AN EX POST EVALUATION OF THE RIDERSHIP IMPACTS OF THE VIVA BUS TRANSIT SYSTEM

by

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A thesis submitted in conformity with the requirements for the degree of Master of Applied Science
Graduate Department of Civil Engineering
University of Toronto

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ABSTRACT

The Regional Municipality of York introduced a new bus service known as VIVA in 2005. Although it has been deemed a success by many, it remains to be seen to what degree transit use was affected by its introduction. This study shows that transit ridership in York jumped substantially immediately after the implementation of VIVA. Furthermore, it is determined that the majority of new transit users in York are making home-based work or post-secondary school trips. To evaluate this, home-based work and post-secondary school generalized extreme value discrete choice models are estimated. Improvements in transit service are found to have a greater impact on transit mode share than increases in congestion for both work and post-secondary school trips. It is also, however, concluded that transit improvements played a relatively small role in the considerable shift to transit amongst post-secondary students.
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1. Introduction

After decades of declining patronage and neglect in North America, public transportation is now becoming an increasingly important component of municipal infrastructure. Cities struggling with worsening traffic congestion, air pollution, and suburban sprawl are becoming attracted to the purported operational, environmental, and social benefits of transit. In particular, Bus Rapid Transit (BRT) has become a popular choice for municipalities seeking a low-capital, high performance transit mode that many claim offers a similar level of service to more capital-intensive rail modes. A great deal of research has gone into investigating the planning, performance, and operation of BRT; however, relatively little has been done to assess whether its introduction has actually had an appreciable effect on transit use.

The Regional Municipality of York, north of the City of Toronto, implemented a new, privately operated bus service known as VIVA in 2005. This distinctly branded system operates primarily in two highly-traveled corridors and features high operating speeds, offline fare payment, advanced traveler information systems, and other ITS technologies. Although this new service has been deemed a success by many, its effect on transit use has yet to be measured. Have existing transit users simply shifted routes? Has increasing traffic congestion exacerbated the increasing use of private automobiles? What types of riders has VIVA attracted? These questions and more have not yet been fully answered.

Using revealed preference survey data collected before and after the implementation of VIVA and ridership data provided by York Region Transit, this thesis will evaluate VIVA’s effect on transit patronage and travel patterns in York Region.

1.1. Research Objectives

This thesis has the following objectives:

- Investigate whether demographic trends in York Region may have influenced overall transit use. If so, which demographic changes have most affected transit patronage?
- Determine whether access distance to VIVA has had an appreciable effect on transit use.
- Determine the extent to which transit trips in VIVA corridors shifted to the new service.
Calculate the impact of improved transit service (including VIVA) on transit mode share in York Region.

Calculate the impact of increased traffic congestion on transit mode share in York Region.

1.2. Thesis Organization

The remainder of this thesis is organized in the following manner:

- Chapter 2 presents a review of the transportation evaluation literature, discrete choice analysis, Bus Rapid Transit (BRT), and past evaluative studies of transit system improvements.
- Chapter 3 provides historical and geographical context for the VIVA bus transit system. Recent population and mode choice trends for York Region are presented along with a description of York Region Transit and the VIVA system.
- Chapter 4 consists of an analysis of the two major corridors in which VIVA operates: Yonge Street and Highway 7. The chapter is divided into two sections. In the first, the impact of access distance to VIVA on transit mode share is examined; in the second, a simple time series analysis of route boardings in the two corridors is undertaken.
- Chapter 5 presents aggregate demographic and travel-related data for both York Region and Peel Region for the years 2001 and 2006, for the purpose of comparing changes in York Region’s travel patterns with a control group and to verify whether there may have been a demographic shift in York Region that would explain any changes in travel behaviour.
- Chapter 6 outlines the specification, estimation, and application of an AM peak period discrete mode choice model for travel to, from or within York Region. These models are used to assess the impact of improved transit service and increased traffic congestion on peak period mode choice.
- Chapter 7 presents conclusions and recommendations for future work related to this study.
2. Literature Review

This chapter is divided into four sections. The first three sections provide basic background information about the topics discussed in this thesis: evaluation, discrete choice analysis and bus rapid transit. The final section presents a review of papers that have attempted to evaluate the impact of new transit projects on transit patronage and other metrics.

2.1. Evaluation

2.1.1. The Transportation Planning Process

Although this thesis is largely evaluative in nature and does not focus significantly on planning, it is instructive to provide a brief overview of transportation planning to examine how evaluation fits within this greater process.

Formalized transportation planning began to take shape in the post-war period in the United States, starting with the Detroit Metropolitan Area Traffic Study (1956) and the Chicago Area Transportation Study (CATS) (1962). These plans followed what is now known as the rational approach to planning and decision-making. That is, their approach was highly scientific and assumed that an optimal solution could be obtained by following a set of steps that led to one alternative being chosen as best. However, given the obvious difficulties associated with arriving at an absolutely optimal solution, other decision models began to be explored within the context of transportation planning. Examples of these models include the satisficing approach (in which an acceptable alternative is selected after a modest search), the incremental approach (in which only a limited number of alternatives are analyzed) and the political bargaining approach (which puts the power of selection in the hands of stakeholders and decision makers) (Meyer & Miller, 2001). At the outset of “Urban Transportation Planning” (1984), Meyer and Miller present a general framework that can encompass a wide variety of these decision structures. This framework is shown in an adapted form in Figure 2.1.
The focus of this thesis will be on the “operations monitoring” component of the urban transportation planning process. At this step, an alternative has already been selected and implemented (in this case, VIVA), and data has been collected to quantify its performance. There are two primary objectives in the monitoring stage. Firstly, we wish to evaluate the consequences of implementing the recommended alternative. These consequences could range from performance impacts to land use changes or social changes. Secondly, we would like to develop a better understanding of the problem of interest; in many cases, this can be inferred by noting the changes in travel behaviour that result from the network modification.

2.1.2. Ex Post Evaluation and the Problem of Causality

The use of the phrase “ex post evaluation” in the title of this thesis refers to the fact that VIVA is being evaluated after its implementation; ex post is Latin for “after the fact”. Although this may seem like the natural way for an evaluation to be undertaken, evaluation in transportation planning most frequently occurs prior to implementation (ex ante), as illustrated in Figure 2.1. As per Meyer and Miller (2001), ex post evaluations seek to answer four basic questions:

- What changes were made to the transportation system?
- What were the impacts of these changes?
- Why did these impacts occur?
- How successful were the actions taken to improve the transportation system?

The first two questions are relatively easy to answer. The changes made to a transportation system can be catalogued by studying maps of the period of interest and by talking to the people...
responsible for those changes. The impacts they caused—at least for the purposes of this study—can be obtained from travel survey data before and after the changes were implemented. The real challenge, as discussed below, is answering what changes were responsible for the impacts observed; that is, establishing causality.

A sound experimental design is the key to identifying the cause of observed changes. In effect, experimental design dictates how the study will sample, measure, and control the actors of that change. If these factors are properly specified, causality can be established more readily. Campbell and Stanley (1963) present a thorough discussion of quasi-experimental and true experimental designs; subsequent work expanded upon that list to include before-and-after experiments common in transportation studies (Charles River Associates, 1972). A summary of these designs is provided below.

1) One-shot case study: A population is observed after a change has been introduced.
2) One-group pretest-posttest design: A population is observed before and after changes are introduced.
3) Static-group comparison: A one-shot study with data collected from two populations; one has been subjected to a change and the other has not.
4) Time series: Several observations are made before and after a change is made
5) Two-group pretest-posttest design: Similar to design 2, but with parallel observations taken from a control group that has not been subject to any treatments.

The preceding designs are known as “quasi-experimental” since they do not incorporate randomness into the assignment of treatments (changes). These designs are used when randomization is either impossible or impractical. True experimental designs, presented below, subject treatments randomly to members of the study population(s).

6) Pretest-posttest control group: Similar to design 5, but with the random assignment of treatments to each population.
7) Posttest-only control group: Similar to design 3, but with random assignment of treatments to each population.
8) Before-and-after user study: This design takes different random samples a population before and after a change is introduced
9) Randomized before-and-after user study with control: Similar to design 8, but with the inclusion of a control group that is not introduced to the change.

Campbell and Stanley (1963) evaluate these common designs against threats to the validity of the findings from the experiments. These threats can be split into those that threaten the *internal* validity and those that threaten the *external* validity of the experiment. Internal validity is defined as the basic minimum without which any experiment is uninterpretable: Did the experimental treatments make a difference in this specific case? Campbell and Stanley examine seven threats to internal validity. The ways each of these seven threats may affect this study are discussed below.

1) Exogenous influences: The effect of external factors on the experiment. In the current context, demographic shifts in income, travel costs, or technology could be responsible for the choice of travel mode rather than the introduction of VIVA.

2) Maturation: Concerned with the changing nature of the experimental subjects from one observation to the next. For this study, a change in the physical layout of York Region (such as increased density) could be considered a maturation threat.

3) Testing: In some instances, an awareness of the testing process may be enough to influence behaviour. This is unlikely to present problems for this thesis since data is taken from a larger travel study.

4) Instrumentation: The procedures used to measure the outcome of the experiment can affect on the results. In a transportation context, this is usually caused by the nature of the survey or the surveyors. For this thesis, this threat has been accounted for by the administrators of the survey from which the data was taken.

5) Statistical regression: The information obtained from a survey may not be indicative of normal conditions. For example, an individual may have taken transit on the day they were surveyed, but they have driven most other days. Given a large enough sample (as is the case here), these effects can be diluted.

6) Selection: This threat has to do with the sample selection process. Transportation studies often make use of data from telephone surveys; this, however, ignores the impacts of those people that do not have household telephones (eg. students). Once again, this is controlled by third parties.
7) Sample mortality: Considers the effect of a differential loss in respondents from a given component of the population. In the context of a high-growth region such as York, this is a minimal concern.

Conversely, external validity is concerned with the ability to generalize the conclusions of the experiment to other populations. Since this study is concerned with evaluating the impacts of a specific project, threats to external validity are not applicable.

This study takes data from two sources: boarding counts of YRT routes and the Transportation Tomorrow Survey (TTS). The ridership counts are used to undertake a simple time series analysis of boarding patterns on routes in major corridors in which VIVA operates. Although the literature states that this method does not control for any of the seven threats to internal validity (Campbell & Stanley, 1963), it is the only option available given the nature of the data. Furthermore, it is unnecessary to take a random sample of monthly ridership counts since it is already a 100% sample. Additionally, there can be no control group with enough similarities to the VIVA corridors to make two-group analysis worthwhile. The TTS data represents a 5% random sample of the Greater Toronto and Hamilton Area (GTHA) for the years 2001 and 2006. For this study, data will be extracted for the Regions of York and Peel, with Peel being used as the control group. In this sense, it represents a randomized before-and-after user study with control. As per Charles River Associates (1972), this methodology accounts for all internal validity threats except for instrumentation. Unfortunately, the control of this threat is outside of the scope of this study. It should also be noted that Peel is not a perfect control group. Although the two regions are similar, they do not have identical infrastructure, job base, and populations. However, they are arguably the two most similar regions in the GTHA.

2.2. Discrete Choice Analysis
Discrete choice analysis is used in this dissertation to analyze the parameters of mode choice before and after the introduction of VIVA. This section provides the mathematical and econometric background required to develop these mode choice models. The topic is presented from the first principles of random utility theory to the development of generalized extreme value models.
2.2.1. Random Utility Theory

When an individual is faced with a heterogeneous set of alternatives, their decision rule can be modeled by assuming they will choose the alternative that is most attractive to them. If that attractiveness is expressed as a scalar-reducible vector of attributes, we have an objective function known as the utility of that alternative. We can thus assume that individual choices are made such that individual utility is maximized. However, consumers will not always make the same choice of alternative, even in seemingly identical circumstances; that is, the actions of individuals are not always perfectly rational in the eyes of an analyst. In the context of transportation, we might observe two commuters with seemingly identical personal and trip characteristics choose different travel modes to make their trip. It is therefore necessary to introduce a probabilistic framework into choice modeling. Luce and Suppes (1965) describe two approaches to incorporate probability into a utility-based choice framework. The first approach, constant utility, assumes that the utilities of each alternative are fixed. Therefore, the random component of the choice process stems from the individual. Conversely, in random utility models, individuals always make a perfectly rational choice, and observed inconsistencies are a result of observational deficiencies on the part of the analyst (Ben-Akiva & Lerman, 1985). In other words, the random component of the choice process is due to unobserved attributes, traits, or imperfect information. Due to its consistency with consumer theory, which assumes rational behaviour, random utility models are typically used in transportation applications.

Manski (1977) formalized random utility models mathematically. The probability that an individual \( n \) chooses alternative \( i \) over all other alternatives in the choice set \( C_n \) can be written as:

\[
P(i|C_n) = P(U_{i,n} \geq U_{j,n}, \text{all } j \in C_n)
\] (2.1)

If we decompose the utility \( U_{i,n} \) into its observable (also known as systematic) component \( V \) and unobservable component \( \varepsilon \), we have the following:

\[
U_{i,n} = V_{i,n} + \varepsilon_{i,n}
\] (2.2)

\[
P(i|C_n) = P(V_{i,n} + \varepsilon_{i,n} \geq V_{j,n} + \varepsilon_{j,n}, \text{all } j \in C_n)
\] (2.3)

Different assumptions regarding the distribution of the random error terms \( \varepsilon_{i,n} \) will result in different choice models; this is illustrated in the next section.
2.2.2. The Generalized Extreme Value Model

The generalized extreme value (GEV) model is an econometric tool that models an individual’s choice of alternatives in a manner that is consistent with random utility theory. The model was developed by McFadden (1978) as a means of modelling the choice of residential location. It is a generalization of the nested logit (NL) model, which is itself a generalization of the multinomial logit (MNL) model. As such, this topic is best explained by beginning with the development of the MNL model and progressing to the NL and GEV models.

The MNL model is a logistic function that models the choice of an alternative \( i \) from a set of \( J \) options. The key assumption of the model is that the error terms \( \varepsilon \) are identically and independently Gumbel-distributed. As per Ben-Akiva and Lerman (1985), if \( \varepsilon \) is Gumbel-distributed, then its cumulative distribution function and probability density function are:

\[
F(\varepsilon) = \exp (-e^{-\mu(\varepsilon-\eta)}) \\
f(\varepsilon) = \mu e^{-\mu(\varepsilon-\eta)} \exp(-e^{-\mu(\varepsilon-\eta)})
\]

Where \( \eta \) is a location parameter and \( \mu \) is a positive scale parameter. This distribution has the following important properties:

1) If \( \varepsilon \) is Gumbel distributed with parameters \((\eta, \mu)\), and \( V \) and \( \alpha > 0 \) are any scalar constants, then \( \alpha \varepsilon + V \) is Gumbel-distributed with parameters \((\alpha \varepsilon + V, \mu/\alpha)\).

2) If \( \varepsilon_1 \) and \( \varepsilon_2 \) are independent Gumbel-distributed variates with parameters \((\eta_1, \mu)\) and \((\eta_2, \mu)\), respectively, then \( \varepsilon^* = \varepsilon_1 - \varepsilon_2 \) is logistically distributed:

\[
F(\varepsilon^*) = \frac{1}{1 + e^{\mu(\varepsilon_1 - \varepsilon_2 - \varepsilon^*)}}
\]

3) If \((\varepsilon_1, \varepsilon_2, ..., \varepsilon_J)\) are \( J \) independent Gumbel-distributed random variables with parameters \((\eta_1, \mu), (\eta_2, \mu), ..., (\eta_J, \mu)\), respectively, then \( \max(\varepsilon_1, \varepsilon_2, ..., \varepsilon_J) \) is Gumbel distributed with parameters \((\frac{1}{\mu} \ln \Sigma_{j=1}^{J} e^{\mu \eta_j}, \mu)\)

We can now derive the multinomial logit model. For convenience, we assume that \( \eta = 0 \) for all error terms. Begin by ordering alternatives such that \( i = 1 \); equation 2.3 therefore becomes:

\[
P_n(1) = P \left( V_{1,n} + \varepsilon_{1,n} \geq \max_{j=2, ..., J_n} \left( V_{j,n} + \varepsilon_{j,n} \right) \right)
\]

Define
From property 3 above, $U^*_n$ is Gumbel-distributed with parameters $\left( \frac{1}{\mu} \ln \sum_{j=2}^{J_n} e^{\mu V_{jn}}, \mu \right)$. From property 1, we can write $U^*_n = V^*_n + \varepsilon^*_n$, where $V^*_n = \frac{1}{\mu} \ln \sum_{j=2}^{J_n} e^{\mu V_{jn}}$ and $\varepsilon^*_n$ is Gumbel-distributed with parameters $(0, \mu)$.

