase in service results in 62 additional one-way runs with a daily cost of $4617. To justify this service, 924 additional riders are required daily based on Brampton Transit's revenue of $2.17 per boarding and R/C ratio of 0.43. In the peak AM period, 403 additional patrons would be required, which is impractical given the demand is currently only 441.

Table 4:23 - Agency's Cost of Proposed Improvements - Brampton to Toronto

Route	Operating Distance [km]	Operating Time [min]	All-Day Runs	Peak AM Runs	All-Day Rev-Veh-Hrs	Peak AM Rev-Veh-Hrs	Expenses/ Veh-Hr	All-Day Cost	Peak AM Cost
GO Train	Varies	41	14	8	9.57	5.47	$407.59	$3,899.32	$2,228.18
GO Train Faster	Varies	33	14	8	7.70	4.40	$407.59	$3,138.48	$1,793.42
Difference		-8			-1.87	-1.07		$(760.84)	$(434.77)
502 Zum	19.5	45	85	41	63.75	30.75	$99.29	$6,329.56	$3,053.08
502 Zum - Add	19.5	45	147	68	110.25	51.00	$99.29	$10,946.42	$5,063.65
Difference			62	27	46.50	20.25		$4,616.86	$2,010.57

4.6 Measuring Current Inter-Jurisdictional Benefits

The benefits of regional integration can also be observed by comparing well-integrated existing service with service confined to its own jurisdiction. The comparative case is determined by removing all regional service (routes that substantially enter another jurisdiction) and increasing the frequency of existing routes to account for the removed service. Three example OD pairs are selected with regional service of different types: regional express-bus, conventional bus, and regional rail. These case studies are explored in more detail below.

4.6.1 McLaughlin & Steeles, Brampton to Hurontario & 401, Mississauga

This route is currently well served by a regional express bus service, the Zum, which takes passengers across the Brampton-Mississauga border located along Highway 407. The local alternative is to take Brampton Route 52 from Steeles and Main Street to Ray Lawson Blvd. and Main Street, walk southeast on Main/ Hurontario to connect with Miway route 19 at Top Flight Drive; refer to Figure 4:20.

Figure 4:20 - McLaughlin & Steeles to Hurontario & 401 Transit Routing (Google Maps, 2013)

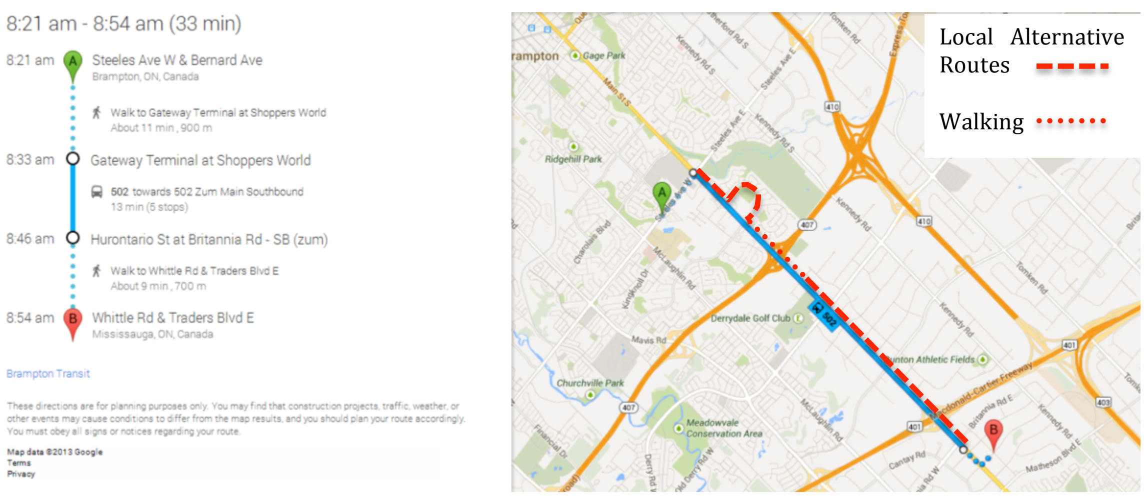


Table 4:24 – McLaughlin & Steeles to Hurontario & 401, Regional vs Local

Trip Description	Total Travel Time [min]	No. of Transfers	Total Transfer Time [min]	Transfer % of Travel Time	Transfer Penalty [min]	Total Disbenefit to Riders [h]
Current Regional	34	0	-	-	-	-
Local Alternative	56	1	17	30%	15	19.5

Although this is an exaggerated example of removing many cross-border routes along the corridor to simulate local-only service, there are arteries between

Brampton and Mississauga that currently do not have any cross-border service. The one transfer increases the total travel time by 22 minutes and creates a large transfer penalty; refer to Table 4:24. In addition to transfer penalties a long walk between routes is required, dissuading potential travellers further. The existing regional service only stands to offer cross-border travellers more benefits if the proposed LRT along this corridor becomes a reality. Travel times would be reduced further and reliability would improve.

Table 4:25 - McLaughlin & Steeles to Hurontario & 401 Generalized Costs

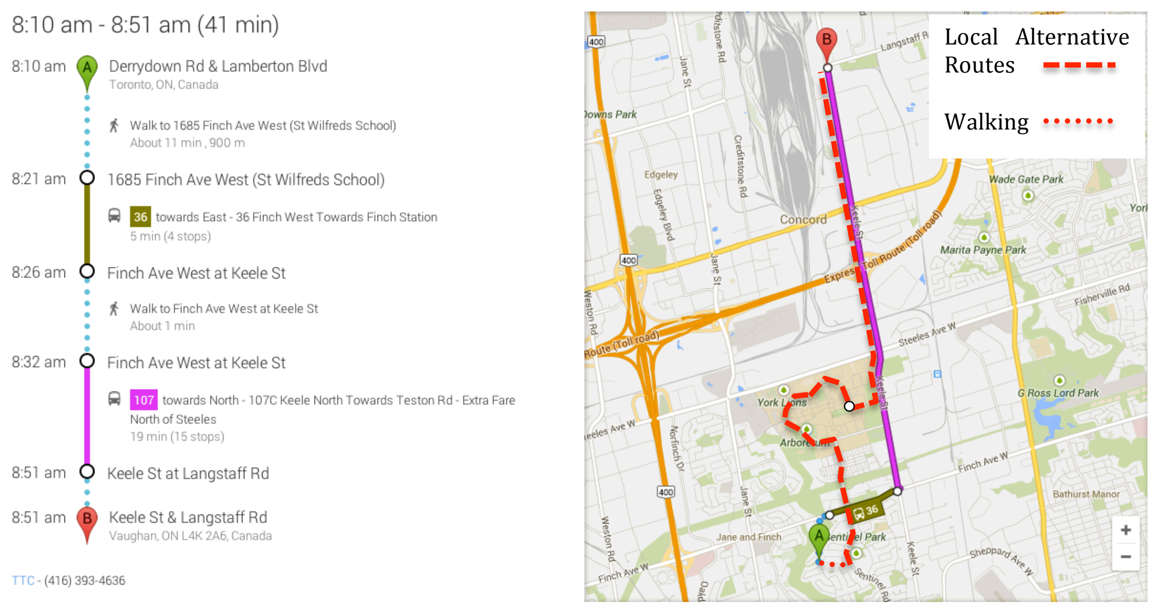
Routing Description	Perceived Total Travel Time [min]	Fare	Generalized Cost	Total Cost Savings
Current	57	$3.50	$18.70	$2,063.58
Local Alt.	113.1	$3.50	$33.66	-

The cost savings to patrons from the current regional service are equally striking. Table 4:25 shows a $15 cost saving per trip for patrons and an aggregated savings of $2000 if travel demand and mode share are considered. These significant savings further prove the importance of regional service.

4.6.2 Keele/Jane & Finch, Toronto to Keele and 407, York Region

The OD pair connecting northern Toronto residents to Vaughan commercial areas is served well through the standard TTC buses that travel well beyond their jurisdiction into York Region. Although an intra-agency transfer is still required for this OD pair, the benefits of a single-seat ride across the border are significant. The current routing connects a high-frequency east-west route along Finch Avenue, route 36, with a north-south route along Keele Street, route 107. The main difference in the local routing is the York Region route 22 along Keele only travels as far south as York University. This forces the Toronto leg of the journey to end at York University using TTC route 106 to get there. Refer to Figure 4:21 for a map of both routes.

Figure 4:21 - Keele/Jane & FInch to Keele & 407 Transit Routing (Google Maps, 2013)



Due to the presence of a transfer in the current optimal routing, some of the comparison metrics in Table 4:26 actually show the local option is better than the current regional plan. However, most generalized cost calculations use travel time as one of the main determinants, and in this case, there is a 44% increase in travel time when using local-only transit. This finding highlights the benefit of transit routes that travel along main arteries across jurisdictional borders; no stops or turn-around locations are required.

Table 4:26 – Keele/Jane & Finch to Keele & 407, Regional vs Local

Trip Description	Total Travel Time [min]	No. of Transfers	Total Transfer Time [min]	Transfer % of Travel Time	Transfer Penalty [min]	Total Disbenefit to Riders [h]
Current Regional	41	1	7	16%	14.5	7.5
Local Alternative	59	1	5	8%	17.5	5.1

The regional TTC route also provides generalized cost savings a measure of the total disutility of travel. The current route saves $6 per trip compared to the local alternative and if aggregated with the travel demand for this OD pair at the region-wide mode share, the savings becomes $760 daily; refer to Table 4:27.