Since

$$P_n(1) = P(V_{1,n} + \varepsilon_{1,n} \geq V^*_n + \varepsilon^*_n) = P[(V^*_n + \varepsilon^*_n) - (V_{1,n} + \varepsilon_{1,n}) \leq 0],$$

property 2 gives

$$P_n(1) = \frac{1}{1 + e^{\mu (V^*_n - V_{1,n})}} = \frac{e^{\mu V_{1,n}}}{e^{\mu V_{1,n}} + e^{\mu V_{jn}}} = \frac{e^{\mu V_{1,n}}}{e^{\mu V_{1,n}} + \exp (\ln \sum_{j=2}^{J_n} e^{\mu V_{jn}})}$$

$$P_n(1) = \frac{e^{\mu V_{1,n}}}{\sum_{j=1}^{J_n} e^{\mu V_{jn}}}$$

Equation 2.10 is the final form of the multinomial logit model. The scale parameter $\mu$ is normally set to 1, reflecting the assumption of homoskedastic error terms.

There may, however, be instances in which the choice set consists of multiple related decisions. For example, in the case of mode choice, there may be a choice among “sub-modes” such as bus, rail, or streetcar related to the choice of taking transit. In these cases, joint multinomial choice models can be used, for which several choice structures are possible. A sequential decision process is structured such that an “upper level” choice is made first and the “lower level” choices are conditioned on that upper choice. Conversely, a simultaneous decision structure assumes that each upper/lower choice combination forms a choice “bundle” and that decisions are made between each bundle. These methods are not without flaws. The sequential model assumes that the attributes of the lower level alternatives have no bearing on the upper level choice. In the simultaneous model, the combinatorial nature of the structure can lead to very large choice sets.

There is also a strong possibility of choice bundles being correlated, which violates the assumption of identically and independently distributed error terms. As an alternative to these choice structures Williams (1977) developed the Nested Logit model to incorporate “feedback” from the lower level choice to the upper level choice by including a new term in the upper level
utility function that incorporates the expected maximum utility of the lower level choice conditioned on the upper level choice.

We can derive the NL model by first considering the structure of the simultaneous MNL. If we have two related choices in categories \(c\) and \(n\), the joint probability of a given choice combination can be written as

\[
P_{cn} = \frac{e^{V_{cn}}}{\sum_{b=1}^{C} \sum_{m=1}^{N_b} e^{V_{bm}}} \tag{2.11}
\]

Systematic utility can be written as \(V_{cn} = \beta' X_{cn} + \alpha' y_c' X_{cn}\) is a vector of observed attributes which vary with both categories \(c\) and \(n\), and \(y_c\) is a vector of observed attributes that vary only with category \(c\). As with all MNL models, the unobserved attributes (errors) are assumed to be identically and independently Gumbel-distributed. We can now decompose this expression into its conditional and marginal components \(P_{cn} = P_{nc} P_c\):

\[
P_{nc} = \frac{e^{V_{nm}}}{\sum_{n=1}^{N_c} e^{V_{nm}}} = \frac{e^{\beta' X_{nm}}}{\sum_{m=1}^{N_m} e^{\beta' X_{nm}}} \tag{2.12}
\]

\[
P_c = \frac{\sum_{n=1}^{N_c} e^{V_{nm}}}{\sum_{b=1}^{C} \sum_{m=1}^{N_b} e^{V_{bm}}} = \frac{\sum_{n=1}^{N_c} e^{\alpha' y_c' X_{cn} + \beta' X_{mn}}}{\sum_{b=1}^{C} \sum_{m=1}^{N_b} e^{\alpha' y_c' X_{bn} + \beta' X_{bm}}} \tag{2.13}
\]

Letting \(I_c = \ln \left( \sum_{n=1}^{N_c} e^{\beta' X_{cn}} \right)\), then

\[
P_{nc} = \frac{e^{V_{nm}}}{e^{I_c}} \tag{2.14}
\]

\[
P_c = \frac{e^{\alpha' y_c' + I_c}}{\sum_{b=1}^{C} e^{\alpha' y_b' + I_b}} \tag{2.15}
\]
If $I_c$ is allowed to have a parameter other than 1 we obtain:

$$P_c = \frac{e^{\alpha'y_c+(1-\sigma)I_c}}{\sum_{b=1}^{C} e^{\alpha'y_b+(1-\sigma)I_b}}$$

(2.16)

This is the nested logit model. It is similar in structure to the joint MNL model, but includes a new parameter $\sigma$ that allows for “feedback” from lower to upper level choices. If $\sigma = 1$, the sequential MNL model is obtained; if $\sigma = 0$, the simultaneous MNL model is obtained.

While the NL model is clearly an improvement over the MNL model for hierarchical decision structures, the original assumption of independent error terms still applies. To overcome this, McFadden (1978) developed the generalized extreme value (GEV) model. McFadden proves that if $G(y_1 \ldots y_J)$ is a non-negative, homogeneous-of-degree-one function of $(y_1 \ldots y_J)$ $\geq 0$ where

$$\lim_{y_i \to \infty} G(y_1 \ldots y_J) = \infty$$

for $i = 1$ to $J$ and for any distinct $(i_1 \ldots i_k)$ from $(1 \ldots J)$, $\frac{\partial^k G}{\partial y_{i_1} \ldots \partial y_{i_k}}$ is nonnegative if $k$ is odd and non-positive is $k$ is even, then:

$$P_i = \frac{e^{V_i G_i(e^{V_1}, \ldots, e^{V_J})}}{G(e^{V_1}, \ldots, e^{V_J})}$$

(2.17)

defines a probabilistic choice model which is consistent with utility maximization, but that also allows a general pattern of dependence among the error terms while yielding an analytically tractable closed form for the choice probabilities.

### 2.3. Bus Rapid Transit

#### 2.3.1. Definition

Definitions of Bus Rapid Transit (BRT) vary from source to source. A fairly broad definition of the mode is sometimes adopted, allowing only mildly upgraded bus service to be labelled as BRT. Although it is not always the case, this type of definition is often adopted by government agencies. The municipally-funded corporation that operates VIVA, for example, defines BRT as a service that “provides fast, frequent service on dedicated lanes using buses, which allow more flexibility than rail-based rapid transit services. Bus rapid transit provides a high level of service and is both less costly and faster to build than rail” (York Region Rapid Transit Corporation, 2010). Under this definition, the only real stipulation for BRT is that the service be offered in a
dedicated lane. The Transportation Research Board’s Transit Co-operative Research Program (Levinson, et al., 2003) gives an equally broad definition, labelling BRT as

*a flexible, rubber-tired rapid-transit mode that combines stations, vehicles, services, running ways, and Intelligent Transportation System (ITS) elements into an integrated system with a strong positive identity that evokes a unique image. BRT applications are designed to be appropriate to the market they serve and their physical surroundings, and they can be incrementally implemented in a variety of environments. In brief, BRT is an integrated system of facilities, services, and amenities that collectively improves the speed, reliability, and identity of bus transit.*

This definition gives a wide array of potential components of a BRT system, but it does not specify the requirements for a system to be considered BRT.

At the other end of the spectrum, some academics and professionals have very formal definitions for BRT. For example, Vuchic (2007) presents a three-tiered definition of bus transit:

*Regular or conventional bus (RB): A bus system consisting of buses operating with fixed schedules on streets in mixed traffic and curbside stop locations equipped with signs and sometimes with passenger protection and information facilities.*

*Bus transit system (BTS): A bus mode developed as a coordinated system with significant improvements in its components for higher operating speed, reliability, and efficiency. Upgraded components may include provision of bus lanes, stops with greater spacings designed for fast boarding due to self-service fare collection (SSFC), multi-channel doors, low floor buses, and others.*

*Bus rapid transit (BRT): Bus transit designed as an integrated system of distinct buses and a separate infrastructure with considerable independence from other traffic, allowing higher speed, reliability and safety than BTS.*

Another example of a strict, detailed definition of BRT can be found in the Bus Rapid Transit Planning Guide (Wright, et al., 2007), published by the Institute for Transportation and Development Policy. They present a short-form definition as “a high-quality bus-based transit system that delivers fast, comfortable, and cost-effective urban mobility through the provision of
segregated right-of-way infrastructure, rapid and frequent operations, and excellence in marketing and customer service. BRT essentially emulates the performance and amenity characteristics of a modern rail-based transit system but at a fraction of the cost.” In a similar manner to Vuchic, the guide goes on to discretize various levels of bus service, as show in Figure 2.2.

<table>
<thead>
<tr>
<th>Informal transit service</th>
<th>Conventional bus services</th>
<th>Basic busways</th>
<th>BRT-lite</th>
<th>BRT</th>
<th>Full BRT</th>
</tr>
</thead>
<tbody>
<tr>
<td>➢ Non-regulated operators</td>
<td>➢ Segregated busway / single corridor services</td>
<td>➢ Segregated busway</td>
<td>➢ Segregated busway</td>
<td>➢ Segregated busway</td>
<td>➢ Segregated busway</td>
</tr>
<tr>
<td>➢ Taxi-like services</td>
<td>➢ On-board fare collection</td>
<td>➢ Typically pre-board fare payment / verification</td>
<td>➢ Higher quality stations</td>
<td>➢ Clean vehicle technology</td>
<td>➢ Metro-quality service</td>
</tr>
<tr>
<td>➢ Poor customer service</td>
<td>➢ Basic bus shelters</td>
<td>➢ Higher quality stations</td>
<td>➢ Marketing identity</td>
<td>➢ Frequent and rapid service</td>
<td>➢ Integrated network of routes and corridors</td>
</tr>
<tr>
<td>➢ Relatively unsafe / insecure</td>
<td>➢ Standard bus vehicles</td>
<td>➢ Clean vehicle technology</td>
<td>➢ Marketing identity</td>
<td>➢ Modern, clean vehicles</td>
<td>➢ Closed, high-quality stations</td>
</tr>
<tr>
<td>➢ Very old, smaller vehicles</td>
<td>➢ Standard bus vehicles</td>
<td>➢ Marketing identity</td>
<td>➢ Superior customer service</td>
<td>➢ Superior customer service</td>
<td>➢ Superior customer service</td>
</tr>
</tbody>
</table>

**Figure 2.2** Levels of Bus Transit Services (Wright, et al., 2007)

Under the Vuchic definition, VIVA would fall under the category of “Bus Transit System”; under the BRT Planning Guide definition, VIVA would fit the “BRT-Lite” category. The more important question, however, is whether or not a given system is successful at attracting passengers, which is the main topic of exploration in this thesis.

### 2.3.2. History

Although the majority of research and implementation of BRT systems has come within the last 40 years, the concept is not new. Levinson et al. (2003) claim the genesis of the BRT concept can be found in Harrington, Kelker, and DeLeuw’s (1937) transportation plan for the city of Chicago. Their recommended scheme replaced several rail rapid transit lines by super highways with express bus operations in the median. While not fitting with the prescriptive definitions of
BRT, this represents the first suggestion of the segregation of bus operations to improve performance. Other major proposals over the next 30 years include the 1956-1959 Washington D.C. plan (DeLeuw Catcher & Co., 1959), the 1959 St. Louis plan (W.C. Gilman and Co., 1959), and the 1970 Milwaukee plan (Barton-Ashman Associates, 1971). None of these plans were implemented as proposed (Levinson, et al., 2003).

Although the concept of BRT was largely a product of the United States, its first wide scale implementation and success was in South America. In the early 1970s, the city of Curitiba, Brazil had a population of roughly 600,000 people and was rapidly growing. Local transportation planners initially sought to build a rail rapid transit system, but were forced to be more creative when it became clear the necessary funds would not be available. The result was a “surface metro” consisting of 20 kilometres of busways with pre-paid boarding, distinctive tube-shaped stations, and high-capacity vehicles. The system was planned, designed, and commissioned within 3 years, opening in 1974. Today, Curitiba has a population of 2.2 million people and has 65 kilometres of exclusive busways (Wright, et al., 2007).

In the Canadian context, Ottawa was the first city to adopt BRT. Since 1983, Ottawa has operated buses in exclusive lanes and roadways on its award-winning Transitway. Today, the system consists of more than 35km of exclusive roadway, 41 stations, and moves a volume of more than 10,000 people per direction in the AM peak hour (OC Transpo, 2009). No other transit operator in Canada offers BRT service comparable to the Ottawa Transitway. However, the last 15 years have seen the emergence of many BRT-lite systems. Examples include Vancouver’s B-line, Quebec City’s Métrobus, Waterloo Region’s iExpress, and, of course, York Region’s VIVA.

2.4. Past Evaluative Studies

The vast majority of the transit evaluation literature focuses on evaluation prior to the implementation of a proposed course of action in relation to other alternatives. Litman (2010) and the Transit Cooperative Research Program (Cambridge Systematics et al., 1998) present thorough compendia of these methods. When ex post evaluations do arise in the literature, their focus is usually on determining, from an economic perspective, whether the accrued benefits of a project were worth the expenditures allocated. Typically, detailed analysis of ridership impacts is not included. Examples of this type of evaluation can be found in many French studies due to
their country’s policies (Jeannesson-Mange, Chapulut, & Taroux, 2007) and in evaluations of BRT demonstration projects sponsored by the Federal Transit Administration (Federal Transit Administration, 2007). The latter also produced reports that included a fair degree of evaluation of ridership impacts, as discussed in the next sub-section.

### 2.4.1. Studies of Specific Systems

The following sources constitute the few available examples in the literature of *ex post* evaluations of specific transit systems that provide sufficient analysis of ridership impacts to be of value to this thesis.

The first source consists of a group of similar evaluative papers written as part of the United States’ Federal Transit Administration (FTA) Bus Rapid Transit Initiative. As part of this initiative, a series of BRT demonstration projects that received funding from the FTA were evaluated based on their operational features, costs and performance. In some cases (depending on the data available), a detailed analysis of ridership impacts was presented. For example, in the evaluation of Honolulu’s BRT project (Cham, et al., 2006), the authors classify BRT ridership into 3 segments: 1) diversion from other transit services 2) diversion from other modes 3) new or “induced” trips that result due to the presence of the new mode. Where feasible, the total boardings on BRT routes were compared to the boardings on parallel routes; the reduction in boardings on the parallel routes was determined to be generated by diversion from other transit services. The difference between total BRT boardings and this diverted ridership was assumed to represent new trips and trips diverted from other modes. No clear patterns were observed in the ridership segments on BRT routes; in some cases, the majority of boardings were attributed to shifts from parallel routes while in others ridership grew well beyond what could be shifted. Similar analysis was conducted for the Las Vegas MAX BRT project (Kim, Darido, & Scheck, 2005), and phases 1 (Schimek, Darido, & Schneck, 2005) and 2 (Schimek, Watkins, Chase, Smith, & Gazillo, 2007) of the implementation of Boston’s Silver Line BRT. Phase 2 of the Silver Line BRT (Washington St.) took the extra step of conducting a passenger survey to determine the previous commuting habits of Silver Line users. Of the 8000 responses received, roughly 85% were previous transit users, while the remaining 15% were diverted from other modes or were “new” trip makers. Less than 2% of respondents claimed to be former single-occupancy vehicle drivers.
The most comprehensive study of the ridership impacts of BRT is a MCP/MST thesis from MIT that analyzed the impact of the Transmilenio system in Bogota, Columbia. This study (Lleras, 2003) consists of two main components: structural equation modeling to test a priori hypotheses about the root causes of travel behaviour and, more relevantly, discrete choice modeling to assess the choice between Transmilenio and conventional bus service. Discrete choice analysis was undertaken using a revealed preference survey for travelers that had a choice between Transmilenio and the traditional system. Models were estimated for two different market segments: one for users traveling from the vicinity of trunk Transmilenio corridors and one for users that require taking feeder bus routes to the trunk corridors. In addition, the markets were further segmented by socio-economic factors to ensure that the results did, in fact, stem from travel improvements and not from exogenous variables. All models showed that the value of time on Transmilenio was lower than on the traditional system; that is, users are willing to pay more to save time in the traditional system than on the Transmilenio, showing that BRT is the less “painful” alternative. Furthermore, Lleras shows that although Transmilenio is favoured over traditional service, this advantage diminishes as distance to the trunk line increases. Moreover, Transmilenio competes with traditional buses on the basis of level of service rather than on price. Finally, it is shown that Transmilenio seems to have the greatest impact on lower income groups, but that the value of time was lowered regardless of demographic group.