Table 4:27 - Keele/Jane & Finch to Keele & 407, Generalized Costs

Routing Description	Perceived Total Travel Time [min]	Fare	Generalized Cost	Total Cost Savings
Current	73.2	$3.35	$22.87	$763.16
Local Alt.	83.7	$6.75	$29.07	-

4.6.3 Hurontario & Burnhamthorpe, Mississauga to Downtown Toronto - South

The final case study OD pair connects central Mississauga with the financial district of Toronto. This trip is exactly where regional rail service thrives – an origin close to a radial rail line and a destination close to the main transit hub downtown. In this case the activity centre centroid is sufficiently close to the Cooksville GO station that walking is the best option to access the rail service. This places this trip at a large advantage over alternatives with zero transfers.

The best alternate path involves use of an express bus east-west route in Mississauga and the subway network in Toronto. Miway route 103 is taken southeast along Hurontario Street to connect with Miway express route 101 travelling east on Dundas Street. The express bus connects with the Bloor-Danforth subway line at Islington Station that is taken east until meeting the Yonge-University-Spadina subway line. Figure 4:22 shows both transit routing.

Figure 4:22 - Burnhamthorpe & Hurontario to Downtown Toronto South Transit Routing (Google Maps, 2013)

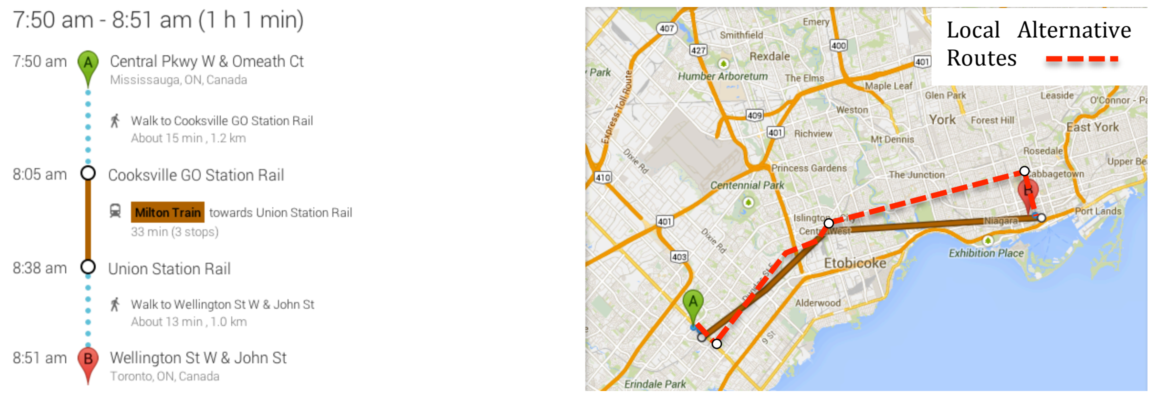


Table 4:28 – Burnhamthorpe & Hurontario to Downtown Toronto South, Regional vs. Local

Trip Description	Total Travel Time [min]	No. of Transfers	Total Transfer Time [min]	Transfer % of Travel Time	Transfer Penalty [min]	Total Disbenefit to Riders [h]
Current Regional	61	0	-	-	-	-
Local Alternative	84	3	13	15%	37.5	23.8

The comparison of routing is more complex because of the different modes involved: the regional rail of the current option versus the bus, express bus, and subway of the alternative option. However, the 13 minutes in transfers alone contributes unnecessarily to the total travel time making it 21% longer; Table 4:28 shows additional metrics. If users perceive the transfers to be as onerous as Metrolinx's assumptions, the total perceived travel time increases by an additional 24.5 minutes making it a very costly trip. The regional rail connection between downtown Toronto and central Mississauga links the two well and provides an important example for other activity centres to be linked in similarly efficient ways.

Table 4:29 - Hurontario & Burnhamthorpe to Downtown Toronto South Generalized Costs

Routing Description	Perceived Total Travel Time [min]	Fare	Generalized Cost	Total Cost Savings
Current	94.6	$5.70	$25.23	$2,772.16
Local Alt.	141.9	$6.25	$37.84	-

The regional rail route also provides a generalized cost savings as shown in Table 4:29. The no transfer rail route saves over $12.50 per trip over the three transfer local alternative – a difference that could be higher if the walk access time of the current trip was perceived to be less onerous than predicted. Regardless, the savings aggregated over the demand at the region-wide mode share still show a daily savings of $2800 to patrons.

4.7 Case Study Summary

Investigating particular OD pairs between activity centres has given evidence for the potential benefits that exist with greater integration between transit agencies. Travel times and generalized costs can be reduced, transfers can be eliminated or reduced, and network access can be improved. In addition, case studies of current trips using regional routes show that regional routes reduce travel time, transfers, and subsequently the generalized cost of travel. These findings correlate with intuition and provide tangible examples of the benefits of planning regionally.

These case studies also illustrate the wide influence of upgrading one link in the network. For example, the proposed LRT between Brampton and Mississauga would significantly influence trips not only along the corridor but also trips far from the corridor as in the McLaughlin Road to Dixie & 401 case. Similarly, a reduction of headway of one link of a trip can influence that trip's total travel time, transfer time, and departure time.

It is these multiplicative factors that also call for a region-wide fully developed network. In the case of McLaughlin Rd to Dixie & 401 and of Keele/Jane & Finch to Keele & 407 the lack or presence of network links along arterials that cross borders affect travel times in a significant way. If an arterial within a jurisdiction needs a transit route then arterials that connect jurisdictions need them also.

4.8 Results Summary

This chapter summarizes the results of applying the prescribed methods for 2006 GTHA data. The establishment of density and total thresholds for both employment and population helped identified activity centres while limiting them to a tractable amount. The thresholds are divided into three geographic areas based on the uniformity of the areas in regards to population and employment: Toronto, Mississauga, and Elsewhere. These definitions help identify activity centres that are dispersed throughout the region. Travel demand between activity centres are obtained for the peak morning period to help focus the analysis on high demand OD pairs that cross a transit-jurisdictional border. A visualization of the trip patterns in the region is completed for all trips between activity centres and for the exclusively cross-border trips.

To understand the current state of transit provisions for these OD pairs, Google Trip Planner is used to select the optimal transit routing based on a 9:00am arrival time on a weekday. Characteristics of the routing, especially the transfer details, are recorded to compare trips. OD pairs with the most onerous transfers as well as OD pairs with efficient inter-jurisdictional service are investigated further to quantify the benefits due to greater regional integration. Schedule adherence or reliability is discussed and its influence on trips with short transfer times is explored.

The last two research questions are answered using a travel time and generalized cost calculation for patrons and an operations cost calculation for transit agencies. Ridership predictions are not explicitly calculated due to the shortcomings of elasticity models and the network impacts of a focused change. The increase in patrons needed to offset the cost of service provision is calculated to provide a foundation for determining the value of the proposal or for decision-making.

Chapter 5: Conclusions

Urban areas around the world are growing rapidly causing strain on urban mobility. In response to this growth and to the ever-rising congestion faced by residents, greater attention is being paid to public transportation and its role in improving mobility. Alongside the mobility challenges is the shift from monocentric to polycentric cities; numerous clusters of dense population and/or employment have arisen dispersing travel flow throughout the region. This dispersed travel flow unifies the metropolitan area and results in, from a transportation perspective, it acting as a single entity. Unfortunately, in regions such as the GTHA, public transit agencies still plan and operate independently of one another.

This thesis seeks to identify the potential benefits to greater integration between transit agencies in the GTHA. Four research questions are created to approach this problem and are listed below:

1) Where are the high travel demand transit OD pairs in the GTHA that cross transit jurisdictional boundaries?

Origin-destination pairs where transit is competitive and possesses high demand are selected as connections between activity centres – clusters of dense population or employment. Total travel demand is obtained for these OD pairs using the 2006 TTS survey.

The analysis excluded any OD pairs that started and ended in the same transit jurisdiction and revealed the strongest cross border flows from York Region to downtown Toronto. Other important travel flows for the morning peak period are from other suburban jurisdictions such as Brampton, Durham Region, and Mississauga to downtown Toronto. For the OD pairs that did not connect to downtown Toronto the trips are shorter and between adjacent jurisdictions exclusively. For instance there are significant travel flows between Hamilton and Burlington, Brampton and Mississauga, and York Region and northern Toronto.

2) Of these high demand trips, which possess onerous transfers?

For every OD pair with significant travel demand that crossed a transit border, the Google Transit Trip Planner is used to determine the optimal transit routing for a 9:00am arrival time. The transfer details of the routing are paid especially close attention to establish the metrics that will identify an onerous transfer. Four metrics are used to try and capture the wide-range of influence a transfer can have on traveller behaviour. Total transfer time quantifies the total delay in the trip due to the transfers. A transfer penalty for each transfer of 10 minutes plus half the headway of the connecting route captures the average wait time plus the premium perception of that time. Transfer percentage is used to relativize the transfer component in relation to the rest of the trip; a 10-minute transfer is more acceptable on a 60-minute trip versus a 30-minute trip. Finally, the last metric used is a demand weighted transfer penalty that aggregates the impact of the transfer based on the demand for that OD pair. This helps quantify the total disutility a transfer may incur for a given OD pair.