In another study, Chapleau, Lavigneuer, and Baass (1987), analyzed the extension of Line 1 of the Montreal Metro for the 1976 Summer Olympics. The data used for the study consisted of OD surveys conducted before (1974) and after (1978) the completion of the extension. It was determined that the presence of the extension increased the transit trip rate; however, there was also an overall increase in personal trips rates. The trips rates increased the most at either end of the extension. It was also observed that, although system-wide transit mode split remained constant, increases were observable near the extensions. The increases in modal share were only observable within 1.6km of the metro line. The effects of the extension were also simulated using travel demand software; significant time savings were observed, notably in the areas to which the metro was expanded (25-30 mins saved). Finally, 1978 AM peak hour demand was loaded onto the 1974 and 1978 transit networks. This showed that the extension saved 11,500 hours of generalized travel time and resulted in a small savings of bus vehicle-hours.
Casello and Hellinga (2008) present an example of corridor-level analysis of a new express bus service in Waterloo Region. The generalized cost of traveling in three short corridors before and after the implementation of the express service is determined and the difference calculated, giving a general idea of whether the new route has led to an increase in level of service. Generalized cost was assumed to be a weighted sum of travel time components and fare, where standard values for weights and value of time were taken from the literature. Waiting and transfer times were calculated as a function of route headway, and scheduled time was assumed to be representative of in-vehicle time. The analysis then focused on a single corridor and identified the different ways the corridor can be accessed and egressed; using data from ridership surveys, the aggregate impact on the generalized cost caused by different trip types was calculated as a 9.5% reduction. The demand elasticity with respect to generalized cost was -1.3.

2.4.2. Other Studies

The following papers, though judged to be of less value to the analysis in this thesis, are relevant enough to be included for review. Generally, they are either qualitative in nature or do not focus on a single transit system.

Two papers were reviewed that contained an analysis of the VIVA system. The first was an evaluation of the VIVA brand which presents an overview of the architectural and design features that give VIVA its unique look and feel (Gast & Turner, 2009). Rather than examining whether this branding had a significant impact on ridership, this study focussed on riders’ perception of the system as a whole. The second paper, published by the Mineta Transportation Institute at San Jose State University (Niles & Callaghan Jerram, 2010), is a study of the benefits of building bus rapid transit in increments; the VIVA system is presented as a case study along with projects in Eugene, Los Angeles and Santa Clara. The authors provide an overview of each system and quantify performance measures such as travel time improvements, corridor ridership, and capital and operating cost. Overall, it is concluded that the strength of BRT lies in its ability to accommodate a wide range of transportation needs through incremental construction.

Several other studies were reviewed that were largely qualitative or meta-analytical. Dueker and Bianco (1998) conducted an analysis of the impact of Portland’s Eastside LRT line; however, much of the analysis focused on land-use impacts. Transit performance measures analyzed included changes in transit mode share, line boardings, and peak load points. Mackett and
Edwards (1998) collected data from more than 100 transit systems worldwide based on a survey of their own design. The authors conclude that, in general, the ridership impacts of the systems studied are much smaller than anticipated and that further study (e.g., before-and-after studies) are required to be able to make rational investments in future public transit systems. Baum-Snow and Kahn (2000) base their study on 1980 and 1990 census data from 5 American cities (Boston, Washington, Atlanta, Portland, and Chicago). The authors use distance to transit (based on census tract centroid to the transit line) as a proxy for accessibility and regress the change in public transit use against this accessibility, demographics, and migration rates. The key finding is that better access to transit encourages more use. Finally, the United States’ Transit Cooperative Research Program (TCRP) Research Digest 69 (Stanley & Hyman, 2005) presents the results of a survey of transit managers from American transit agencies that experienced the highest growth in ridership over the period 2000 to 2002. In general, it was found that the greatest increases were a result of multiple factors, namely: service adjustments, fare and pricing adaptations, marketing and information initiatives, shifts in planning orientation, and new efforts in service coordination, collaboration and partnering.

2.4.3. Conclusions
A thorough review of the literature has found very few examples of past efforts to evaluate the success with which specific transit projects attract new ridership. Although there are some similarities between this work and the Lleras Transmilenio thesis, it should be noted that VIVA has been implemented in a vastly different demographic and geographic context in which private automobiles are the dominant form of travel. As such, the methods used in Lleras’ work are not directly applicable to this study. Furthermore, Lleras only used revealed preference (RP) data from after the implementation of Transmilenio; this study compares RP data before and after VIVA’s introduction. Finally, the majority of the work reviewed focuses its analysis on the areas immediately surrounding the new transit infrastructure. This study adopts a region-wide focus in order to understand how VIVA has affected transit patronage in the municipality as a whole.
3. Historical and Geographical Context

This chapter is divided into three sections. The first two sections provide a short history and overview of York and Peel regions. This provides background and establishes Peel Region as an adequate control region against which to compare the changes in travel patterns in York. The third section presents a description of York Region Transit and VIVA’s routes, fares, stations, vehicles, and future plans.

3.1. York Region

The Regional Municipality of York was formed in 1971 upon the dissolution of the historical County of York into Metropolitan Toronto and York Region (Ontario Geneaological Society: York Region Branch, 2008). It is located in central Ontario and is bordered by the City of Toronto to the South, Lake Simcoe to the North, Peel Region and Simcoe County to the West, and Durham Region to the East. It is an upper-tier municipality comprising 9 lower-tier local divisions: the Town of Richmond Hill, the Town of Markham, the City of Vaughan, the Town of Aurora, the Town of Newmarket, the Town of Whitchuch-Stouffville, the Town of East Gwillimbury, the Township of King, and the Town of Georgina. By land area, York Region is mostly rural; the high quality of soil in the vicinity of the Oak Ridges Moraine makes for excellent farming. As illustrated in Figure 3.1 (Regional Municipality of York, 2011), the majority of the regional population is concentrated near the border with Toronto and along the north-south Yonge St. corridor.

York Region has experienced a rapid growth in population and commercial activity since its establishment. This growth has been largely fuelled by its close proximity to the City of Toronto, which has run out of “greenfield” development sites within its municipal boundaries. Figure 3.2 illustrates York’s population growth over a 20 year period, as recorded by the Transportation Tomorrow Survey.
Figure 3.1  Regional Municipality of York (used by permission)
The figure above indicates that the Region’s population has increased by nearly half a million people over a twenty year time span. This rapid population growth manifested itself in a manner typical of North American suburban development in the latter half of the 20\textsuperscript{th} century. Residential density in York Region is low in comparison to its southern neighbour, Toronto, and land use generally caters to automobile users. This, among other factors, has resulted in low transit use. Figures Figure 3.3 and Figure 3.4 present York Region’s 24 hour transit share and overall mode split as per the Transportation Tomorrow Survey.
These figures show that York Region is highly auto dominated, with more than 85% of all trips by York Region residents being made by car. The general trend from 1986 to 2001 was one of increasing auto use and decreasing transit use; however, the trend reversed between 2001 and 2006 and transit share increased. This thesis investigates the degree to which this reversal was influenced by the introduction of the VIVA bus transit system.

**3.2. Peel Region**

The Regional Municipality of Peel is used as a control to which patterns in York Region are compared. The geography and demographics of the area make it a suitable candidate for comparison with York, and Peel did not make any substantial changes to its transit network between 2001 and 2006. A map of Peel Region is shown in Figure 3.5 (Regional Municipality of Peel, 2011).

In a similar fashion to York, Peel has grown as a result of its status as a large suburb of the City of Toronto. Originally formed from what was known as Peel County, Peel Region is—like York Region—an upper tier municipality. It consists of three local lower-tier governments: the City of Mississauga, the City of Brampton, and the Town of Caledon. The bulk of the population is concentrated in the southern portion of the region in a similar manner to York Region. Figure 3.6 charts population growth in Peel Region between 1986 and 2006.
Figure 3.5  Regional Municipality of Peel (used by permission)
Although Peel has a larger population than York, population increases over the past two decades are both roughly half a million new residents. Furthermore, as shown in Figure 3.7 and Figure 3.8, the 24 hour transit share and overall modal split trends have been very similar in Peel compared to those in York despite the fact that transit share has traditionally been slightly higher in Peel than in York.
Figure 3.8  York Region Mode Choice: 1986-2006

The preceding figures show that traveler behaviour in Peel Region has followed a very similar pattern to that of York Region. Despite the fact that Peel is slightly larger than York, it is the most suitable control against which to judge the benefits of the VIVA bus transit system.

3.3. York Region Transit and VIVA

3.3.1. Overview

York Region Transit (YRT) was formed in 2001 as an amalgamation of the transit services of four municipally-managed transit systems operating in York Region: Vaughan Transit, Markham Transit, Richmond Hill Transit, and Newmarket Transit (Wyatt, 2010). Although overseen and subsidized by the regional government, all YRT routes (including VIVA) are operated by private companies. As of 2010, YRT operates a total of 121 routes and records approximately 18.3 million boardings per year (Regional Municipality of York, 2010).

VIVA was planned as a component of the York Rapid Transit Plan (YRTP), developed as a Public Private Partnership (PPP) between York Region and York Consortium 2002. Under this contract, the private sector is responsible for planning, financing, construction, and implementation of the YRTP, while the public sector retains ownership of the infrastructure and control over fare and service policy (Regional Municipality of York, 2002). After a three year planning and construction period, the system began initial service in 2005. Veolia Transport is
contracted to operate VIVA’s 90 standard and articulated buses and is also responsible for vehicle maintenance (Veolia Transport, 2009). As previously reviewed in Niles and Callaghan Jerram (2010), the YRTP is being implemented using an incremental approach. As of 2011, the current implementation has reached the first phase of operation: buses operating in mixed traffic. As described in Section 3.3.3, future phases will feature enhanced operating elements.

3.3.2. **Operating Characteristics of VIVA**

3.3.2.1. Routes

VIVA operates five colour-coded routes: Blue, Purple, Pink, Green, and Orange. VIVA Blue runs along Yonge Street between Finch subway station in Toronto and the GO Bus Terminal in Newmarket. Weekday service is offered from roughly 5AM until midnight at a headway ranging from 3 minutes during the peak period to 15 minutes off-peak. VIVA Purple runs mainly along Highway 7 between York University in Toronto and Markham Stouffville Hospital. Weekday service is offered between 5AM and 1AM with headways ranging from 10 to 15 minutes. VIVA Orange runs between Martin Grove in Vaughan and Downsview subway station in Toronto via Highway 7 and Keele Street. The route is operated from 5AM to midnight at 15 minute headways. VIVA Pink and Green are rush-hour-only routes that connect Finch subway station to Unionville GO Station and McCowan Station in Markham to the Don Mills subway station in Toronto, respectively. Headways for both routes are 15 minutes. VIVA’s service map is shown in Figure 3.9.

3.3.2.2. Fares

Although branded and operated as a distinct entity, fares on VIVA are completely integrated with the rest of the York Region Transit system. The basic fare is $3.25, with the option of purchasing either 10 ride tickets for a volume discount or an unlimited-ride monthly pass. Discounted fares are also available for students, children and the elderly. Additional fare applies when using an express route or when crossing the fare boundary separating Richmond Hill from Aurora. If using YRT or VIVA to access the GO commuter rail network, special 50-cent tickets can be used as valid fare. A summary of all YRT fares as of January 1st, 2009 is shown in Table 3.1.
<table>
<thead>
<tr>
<th>Fare Category</th>
<th>Cash Fare</th>
<th>10 Tickets</th>
<th>Monthly Pass</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1 zone</td>
<td>2 zone</td>
</tr>
<tr>
<td>Adult</td>
<td>$3.25</td>
<td>$26.00</td>
<td>$36.00</td>
</tr>
<tr>
<td>High School Student</td>
<td>$3.25</td>
<td>$19.00</td>
<td>$29.00</td>
</tr>
<tr>
<td>Senior / Child</td>
<td>$3.25</td>
<td>$15.00</td>
<td>$25.00</td>
</tr>
<tr>
<td>Express</td>
<td>$3.50</td>
<td>$32.50</td>
<td>--</td>
</tr>
</tbody>
</table>

VIVA operates under a proof-of-payment (also known as offline or self-service payment) scheme. Passengers purchase their ride tickets at vending machines located at stations; when the vehicle arrives, any door can be used for boarding. Payment is enforced by random spot-checks with fines for those who attempt to evade the fare. This scheme has the advantage of reducing boarding time at stations by eliminating the transaction time when boarding and by increasing the number of channels available for passengers.
Figure 3.9  VIVA System Map – Fall 2010 (used by permission)
3.3.2.3. Stations

As of 2011, the VIVA system has 64 stations and 6 major terminals. Each station consists of a branded shelter with a ticket vending machine, electronic ticket validation, and a real-time display of information for the next-arriving bus. A typical VIVA station is pictured in Figure 3.10. These stations are “on-line” in the sense that they are located within the right-of-way of the street that the route serves. The major terminals served by VIVA (Richmond Hill Centre, Bernard, Promenade, York University, Finch, and Newmarket) are off-line and typically serve multiple transit agencies and/or modes. In order to ensure a high operating speed, stations are spaced relatively far apart; typically, there are between 0.5 and 2 kilometres between stations.

Figure 3.10  Typical VIVA Station Layout (photo by author)
3.3.2.4. Vehicles

The vehicles used by VIVA are modern in appearance in order to project the image of a system that is more than just traditional bus service. Currently, the VIVA fleet consists of 90 standard and articulated diesel buses manufactured by the Belgian company Van Hool. Figure 3.11 shows these buses at Finch Terminal in Toronto. In November 2010, the first of 46 new Canadian-built Nova hybrid buses was unveiled as a supplement to the original fleet (York Region Rapid Transit Corporation, 2010).

![VIVA Buses at Finch Terminal (photo by author)](image)

**Figure 3.11** VIVA Buses at Finch Terminal (photo by author)

3.3.2.5. Intelligent Transportation Systems and Transit Priority Measures

VIVA employs several Intelligent Transportation Systems (ITS) and transit priority tools to enhance the performance of the system. Firstly, conditional transit signal priority (TSP) is provided at signalized intersections along the routes operated by VIVA. The TSP measures can
either extend the green phase of the through-street or truncate the red phase of the cross-street. The duration of this extension/duration varies depending on the route’s adherence to schedule, as determined by the Computer Aided Dispatch/Automatic Vehicle Location (CAD/AVL) system (York Region Transit, 2006). Secondly, queue jump lanes are provided at some intersections on roads with VIVA service. Formerly right-turn bays, queue jump lanes allow buses to bypass traffic at intersections and reduce delays (Niles & Callaghan Jerram, 2010). Finally, VIVA employs Advanced Traveller Information Systems (ATIS) in the form of next bus notification signs at stations. As shown in Figure 3.12, these variable message signs display real-time predictions for the arrival of the next vehicle at the station using AVL data and travel time prediction algorithms (Niles & Callaghan Jerram, 2010).

![Figure 3.12 VIVA Advanced Traveler Information System (photo by author)](image-url)
3.3.3. **Future Plans**

The second phase of the VIVA deployment plan, known as VIVAnext, is currently in the planning and construction stage. At the core of this second phase is the implementation of what are termed “rapidways” by York Region and its private sector partners. In essence, a rapidway is one exclusive bus lane per direction located in the roadway median, similar to those in many BRT systems operating in South America. New stations will be constructed adjacent to the rapidways with access by signalized crosswalks and sidewalks (York Region Rapid Transit Corporation, 2010). Currently, VIVA is working on five rapidway projects: Davis Drive in Newmarket, Highway 7 in Markham, Highway 7 in Vaughan, Yonge Street in Richmond Hill and Yonge Street in Newmarket. Construction on segments of the Davis Drive and Highway 7 (Markham) rapidways has already commenced. All rapidways are scheduled to be complete by 2020 (York Region Rapid Transit Corporation, 2010).

In addition to the BRT rapidways, there are several transit projects originating in the City of Toronto that will cross the municipal boundary into York Region and connect with the VIVA system. These projects include the extension of the Spadina subway line into Vaughan (under construction as of 2011), the extension of the Yonge subway line to Richmond Hill (in planning), and the proposed Don Mills and Jane light rail transit (LRT) lines (on hiatus due to a change in Toronto’s municipal government). All of these projects are shown in Figure 3.13 VIVAnext Projects. It should be noted that the term “rapid transit”, as applied on the map, is used loosely to denote rapidways.
Figure 3.13  VIVAnext Projects (used by permission)
4. Corridor Trends

This chapter evaluates VIVA’s ridership impacts at the level of the corridors in which the service operates. This is done in two ways. The first section contains an evaluation of the impact of access distance to VIVA on transit patronage. The second section presents a simple time series analysis of ridership counts on VIVA routes in the Yonge Street and Highway 7 corridors.

4.1. Patronage by Proximity to Corridors

4.1.1. Procedure

The method used to determine the transit mode share by access distance to VIVA required three different sources of data. First, a geocoded file of VIVA station locations was obtained from York Region and input into an ArcGIS database of the GTA road network. Buffer zones of 500, 1000 and 1500m were then generated around each station based on actual walking distance on the road network. Second, the 2001 TTS zone system was obtained in GIS format, and using ArcGIS, the geometric centroid of each zone was calculated. Then, centroids were allocated to a buffer zone depending on their location. Lastly, the transit mode share of all zones whose centroids were located within the 1500m threshold were retrieved from the TTS database and sorted according to their buffer zone.

Admittedly, there are shortcomings associated with this method. This analysis is at an aggregate level, not a disaggregate level. That is, the access distance is based on a geometric mean location, not the actual distances that people must travel to access VIVA. This strategy was used because privacy issues associated with disaggregate geocoded data prevented a more detailed analysis. Additionally, geometric centroids were used to represent the point from which all trip makers accessed, rather than population centroids. Unfortunately, this metric could not be calculated with the data available. Despite its drawbacks, the method presented here is not significantly different from the techniques used to obtain road and transit access distances and times in network assignment software and is therefore not without merit.

4.1.2. Results

The results of the procedure described above are shown in Figure 4.1 and Figure 4.2.
Figure 4.1  Transit mode share by access distance to VIVA

![Transit Mode Share by VIVA Access Distance](image)

Figure 4.2  Rate of transit trip increase by access distance to VIVA

In Figure 4.1, a decreasing trend in transit mode share is observed as the access distance to VIVA increases. The reason for this is fairly intuitive; access distance can constitute a sizeable chunk of total travel time—the longer the access distance, the longer the total travel time. Therefore, we expect transit use to be higher amongst those with better access to transit service. Although this trend was similar in 2001 and 2006, it is interesting to note that there was more growth in transit patronage in zones that were further away from VIVA stations. This is best

![Rate of Transit Trip Increase by VIVA Access Distance](image)
illustrated by the trend shown in Figure 4.2; as access distance increases, the growth in transit trips also increases. One could posit that this was due to the improved service offered by VIVA. If the in-vehicle travel time on transit is dramatically reduced because of an improvement in service, then it may be more reasonable to the trip-maker to walk the added distance to that service. There are, however, many other potential explanations for this pattern. For example, if there was an increase in people that are captive to transit in households further away from VIVA stations, this pattern would also be observed.

4.2. Corridor Boardings

This section presents basic time series analyses for the two primary corridors in which VIVA operates: Yonge Street and Highway 7. For each corridor, monthly ridership for all bus services are presented and analyzed by qualitatively relating increases in ridership to seasonal patterns and the introduction of new lines. Furthermore, an estimate of new versus shifted riders in each corridor is undertaken.

4.2.1. Yonge Street Corridor

In York Region, Yonge Street is served by 3 different bus systems: GO Transit’s Newmarket “B” service, VIVA’s Blue line, and York Region Transit routes 98 and 99. GO buses offer a high-speed service with only seven stops between Newmarket and York Mills subway station in Toronto. VIVA Blue offers an intermediate level of service with stations spaced 500m-2km between Newmarket and Finch subway station. YRT routes 98 and 99 offer local bus service, with stops at most intersections. Route 98 serves Newmarket, Aurora, and Richmond Hill, while route 99 serves Richmond Hill and Thornhill.

Figure 4.3 charts the total weekday revenue boardings for each service between September 2003 and December 2006. Prior to September 2003, GO operated a Yonge “C” route that was similar in operating characteristics to YRT routes 98 and 99. Unfortunately, monthly boarding data was not available for this line. Adequate analysis could therefore not be performed for earlier dates.
From September 2003 to September 2005, we observe a slight growth in total ridership. We can also observe seasonal variations associated with major holidays and the school year. For example, ridership exceeding the six month moving average in September, October and November coincides with the beginning of the school year; also, this time of year generally coincides with relatively low vacation travel. Ridership drops below the moving average in December and January during the holiday season and then rises again, before dropping once more during the summer. In September 2005, however, a significant increase over the moving average occurred; this coincided with the introduction of the VIVA Blue service. Although ridership on competing routes 99 and GO “B” dropped significantly, the increasing moving average corridor ridership clearly shows that these losses were offset by new riders.

4.2.2. **Highway 7 Corridor**

Highway 7 is served by four different bus routes. YRT route 1 is a local route between Markham-Stouffville Hospital and Richmond Hill Centre. YRT route 77 is a local route between Bramalea City Centre in Peel Region to Finch Subway Station in Toronto via Richmond Hill
Centre. VIVA Purple runs from Martin Grove Road in Woodbridge to McCowan Road in Markham. Finally, VIVA Orange runs from Martin Grove Road to Downsview Subway Station in Toronto via York University. Figure 4.4 charts the monthly revenue boardings of these four routes from January 2001 to November 2006.

**Monthly Revenue Boardings: Highway 7 Corridor**

![Graph](image)

**Figure 4.4**  Highway 7 corridor revenue boardings

The pattern for Highway 7 is very similar to that of Yonge Street. Until October 2005, ridership growth was slow, with most changes attributable to seasonal variations. However, when VIVA Purple was introduced in October 2005, ridership jumped dramatically above the six month moving average; another jump occurred the following month when VIVA Orange began service. Interestingly, competing routes did not show the same dramatic drop in ridership that was observed in the Yonge Street corridor. This suggests that there were a greater percentage of new riders along Highway 7 than along Yonge Street. To illustrate this, Figure 4.5 shows the percentage of new versus diverted ridership on VIVA routes in both corridors. New ridership is calculated as the difference between the total corridor ridership in 2006 and 2004. Diverted ridership is calculated as the 2006-2004 decrease of local and GO transit ridership. By
definition, the sum of new and diverted ridership must equal 2006 VIVA ridership; therefore, each can be expressed as a percentage of VIVA ridership. The graph clearly shows that new riders constitute a much larger percentage of VIVA passengers in the Highway 7 corridor than in the Yonge Street corridor.

![VIVA Ridership - New vs. Diverted](image)

**Figure 4.5** New and diverted ridership on VIVA routes

**4.3. Discussion**

This chapter revealed a number of interesting facts about transit patronage in the Highway 7 and Yonge corridors before and after the introduction of VIVA. We first observed that as access distance to VIVA increased, transit mode share decreased; this reflects the assumption that increased access time leads to increased total travel time, resulting in lower transit use. It was also observed, however, that the growth rate of transit patronage after the introduction of VIVA was higher for traffic zones that were further away from VIVA stations. One can posit that this is a manifestation of latent transit demand as a result of better in vehicle travel time offered by VIVA. In the second section of the chapter, a simple time series analysis of the Yonge and Highway 7 corridors revealed sharp increases in corridor ridership after the start of VIVA service. This is solid supporting evidence to the argument that the introduction of VIVA was an important factor in the major changes in overall transit mode share in York Region. Finally, it was observed that VIVA routes operating in the Highway 7 corridor attracted a greater percentage of new riders than Yonge Street’s VIVA Blue. There are likely two reasons for this. First, unlike Yonge Street, Highway 7 was not served by an express transit route prior to the introduction of VIVA. Whereas Yonge was served by multiple GO transit routes, the only routes
serving Highway 7 were local in scale and thus stopped very frequently. When VIVA was introduced, transit travel time was greatly reduced because stops were separated by greater distances. A second explanation for the greater percentage of new riders along Highway 7 can be linked with increases in auto traffic. According to the EMME travel forecasting model used for input to the mode choice model presented in Chapter 6, the peak-direction peak-hour traffic volume on Highway 7 in Richmond Hill increased roughly 25% between 2001 and 2006. By comparison, the peak-hour peak-direction volume on Yonge Street increased only 10%. Therefore, individuals living in the Highway 7 corridor had the additional impetus to switch to transit because traffic grew proportionally worse in comparison to the traffic on Yonge Street.
5. Regional Trends

This chapter presents aggregate demographic and trip-related data for both York Region and Peel Region for the years 2001 and 2006. The purpose of this is threefold. First, it verifies whether there have been any significant exogenous demographic influences particular to York Region that may have affected transit patronage. Second, it provides insight into the demography of new transit riders. Finally, it allows for a comparison between the changes in travel behaviour in two similar regions. The chapter is divided into two sections: the first section describes the source and nature of the data, while the second section presents and discusses the trends extracted from the data.

5.1. Procedure

5.1.1. The Transportation Tomorrow Survey

The Transportation Tomorrow Survey (TTS) is a major travel survey of the Greater Toronto and Hamilton Area (GTHA). The survey has been conducted every five years since 1986 and collects information about households, residents, and the trips made by those residents over a 24-hour period. The survey is a joint endeavour between the member agencies of the Transportation Information Steering Committee (TISC), which includes representatives from the Cities of Toronto and Hamilton, the Regions of York, Durham, Peel and Halton, the Toronto Transit Commission, GO Transit, and the Ontario Ministry of Transportation. The Data Management Group (DMG) at the University of Toronto is responsible for the management and distribution of data to TISC agencies (Data Management Group, UTRAC, 2008). The data for this study was taken from the 2001 and 2006 instalments of the TTS in order to provide a picture of the state of travel patterns in York Region before and after the introduction of VIVA.

In 2001, 137,000 interviews were completed for households in TISC municipalities, as well as the Regional Municipalities of Niagara and Waterloo, the counties of Peterborough, Simcoe, Victoria and Wellington, the Cities of Barrie, Guelph, and Peterborough and the Town of Orangeville. The 2006 survey was similar to that of 2001, except roughly 150,000 surveys were performed and the survey area grew to include the Regional Municipality of Waterloo, the City of Brantford and the County of Dufferin (Data Management Group, UTRAC, 2008). The
boundaries for various years of the TTS are shown in Figure 5.1 (Data Management Group, UTRAC, 2007).

Figure 5.1  Transportation Tomorrow Survey Boundaries

5.1.2. Data Retrieval

Data from the Transportation Tomorrow Survey was retrieved using the Data Management Group’s Internet Data Retrieval System (iDRS) (Data Management Group, UTRAC, 2008). This service allows users to perform queries on TTS data and return output in the form of a text-based matrix, frequency distribution or record count.

For this chapter, frequency distribution queries were performed to return the number of trips by mode for different trip and demographic attributes. In order to ensure the sampled data reflected actual conditions, expansion factors were multiplied by each individual data point. The mode classifications presented here are aggregations of the many sub-mode options defined in the TTS: “Transit” is defined as the sum of the “Transit excluding GO rail”, “GO rail only” and “Joint GO rail and public transit” modes; “Auto” is defined as the sum of “Auto driver”, “Auto
passenger” and “Taxi passenger”; “Walk/Cycle” is defined as the sum of “Cycle” and “Walk”; “Other” is defined as the sum of “Unknown”, “Motorcycle”, “Schoolbus” and “Other”.

5.2. Results

Five basic graph types are used here to present results:

1. The frequency distribution graph breaks each region down by household, person or trip characteristic. This permits an analysis of potential demographic or trip characteristic shifts that may account for a change in transit patronage.

2. The mode split graph expresses the number of trips made by each mode as a percentage of the total number of trips made over a 24 hour period. This is a common tool to assess the relative use of a mode.

3. The rate of trip increase graph presents the percentage increase in the number of trips made on a particular travel mode. It is calculated as the difference between the number of trips made on that mode in 2006 minus those from 2001, all divided by the 2001 trips on that mode. This illustrates the use of a mode relative to its past performance.

4. The share of trip increase graph is similar to the mode split graph, except it only accounts for new trips. Each data bar is calculated as the increase in trips on that mode divided by the total increase in trips.

5. The contribution to transit increase graph illustrates how each household/individual/trip characteristic contributed to the increase in the number of transit trips. It is calculated as the increase in transit trips by the demographic subset of interest divided by the total increase in transit trips. This permits an analysis of the relative importance of these characteristics on the increase in transit use.

For the sake of brevity, not every graph is included for every characteristic; the intent of this section is to present a selection of the relevant or interesting queries performed. The following subsections present these results for various indicators of transit demand. The complete collection of graphs can, however, be found in the Appendix.
5.2.1. **Overall**

A logical starting point for the presentation of this data is to obtain an overall picture of the state of travel behaviour for the years 2001 and 2006 for the residents of York and Peel. This begins with Figure 5.2 and Figure 5.3, which present the 24-hour mode split for all trips.

**Figure 5.2** 24-hour mode split in York Region: 2001 and 2006

**Figure 5.3** 24-hour mode split in Peel Region: 2001 and 2006
The preceding figures show that both regions are very auto-dominated, with more than 80% of all trips being made by car. However, 24-hour transit mode share has increased in both York and Peel Regions at the expense of auto share. In York Region, the increase was from 5% to 7% and in Peel Region from 7% to 8%, while auto share has dropped from 88% to 86% and 86% to 85%, respectively. For the purpose of comparison, Figure 5.4 and Figure 5.5 present the AM peak period mode share for York and Peel for the years 2001 and 2006.

**Figure 5.4**  AM peak period mode split in York Region: 2001 and 2006

**Figure 5.5**  AM peak period mode split in Peel Region: 2001 and 2006
Comparing Figure 5.4 and Figure 5.5 to Figure 5.2 and Figure 5.3, we note that mode split patterns are similar during the AM peak and 24-hour periods for both regions. As such, the rest of the trip data presented in this chapter is based on a 24 hour analysis period. This can be justified by the fact that analyzing an entire day’s worth of data arguably paints a more complete picture of overall transit use. Studying peak periods tends to inflate the importance of transit because of factors such as higher auto congestion and better transit levels of service. Furthermore, a 24-hour analysis period permits an examination of how transit use varies by time of day.

The data can be further analyzed by calculating the percent increase in trips for each mode and the share of the total increase in trips by each mode.

**Figure 5.6** 24-hour rate of trip increase by mode

Figure 5.6 shows that in York Region, transit use increased at a higher rate than the average and at a higher rate than Peel Region. Furthermore, the increase in auto use in York is slower than in Peel and the rate of increase in walking/cycling is higher in York than in Peel.
Figure 5.7 24-hour share of travel increase by mode

Figure 5.7 shows that the auto mode accounted for the majority of the increase in travel in both regions, but that transit accounted for a greater percentage of the increase in York Region than in Peel Region.