Using these metrics the OD pairs are compared and their penalties relativized and averaged. OD pairs with high transfer penalties relative to other OD pairs are defined as possessing onerous transfers. The OD pairs with the three highest aggregate ranks are selected as case study OD pairs.

3) What are the (dis)benefits to patrons and agencies by providing greater inter-agency integration for these trips?

The three case study OD pairs were investigated further to propose alternative inter-jurisdictional routes that increase integration between agencies and reduce the transfer penalties. The benefits achieved through greater integration vary, but in general travel time, transfer time, and generalized cost are reduced for patrons.

On the agency side, a change in ridership could not be predicted accurately so the analysis was limited to an operations cost calculation on the provision of new service. However, this cost could determine how many riders are needed to justify the investment providing a good indication of whether the improvement would be successful. The ridership needed to break-even for some proposals seemed plausible to achieve whereas for others the proposal simply cost too much and therefore had unrealistic ridership demands.

4) What are the benefits to patrons achieved by existing well-integrated inter-jurisdictional service?

For patrons the current inter-jurisdictional service compared to the local-only options is always faster in total travel time and reduces the disutility of travel. In one of the instances the local option added one transfer and in another instance it added three transfers. The benefits to agencies that current regional service provides is difficult to quantify since it relies on a reliable ridership difference between current regional service and local-only service.

5.1 Limitations

5.1.1 Data

The data used in this study has its limitations in explaining the travel patterns of the entire GTHA. Firstly, the data is obtained through phone surveys of 5% of the population and then expanded, with calibration, to the rest of the population. This presents potential errors when the survey's output, travel demand, is used to sort OD pairs. Secondly, the TTS data is from 2006 and is therefore not current. Significant development in the GTHA has occurred in the past few years potentially altering the activity centre landscape. Furthermore, the Google trip planning data was obtained in 2013, incorporating different transit service than was available in 2006. During this time gap, there have been many interregional transit services added. We expect that these services have increased interregional demand in addition to demand growing naturally.

5.1.2 Methods

The process of selecting OD pairs that possess opportunities for greater integration could have been achieved using a transportation modelling approach instead of the activity centre method used in this thesis. First, the region-wide transportation model would be simulated and the trip costs and travel demand between all OD pairs would be retained. Next, relevant OD pairs that cross a transit jurisdictional border would be selected based on: a high number of trips made, the presence of an onerous transfer cost, and transit costs that are competitive with the private auto. The end result of selecting OD pairs for integration analysis would be the same as this thesis; however, the method chosen to get there would differ. The approach used in this thesis, using land use density as the starting point to determine relevant OD pairs, is a more tangible metric than trip costs from the transportation model. That is why the land use method is preferred.

Other limitations in the methods are less broad in scope and more specific. For instance, identifying activity centres through a density and total threshold method is limited by the number of thresholds defined and by the value of those thresholds. Using a smoothed density surface and measuring the difference between actual and predicted would be a much better, albeit more complex, method to identify activity centres.

Also, using land use density as a proxy for where transit competes well also presents some limitations. First, there are industries that do not cluster and these are not captured in the density analysis. Does transit unequally prioritize certain industries? Secondly, transit can still compete well in a low-density to high-density environment such as from suburbs to downtown. The analysis used does not capture these trips either.

Additionally, after identifying the activity centres, the centroids of each activity centre are used as inputs into Google Transit Trip Planner. Since the OD pairs are ranked based on how onerous their transfers are, the start and end points entered into the trip planner become critical. For instance, a centroid that is not along an artery may induce a long access time to the transit network or an additional transfer. This method is still preferred though because it averages the experience of departing or arriving at any of the locations within an activity centre.

The definition of onerous transfers in this thesis also is not a perfect description. Transfers come in many varieties and impact patrons in many ways. The presence of transfer infrastructure, for example at a train station, may cause much less of a penalty than having to walk across a busy arterial. Also, modes may have significant influence on the perceived impact of a transfer. Does a rider perceive the transfer between subway lines equally as onerous as the transfer between buses? Having a more accurate description of how riders perceive the different types of transfers would help prioritize investment and analysis.

This thesis also focuses narrowly on the network and infrastructure aspect of transit system integration and neglects the integration of fares and information and marketing. These factors play a large role in the overall integration of transit agencies and the ability for agencies to realize net ridership gains; however, they are outside the scope of this thesis.

5.2 Extensions/ Recommendations

Despite the limitations to this thesis there are many applications for its findings. The activity centre analysis of both employment and population centres provide planners with a map of where the density and clustering currently exists. This can inform planners to focus future development where nodes already exist, or to plan transportation infrastructure to serve the existing needs. The comparison of activity centres to mobility hubs is also beneficial to see how the existing clusters compare to the prioritized clusters. Mobility hubs are generally focused around public transit infrastructure so the activity centres that are not near a mobility hub may require additional attention for transit planners.

A focused approach cannot always provide wider applicability to a region but it can provide important insight. For example, OD pairs that are analyzed are connections between dense clusters of employment and population. If onerous transfers between agencies exist in this context, there are most certainly additional delays throughout the transit network in less dense settings. Also, the individual OD pairs selected for analysis reveal the advantages of greater integration: reduced travel time, generalized cost, and transfer penalties. If greater integration is promoted throughout the region, these are the potential outcomes to be achieved. Finally, two of the cases exhibited the network-wide benefits of upgrading one of the links in the network. If LRT is implemented in a given corridor, it does not impact only those patrons living or working near the corridor but also provides much wider impacts to those who may now be able use the corridor in their trip.

Finally, this thesis provides additional evidence to the plethora of research that concludes greater integration provides significant benefits to the transit usage in a metropolitan region. Politically there needs to be greater openness to cooperation between agencies for everything from route planning and scheduling to revenue collection and information delivery. The creation of Metrolinx by the province of Ontario is a great first step to providing more seamless transit delivery in the region. Giving Metrolinx more authority might be the next step required to improve integration even more.

5.3 Future Work

This research has some logical next steps that could provide interesting comparisons or more detailed information. Updating the activity centre analysis to the latest TTS data when it is released could provide a great comparison to track trends over time or to reveal the significant changes made in the GTHA. Answering the questions of which activity centres have grown, which have disappeared, and which have been newly identified could be very interesting.

Creating a detailed study to determine the effects of new regional infrastructure, like a Hurontario-Main LRT, could also provide some great insight into the advantage of greater integration. Additionally, since unnecessary transfers can be the result of poor integration, a greater understanding of how travellers perceive the various types of transfers would be very useful in identifying routes where integration is needed most.

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Appendix A Employment Activity Centres

	Activity Centres	Total Employment	Total Hectares	Employment Density [emp/ ha]	# of TAZ's	Mobility Hub Proximity
Toronto	DT Toronto - South	220215	603.49	364.90	29	Within
	DT Toronto - Centre	106507	312.33	341.01	11	Within
	DT Toronto North	101144	602.40	167.90	20	Within
	Yorkdale	27521	620.09	44.38	7	N/A
	Yonge & St. Clair	14653	171.75	85.31	3	N/A
	Yonge & Eglinton	32058	466.11	68.78	6	Within
	Don Mills & Eglinton	27142	687.49	39.48	5	Within
	Leslie & 401	18485	349.86	52.84	3	N/A
	Kipling & Bloor	25768	650.50	39.61	7	Within
	York University	37548	977.35	38.42	7	Within
	North York	33694	187.72	179.49	7	Within
	404 & Sheppard	15734	216.84	72.56	2	Within
	Scarborough Town Centre	45757	1174.72	38.95	14	Within
	Warden & Eglinton	16126	405.03	39.81	6	N/A
Elsewhere	Pickering Town Centre / OPG	25197	1287.90	19.56	9	Within
	Oshawa City Centre	16185	376.97	42.93	8	Within
	Oshawa Waterfront	16153	534.47	30.22	2	Within
	403 & QEW	21729	1099.18	19.77	6	N/A
	403 & 4th Line - Oakville	14561	738.99	19.70	4	N/A
	Ford Motor	18208	888.60	20.49	6	Within
	Burlington Mall	36590	1762.92	20.76	8	Adjacent
	Mohawk-HendersonHosp-LimeRidge	12146	589.04	20.62	8	Within
	Gray & Barton	15460	811.68	19.05	7	N/A
	McMaster	13029	611.60	21.30	4	N/A
	Downtown Hamilton	33475	576.60	58.06	17	Within
	Brampton City Centre	15750	585.33	26.91	8	Within
	Bramalea City Centre	25674	883.04	29.07	8	Within
	Daimler-Chrysler	28749	1274.38	22.56	8	N/A
	400 & 407 - West of 400	14449	669.24	21.59	8	N/A
	400 & Steeles - West of 400	24731	763.30	32.40	6	N/A
	400 & 407 - East of 400	28084	1046.90	26.83	9	Within
	Keele & 407	23028	1094.14	21.05	8	N/A
	404 & 407 - Richmond Hill	28422	778.55	36.51	8	Within
	404 & 407 - Markham	22619	751.60	30.10	9	N/A
	Woodbine & Steeles	55455	1332.89	41.61	14	N/A
	Newmarket	28391	1340.15	21.18	10	Within
Mississauga	Dixie & 401	48391	1296.52	37.32	7	Within
	Mississauga Rd & 401	22501	614.97	36.59	7	N/A
	Hurontario & 401	23944	525.40	45.57	6	N/A
	Square One	20048	136.12	147.28	11	Within
	AC TOTALS	1355321	29796.16	45.49	333	
	TOTALS	2824452	770351.15	3.67	2194	
	AC %	48.0%	3.9%		15.2%	