It has now been established that there was, in fact, an increase in the use of transit in York after the introduction of VIVA over and above the increases observed in the control region. With this established, we can now explore the possible causes of this phenomenon by breaking the regions down by demographic and trip characteristics that serve as indicators of transit demand.

5.2.2. Trip Purpose

Trip purpose serves as a useful classifier of transit demand because of the characteristics associated with each trip type. For example, work and post-secondary (PS) school trips are more likely to occur on transit in comparison to other trip types. These trips tend to be made during peak hours when traffic congestion is high, making transit more competitive. Furthermore, post-secondary school trips are often made by young people who cannot afford to drive, while work trips often have a trip end that is difficult or expensive to access by private auto (ie, the downtown core). Conversely, non home-based and discretionary trips are less likely to be served by transit because they either occur between locations that are typically easier to reach by car or are part of a larger trip chain, which is also more easily served by car. As a corollary, it can be argued that one quality of a strong transit system would be its ability to serve non home-based
and discretionary trips. Finally, elementary and high school (ES/HS) trips are generally poorly served by transit. This is due to the fact that school bus service is often provided (occasionally by the local transit agency) and the trip distance is often short enough to be served by non-motorized modes. Figure 5.8 presents a breakdown of York and Peel trips by purpose for the years 2001 and 2006.

**Figure 5.8** Frequency distribution of trip purpose

The data presented above do not show any unexpected trends. The increase in each trip type is fairly consistent across the board, although the percentage increase in home-based school and discretionary trips is larger in Peel than in York. That said, there is no considerable shift in trip purpose in York that would directly explain a jump in transit patronage.

Amongst the five trip purposes defined by the survey, post-secondary school trips produced the most interesting results. There was a 105% increase in the number of home-based post-secondary school transit trips made in York between 2001 and 2006 despite only a 5% increase in the total number of home-based post-secondary school trips. In Peel, there was a 94% increase in post-secondary school transit trips with a 14% increase in the total number of post-secondary school trips. Figure 5.9 further illustrates this trend, showing the mode split of home-based post-secondary school trips in York and Peel.
The transit share for post-secondary school trips by York Region residents jumped from 22% to 44%; in Peel Region the increase was from 24% to 40%. This very large increase came largely at the expense of auto trips; as shown in Figure 5.9, the auto mode share in York dropped more significantly than the auto share in Peel. One could posit that these large increases in transit mode split are a result of improved service to post-secondary institutions in the vicinity of York and Peel. In York, VIVA Purple and Orange both serve York University at a level of service that was not provided in 2001. In Peel, Mississauga and Brampton Transit also improved service to the University of Toronto at Mississauga and Sheridan College, respectively. Figure 5.10 further illustrates the importance of post-secondary trips to the overall increase in transit patronage in both York and Peel.
This figure shows some interesting results. We observe that home-based work and elementary/secondary school trips constituted a larger percentage of new transit trips in York Region than in Peel Region, whereas the opposite was true for post-secondary, home-based discretionary trips and non home-based trips. Furthermore, home-based post-secondary school trips were the second largest contributor to new transit trips in both York and Peel, despite the fact that they account for the smallest percentage of total trips. This is not entirely surprising given the low income typically associated with those attending post-secondary school.

5.2.3. Age

Age is another important determinant of mode choice. The predominant mode for children under the age of 16 is auto passenger since they are not old enough to drive a car and generally do not take transit alone. Other highly-used modes for this age demographic are Walk/Cycle and Schoolbus. Transit use is highest for trip-makers aged 16-25; at this stage in life, people are more independent and able to drive a car, but typically lack the income to own one. Above the age of 25, transit use declines significantly as income rises. There is, however, a slight reversal of this trend above the age of 65 when income decreases and individuals may have to give up their license for health reasons. Figure 5.11 breaks down the populations of York and Peel Regions by age in order to assess if there have been any major demographic shifts in York that could have caused an increase in transit patronage.

![Frequency Distribution of Age](image)

**Figure 5.11** Frequency distribution of age
Once again, the data do not indicate any major changes in age breakdown that would explain an increase in transit use. The largest percentage increase for both regions was observed in the 45-65 age bracket; this is consistent with the aging “baby-boom” generation. However, given that this age group has very low transit use, it is unlikely that this increase caused a jump in transit patronage. The following two figures provide further detail for the age bracket with the highest transit use.

**Mode Split - York Region: Ages 16-25**

![Mode Split Chart](image)

**Figure 5.12** Mode split – York Region: Ages 16-25

**Rate of Trip Increase: Ages 16-25**

![Rate of Trip Increase Chart](image)

**Figure 5.13** Rate of trip increase: Ages 16-25
In Figure 5.12, we can observe a nearly two-fold increase in transit mode split and a corresponding decrease of 9 percentage points in auto mode split. This is further illustrated in Figure 5.13, which shows the number of auto trips made by 16-25 year olds actually decreased 10% amongst York Region residents, despite a 2% increase in the total number of trips by this age bracket. This trend was also observed in Peel Region, but the decrease in auto trips was only 7%. Below, Figure 5.14 further reinforces the significance of the 16-25 age demographic with regards to transit use.

**Figure 5.14**  Contribution to transit increase by age

With roughly 45% of new transit trips in both York and Peel attributed to them, it is clear that 16 to 25 year olds represent the most important age demographic for transit use. However, another interesting trend is shown in this figure. In York Region, 26-45 year olds contributed significantly more to new transit trips than in Peel Region, whereas the reverse was true for 46-65 year olds. Given that the proportional representation of these two age brackets is very similar, the underlying reason for this trend is not obvious. However, it may indicate that the introduction of VIVA was more enticing to a younger demographic due to factors such as branding, technology, or access distance. This, however, is merely speculation.

5.2.4. **Number of Vehicles**

There are two primary reasons why the number of vehicles owned by a household is indicative of transit use. First, and most importantly, a high number of vehicles per household increases the
likelihood that an auto will be available to make a given trip. This auto availability is an extremely important factor in the determination of mode choice. Second, the number of household vehicles can be used as a rough proxy for income. Household income is another important determinant of mode choice, but unfortunately it is not one of the questions asked in the Transportation Tomorrow Survey. Income is, however, collected by the national long-form census but it cannot be related directly to transit use at the household level of aggregation. Below, Figure 5.15 presents the frequency distribution of the number of vehicles per household in both Peel and York for the years 2001 and 2006.

![Frequency Distribution of Vehicles Per Household](image)

**Figure 5.15** Frequency distribution of number of vehicles per household

This figure shows a definite discrepancy between vehicle ownership patterns in York and Peel regions. In York Region, 2 and 3+ vehicle households constitute a larger proportion of the total than in Peel Region. It can be posited that this is due to higher household income in York. According to data from the Canadian census (Statistics Canada, 2010), the median family income in 2000 was roughly $87,000 in York and $79,000 in Peel (in 2005$). For 2005, this statistic dropped to $83,000 for York and $73,000 for Peel. While this income difference may explain vehicle ownership trends, it remains to be seen whether it is an important explanatory factor for York Region’s increase in transit patronage. The following figures explore this in greater detail.
Figure 5.16 Mode split: 0-vehicle households

Figure 5.17 Share of trip increase: 2-vehicle households

Figure 5.16 and Figure 5.17 provide insight into the trends of two different auto-ownership categories. Figure 5.16 shows that transit mode share amongst 0-vehicle households in York Region actually declined between 2001 and 2006, whereas the opposite was true in Peel Region. However, Figure 5.17 shows that, amongst 2-vehicle households, transit represented a larger share of new trips in York than in Peel. This suggests that York Region Transit service is better at attracting choice riders than captive riders.

5.2.5. Gender

Due to the fact that females have historically been more likely to take transit than males, gender remains an important indicator of transit demand. Below, Figure 5.18 and Figure 5.19 present
the gender breakdown of York and Peel Regions and their contribution to the increase in transit patronage.

**Figure 5.18** Frequency distribution of gender

**Figure 5.19** Contribution to transit increase by gender

First, we can observe that there has been negligible change in the gender breakdown of either region between 2001 and 2006. It is worth noting, however, that females represent a slightly higher percentage of the population in both York and Peel; this is likely a result of longer life expectancy for females. With respect to the contribution to the transit trip increase by each sex,
York Region males contributed more to the increase in transit trips than in Peel Region. Once again, there is no way of assessing exactly why this is the case, but it can be surmised that some aspect of the transit service in York Region led to a disproportionately large increase in male patronage in comparison to service in Peel Region.

5.2.6. **Departure Time**

Departure time is an important explanatory variable for transit patronage given the characteristics of transit and auto levels of service at different times of day. During the AM and PM peak periods, transit levels of service are higher than average to meet increases in demand; conversely, auto levels of service are lower during peak periods because of increased congestion. As such, it is typical to observe a higher transit mode share during peak periods. Below, Figure 5.20 breaks down the total number of trips in York and Peel by departure time in order to analyze the spread of trips made throughout the day.

![Frequency Distribution of Departure Time](image)

**Figure 5.20** Frequency distribution of departure time

Unsurprisingly, this figure shows the majority of trips made throughout the day are made during peak periods. Trip increases are fairly consistent across the board, with the exception of AM peak period trips in Peel (which increased 24% vs. 18% in York). As before, there is not any significant shift in departure time trends that could explain the sizeable increase in transit use in York Region. Figure 5.21 and Figure 5.22 show the mode split of new trips for the AM and PM peak periods in both York and Peel.
The preceding figures illustrate a discrepancy between the two regions with respect to the transit share of new trips during peak periods. While the transit share for new trips in York was consistent for both the AM and PM peak periods, there was a lower share in the AM peak period for Peel. This trend is also shown in the contribution to transit increase chart below.
Figure 5.23 Contribution to transit increase by departure time

Figure 5.23 shows that in York Region, trips started during the AM peak period constitute a larger percentage of new transit trips than in Peel Region. This may indicative greater “peak spreading” during the AM peak period in Peel. This is a growing phenomenon in which trips formerly made during peak periods have shifted in order to avoid congestion. Although this spreading is more common with auto users, it is also applicable to transit. Another possible explanation for the discrepancy could be that some attribute of the transit systems in Peel made midday trips more appealing in comparison to York. This is consistent with the observation that Peel had a larger contribution of home-based discretionary and non home-based transit trips than York.

5.2.7. Trip Distance

The final indicator of transit demand to be examined is trip length. For very short trip lengths (less than 2km), transit use is quite low. Because of the significance of access and wait time to the total trip time, these trips are better served by non-motorized modes and auto. Transit becomes more competitive for mid-range trip lengths depending on the quality of the service and the land use characteristics of the origin and destination. As shown in Figure 5.24, mid-length trips represent a large proportion of trips being made in both York and Peel.
The preceding figure shows that although there are a significant number of trips below 2km, mid-length trips between 2 and 20km make up a significant proportion of all trips in York and Peel. This trend did not change significantly between 2001 and 2006, although York Region did experience larger growth in trips 30-40km and 40+km. Below, Figure 5.25 illustrates how each trip length segment contributed to the total increase in transit trips.

Figure 5.24 Frequency distribution of trip length

Figure 5.25 Contribution to transit increase by trip length
The preceding figure shows that the largest contributors to the increase in transit trips were trips of length between 20km and 40km. The most likely reason behind this finding is the importance of downtown Toronto as a destination for York Region residents. Although York does have a significant amount of employment within its boundaries, it is mostly easily accessed by private auto. Furthermore, the most important employment and post-secondary education destination in the GTA continues to be downtown Toronto, which is roughly 30km from the geographic centroid of urban York Region. It was also observed that transit trips of this length did not rely heavily on GO Transit. For 20-30km trips by York residents, local transit had a 15% total mode share, compared to 4% by GO; in Peel Region, local transit had a 8% share and GO had 6% share over this distance.

5.2.8. Discussion
The preceding analysis has revealed some important information about the travel and demographic patterns in the regions of York and Peel. It has been shown that there has been an appreciable increase in transit use in York above what was observed in the control region of Peel. It was also shown that transit use is increasing more rapidly in York and that auto mode split decreased more in York. Further analysis revealed that certain demographic segments contributed much more to this change than others. For example, trip-makers between the ages of 16-25 contributed to 45% of new transit trips in York Region despite making up only 12% of the 2006 population. This can likely be attributed to the income level of this demographic. The contribution of home-based work and post-secondary school trips was also significant; together, these trips account for 76% of York’s new transit trips. The reason for this likely stems from two sources. Firstly, the school or work end of these trips are generally easier to serve by transit than other destinations because they typically occur during peak hour and are usually located in areas of higher density of land use than the trip origin. Secondly, individuals making post-secondary school trips generally have low incomes and are often captive to transit. Finally, it was observed that trips 20-40km contributed disproportionately to York’s new transit trips in comparison to Peel. This is likely a reflection of work and school trips destined for downtown Toronto. Although it is a considerable distance from York, the high price of parking and lengthy auto travel time to downtown likely make transit a viable choice for many York Region residents. This can also be said of trips originating in Peel; however, their average distance to downtown is likely longer considering the proportionally larger increase in 40km+ trips in Peel.
As previously noted, one significant explanatory variable that has been absent from this analysis is income. Because of the high costs associated with operating a private vehicle, it is reasonable to expect that transit ridership will increase if household income decreases. In this study, transit mode share increased over a period when inflation-adjusted income decreased (as per census data), but the disaggregate trip data does not contain the trip maker’s income. Without this data, it is not possible to directly associate mode choice with a decrease in income. This is an unfortunate disadvantage of using the TTS dataset and introduces a significant caveat into the findings of this study.

Despite the observations of this chapter, the root cause for the changes in behaviour is still unknown. Specifically, it is not clear whether the introduction of VIVA was a major contributor to the increase in transit patronage. All that has been confirmed is that there have been no significant changes in demographic or trip patterns in York Region that might be responsible for a significant increase in transit patronage. Therefore, the source of the change must be a result of either a change in the perception of transit or a change in transit or auto levels of service. To analyze how these factors may have influenced transit use, a mode choice model of travel in York Region is estimated in the following chapter.
6. Mode Choice Model

In this chapter, VIVA’s region-wide impact on home-based work and home-based post-secondary school mode share is estimated quantitatively through the use of mode choice models. The first section in this chapter defines the EMME network model used to obtain level of service data for the years 2001 and 2006. The second section then outlines the formulation of a generalized extreme value mode choice model. The third section presents model estimation results for home-based work and post-secondary school trips and describes the procedure for estimating the impact of improved transit service and increased congestion on transit mode share.

6.1. Network Model

In order to obtain travel time and cost inputs for the mode choice model, it was necessary to run a computer simulation of travel demand in the Greater Toronto Area (GTA). This was accomplished using the assignment modules of Prof. Eric Miller’s GTAModel (Miller, 2007), which is a suite of EMME macros and Fortran programs used to model GTA road and transit trips. Because the transit network coded into GTAModel represents the level of service offered during the AM peak period, all modeling work in this chapter corresponds to this time of day.

The first step in running the network model was to obtain the AM peak period auto and transit trip matrices from the Transportation Tomorrow Survey. For auto trips, the trip matrix was a necessary input to the model since EMME’s auto assignment algorithm is based on the concept of user equilibrium; that is, the results of the assignment are dependent on the number of trips assigned. This is not the case for transit assignment, but the trip matrix was used to validate the results of the assignment. With these matrices prepared, the next step was to run the auto assignment module of GTAModel. The procedure for this consisted of a standard generalized cost user equilibrium road assignment. The cells in the auto matrix were first multiplied by an assumed peak-hour factor of 0.43 and then assigned according to a generalized cost equilibrium defined by the auto cost and toll road cost factors defined in Table 6.1. Zone-to-zone auto costs and times were collected during this procedure for input into the mode choice model. The transit assignment procedure used was based on the concept of optimal strategies, with time (rather than cost) being the basis for the assignment. Table 6.1 presents the parameters used for this assignment. Walk speed is the assumed speed at which people walk to leave their home zone or
reach their destination zone; the various time weights define how individuals value the different components of transit travel time when making path decisions; transit fares are not a determinant of path choice in this model, however accrued fares were collected for each zone pair for input into the mode choice model; finally, boarding times were used to calibrate ridership counts by introducing an artificial time penalty to meter ridership on different systems.