Appendix B Population Activity Centres

	Activity Centres	Total Population	Total Hectares	Population Density [Ppl/ ha]	# of TAZs	Mobility Hub Proximity
Toronto	Yonge St South	45272	311.44	145.37	12	Within
	Yonge St - North of College	52127	176.67	295.04	9	Within
	West Toronto - South of Dundas	66960	502.63	133.21	9	Within
	West Toronto - Dundas to Bloor	47138	469.56	100.40	9	Within
	Bloor St West	47277	387.78	121.92	7	Within
	Oakwood	45816	432.62	105.91	6	Within
	Yonge - St. Clair to Eglinton	38659	267.78	144.36	5	Within
	Thorncliffe Park	34083	344.77	98.87	2	Within
	Keele/ Jane & Finch	45065	539.59	83.52	5	Within
	North York Centre	36118	163.86	220.42	6	Within
Elsewhere	Westney Rd & Hwy 2 - Ajax	32764	732.84	44.71	6	N/A
	Hwy 400 & Major Mackenzie	33556	764.22	43.91	4	N/A
	Bathurst & Steeles	56559	1022.06	55.34	8	Adjacent
	Yonge & Carrville	63522	1408.58	45.10	12	Adjacent
	Warden & Steeles	30888	584.12	52.88	4	N/A
	McCowan & Steeles	75692	1250.13	60.55	6	N/A
	Kennedy & Williams	39550	811.46	48.74	7	Adjacent
	McLaughlin & Steeles	53023	1147.30	46.22	8	Within
	Bramalea	69219	1332.94	51.93	8	N/A
	McLaughlin Rd Brampton	63673	1256.03	50.69	8	N/A
	Upper Sherman	29211	691.55	42.24	7	N/A
	Centennial & Queenston	27088	644.96	42.00	7	N/A
	DT Hamilton	31032	404.12	76.79	13	Within
	East Hamilton	27846	518.92	53.66	9	Within
	DT Hamilton - East Side	28506	435.10	65.52	8	N/A
Mississauga	Goreway & Derry	20570	323.06	63.67	4	N/A
	Hurontario & Eglinton	27847	383.80	72.56	4	N/A
	Hurontario & Burnhamthorpe	27133	219.94	123.36	7	Adjacent
	Hurontario & Dundas	20677	327.79	63.08	7	Within
	AC TOTALS	1216871	17855.60	68.15	137	
	TOTALS	5764963	770351.15	7.48	2194	
	AC %	21.1%	2.3%		6.2%	

Appendix C Mobility Hubs & Activity Centres

Mobility Hub Name	Hub Type	Employment AC Proximity	Employment AC Names	Population AC Proximity	Population AC Names
Downtown Brampton	Anchor	Within	Brampton City Centre	Adjacent	Kennedy & Williams
Downtown Burlington	Anchor	-	-	-	-
Downtown Hamilton	Anchor	Within	Downtown Hamilton	Within	DT Hamilton
Downtown Milton	Anchor	-	-	-	-
Downtown Oshawa	Anchor	Within	Oshawa City Centre	-	-
Downtown Pickering	Anchor	Within	Pickering Town Centre / OPG	-	-
Etobicoke Centre	Anchor	Within	Kipling & Bloor	-	-
Markham Centre	Anchor	-	-	-	-
Midtown Oakville	Anchor	Within	Ford Motor	-	-
Mississauga City Centre	Anchor	Within	Square One	Adjacent	Hurontario-Burnhamthorp e
Newmarket Centre	Anchor	Within	Newmarket	-	-
North York Centre	Anchor	Within	North York	Within	North York Centre
Pearson Airport (Lbpia)	Anchor	-	-	-	-
Richmond Hill-Langstaff Gateway	Anchor	-	-	Adjacent	Yonge & Carrville
Scarborough Centre	Anchor	Within	Scarborough Town Centre	-	-
Union Station	Anchor	Within	DT Toronto - South	Adjacent	Yonge St South
Vaughan Corporate Centre	Anchor	Within	400 & 407 - East of 400	-	-
Yonge-Eglinton Centre	Anchor	Within	Yonge & Eglinton	Within	Yonge - St. Clair to Eglinton
Beaver Creek-Leslie/407	Gateway	Within	404 & 407 - Richmond Hill	-	-
Bramalea Go	Gateway	Within	Bramalea City Centre	-	-
Cooksville Go	Gateway	-	-	Within	Hurontario & Dundas
Don Mills-Eglinton	Gateway	Within	Don Mills & Eglinton	Within	Thorncliffe Park
Don Mills-Sheppard	Gateway	Within	404 & Sheppard	-	-
Don Mills-Steeles	Gateway	-	-	-	-
Dundas West Station	Gateway	-	-	Within	Bloor St West
Eglinton West Station	Gateway	-	-	Within	Oakwood
Eglinton-Weston	Gateway	-	-	-	-

Mobility Hub Name	Hub Type	Employment AC Proximity	Employment AC Names	Population AC Proximity	Population AC Names
Fairview Go	Gateway	Adjacent	Burlington Mall	-	-
Finch West-Keele	Gateway	Within	York University	Within	Keele/ Jane & Finch
Finch-Yonge	Gateway	Within	North York	Within	North York Centre
Hamilton-Liuna	Gateway	Within	Downtown Hamilton	Within	DT Hamilton - East Side
Hurontario-Steeles	Gateway	-	-	Within	McLaughlin & Steeles
Jane-Bloor	Gateway	-	-	-	-
Jane-Eglinton	Gateway	-	-	-	-
Jane-Finch	Gateway	-	-	Within	Keele/ Jane & Finch
Kennedy-Eglinton	Gateway	-	-	-	-
Main Station	Gateway	-	-	-	-
Mohawk-James	Gateway	Within	Mohawk-HendersonHosp-LimeRidge	-	-
Newmarket Go	Gateway	Within	Newmarket	-	-
Osgoode Station	Gateway	Within	DT Toronto - Centre, DT Toronto - South	Within	West Toronto - South of Dundas
Oshawa Go	Gateway	Within	Oshawa Waterfront	-	-
Pape Station	Gateway	-	-	-	-
Port Credit Go	Gateway	-	-	-	-
Queen Station	Gateway	Within	DT Toronto - Centre, DT Toronto - South	Within	Yonge St South
Renforth Gateway	Gateway	Within	Dixie & 401	-	-
Seaton	Gateway	-	-	-	-
Sheppard-Yonge Station	Gateway	Within	North York	Within	North York Centre
St. George Station	Gateway	Within	DT Toronto North	Within	West Toronto - Dundas to Bloor
Steeles Station	Gateway	-	-	Adjacent	Bathurst & Steeles
Yonge-Bloor	Gateway	Within	DT Toronto North	Within	Yonge St - North of College
York University/Steeles West	Gateway	Within	York University	Adjacent	Keele/ Jane & Finch

Appendix D Activity Centre TAZ Identification

	Employment Activity Centres	TAZ IDs														
Toronto	DT Toronto - South	15	16	25	26	27	28	31	32	33	34	35	36	54	55	56
		57	58	59	60	61	62	63	64	65	66	77	78	89	90	
	DT Toronto - Centre	23	37	38	50	51	52	53	67	68	75	76				
	DT Toronto North	21	22	39	40	41	42	43	44	45	46	47	48	49	69	70
		71	72	73	74	168										
	Yorkdale	179	180	157	156	159	158	160								
	Yonge & St. Clair	202	203	204												
	Yonge & Eglinton	201	209	210	211	216	212									
	Don Mills & Eglinton	224	243	223	220	242										
	Leslie & 401	231	236	465												
	Kipling & Bloor	312	313	307	311	310	309	300								
	York University	391	392	393	394	395	2118	2119								
	North York	442	443	444	448	450	452	454								
	404 & Sheppard	481	484													
	Scarborough Town Centre	490	491	580	604	492	489	488	605	487	500	582	612	614	486	
	Warden & Eglinton	525	527	530	529	526	508									
Elsewhere	Pickering Town Centre / OPG	1042	1041	1043	1051	1053	1056	1055	1094	1088						
	Oshawa City Centre	1196	1199	1205	1206	1208	1193	1195	1197							
	Oshawa Waterfront	1217	1155													
	403 & QEW	4024	3633	3869	3870	3662	3634									
	403 & 4th Line - Oakville	4008	4009	4003	4012											
	Ford Motor	4014	4015	4022	4027	4016	4030									
	Burlington Mall	4063	4068	4082	4069	4077	4081	4078	4062							
	Mohawk-HendersonHosp-LimeRidge	5087	5110	5135	5092	5097	5121	5142	5125							
	Gray & Barton	5126	5136	5128	5145	5153	5119	5099								
	McMaster	5198	5175	5196	5203											
	Downtown Hamilton	5159	5163	5168	5170	5171	5172	5181	5184	5186	5187	5188	5190	5192	5193	5194
		5195	5199													
	Brampton City Centre	3340	3342	3349	3351	3352	3492	3497	3499							
	Bramalea City Centre	3328	3338	3341	3343	3355	3357	3424	3504							
	Daimler-Chrysler	3421	3423	3339	3329	3331	3509	3335	3422							
	400 & 407 - West of 400	2061	2062	2063	2068	2069	2070	2071	2059							
	400 & Steeles - West of 400	386	387	388	2065	2066	2087									
	400 & 407 - East of 400	2081	2082	2083	2084	2085	2091	2093	2094	2096						
	Keele & 407	2092	2109	2111	2112	2113	2114	2116	2097							
	404 & 407 - Richmond	2253	2254	2271	2272	2369	2370	2270	2251							