Table 6.1  Assignment parameters

<table>
<thead>
<tr>
<th>Description</th>
<th>2001</th>
<th>2006</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Auto Assignment Parameters</strong></td>
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<td></td>
</tr>
<tr>
<td>Peak-hour factor</td>
<td>0.43</td>
<td></td>
</tr>
<tr>
<td>Auto cost factor ($/km)</td>
<td>0.081</td>
<td>0.047</td>
</tr>
<tr>
<td>Toll road value of time ($/hr)</td>
<td>30</td>
<td>10.22</td>
</tr>
<tr>
<td>Max. No. Iterations per assignment</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Relative gap (%)</td>
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<td></td>
</tr>
<tr>
<td>Normalized (min)</td>
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<td></td>
</tr>
<tr>
<td>Unit toll road cost ($/km)</td>
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<td></td>
</tr>
<tr>
<td><strong>Transit Assignment Parameters</strong></td>
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<td></td>
</tr>
<tr>
<td>Walk speed (km/hr)</td>
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<td></td>
</tr>
<tr>
<td>Wait time factor</td>
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<td></td>
</tr>
<tr>
<td>Wait time weight</td>
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<td></td>
</tr>
<tr>
<td>Walk time weight</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Boarding time weight</td>
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<td></td>
</tr>
<tr>
<td>Toronto base fare ($)</td>
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<td>1.83</td>
</tr>
<tr>
<td>GO Transit base fare ($)</td>
<td>2.75</td>
<td>3.55</td>
</tr>
<tr>
<td>York base fare ($)</td>
<td>1.92</td>
<td>2.28</td>
</tr>
<tr>
<td>Peel base fare ($)</td>
<td>1.75</td>
<td>1.95</td>
</tr>
<tr>
<td>Halton base fare ($)</td>
<td>1.87</td>
<td>2.15</td>
</tr>
<tr>
<td>Hamilton base fare ($)</td>
<td>1.68</td>
<td>1.41</td>
</tr>
<tr>
<td>Durham base fare ($)</td>
<td>1.75</td>
<td>2.33</td>
</tr>
<tr>
<td>TTC subway boarding time (min)</td>
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</tr>
<tr>
<td>TTC regular bus boarding time (min)</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>TTC premium bus boarding time (min)</td>
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<td></td>
</tr>
<tr>
<td>TTC streetcar boarding time (min)</td>
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<td></td>
</tr>
<tr>
<td>GO Train boarding time (min)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>GO Bus boarding time (min)</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Durham Region bus boarding time (min)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>York Region bus boarding time (min)</td>
<td>6.4</td>
<td></td>
</tr>
<tr>
<td>Peel Region bus boarding time (min)</td>
<td>3.1</td>
<td></td>
</tr>
<tr>
<td>Halton Region bus boarding time (min)</td>
<td>4.1</td>
<td></td>
</tr>
<tr>
<td>Hamilton Region bus boarding time (min)</td>
<td>2.3</td>
<td></td>
</tr>
</tbody>
</table>
The results of the transit assignment procedure were validated against actual route ridership from the TTS. Graphs of this validation are given in Figure 6.1 and Figure 6.2, which show a fairly high $R^2$ value for both 2001 and 2006 and thus a high correlation between modeled and actual ridership.

Figure 6.1  Actual vs. modeled ridership - 2001 local transit

Figure 6.2  Actual vs. modeled ridership - 2006 local transit
6.2. Mode Choice Model Formulation

The mode choice model used for this analysis was based on a model developed by Habib and Swait (2011). In brief, the goal of the formulation is to introduce choice heterogeneity into a model that allows for general dependence amongst alternatives. The result of this is a generalized extreme value (GEV) model that parameterizes the positive scale parameter that is an artefact of the assumption of extreme value distributed error terms.

Consider a GEV model with random utility component $\epsilon_{in}$ and a cumulative distribution function of:

$$F(\epsilon_{i1}, \epsilon_{i2}, ..., \epsilon_{i3}) = \exp (-G(e^{-\epsilon_{in}\mu_n}))$$  \hspace{1cm} (6.1)

The marginal distribution of any random element $\epsilon_{in}$ is thus:

$$F(\epsilon_{in}) = F(\infty, \ldots, \epsilon_{in}, \ldots, \infty) = \exp(-G(0, \ldots, e^{-\epsilon_{in}\mu_n}, \ldots, 0)) = \exp (-a_m e^{-\epsilon_{in}\mu_n})$$  \hspace{1cm} (6.2)

Where $a_m = G(\delta_{1n}\delta_{2n}, \ldots, \delta_{jn})$; $\delta_{1n} = 1$ if $i=m$, 0 otherwise. From this, we can derive the probability of individual $i$ choosing mode $n$ as:

$$p_{im} = e^{V_{in}\mu_n} G_n(e^{V_{in}\mu_n}) / G(e^{V_{in}\mu_n})$$  \hspace{1cm} (6.3)

To obtain the function $G$, we need to assume a choice structure. Following the work of Habib and Swait, the choice structure for this model follows what is illustrated in Figure 6.3. Each choice cluster has a separate scale parameter $\mu$, as indicated on the graph.

---

**Figure 6.3** Mode Choice Structure
The choice structure above leads to the following generating function:

\[ G_i = \left( \sum_{n=AD,AP} e^{V_{in} \mu_A} \right)^{\mu/\mu_A} + \left( \sum_{n=L,T,SAA,GAA,GT} e^{V_{in} \mu_T} \right)^{\mu/\mu_T} + e^{V_i(NMT)\mu} \]  

(6.4)

The non-motorized cluster has same value as the root; we identify the auto and transit scale parameters relative to the non-motorized scale parameter.

In order to isolate the effects of heterogeneity, this model parameterizes the scale parameter as a function of occupation category. We express the scale for mode cluster \( c \) and individual \( i \) as:

\[ \mu_{ic} = \exp(\theta_k \varphi_k) \text{ all } i, c \]  

(6.5)

Where \( \varphi_k \) is a vector of zeroes except element \( k \), which is equal to 1 if individual \( i \) has job occupation category \( k \). \( \theta_k \) is the vector of estimation parameters for all \( k \) job categories. By parameterizing scale in this way, it is possible to assess which professions are more likely to have a high degree of variance in their choice preferences. Since the scale parameter is inversely proportional to the standard error of the random utility components, we can conclude that higher values of scale indicate a lower degree of choice variability (Ben-Akiva & Lerman, 1985).

We can now express the model using the following conditional probability equations. Here, the commuter subscript \( i \) is omitted for clarity.

**Construct Nodes:**

\[ Q_{NMT} = \frac{\exp(\mu_{NMT})}{\exp(\mu_{NMT}) + \exp(\mu_A) + \exp(\mu_T)} \]  

(6.6)

\[ Q_A = \frac{\exp(\mu_A)}{\exp(\mu_{NMT}) + \exp(\mu_A) + \exp(\mu_T)} \]  

(6.7)

\[ Q_T = \frac{\exp(\mu_T)}{\exp(\mu_{NMT}) + \exp(\mu_A) + \exp(\mu_T)} \]  

(6.8)

**Inclusive Values:**

\[ I_{NMT} = \frac{1}{\mu} \ln \left( \exp(\mu V_{NMT}) \right) = V_{NMT} \]  

(6.9)

\[ I_A = \frac{1}{\mu_A} \ln \left( \exp(\mu_A V_{AD}) + \exp(\mu_A V_{AP}) \right) \]  

(6.10)
\[ I_T = \frac{1}{\mu_T} \ln (\exp(\mu_T V_{LT}) + \exp(\mu_T V_{SAA}) + \exp(\mu_T V_{GAA}) + \exp(\mu_T V_{GTA})) \]  

(6.11)

**Elemental Alternatives:**

\[ P_{NMT|NMT} = 1 \]  

(6.12)

\[ P_{AD|A} = \frac{\exp(\mu_A V_{AD})}{\exp(\mu_A V_{AD}) + \exp(\mu_A V_{AP})} \]  

(6.13)

\[ P_{AP|A} = \frac{\exp(\mu_A V_{AP})}{\exp(\mu_A V_{AD}) + \exp(\mu_A V_{AP})} \]  

(6.14)

\[ P_{LT|T} = \frac{\exp(\mu_T V_{LT})}{\exp(\mu_T V_{LT}) + \exp(\mu_T V_{SAA}) + \exp(\mu_T V_{GAA}) + \exp(\mu_T V_{GTA})} \]  

(6.15)

\[ P_{SAA|T} = \frac{\exp(\mu_T V_{SAA})}{\exp(\mu_T V_{LT}) + \exp(\mu_T V_{SAA}) + \exp(\mu_T V_{GAA}) + \exp(\mu_T V_{GTA})} \]  

(6.16)

\[ P_{GAA|T} = \frac{\exp(\mu_T V_{GAA})}{\exp(\mu_T V_{LT}) + \exp(\mu_T V_{SAA}) + \exp(\mu_T V_{GAA}) + \exp(\mu_T V_{GTA})} \]  

(6.17)

\[ P_{GTA|T} = \frac{\exp(\mu_T V_{GTA})}{\exp(\mu_T V_{LT}) + \exp(\mu_T V_{SAA}) + \exp(\mu_T V_{GAA}) + \exp(\mu_T V_{GTA})} \]  

(6.18)

**Unconditional Mode Choice Probabilities:**

\[ P_{NMT} = P_{NMT|NMT} \cdot Q_{NMT} = Q_{NMT} \]  

(6.19)

\[ P_{AD} = P_{AD|A} \cdot Q_A \]  

(6.20)

\[ P_{AP} = P_{AP|A} \cdot Q_A \]  

(6.21)

\[ P_{LT} = P_{LT|T} \cdot Q_T \]  

(6.22)

\[ P_{SAA} = P_{SAA|T} \cdot Q_T \]  

(6.23)

\[ P_{GAA} = P_{GAA|T} \cdot Q_T \]  

(6.24)

\[ P_{GTA} = P_{GTA|T} \cdot Q_T \]  

(6.25)

In the preceding expressions, the systematic utilities are linear-in-the-parameters:

\[ V_n = \beta^\prime X_n \]  

(6.26)

### 6.3. Results

As was shown in chapter 5, the increase in transit trips observed in York Region was largely due to increases in the number of post-secondary school and work trips being made by transit. These two trip types accounted for more than 75\% of new transit trips by York Region residents, and it
follows that these should be the two trip types modeled. Table 6.2, Table 6.3, Table 6.4, Table 6.5 present the results of the model estimation process. In all tables, the number in parentheses below the parameter denotes the t-statistic. Bold type denotes parameters not significant at a 95% level of confidence.

6.3.1. Validation

6.3.1.1. Home-Based Work Model

We first note the high value of the rho-squared statistic; this indicates that a good degree of choice information is explained by the model. Furthermore, by calculating the difference between the rho-squared statistic for this model and the market share model, we find that the model explains roughly 17% more information than the market share model. Finally, the likelihood ratio statistics show that the model is a statistically better model than both the null and market share models to a very high level of confidence.

With respect to the structure of the model, Table 6.3 indicates that only two mode clusters were found to be statistically different in their choice behaviour: an “Auto” nest—consisting of the auto driver and passenger modes—and the “Root” nest—consisting of all transit modes and the non-motorized mode. In other words, it was not possible to isolate a “transit nest” as defined in the model formulation.
Table 6.2  2006 HBW Model Estimation – Systematic Utility Functions

<table>
<thead>
<tr>
<th></th>
<th>Auto Driver</th>
<th>Auto Passenger</th>
<th>Local Transit</th>
<th>Subway P&amp;R</th>
<th>GO Rail Transit Access</th>
<th>GO Rail P&amp;R</th>
<th>Non-motorized</th>
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<tr>
<td>ASC</td>
<td>8.4613</td>
<td>5.8076</td>
<td>8.3820</td>
<td>7.7358</td>
<td>9.4636</td>
<td>-</td>
<td>1.9208</td>
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<tr>
<td></td>
<td>(108.400)</td>
<td>(74.847)</td>
<td>(93.830)</td>
<td>(74.168)</td>
<td>(91.563)</td>
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<td>(21.266)</td>
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<td>-0.0209</td>
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<td>-0.1504</td>
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<td>(-33.189)</td>
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<td>(-33.189)</td>
<td>(-33.189)</td>
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<td>-</td>
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<td>Walk Time</td>
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Table 6.3  2006 HBW Model Estimation – Scale Parameter Functions

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<th>0</th>
<th>μ</th>
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<tbody>
<tr>
<td>Retail, Sales and Service Dummy</td>
<td>0.0918</td>
<td>1.09614557</td>
<td>-0.1757</td>
<td>0.8388696</td>
</tr>
<tr>
<td></td>
<td>(11.190)</td>
<td>(-18.829)</td>
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<td></td>
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<tr>
<td>General Office/Clerical Dummy</td>
<td>0.1265</td>
<td>1.13484945</td>
<td>-0.2507</td>
<td>0.7782558</td>
</tr>
<tr>
<td></td>
<td>(13.374)</td>
<td>(-26.157)</td>
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<td></td>
</tr>
<tr>
<td>Professional Dummy</td>
<td>0.2775</td>
<td>1.31982612</td>
<td>-0.1674</td>
<td>0.8458612</td>
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<tr>
<td></td>
<td>(35.260)</td>
<td>(-19.376)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 6.4  2006 HB Post-Secondary School Model Estimation