	Hill															
	404 & 407 - Markham	2373	2374	2375	2385	2387	2388	2389	2405							
	Woodbine & Steeles	2371	2372	2393	2394	2395	2396	2397	2400	2401	473	589	2391	2398	2399	
	Newmarket	2606	2609	2612	2611	2620	2614	2613	2619	2623	2624					
Mississauga	Dixie & 401	3605	3702	3700	3701	3699	3609	3698								
	Mississauga Rd & 401	3821	3823	3618	3611	3612	3822	3818								
	Hurontario & 401	3608	3825	3831	3834	3835	3693									
	Square One	3815	3847	3848	3849	3850	3851	3852	3853	3854	3864	3866				
Population Activity Centres		TAZ IDs														
Toronto	Yonge St South	17	18	24	26	34	38	50	23	25	37	36	35			
	Yonge St - North of College	21	22	39	40	41	42	43	46	48						
	West Toronto - South of Dundas	67	76	90	91	68	109	110	99	108						
	West Toronto - Dundas to Bloor	72	92	93	100	102	71	96	97	101						
	Bloor St West	103	104	105	116	119	167	106								
	Oakwood	171	177	170	172	173	175									
	Yonge - St. Clair to Eglinton	202	204	209	210	211										
	Thorncliffe Park	222	223													
	Keele/ Jane & Finch	397	390	396	400	412										
	North York Centre	442	443	448	450	452	454									
Elsewhere	Westney Rd & Hwy 2 - Ajax	1068	1069	1075	1082	1076	1083									
	Hwy 400 & Major Mackenzie	2078	2100	2072	2055											
	Bathurst & Steeles	2120	2121	2122	2123	2124	2141	2142	431							
	Yonge & Carrville	2207	2244	2246	2248	2252	2251	2241	2206	2209	2213	2242	2257			
	Warden & Steeles	2398	2397	590	591											
	McCowan & Steeles	2425	2426	2427	2428	608	600									
	Kennedy & Williams	3360	3361	3370	3371	3377	3496	3520								
	McLaughlin & Steeles	3324	3366	3367	3488	3493	3495	3494	3368							
	Bramalea	3373	3418	3419	3363	3355	3357	3358	3364							
	McLaughlin Rd Brampton	3346	3369	3375	3436	3458	3459	3482	3486							
	Upper Sherman	5110	5130	5135	5143	5082	5074	5068								
	Centennial & Queenston	5118	5123	5099	5113	5106	5096	5090								
	DT Hamilton	5159	5163	5167	5168	5171	5172	5174	5179	5180	5187	5195	5200	5204		
	East Hamilton	5149	5150	5154	5157	5161	5162	5165	5176	5183						
	DT Hamilton - East Side	5164	5170	5181	5186	5188	5194	5199	5155							
Mississauga	Goreway & Derry	3630	3829	3830	3629											
	Hurontario & Eglinton	3841	3855	3689	3606											
	Hurontario & Burnhamthorpe	3672	3723	3724	3863	3864	3865	3866								
	Hurontario & Dundas	3657	3666	3867	3872	3862	3667	3656								

Appendix E Code to Remove Intra-Jurisdictional OD Pairs

```
Sub CrossBorder()

Dim r1, r2, r3, r4, c1, c2, c3, c4, k, Col1, Col2, tv, x, y, w, Z As Integer
Dim trip, ac1, ac2 As String

r1 = 4
r2 = 43
c1 = 4
c2 = 72

r3 = 2
r4 = 26
c3 = 1
c4 = 8

k = 2

For x = r1 To r2:
  For y = c1 To c2:
    Sheets("Trip Matrix ACs").Select
    ac1 = ActiveSheet.Cells(2, y)
    ac2 = ActiveSheet.Cells(x, 2)
    tv = ActiveSheet.Cells(x, y)
    Sheets("ACs by Transit System").Select
    Col1 = 0
    Col2 = 0

    For Z = r3 To r4:
      For w = c3 To c4:
        If ActiveSheet.Cells(Z, w) = ac1 Then
          Col1 = w
          Exit For
        End If
      Next w
      If Col1 <> 0 Then Exit For
    Next Z

    For Z = r3 To r4:
      For w = c3 To c4:
        If ActiveSheet.Cells(Z, w) = ac2 Then
          Col2 = w
```

```
                Exit For
            End If
        Next w
        If Col2 <> 0 Then Exit For
    Next Z

    If Col1 <> Col2 Then
        trip = ac1 & " - " & ac2
        ActiveSheet.Cells(k, 10) = trip
        ActiveSheet.Cells(k, 11) = tv
        k = k + 1
    End If
  Next y
Next x


End Sub
```

Appendix F Code to Convert Matrix to List

```
Sub MatrixToColumn()

Dim r1, r2, c1, c2, k As Integer
Dim trip As String

r1 = 4
r2 = 43
c1 = 33
c2 = 72

k = r2 + 2

For x = r1 To r2:
   For y = c1 To c2:
      trip = ActiveSheet.Cells(2, y) & " - " & ActiveSheet.Cells(x, 2)
      ActiveSheet.Cells(k, 2) = trip
      ActiveSheet.Cells(k, 4) = ActiveSheet.Cells(x, y)
      k = k + 1
      Next y
   Next x
End Sub
```

Appendix G Trip Matrix

Origin Activity Centre	Destination Activity Centre	1 DT Toronto - South	2 DT Toronto - Centre	3 DT Toronto North	4 Yorkdale	5 Yonge & St. Clair	6 Yonge & Eglinton	7 Don Mills & Eglinton	8 Leslie & 401	9 Kipling & Bloor	10 York University	11 North York	12 404 & Sheppard	13 Scarborough Town Centre	14 Warden & Eglinton	15 Pickering Town Centre / OPG	16 Oshawa City Centre	17 Oshawa Waterfront	18 403 & QEW	19 403 & 4th Line - Oakville	20 Ford Motor
1	Yonge St South	5216	4047	3442	130	109	430	245	156	66	310	120	66	309	52	24	0	0	30	24	66
2	Yonge St - North of College	4537	3043	6862	341	376	581	247	219	154	361	296	46	168	113	0	0	20	38	0	0
3	West Toronto - South of Dundas	5582	3596	2917	430	289	415	81	160	343	343	179	138	149	74	42	0	0	35	0	17
4	West Toronto - Dundas to Bloor	3534	2305	4419	371	320	496	158	138	131	406	227	20	157	66	0	0	0	18	18	18
5	Bloor St West	2065	1818	2116	407	215	286	81	0	363	337	248	49	82	129	0	0	0	84	0	59
6	Oakwood	2184	1655	1796	599	362	770	145	125	149	623	253	58	72	54	22	18	0	16	34	0
7	Yonge - St. Clair to Eglinton	3303	1963	2372	182	795	2838	432	224	104	209	437	42	106	128	59	23	0	0	0	0
8	Thorncliffe Park	929	739	855	95	149	334	3764	247	129	72	175	216	172	254	25	0	0	0	0	12
9	Keele/ Jane & Finch	668	538	321	729	81	143	61	68	85	1751	365	0	57	0	42	21	0	0	0	0
10	North York Centre	2031	1659	1522	273	199	436	236	141	66	762	2207	247	166	38	24	224	185	0	0	0
11	Westney Rd & Hwy 2 - Ajax	1001	550	243	44	70	89	196	66	0	91	203	89	385	339	1394					
12	Hwy 400 & Major Mackenzie	714	184	308	286	0	41	81	81	62	941	262	41	20	21	21	0	0	62	0	20
13	Bathurst & Steeles	1252	1006	1043	529	167	262	155	185	74	2123	765	132	153	84	21	35	21	43	0	0
14	Yonge & Carrville	1955	1131	1125	161	73	336	211	262	80	760	732	160	275	21	38	0	0	0	19	20
15	Warden & Steeles	924	620	489	91	35	104	129	226	50	292	425	189	563	194	72	0	0	0	0	16
16	McCowan & Steeles	2018	1058	909	202	82	134	388	356	21	804	539	113	1847	381	75	20	0	21	0	19
17	Kennedy & Williams	472	441	152	23	23	87	45	23	65	152	63	0	41	21	0	0	21	59	110	0
18	McLaughlin & Steeles	576	233	129	106	45	64	17	44	81	123	88	21				0	0	87	22	66
19	Bramalea	862	285	298	141	39	0	21	19	132	367	117	0	44	40	0	22	0	79	27	46
20	McLaughlin Rd Brampton	921	349	287	111	43	43	108	67	153	240	43	43	43	0	0	0	0	154	21	21
21	Upper Sherman	42	22	40	0	0	0	0	0	20	0	0	0				0	0	22	104	22
22	Centennial & Queenston	78	0	60	0	0	22	0	0	0	0	0	0	21	0	0	0	0	0	140	38
23	DT Hamilton	141	80	117	0	20	0	25	0	0	0	0	0				0	0	65	106	44
24	East Hamilton						0	0	0	21	24	0	0				0	0	22	181	86
25	DT Hamilton - East Side	25	87	25	0	0	0	23	0	0	0	0	17	23	20	23	0	0	148	47	45
26	Goreway & Derry	166	147	39	68	0	40	20	0	66	226	86	23	0	21	21	0	0	20	20	0
27	Hurontario & Eglinton	440	515	322	60	19	21	75	0	190	101	100	0	21	66	0	0	0	165	79	19
28	Hurontario & Burnhamthorpe	666	296	280	24	44	48	0	0	114	92	44	0				0	0	190	0	94
29	Hurontario & Dundas	499	139	200	40	0	0	0	43	217	56	37	0	0	0	19	0	0	141	40	45

Origin Activity Centre	Destination Activity Centre	21 Burlington Mall	22 Mohawk-HendersonHosp-LimeRidge	23 Gray & Barton	24 McMaster	25 Downtown Hamilton	26 Brampton City Centre	27 Bramalea City Centre	28 Daimler-Chrysler	29 400 & 407 - West of 400	30 400 & Steeles - West of 400	31 400 & 407 - East of 400	32 Keele & 407	33 404 & 407 - Richmond Hill	34 404 & 407 - Markham	35 Woodbine & Steeles	36 Newmarket	37 Dixie & 401	38 Mississauga Rd & 401	39 Hurontario & 401	40 Square One
1	Yonge St South	15	0	0	0	19	0	22	22	0	20	61	0	125	64	339	0	132	38	57	24
2	Yonge St - North of College	0	18	0	20	0	0	23	0	20	0	45	17	212	45	152	0	98	52	38	37
3	West Toronto - South of Dundas				0	22	39	17	17	18	39	82	99	78	94	105	0	264	98	64	64
4	West Toronto - Dundas to Bloor				22	0	19	22	19	21	107	42	59	23	99	84	21	184	21	38	20
5	Bloor St West	23	0	0	0	0	23	81	40	18	46	89	82	82	49	105	24	41	84	21	0
6	Oakwood	16	0	0				18	18	122	86	141	88	16	95	137	0	145	18	65	53
7	Yonge - St. Clair to Eglinton	20	0	0				21	19	23	80	66	20	254	88	290	0	152	0	20	0
8	Thorncliffe Park							12	66	0	21	0	117	95	32	194	0	12	51	19	19
9	Keele/ Jane & Finch				0	0	47	21	133	141	345	703	373	75	0	111	26	105	26	42	73
10	North York Centre				22	0	0	21	24	43	252	59	42	240	180	318	38	80	61	0	59
11	Westney Rd & Hwy 2 - Ajax										89	64	0	150	174	318	89	64	23	0	0
12	Hwy 400 & Major Mackenzie							0	104	674	492	693	649	122	143	162	81	121	61	81	0
13	Bathurst & Steeles	85	0	0	36	0	58	22	74	177	262	391	629	312	177	411	18	145	41	22	0
14	Yonge & Carrville							78	61	194	279	466	457	1691	682	1113	243	93	17	40	0
15	Warden & Steeles	21	0	0	16	0	0	16	34	55	101	162	56	384	293	2487	69	117	36	0	34
16	McCowan & Steeles	20	0	0	0	0	39	40	0	20	60	55	77	649	534	2799	39	135	36	61	20
17	Kennedy & Williams	0	23	0	0	42	1083	1120	1174	23	188	83	68	23	0	80	0	421	212	371	108
18	McLaughlin & Steeles	23	42	0	0	17	1252	977	689	105	150	87	142	0	0	66	0	564	364	418	154
19	Bramalea	100	0	0	21	0	1376	2730	3454	157	220	204	140	22	81	82	0	765	282	494	271
20	McLaughlin Rd Brampton	88	0	0	0	22	1366	990	839	44	198	156	134	65	22	43	64	869	718	613	262
21	Upper Sherman	658	1853	353	351	1365	0											22	0	21	22
22	Centennial & Queenston	617	392	1744	227	690	0											76	21	0	21
23	DT Hamilton	478	963	229	1965	4259	20	0	20	0								20	0	41	46
24	East Hamilton	409	308	874	439	1819	0	22	22	0	0	0	0	22				0	21	0	0
25	DT Hamilton - East Side	399	483	281	1045	4264	0				0	0	25	0				25	0	0	0
26	Goreway & Derry				0	0	63	207	161	23	188	86	23	0	0	66	0	169	20	43	87
27	Hurontario & Eglinton	81	0	0	39	21	41	60	0	40	81	21	116	62	0	59	0	879	318	701	369
28	Hurontario & Burnhamthorpe	92	0	0	24	24	44	90	137	22	48	22	48	46	22	22	0	549	114	510	868
29	Hurontario & Dundas	19	0	0	21	0	59	80	86	0	19	63	0	0	37	40	0	405	178	324	383

Origin Activity Centre / Destination Activity Centre

#	Origin \ Destination	1 DT Toronto - South	2 DT Toronto - Centre	3 DT Toronto North	4 Yorkdale	5 Yonge & St. Clair	6 Yonge & Eglinton	7 Don Mills & Eglinton	8 Leslie & 401	9 Kipling & Bloor	10 York University	11 North York	12 404 & Sheppard	13 Scarborough Town Centre	14 Warden & Eglinton	15 Pickering Town Centre / OPG	16 Oshawa City Centre	17 Oshawa Waterfront	18 403 & QEW	19 403 & 4th Line - Oakville	20 Ford Motor
1	DT Toronto - South		3435	3267	129	252	579	396	144	125	315	317	84	307	115	85	0	0	123	0	124
2	DT Toronto - Centre	3490		3103	125	94	389	146	191	143	224	118	67	97	17	24	24	0	0	24	24
3	DT Toronto North	7365	5006		495	801	943	404	290	253	694	491	66	260	148	0	0	20	54	0	0
4	Yorkdale	305	335	372		0	20	55	16	34	194	66	0	0	0	18					
5	Yonge & St. Clair	1447	1045	1015	20		607	61	59	80	20	51	0	56	0	20					
6	Yonge & Eglinton	4175	1996	2917	263	737		709	329	75	289	551	141	86	215	57	23	0	0	0	0
7	Don Mills & Eglinton	957	680	812	82	156	424		332	96	59	200	169	193	293	45	0	0	0	18	0
8	Leslie & 401	114	110	46	0	0	55	172		0	39	36	190	30	0	0					
9	Kipling & Bloor	791	404	318	105	100	112	50	69		39	164	67	25	75	0	0	25	40	0	17
10	York University	178	82	54	39	0	22	0	50	20		21	44	79	0	0	0	17	0	0	0
11	North York	2156	1729	1580	329	199	474	275	195	66	866		284	166	38	56					
12	404 & Sheppard	271	142	147	42	42	188	59	142	82	84	126		157	0	21	0	21	0	0	0
13	Scarborough Town Centre	823	648	366	57	43	81	75	205	92	183	85	305		273	89	21	22	17	0	0
14	Warden & Eglinton	138	20	43	0	0	14	0	0	0	0	39	19	61		0	0	0	20	0	0
15	Pickering Town Centre / OPG	167	114	37	21	0	0	47	0	0	0	41	48	48	0		92	44	0	0	0
16	Oshawa City Centre	193	61	19	0	0	0	0	0	0	0	24	22	67	0	118		180	0	0	0
17	Oshawa Waterfront	36	0	0	0	0	0	24	25	0	0	17	0	0	0	59	120		0	0	20
18	403 & QEW	192	110	77	19	0	0	0	0	57	58	52	0				0	0		33	69
19	403 & 4th Line - Oakville	38	54	0	0	0	21	0	21	0	0	0	0				0	0	133		214
20	Ford Motor	375	32	98	31	0	0	16	0	0	0	17	0				0	0	200	360	
21	Burlington Mall	226	122	29	0	0	11	16	18	19	0	34	0				0	18	181	235	129
22	Mohawk-HendersonHosp-LimeRidge	18	0	20	0	0	21	0	0	0	21	0	0				0	0	0	101	0
23	Gray & Barton	22	0	22	0	0											0	0	0	24	0
24	McMaster	18	0	0	0	0															
25	Downtown Hamilton	103	100	83	0	20	0	49	0	0	20	0	17				0	0	127	88	25
26	Brampton City Centre	126	0	22	0	0	0	0	0	0	57	22	0				0	0	18	0	0
27	Bramalea City Centre	49	46	120	0	0	0	0	0	53	102	0	0	22	0	0	22	0	0	27	43
28	Daimler-Chrysler	19	0	19	19	0	0	0	19	20	62	0	0	45	0	0					
29	400 & 407 - West of 400	165	184	39	62	20	21	20	21	17	226	61	0	0	20	0					
30	400 & Steeles - West of 400	16	0	54	19	21	0	0	0	36	59	0	0	21	0	0					
31	400 & 407 - East of 400	38	0	0	0	0	21	20	0	21	38	20	0	0	24	0	0	0	0	0	22
32	Keele & 407	129	63	0	45	0	23	0	0	0	81	23	19				0	18	0	19	0
33	404 & 407 - Richmond Hill	115	97	81	78	39	19	39	0	19	99	58	153	40	0	19	0	0	0	19	20
34	404 & 407 - Markham	150	64	20	0	0	0	21	21	0	22	22	0	178	20	0					
35	Woodbine & Steeles	371	166	164	57	20	0	101	94	18	105	127	53	242	123	0					
36	Newmarket	223	140	162	38	21	21	62	77	37	135	127	97	83	21	19	39	0	0	19	0
37	Dixie & 401	96	0	46	17	0	0	22	0	43	0	40	0	63	0	0	0	0	0	61	22
38	Mississauga Rd & 401	64	0	0	16	0	0	0	0	43	0	24	19				0	0	125	0	21
39	Hurontario & 401	21	0	0	16	0											0	0	24	0	0
40	Square One	185	103	88	0	0	24	0	0	49	0	0	22	20	0	0	0	0	72	38	45