<table>
<thead>
<tr>
<th></th>
<th>Drive Alone</th>
<th>Auto Passenger</th>
<th>Local Transit Walk Access</th>
<th>Subway P&amp;R</th>
<th>GO Rail Transit Access</th>
<th>GO Rail P&amp;R</th>
<th>Non-motorized</th>
</tr>
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<tbody>
<tr>
<td>ASC</td>
<td>5.5587</td>
<td>5.1531</td>
<td>6.0051</td>
<td>5.3497</td>
<td></td>
<td></td>
<td>3.2361</td>
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<td>(32.883)</td>
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<td>(31.686)</td>
<td>(22.630)</td>
<td></td>
<td></td>
<td>(15.815)</td>
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<tr>
<td>IVTT</td>
<td>-0.0088</td>
<td>-0.0088</td>
<td>-0.0088</td>
<td>-0.0088</td>
<td>-0.0088</td>
<td>-0.0088</td>
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<tr>
<td>(-7.371)</td>
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<td>(-7.371)</td>
<td>(-7.371)</td>
<td>(-7.371)</td>
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<tr>
<td>Travel Cost</td>
<td>-0.1776</td>
<td>-0.1776</td>
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<tr>
<td>(-22.012)</td>
<td>(-22.012)</td>
<td>(-22.012)</td>
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<td>(-22.012)</td>
<td>(-22.012)</td>
<td>(-22.012)</td>
<td>-</td>
</tr>
<tr>
<td>Walk Time</td>
<td>-</td>
<td></td>
<td>(-8.228)</td>
<td>-0.0217</td>
<td>-0.0217</td>
<td>-0.0217</td>
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<td>-</td>
<td></td>
<td>(-8.228)</td>
<td>(-8.228)</td>
<td>(-8.228)</td>
<td>(-8.228)</td>
<td>-</td>
</tr>
<tr>
<td>Wait Time</td>
<td>-</td>
<td></td>
<td></td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>-</td>
<td></td>
<td></td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>nveh=1</td>
<td>-</td>
<td>8.2641</td>
<td></td>
<td>-</td>
<td>-</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2.109)</td>
<td></td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
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<tr>
<td>nveh=2</td>
<td>1.8698</td>
<td></td>
<td></td>
<td>-</td>
<td>-</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>(25.054)</td>
<td></td>
<td></td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>nveh&gt;2</td>
<td>3.3541</td>
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<td></td>
<td>-</td>
<td>-</td>
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<td></td>
<td>(42.730)</td>
<td></td>
<td></td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>nveh&gt;=2</td>
<td>-</td>
<td>9.0002</td>
<td></td>
<td>-</td>
<td>-</td>
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<tr>
<td></td>
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<td>(2.297)</td>
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<tr>
<td>nveh</td>
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<td>0.7351</td>
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<td></td>
<td></td>
<td>(21.155)</td>
<td></td>
<td>(9.131)</td>
<td></td>
</tr>
<tr>
<td>tripdist&lt;1</td>
<td>-</td>
<td></td>
<td></td>
<td>-</td>
<td>-</td>
<td></td>
<td>6.2799</td>
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<tr>
<td></td>
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<td></td>
<td></td>
<td>-</td>
<td>-</td>
<td></td>
<td>(35.816)</td>
</tr>
<tr>
<td>1&lt;=tripdist&lt;2</td>
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<td></td>
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<td>-</td>
<td>-</td>
<td></td>
<td>3.9107</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-</td>
<td>-</td>
<td></td>
<td>(33.544)</td>
</tr>
<tr>
<td>2&lt;=tripdist&lt;3</td>
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<td></td>
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<td>-</td>
<td>-</td>
<td></td>
<td>2.5304</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-</td>
<td>-</td>
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<td>(20.064)</td>
</tr>
<tr>
<td>Male Dummy</td>
<td>-</td>
<td></td>
<td></td>
<td>-0.0737</td>
<td>-0.1376</td>
<td>0.3479</td>
<td>0.3112</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(-1.587)</td>
<td>(-1.632)</td>
<td>(1.614)</td>
<td>(3.760)</td>
</tr>
<tr>
<td>Age&lt;=23</td>
<td>-</td>
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<td></td>
<td>3.6754</td>
<td>1.8628</td>
<td>7.1798</td>
<td>0.6371</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(2.5816)</td>
<td>(10.9768)</td>
<td>(22.829)</td>
<td>(4.700)</td>
</tr>
<tr>
<td>Dummy</td>
<td>-</td>
<td></td>
<td></td>
<td>(27.400)</td>
<td>(11.303)</td>
<td>(22.48)</td>
<td>(7.6201)</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>(28.418)</td>
<td>(49.172)</td>
<td>(22.829)</td>
<td>(7.6201)</td>
</tr>
<tr>
<td>23&lt;Age&lt;=28</td>
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<td></td>
<td></td>
<td>2.4755</td>
<td>1.5741</td>
<td>11.0483</td>
<td>-1.5920</td>
</tr>
</tbody>
</table>

Table 6.5  Goodness of Fit Statistics

<table>
<thead>
<tr>
<th></th>
<th>Home-Based Work</th>
<th>Home-Based Post-Secondary School</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Observations</td>
<td>19862</td>
<td>1046</td>
</tr>
<tr>
<td>No. of Cases</td>
<td>384564</td>
<td>20548</td>
</tr>
<tr>
<td>L(Null)</td>
<td>-429635</td>
<td>-23298</td>
</tr>
<tr>
<td>L(Share)</td>
<td>-216614</td>
<td>-23012</td>
</tr>
<tr>
<td>L(β)</td>
<td>-144451</td>
<td>-16957</td>
</tr>
<tr>
<td>ρ²</td>
<td>0.663781</td>
<td>0.272171</td>
</tr>
<tr>
<td>ρ²Share</td>
<td>0.495819</td>
<td>0.012268</td>
</tr>
<tr>
<td>No. of parameters</td>
<td>42</td>
<td>35</td>
</tr>
<tr>
<td>Adj. ρ²</td>
<td>0.663744</td>
<td>0.270929</td>
</tr>
<tr>
<td>Likelihood Ratio (Null)</td>
<td>570367.064</td>
<td>12682.267</td>
</tr>
<tr>
<td>Likelihood Ratio (Share)</td>
<td>144325.064</td>
<td>12110.621</td>
</tr>
</tbody>
</table>
The parameters estimated for the work model are generally logical in their magnitude and sign. Starting with the alternative specific constants (labelled ASC), we note that they are fairly large in magnitude, but not to the extent that the model should be rejected. Instead, their magnitude is likely an indication that there is a determinant of mode choice absent from the model. It could be hypothesized that the inclusion of an income parameter might have a sizeable effect on the magnitude of the constants, but this data is not available to be modelled. The ASC parameter values for GO transit local and auto access are not listed; the former is the reference mode and cannot be identified while the latter returned an insignificant t-statistic. Instead, their magnitude is likely an indication that there is a determinant of mode choice absent from the model. It could be hypothesized that the inclusion of an income parameter might have a sizeable effect on the magnitude of the constants, but this data is not available to be modelled. The ASC parameter values for GO transit local and auto access are not listed; the former is the reference mode and cannot be identified while the latter returned an insignificant t-statistic. Instead, their magnitude is likely an indication that there is a determinant of mode choice absent from the model. It could be hypothesized that the inclusion of an income parameter might have a sizeable effect on the magnitude of the constants, but this data is not available to be modelled. The ASC parameter values for GO transit local and auto access are not listed; the former is the reference mode and cannot be identified while the latter returned an insignificant t-statistic. Cost and time parameters are entered into the model as generic variables. We observe that individuals find in-vehicle travel time (labelled IVTT) to be the least burdensome component of travel time, while wait time is found to be the most burdensome. This is consistent with past models of mode choice in the GTA (Miller, 2007). Variables relating to the number of household vehicles are specific to modes that require an automobile. For the Auto Driver mode, the dummy variable nveh=1 is the reference case (since nveh=0 is impossible for this mode); for Auto Passenger, nveh=0 is the reference case. For both modes, we observed that as the number of household vehicles increases, the utility of the mode increases. For the auto access to transit modes, the number of vehicles is entered as a standard alternative specific variable; it is interesting to note that the number of vehicles has a larger impact on the utility of GO Rail Park and Ride than on Subway Park and Ride. The trip distance variables (labelled tripdist) are specific to the Non-Motorized mode. The transformation of this quantity into dummy variables can be justified by noting its non-linear nature. We do not expect there to be a linear relationship between trip distance and the utility of walking or cycling; rather, we expect the utility to drop for trips longer than a comfortable walking/cycling distance. This is shown by the parameter values in the model. The male dummy variable parameters are measured relative to the Auto Driver mode. Although this explains the negativity of the Auto Passenger parameter, it is not entirely clear why it is more negative than the local transit parameter value. For the age dummy variables, the general pattern is one of decreasing utility with increasing age for transit and non-motorized modes. This is intuitive given the general upward trend in income as age increases. Although this trend is not always present, any deviation from it can likely be explained by instances of a low number of observations (for example, non-motorized trips by individuals over the age of 55). Finally, the transit pass dummy variables proved to be highly significant components of the
utilities of transit modes. It could be argued that the inclusion of this variable is somewhat redundant since it seems likely that if an individual possesses a transit pass, they will take transit. However, not every individual with a transit pass will use it for a work trip and therefore these variables were left in the model.

The scale parameters listed in Table 6.3 can be compared across two dimensions. We can first compare them amongst occupation categories, thus illustrating choice heterogeneity across different population segments. There are 4 categories defined by the TTS: Retail/Sales/Service, General Office/Clerical, Professional, and Manufacturing/Trades/Construction (the reference case). All scale parameter values are measured relative to the reference case, which has an assumed value of 1. This defines a simple multinomial logit model for that occupation category. We observe that, in the “Auto” nest, the scale parameter values are all greater than one. Therefore, for this nest, we can conclude that the occupation categories listed are more predictable than the reference case. Conversely, in the transit nest, the listed occupations have a lower scale and therefore lower variability than the reference case. The general pattern observed among occupation categories is that choice predictability tends to increase with the “regularity” or “stability” of the occupation. For example, the Professional category has a consistently high scale parameter relative to the other occupations. This can be explained by the fact that professionals tend to work at predictable locations at predictable hours, making their mode choices more predictable. By contrast, those in the Retail/Sales/Services category are more prone to shift work and therefore volatility in shift time and duration; the mode choice behaviour resulting from this lifestyle is inherently more difficult to predict.

The second dimension of comparison is between mode clusters; this captures heteroskedasticity in the mode choice process. Table 6.3 shows that scales in the “Root” nest are consistently lower than in the “Auto” nest, implying that trips by auto are consistently more predictable than modes in the “Root” nest. There may be several reasons for this. First, the choice to travel by transit may be a result of factors that are difficult to capture in a model. For example, transit may be chosen for environmental reasons or because the prospect of heavy traffic may be stressful for some. Furthermore, network and mode choice models often have difficulty capturing the capital costs associated with auto ownership. There may be certain situations in which the choice of auto is economically superior on the basis of time and out-of-pocket costs,
but in reality the capital costs outweigh those short term cost savings. If individuals are
cognizant of these scenarios, they may make the choice to take transit which, in the logic of the
model, would not be easily predicted.

6.3.1.2. Home-Base Post-Secondary School Model

Unlike the work trip model, the rho-squared statistic for the post-secondary school model is
fairly low; the model explains only 27% of mode choice information. This can be partially
attributed to the smaller number of observations for this model (roughly 1/20 the number of
observations of the work model). However, the post-secondary school model is better than the
market share model by a greater margin than the work trip model. While the work model
outperformed the market share model by 17%, this model was better by 26%. As with the work
model, the likelihood ratio statistics show that the school model is statistically better than both
the null and market share models at a high level of confidence. Unfortunately, no statistically
significant nesting was observed in the post-secondary model. As such, all scale parameters are
set to 1 and the model simplifies to a multinomial logit model.

The parameter values resulting from the estimation of the post-secondary school model were not
all as intuitive as those in the work model. The first notable difference is the negative alternative
specific constant for the Auto Passenger mode. The reason for this result may be due to the
dearth of observations for the reference alternative (GO Rail Transit Access); this may have led
to a scenario in which difference between the two parameters resulted in a negative value. It
should also be noted that although this parameter is not statistically significant at a 95%
confidence level, it was deemed close enough to be included in the model. The time and cost
terms for this model are specified in the same manner as in the work model. It was not possible,
however, to estimate a parameter for wait time that had a negative sign. As such, it was omitted
from the model. The parameter values for the number of household vehicles are similar to those
estimated for the work model. However, there are two differences of note. Firstly, the increase
in utility between 2 and greater than 2 household vehicles for the Auto Driver mode is greater for
the post-secondary school model. Assuming an average of 2 workers per household, having
more than 2 vehicles would greatly facilitate the Auto Driver mode for a post-secondary student.
Secondly, the parameter values for the Auto Passenger mode are considerably higher than in the
work model, likely a result of the negative alternative specific constant of the post-secondary
model. With respect to the trip distance variables, we observe a greater drop in utility from trips between 0 and 1km to trips between 1 and 2 kms than from 1-2kms to 2-3kms. For the work trip model, the opposite is true. This suggests that the “threshold” distance for post-secondary walking trips is lower than for work trips. The estimation of the Male Dummy parameters returned some statistically insignificant results; however, they were left in the model because they were either very close to a 95% level of confidence or they amounted to a minimal impact on overall utility. Generally, the magnitude and sign of the parameters are logical. For example, the modes that involve some auto component are all more positive than the transit-only modes; this is consistent with the higher likelihood of females taking transit. Finally, the dataset was split into 3 age categories: younger than 23, between 23 and 28, and older than 28 (the reference case). We observe a predictable decrease in the utility of transit and non-motorized modes as age increases. This is generally consistent with the home-based work trip model.

6.3.1.3. Values of Time Savings

Based on the preceding findings, the marginal rates of substitution for both models were calculated and presented in Table 6.6. Since an acceptable wait time parameter could not be calculated for the post-secondary school model, it was not possible to determine the value of time savings.

Table 6.6 Marginal Rates of Substitution

<table>
<thead>
<tr>
<th></th>
<th>Home-Based Work</th>
<th>Home-Based Post-Secondary School</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value of IVTT ($/hr)</td>
<td>8.34</td>
<td>2.97</td>
</tr>
<tr>
<td>Value of Walking Time ($/hr)</td>
<td>17.35</td>
<td>7.33</td>
</tr>
<tr>
<td>Value of Waiting Time ($/hr)</td>
<td>35.98</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 6.6 shows two distinct patterns. First, we observe that in-vehicle travel time is the least onerous component of travel, followed by walking time and waiting time. For both work and post-secondary trips, travellers are willing to pay twice as much to save an hour of walking time than to save an hour of in-vehicle time. For work trips, travellers are willing to pay 4 times as much to save an hour of waiting time than to save an hour of in-vehicle time. The second observation made is that travel time is valued at roughly 2.5 times higher for work trips than for
post-secondary school trips. The reason for this is likely that school transit trips tend to be made by individuals captive to transit; that is, they do not have a choice in mode.

6.3.2. Estimation of Travel Time Impacts

In this subsection, the impact of travel time changes on mode choice will be evaluated using the models estimated on the preceding pages. To accomplish this, several model runs were performed to assess two separate impacts:

1) Congestion impacts: changes in transit mode split resulting from increased congestion
2) Transit impacts: changes in transit mode split resulting from improved transit service (including VIVA).

The 2001 and 2006 auto and transit levels of service are available from the EMME network model; by substituting 2001 travel time data into the 2006 data file, it was possible to isolate the effects described above. The procedure by which this was undertaken is best explained visually, as illustrated in Table 6.7.

Table 6.7 Comparison Procedure

<table>
<thead>
<tr>
<th>Transit Times</th>
<th>Auto Times</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>2001</td>
</tr>
<tr>
<td>2006</td>
<td>2006</td>
</tr>
</tbody>
</table>

Each arrow in the diagram corresponds to one of the effects listed above and the head or tail of each arrow represents a model run. Congestion impacts are represented by the blue arrow, and transit impacts by the purple arrow. The impact is calculated by subtracting the predicted mode splits at the tail of the arrow from the predicted mode splits at the head of the arrow.

Consider the case of congestion impacts. The tail of that arrow corresponds to a data file with 2006 transit times combined with 2001 auto times. The head of the arrow points to the data file with 2006 times for both transit and auto. The difference between the predicted mode splits of these two runs will give the congestion impacts because transit times are held constant while auto times should increase from 2001 to 2006. Similarly, the purple arrow shows that transit impacts can be calculated by finding the difference between the mode splits from the 2006 data
file with 2001 transit times and the mode splits from the data file with 2006 auto and transit times.

First, we will examine the impacts of congestion and transit improvements on home-based work trips. Table 6.8 presents the calculated impact of both congestion and improved transit service along with the actual changes observed in the TTS between 2001 and 2006. The results are presented as the difference in percentage points of mode share.

Table 6.9 then presents the average and median increases (or in some cases, decreases) in travel time among work trip makers. This table gives insight into the source of the congestion and transit impacts.

Table 6.8  Change in Mode Share – Home-Based Work Trips

<table>
<thead>
<tr>
<th></th>
<th>Auto</th>
<th>Transit - Local Access</th>
<th>Transit - Auto Access</th>
<th>NMT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Congestion Impact</td>
<td>0.15%</td>
<td>0.10%</td>
<td>-0.24%</td>
<td>-0.01%</td>
</tr>
<tr>
<td>Transit Impact</td>
<td>-0.91%</td>
<td>0.89%</td>
<td>0.06%</td>
<td>-0.04%</td>
</tr>
<tr>
<td>Actual Change</td>
<td>-1.06%</td>
<td>0.65%</td>
<td>0.46%</td>
<td>-0.05%</td>
</tr>
</tbody>
</table>

Table 6.9  Increase in Work Trip Travel Time: 2006-2001

<table>
<thead>
<tr>
<th></th>
<th>AIVTT</th>
<th>TIVTT</th>
<th>TWalk</th>
<th>TWait</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mins</td>
<td>%</td>
<td>Mins</td>
<td>%</td>
</tr>
<tr>
<td>Average</td>
<td>1.19</td>
<td>4.75%</td>
<td>2.70</td>
<td>6.09%</td>
</tr>
<tr>
<td>Median</td>
<td>1.35</td>
<td>6.36%</td>
<td>1.78</td>
<td>4.39%</td>
</tr>
</tbody>
</table>

Beginning with the impact of congestion, we observe that auto access to transit modes lost share at the expense of local access to transit and auto modes. The increase in auto mode share is not intuitive because one would expect that an increase in auto times (as illustrated in Table 6.9) would result in an auto mode share decrease. However, average and median transit in-vehicle times also increased. Since auto access to transit was the only mode group whose share declined, it is reasonable to assume that the increase in auto trips comes at the expense of auto access to transit trips. It is possible that links leading to P&R stations became more congested (in the network model or otherwise) or that subway parking lots reached capacity, making the total travel time by auto more competitive. Moreover, there may have been road improvements made that benefited a certain segment of the population enough to change their choice in mode, even if
the average and median travel times increased. Regardless of the cause, the impact increase equates to only 30 additional HBW trips.