#	Origin \ Destination	21 Burlington Mall	22 Mohawk-HendersonHosp-LimeRidge	23 Gray & Barton	24 McMaster	25 Downtown Hamilton	26 Brampton City Centre	27 Bramalea City Centre	28 Daimler-Chrysler	29 400 & 407 - West of 400	30 400 & Steeles - West of 400	31 400 & 407 - East of 400	32 Keele & 407	33 404 & 407 - Richmond Hill	34 404 & 407 - Markham	35 Woodbine & Steeles	36 Newmarket	37 Dixie & 401	38 Mississauga Rd & 401	39 Hurontario & 401	40 Square One
1	DT Toronto - South	55	0	0	0	44	21	46	22	20	37	143	42	108	58	269	0	287	146	77	153
2	DT Toronto - Centre				0	40	0	0	0	36	0	22	65	109	79	126	0	165	0	85	24
3	DT Toronto North	0	34	16	20	0	16	23	0	52	42	103	54	212	85	240	21	140	74	58	77
4	Yorkdale							0	19	68	37	143	72	18	0	53	0	97	0	38	0
5	Yonge & St. Clair	35	0	0				21	15	0	0	0	16	59	20	95	16	20	0	0	0
6	Yonge & Eglinton	37	0	0	0	0	14	0	32	23	107	66	70	212	87	300	18	159	0	20	0
7	Don Mills & Eglinton							18	45	0	54	0	92	162	38	220	0	0	69	19	19
8	Leslie & 401							0	0	17	0	25	0	0	0	29	0				
9	Kipling & Bloor	21	0	0				91	20	0	57	21	106	22	0	14	0	273	63	84	153
10	York University							17	26	75	267	100	60	276	0	20	0	58	42	0	0
11	North York				22	0	0	21	24	43	21	0	0	140	238	468	38	97	61	0	59
12	404 & Sheppard							0	21	42					42	278	0	21	0	0	0
13	Scarborough Town Centre							41	50	38	44	120	46	323	103	418	0	44	41	21	0
14	Warden & Eglinton										16	0	0	0	0	36	0	0	16	0	0
15	Pickering Town Centre / OPG										25	0	0	0	0	67	0				
16	Oshawa City Centre														20	91	0	23	0	0	0
17	Oshawa Waterfront																				
18	403 & QEW	109	0	0	0	0	75	19	41	0	0	0	0	19				90	93	77	133
19	403 & 4th Line - Oakville	21	21	0	17	20	0	20	0	0	17	0	0	15				40	17	41	0
20	Ford Motor	101	20	0	0	35	0	17	0	0								48	0	33	31
21	Burlington Mall		75	33	78	153	0	70	0	0	0	0	17	0	0	11	0	128	29	0	51
22	Mohawk-HendersonHosp-LimeRidge	330		242	382	1239	0											0	0	21	0
23	Gray & Barton	39	87		64	213	0	17	0	0	0	0	0	16							
24	McMaster	65	258	82		735	0	16	0	0								21	0	18	0
25	Downtown Hamilton	626	1088	295	1416		0	0	20	0	0	0	25	0				25	0	0	25
26	Brampton City Centre				0	0		168	42	0	56	43	21	0				108	0	66	21
27	Bramalea City Centre	22	0	0	0	0	260		737	0	24	86	22	0	19	0	0	187	66	113	27
28	Daimler-Chrysler	0	0	18	0	0	108	158		19	40	92	22	0	0	37	0	38	21	24	0
29	400 & 407 - West of 400							52	20		65	231	140	0	40	19	0	21	21	0	0
30	400 & Steeles - West of 400				0	0	36	20	39	99		56	61	0				0	0	52	0
31	400 & 407 - East of 400							0	0	59	21		76	21	35	0	20	38	0	40	0
32	Keele & 407							18	0	20	23	148		44	0	23	0				
33	404 & 407 - Richmond Hill							0	0	39	0	58	39		121	259	0	0	0	19	0
34	404 & 407 - Markham							0	18	0	0	19	21	148		206	0	20	36	22	0
35	Woodbine & Steeles	18	0	0	0	0	22	0	38	75	35	55	39	197	132		38	0	18	0	18
36	Newmarket							36	0	0	57	143	127	255	286	257					
37	Dixie & 401	19	0	0	0	0	62	96	20	24	20	26	0	14					40	89	60
38	Mississauga Rd & 401	41	0	0				17	58	0	24	16	0	0	60	21	0	169		76	59
39	Hurontario & 401	21	0	0	0	0	21	0	39	22	0	0	38	0	0	21	21	106	38		74
40	Square One	24	0	0	40	41	0	0	45	0	0	0	24	0				330	67	234	

Appendix H Transfer Metrics

Origin Activity Centre - Destination Activity Centre	Trip Volume [6-9am]	Transit Routing	Travel Time [min]	Total Transfer Time [min]	Transfer Penalty [min]	Demand Weighted Transfer [h]	Transfer % of Travel Time	Average Penalty
Centennial & Queenston - Burlington Mall	617	HSR Route 2 to GO Route 12 to BurT Route 81	82	24	60	40.72	29.3%	91%
McLaughlin Rd Brampton - Dixie & 401	869	BT Route 4 to BT Route 502 to MT Route 35	80	24	28.25	57.35	30.0%	86%
Kennedy & Williams - DT Toronto - Centre	441	BT Route 29 to BT Route 502 to Brampton GO Station to TTC Subway	90	25	48.25	30.32	27.8%	81%
Upper Sherman - Burlington Mall	658	HSR Route 24 to HSR Route 5 to BurT Route 101 to BurT Route 81	82	17	41.25	30.76	20.7%	65%
Westney Rd & Hwy 2 - Ajax - DT Toronto - Centre	550	DRT Route 915 to Ajax GO Station to TTC YUS Subway	65	18	28.75	27.23	27.7%	65%
McLaughlin Rd Brampton - Mississauga Rd & 401	718	BT Route 4 to BT Route 51 to MT 82	40	12	41	23.69	30.0%	64%
Kennedy & Williams - Dixie & 401	421	BT Route 7 to MT Route 42 to MT Route 5	64	17	32.25	19.68	26.6%	61%
Kennedy & Williams - DT Toronto - South	472	BT Route 29 to BT Route 502 to Brampton GO Station	88	18	37	23.36	20.5%	61%
Hwy 400 & Major Mackenzie - DT Toronto - South	714	YRT Route 4A to Maple GO Station	72	16	25	31.42	22.2%	59%
McLaughlin Rd Brampton - DT Toronto - South	921	BT Route 5 to Mount Pleasant GO Station	87	15	25	37.99	17.2%	56%
Hwy 400 & Major Mackenzie - York University	941	YRT Route 4A to YRT Route 20	52	13	20	33.64	25.0%	57%
McCowan & Steeles - DT Toronto - South	2018	TTC Route 53 to Milliken GO Station	70	9	25	49.95	12.9%	52%

Origin Activity Centre - Destination Activity Centre	Trip Volume [6-9am]	Transit Routing	Travel Time [min]	Total Transfer Time [min]	Transfer Penalty [min]	Demand Weighted Transfer [h]	Transfer % of Travel Time	Average Penalty
Westney Rd & Hwy 2 - Ajax - Scarborough Town Centre	385	DRT 915 to GO Bus #95	58	15	20	15.88	25.9%	52%
Bramalea - DT Toronto - South	862	BT Route 15 to Bramalea GO Station	85	13	20	30.82	15.3%	48%
Bramalea - Dixie & 401	765	BT Route 15 to BT Route 18 to MT Route 5	52	10	28	21.04	19.2%	47%
Scarborough Town Centre - Woodbine & Steeles	418	TTC Route 129A (Extra Fare of $0.35 required north of Steeles) to YRT Route 2A	55	12	25	13.79	21.8%	47%
Westney Rd & Hwy 2 - Ajax - DT Toronto - South	1001	DRT Route 915 to Ajax GO Station	67	11	17.5	30.28	16.4%	45%
McCowan & Steeles - DT Toronto North	909	TTC Route 129 to Scarborough Station - TTC SRT to BLR Subway	78	11	23.5	27.50	14.1%	45%
Hurontario & Eglinton - DT Toronto - South	440	MT Route 10 to MT Route 103 to Port Credit GO Station	91	12	36	14.52	13.2%	44%
McLaughlin & Steeles - DT Toronto - South	576	BT Route 511 to Bramalea GO Station	87	13	20	20.59	14.9%	43%
Bathurst & Steeles - North York	765	YRT Route 5 to Finch Station - TTC Subway	30	8	11.25	16.83	26.7%	42%
Ford Motor - DT Toronto - South	375	OT Route 4 to Oakville GO Station	70	13	15	13.41	18.6%	41%
DT Hamilton - East Side - Burlington Mall	399	HSR Route 1 to BurT Route 101 to BurT Route 81	62	8	42.5	8.78	12.9%	40%
Yonge & Carrville - North York	732	YRT Viva Blue to Finch Station - TTC Subway	49	9	11.25	18.12	18.4%	37%
Bathurst & Steeles - DT Toronto - South	1252	YRT Route 5 to Finch Station - TTC Subway	55	8	11.25	27.54	14.5%	37%
McCowan & Steeles - Don Mills & Eglinton	388	TTC Route 129 (Extra Fare) to Scarborough Station - SRT to TTC Route 34	70	10	24.5	10.67	14.3%	37%