The impact of transit improvements is easier to explain. Table 6.8 shows that gains in transit mode share as a result of improvements to transit service came almost entirely at the expense of auto mode share. Furthermore, these impacts are greater in magnitude than the congestion impacts, suggesting that improved transit service has been more successful at changing the travel behaviour of individuals than increased congestion. Interestingly, as both in-vehicle and walk times increased between 2001 and 2006, the observed impact on transit mode share must be a result of the improvement in wait time. This is a reasonable result since the mode choice model has shown that wait time is the most onerous component of transit travel time. On a final note, it is worth consideration that the observed local transit improvement impact is greater than the actual increase in local transit mode share. It is likely that issues estimating auto access to transit trips contributed to this result; if auto-access and local-access to transit modes are summed, the total transit improvement impact is less than the observed increase in transit mode share.

Table 6.10 shows the impact of congestion and improved transit service on post-secondary trips in addition to the actual changes observed, while Table 6.11 presents the average and median increases/decreases in travel time. As before, the results are presented as the difference in percentage points of mode share.

Table 6.10  Change in Mode Share – Home-Based Post-Secondary School Trips

<table>
<thead>
<tr>
<th></th>
<th>Auto</th>
<th>Transit - Local Access</th>
<th>Transit - Auto Access</th>
<th>NMT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Congestion Impact</td>
<td>0.90%</td>
<td>1.05%</td>
<td>-1.96%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Transit Impact</td>
<td>-2.90%</td>
<td>3.83%</td>
<td>0.11%</td>
<td>-1.04%</td>
</tr>
<tr>
<td>Actual Change</td>
<td>-19.62%</td>
<td>17.07%</td>
<td>3.10%</td>
<td>-0.55%</td>
</tr>
</tbody>
</table>

Table 6.11  Increase in Post-Secondary School Trip Travel Time: 2006-2001

<table>
<thead>
<tr>
<th></th>
<th>AIVTT</th>
<th>TIVTT</th>
<th>Walk</th>
<th>Wait</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mins</td>
<td>%</td>
<td>Mins</td>
<td>%</td>
</tr>
<tr>
<td>Average</td>
<td>0.29</td>
<td>1.18%</td>
<td>0.07</td>
<td>0.16%</td>
</tr>
<tr>
<td>Median</td>
<td>1.09</td>
<td>5.92%</td>
<td>0.14</td>
<td>0.33%</td>
</tr>
</tbody>
</table>
The preceding tables show that the calculated impacts on post-secondary school trips are considerably larger than the impacts on work trips. With respect to congestion impacts, we can observe a similar—although scaled-up—trend of the impact on auto and transit mode shares. Once again, auto access to transit was the only mode group to lose share; the benefactors of this loss were the auto and local access to transit modes. The explanations used to understand this phenomenon in work trips apply here. Again, the unexpected increase in auto mode share represents a very small number of trips.

Transit improvement impacts on post-secondary trips also follow a similar trend to work trips; the improvement in transit times resulted in an increase in transit mode share roughly offset by auto mode share. It is interesting to note that among post-secondary students, both wait and walk times decreased from 2001 and transit in-vehicle travel time also increased by a smaller margin than for work trips. This is indicative of a concerted effort by York Region to target post-secondary trip makers. VIVA was clearly an integral part of that strategy given that two of the five VIVA routes serve York University.

One notable characteristic of the post-secondary school trip impacts is that they are considerably less than the actual change in mode share observed. This suggests that the impetus for a change in behaviour was a factor other than travel time. To test this hypothesis, the 2006 model was run using exclusively 2001 data (both level of service and demographic). The result of this exercise was a very large overestimation of transit ridership. This may be indicative of a change in tastes and preferences between 2001 and 2006, unexplained by the mode choice model. It is possible that factors such as improved branding, advertising, and communications to post-secondary students may have caused this change in preferences.

### 6.4. Discussion

This chapter has presented several novel concepts related to the evaluation of the impact of VIVA on ridership in York Region. To start, the mode choice model used to estimate the impact featured two improvements over traditional logit models. The assumption of choice independence is often ignored in traditional multinomial logit estimations. As a GEV-class model, however, the model presented here allows a general pattern of dependence between modes. A second advantage of this model is its parameterization of the scale parameter. In so doing, we were not only able to identify how choice variability differed by occupation and mode,
but we were arguably also able to arrive at more accurate level of service and demographic parameter estimates by “filtering out” the choice variability from those parameters. However, one obvious failing of the model was that income could not be considered as an explanatory variable for mode choice. This is a fairly significant shortcoming of the analysis, especially given the fact that transit patronage increased over a period when incomes decreased.

Another important finding of this chapter was that, in general, the impact of new transit on mode choice was more significant than the impact of congestion. This was not an expected result given that it can be difficult to entice people out of their cars with improved transit service while auto levels of service have only marginally changed. It was also observed that the impacts of both congestion and transit improvements on post-secondary school trips were minimal in the context of the actual change in mode split. This led to the hypothesis that there has been a change in tastes and preferences amongst post-secondary students between 2001 and 2006. The source of that change is debatable; it could have come from the influx of a generation that is more sensitive to environmental concerns, but it also could have been a result of the unquantified income drop. There is a distinct possibility, however, that this change in preferences is a direct response to the branding and advertising efforts undertaken by York Region and its private sector partners to sell the benefits of the VIVA bus transit system.
7. Conclusions and Future Work

This chapter is divided into two parts. The first outlines conclusions that follow from the contents of this thesis; these conclusions relate directly to the objectives enumerated in the first chapter. The second part lists recommendations for future work on the topic of VIVA and its impact on transit patronage.

7.1. Conclusions

1. There were no major demographic shifts in York Region between 2001 and 2006 that might have influenced transit patronage

In Chapter 5, a demographic analysis of York Region was undertaken that isolated several characteristics of transit demand and examined any changes substantial enough to explain the observed increase in transit patronage. The characteristics examined were trip purpose, age, number of household vehicles, gender, departure time, and trip length. None of these showed any considerable changes that might indicate a shift to transit. One caveat to this conclusion is that, according to census data, income in constant dollars dropped between 2000 and 2005. Unfortunately, it was not possible to relate this change to travel choices due to limitations associated with the Transportation Tomorrow Survey.

2. There was a very large shift to transit amongst post-secondary school students.

As per the descriptive analysis of transit demand in Chapter 5, there was a considerable change in travel behaviour amongst post-secondary school students that saw transit mode share for that demographic double from 22% to 44% in York Region. It is shown that, despite constituting only 3% of the total number of trips made in York Region, home-based post-secondary trips accounted for 35% of new transit trips made between 2001 and 2006. Although this trend was also observed in Peel Region, the effect was more pronounced in York Region.

3. Sizeable increases in corridor ridership were observed beginning immediately after the introduction of VIVA.

As per the time series analysis of corridor ridership conducted in Chapter 4, the introduction of VIVA was followed by a large increase in ridership in the two busiest corridors in the York
Region Transit network. Furthermore, it was shown that roughly 60% of VIVA riders in the Highway 7 corridor were “new” riders; they were not diverted from existing routes after VIVA’s introduction. Both of these observations suggest that VIVA had an important role in serving latent demand for transit and, thus, increasing transit mode share.

4. The modeled impact of improved transit service was found to be more significant to the increase in transit patronage than increased congestion.

An application of the mode choice models derived in Chapter 6 indicates that, for both post-secondary and work trips, improved transit service had a greater impact on the increase in transit mode split than increased auto congestion. For work trips, the model predicted that increased auto congestion was responsible for an increase of 0.10 percentage points of local access to transit mode share, whereas improved transit service was responsible for a 0.89 percentage point increase. For post-secondary school trips, auto congestion was responsible for a 1.05 percentage point increase in local access to transit mode share, while improved transit service was responsible for a 3.83 percentage point increase. Additional model work hinted suggested a shift in tastes and preferences amongst post-secondary students, possibly due to the influence of VIVA.

There are several caveats that should be considered when interpreting these findings. Firstly, it is important to note that there was relatively little time between the implementation of the VIVA bus transit system and the Transportation Tomorrow Survey. VIVA Blue, the first route to enter operation, began service in September 2005; the TTS was conducted between August and December 2006. It could be argued that the year between implementation and observation was an insufficient amount of time for trip makers to change their travel patterns. Having said this, the significant change in mode split observed amongst post-secondary school students seems to reject that assertion. A further caveat to these findings is that, between the 2001 TTS and the 2006 TTS, the four separate transit agencies that served York Region merged into a single, cohesive system (York Region Transit). This action undoubtedly impacted the quality and cost of transit service offered to York Region residents; therefore, it could be argued that this is a potential explanatory factor for the increase in transit mode split in York. As demonstrated in Chapter 4, however, the most significant increases in ridership in York’s most highly travelled corridors occurred immediately after the introduction of VIVA service. This suggests that VIVA
had a more significant impact than the merging of the old agencies. Finally, there is some ambiguity in determining what exactly defines a VIVA impact. For example, as part of the York Rapid Transit Plan, some bus routes were realigned to serve VIVA corridors more effectively. Should ridership gains as a result of these changes be considered an impact of VIVA? Despite this ambiguity, it can be argued that the introduction of VIVA is still the motivation for these changes; their impacts can therefore still be included in the sphere of VIVA’s impact.

It is also important to understand that this study does not suggest that systems similar to VIVA are a panacea for urban areas struggling to increase transit patronage. In fact, the literature review for this thesis found examples of several systems (mostly in the United States) that experienced decreases in ridership after the introduction of an improved bus system. VIVA’s success is likely a manifestation of latent demand for transit resulting from the economic, social, and land use characteristics of the region. As such, transit improvements cannot be viewed as “one-size-fits-all” solutions; it is important to understand the factors that determine travel demand in a given region and tailor transportation systems to respond to those factors.

7.2. Future Work

1. Monitor the evolution of travel behaviour in York Region in future undertakings of the Transportation Tomorrow Survey.

An analysis of future Transportation Tomorrow Surveys would help to establish whether the increases observed between 2001 and 2006 were merely a spike in ridership caused by external factors (eg. decrease in income, increase in gas prices), or permanent changes in behaviour resulting from improved transit service. At a minimum, a descriptive analysis of transit demand indicators should be undertaken for subsequent TTS instalments.

2. Conduct a customized survey of VIVA riders.

Conducting a purpose-designed survey of VIVA riders would allow for the isolation of factors that were not possible to analyze using data from the TTS. Firstly, the effect of income on an individual’s choice of VIVA could be quantified by including it as part of the survey. Furthermore, with a customized survey, more accurate information about individuals’ past mode and transit route choice prior to the implementation of VIVA could be analyzed. Finally, a customized survey would permit an estimation of the impact of branding on transit mode choice.
Branding and marketing were a large part of the VIVA project; it would be of interest to analyze whether these efforts had an appreciable effect on transit patronage or if the same results could have been achieved while spending less money advertising the service.

3. Conduct a formal time series analysis of corridor ridership.

The time series analysis presented in Chapter 4 was largely qualitative in nature. A formal statistical time series analysis of ridership would facilitate a more in-depth examination of the causes of ridership changes. Such an analysis would likely consist of developing a model by which the route and/or system ridership are the dependent variable and the changes to the route and/or system are the independent variables. Such a model would also allow the testing of alternate future strategies to analyze their potential impact on route or system ridership.

4. Attempt to quantify the impact of land use on transit patronage

As mentioned in the last subsection, VIVA’s success in York Region is likely not simply a result of added infrastructure. Rather, the social, economic, and land use conditions were likely such that there was a latent demand for this system. There is a growing realization amongst researchers and practitioners that such factors, particularly land use, play a much stronger role than the simple introduction of new infrastructure. Knowing this it would be beneficial to this research to be able to quantify (or qualify) why the land use in York Region was suitable for a bus transit system like VIVA.
8. References


Detroit Metropolitan Area Traffic Study. (1956).


9. Appendix

Trip Purpose Graphs

24-hr Home Based Work Mode Share - York Region

24-hr Home Based Work Mode Share - Peel Region

Increase in Home Based Work Travel by Mode (24-hr): 2001-2006

Share of Home Based Work Travel Increase (24-hr): 2001-2006

Increase in Home Based Post-Secondary School Travel by Mode (24-hr): 2001-2006

Share of Home Based Post-Secondary School Travel Increase (24-hr): 2001-2006
Number of Household Vehicles Graphs

24hr Mode Share: 66+ - York Region

24hr Mode Share: 66+ - Peel Region

Increase in Travel by Mode (24hr, 66+): 2001-2006

Share of Travel Increase (24hr, 66+): 2001-2006

24hr Mode Split: 0 Vehicle Households - York Region

24hr Mode Share: 0 Vehicle HH - Peel Region
24hr Mode Share: 2 Vehicle HH - York Region

24hr Mode Share: 2 Vehicle HH - Peel Region

Increase in Travel by Mode (24hr, 2 Vehicle HH): 2001-2006

Share of Travel Increase (24hr, 2 Vehicle HH): 2001-2006

24hr Mode Share: 3+ Vehicle HH - York Region

24hr Mode Share: 3+ Vehicle HH - Peel Region
Increase in Travel by Mode (24hr, 3+ Vehicle HH): 2001-2006

Share of Travel Increase (24hr, 3+ Vehicle HH): 2001-2006

Gender Graphs

24hr Mode Share: Males - York Region

24hr Mode Share: Males - Peel Region

Increase in Travel by Mode (24hr, Males): 2001-2006

Share of Travel Increase (24hr, Males): 2001-2006
Departure Time Graphs

24hr Mode Share: Females - York Region

24hr Mode Share: Females - Peel Region

Increase in Travel by Mode (24hr, Females): 2001-2006

Share of Travel Increase (24hr, Females): 2001-2006

Mode Share: 6:00-8:59 - York Region

Mode Share: 6:00-8:59 - Peel Region
Mode Share: 15:00-17:59 - York Region

Mode Share: 15:00-17:59 - Peel Region

Increase in Travel by Mode (15:00-17:59): 2001-2006

Share of Trip Increase: 15:00-17:59

Mode Share: 18:00-27:59 - York Region

Mode Share: 18:00-27:59 - Peel Region
Trip Length Graphs

Increase in Travel by Mode (18:00-27:59): 2001-2006

Share of Travel Increase (18:00-27:59): 2001-2006

Mode Share: 0-2km - York Region

Mode Share: 0-2km - Peel Region

Increase in Travel by Mode (0-2km): 2001-2006

Share of Travel Increase (0-2km): 2001-2006
**Mode Share: 15-20km - York Region**

- **York 2001**
- **York 2006**

**Mode Share: 15-20km - Peel Region**

- **Peel 2001**
- **Peel 2006**

**Increase in Travel by Mode (15-20km): 2001-2006**

- **York**
- **Peel**

**Share of Travel Increase (15-20km): 2001-2006**

- **York**
- **Peel**

**Mode Share: 20-30km - York Region**

- **York 2001**
- **York 2006**

**Mode Share: 20-30km - Peel Region**

- **Peel 2001**
- **Peel 2006**