Origin Activity Centre - Destination Activity Centre	Trip Volume [6-9am]	Transit Routing	Travel Time [min]	Total Transfer Time [min]	Transfer Penalty [min]	Demand Weighted Transfer [h]	Transfer % of Travel Time	Average Penalty
Hurontario & Eglinton - DT Toronto - Centre	515	MT Route 35 to TTC BLR Subway to TTC YUS Subway	96	11	22.5	15.58	11.5%	37%
Yonge & Carrville - DT Toronto - South	1955	YRT Viva Blue to Finch Station - TTC Subway	71	7	11.25	37.63	9.9%	36%
Bathurst & Steeles - DT Toronto North	1043	YRT Route 5 to Finch Station - TTC Subway	53	8	11.25	22.95	15.1%	35%
Bathurst & Steeles - DT Toronto - Centre	1006	YRT Route 5 to Finch Station - TTC Subway	57	8	11.25	22.13	14.0%	34%
East Hamilton - Burlington Mall	409	HSR Route 2 to BurT Route 101 to BurT Route 81	73	6	42.5	6.75	8.2%	33%
North York - Woodbine & Steeles	468	TTC Route 97 to YRT Route 2	42	7	20	9.01	16.7%	33%
Warden & Steeles - Scarborough Town Centre	563	TTC Route 17 to TTC Route 199	36	7	11.5	10.84	19.4%	33%
Warden & Steeles - DT Toronto - South	924	TTC Route 53 to Milliken GO Station	53	6	25	15.25	11.3%	32%
McLaughlin & Steeles - Mississauga Rd & 401	364	BT Route 51 to MT Route 82	33	5	25	5.01	15.2%	30%
Keele/ Jane & Finch - Keele & 407	373	TTC Route 36 to TTC Route 107 (Extra Fare Req'd North of Steeles)	43	7	14.5	7.18	16.3%	30%
Yonge & Carrville - DT Toronto North	1125	YRT Viva Blue to Finch Station - TTC Subway	69	7	11.25	21.66	10.1%	30%
McLaughlin Rd Brampton - Hurontario & 401	613	BT Route 5 to BT Route 502	51	7	14.5	11.80	13.7%	30%
McCowan & Steeles - York University	804	TTC Route 53 to TTC Route 60	79	8	12.5	17.69	10.1%	29%
Yonge & Carrville - York University	760	YRT Viva Blue to Richmond Hill Centre GO Terminal - GO Bus	42	6	14.25	12.54	14.3%	29%
Yonge & Carrville - DT Toronto - Centre	1131	YRT Viva Blue to Finch Station - TTC Subway	73	7	11.25	21.77	9.6%	29%

Origin Activity Centre - Destination Activity Centre	Trip Volume [6-9am]	Transit Routing	Travel Time [min]	Total Transfer Time [min]	Transfer Penalty [min]	Demand Weighted Transfer [h]	Transfer % of Travel Time	Average Penalty
Bathurst & Steeles - Yorkdale	529	TTC Route 160 (Extra Fare required north of Steeles) to TTC Route 29	62	8	12.5	11.64	12.9%	29%
Bramalea - Hurontario & 401	494	BT Route 29 to BT Route 502	57	7	14.5	9.51	12.3%	27%
Kennedy & Williams - Hurontario & 401	371	BT Route 7 to BT Route 502	44	6	14.5	6.12	13.6%	26%
Woodbine & Steeles - DT Toronto - South	371	YRT Route 2 to Finch Station - TTC Subway	74	8	11.25	8.16	10.8%	25%
McCowan & Steeles - North York	539	TTC Route 53 to Finch Station - TTC Subway	66	7	11.25	10.38	10.6%	25%
Bramalea - York University	367	BT Route 15 to Bramalea GO Station - GO Bus	53	6	15	6.06	11.3%	24%
Warden & Steeles - North York	425	TTC Route 53 to Finch Station - TTC Subway	49	6	11.25	7.01	12.2%	24%
McCowan & Steeles - DT Toronto - Centre	1058	TTC Route 53 to Finch Station - TTC Subway	93	6	11.25	17.46	6.5%	24%
McCowan & Steeles - Warden & Eglinton	381	TTC Route 53 to TTC Route 68	63	6	12.5	6.29	9.5%	22%
Warden & Steeles - DT Toronto - Centre	620	TTC Route 53 to Finch Station - TTC Subway	76	6	11.25	10.23	7.9%	22%
Warden & Steeles - DT Toronto North	489	TTC Route 17 to Warden Station - TTC BLR Subway	69	6	11.25	8.07	8.7%	21%
McLaughlin & Steeles - Dixie & 401	564	MT Route 66 to MT Route 35	58	5	13.75	7.76	8.6%	21%
Downtown Hamilton - Burlington Mall	626	BurT Route 101 to BurT Route 81	55	0	25	0.00	0.0%	10%
DT Hamilton - Burlington Mall	478	BurT Route 101 to BurT Route 81	54	0	25	0.00	0.0%	10%
Bathurst & Steeles - York University	2123	YRT Route 3	16	-	-	-	-	-

Origin Activity Centre - Destination Activity Centre	Trip Volume [6-9am]	Transit Routing	Travel Time [min]	Total Transfer Time [min]	Transfer Penalty [min]	Demand Weighted Transfer [h]	Transfer % of Travel Time	Average Penalty
McCowan & Steeles - Scarborough Town Centre	1847	TTC Route 129A	38	-	-	-	-	-
Keele/ Jane & Finch - 400 & 407 - East of 400	703	TTC Route 35 (Extra Fare Req'd North of Steeles)	32	-	-	-	-	-
Hurontario & Burnhamthorpe - DT Toronto - South	666	Walk to Cooksville GO Station	61	-	-	-	-	-
Hurontario & Dundas - DT Toronto - South	499	Cooksville GO Station	60	-	-	-	-	-
McLaughlin & Steeles - Hurontario & 401	418	BT Route 502	34	-	-	-	-	-

Appendix I Generalized Cost Calculations

Transfer Penalty VOT	10	Relative Valuation	Access	Route 1	Transfer 1	Route 2	Transfer 2	Route 3	Transfer 3	Route 4	Egress	Total Minutes	Fare	Gen Cost
	$ 16.00		2.2	1	2.5	1	2.5	1	2.5	1	2.2			
McLaughlin Rd Brampton - Dixie & 401	Actual Mins	Current	1	18	12	19	12	12			6	80		
		Proposed 1	1	38	10	16					6	71		
		Proposed 2	1	18	2	18	3	12			6	60		
	Perceived Mins	Current	2.2	18	40	19	40	12	0	0	13.2	144.4	$ 3.50	$ 42.01
		Mavis Ext.	2.2	38	35	16	0	0	0	0	13.2	104.4	$ 3.50	$ 31.34
		LRT	2.2	18	15	18	17.5	12	0	0	13.2	95.9	$ 3.50	$ 29.07
Centennial & Queenston - Burlington Mall	Actual Mins	Current	16	8	9	20	17	13			1	84		
		Proposed 1	16	8	9	20	1	13			1	68		
		Proposed 2	5	9	11	20	17	13			1	76		
	Perceived Mins	Current	35.2	8	32.5	20	52.5	13	0	0	2.2	163.4	$ 8.00	$ 51.57
		Red. Headway	35.2	8	32.5	20	12.5	13	0	0	2.2	123.4	$ 8.00	$ 40.91
		Imp. Coord.	11	9	37.5	20	52.5	13	0	0	2.2	145.2	$ 8.00	$ 46.72
Kennedy & Williams - DT Toronto - Centre	Actual Mins	Current	1	4	10	5	8	51	6	4	1	90		
		Proposed 1	1	4	10	5	8	43	6	4	1	82		
		Proposed 2	1	4	1	5	2	51	6	4	1	75		
	Perceived Mins	Current	2.2	4	35	5	30	51	25	4	2.2	158.4	$11.40	$ 53.64
		Inc. Speed	2.2	4	35	5	30	43	25	4	2.2	150.4	$11.40	$ 51.51
		Red. Headway	2.2	4	12.5	5	15	51	25	4	2.2	120.9	$11.40	$ 43.64
McLaughlin & Steeles - Hurontario & 401	Actual Mins	Current	11	13							9	33		
		Proposed 1	9	7	17	14					9	56		
	Perceived Mins	Current	24.2	13							19.8	57	$ 3.50	$ 18.70
		Local Alt.	19.8	7	52.5	14					19.8	113.1	$ 3.50	$ 33.66
Keele/ Jane & Finch - Keele & 407	Actual Mins	Current	11	5	6	19					0	41		
		Proposed 1	6	31	5	17					0	59		
	Perceived Mins	Current	24.2	5	25	19					0	73.2	$ 3.35	$ 22.87
		Local Alt.	13.2	31	22.5	17					0	83.7	$ 6.75	$ 29.07
Hurontario & Burnhamthorpe - DT Toronto - South	Actual Mins	Current	15	33							13	61		
		Proposed 1	1	7	3	28	4	21	6	8	6	84		
	Perceived Mins	Current	33	33							28.6	94.6	$ 5.70	$ 25.23
		Local Alt.	2.2	7	17.5	28	20	21	25	8	13.2	141.9	$ 6.25	$ 37.84