Impacts of the Introduction of an Express Transit Service in Waterloo Region

by

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AUTHOR'S DECLARATION

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

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Abstract

For more than a century, public transportation has played a significant role in society. Transit agencies, like other service industries, are intent on improving their quality of service so as to increase transit ridership and attract passengers from other modes. In recent years transportation technologies have been improved which increase safety, mobility for people and goods, and reduce Green House Gas (GHG) emissions. An evaluation of the impacts of these operational and technological advancements is required for transit agencies to capture the potential benefits for their systems.

The Region Municipality of Waterloo (RMOW), a mid-size region in Ontario has implemented an express transit service (*iXpress*) in Sept, 2005. The service has longer distances between stops and incorporates advanced technologies. The goal is to increase transit ridership and, as a result, to reduce GHG emissions.

This research has been conducted to study the *iXpress* service and to develop several methods to determine the impacts of high speed transit service on passenger attraction, operational efficiency, and regional air quality. In this research, the change in total cost of travel between origin destination pairs is correlated to changes in observed ridership. Further, several surveys were conducted in the RMOW to evaluate the travel pattern changes of residents who switched from other modes to *iXpress*. Based on fuel consumption data, a model of GHG emissions as a function of route and vehicle characteristics has been developed to capture the operational impacts of a new *iXpress* service.

The *iXpress* service of Grand River Transit (GRT) has been successful in attracting riders despite delays in technology implementation. The cost analysis presented in this research shows that the introduction of *iXpress* resulted in approximately 30% reduction in overall cost of travel by transit. As a result, ridership (boardings) has increased by 11% and 46% in

the northern and southern sections of the *iXpress* service area respectively, while accounting for overall growth in the system. An analysis of travel patterns and mode shifts suggest that travelers switching from auto mode to *iXpress* have resulted in annualized reduction of approximately 530 tonnes of GHG. A fuel consumption analysis indicates that buses on the *iXpress* route have an average fuel consumption rate of 0.54 L/km while, buses serving local route consumes fuel of a rate of 0.62 L/km. Attempts to determine a model which is able to describe the difference in the data as a function of bus and/or route characteristics were not successful.

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1. INTRODUCTION

1.1 Background

Today, the increase in population and the need for mobility over large land areas have resulted in more vehicles and greater travel demands. The energy consumption of cars can be thought of as low, if looked at in isolation. However, since the number of motor vehicles is large and increasing, the combination of fuel consumption and GHG emissions has become a critical issue for transportation engineers and planners.

Forty years ago, in most developed economies, transport's proportion of the total energy was between 15% and 20%, but today, is approximately 35% of all the energy consumption and is still rising (Potter, 2003). In addition, on-road vehicles, which contribute more than one-third of the emissions in the US, are the largest source of transportation-related emissions (Nizich et al. 1994). The increase in the use of transport energy is raised by the increase in the use of private cars (Potter, 2003).

Recently, there has been a move toward improving the quality of transit services in urban areas in order to shift travel from private cars to public transport. Public transit provides safe, efficient and economical services that benefit the users and non-users in the reduction of CO_2 and GHG emissions, road congestion, and energy use (Xin, 2004).

In past decades, several developments in transit services, such as Transit Signal Priority (TSP), exclusive or express rights-of-way, and smart growth have increased the reliability and convenience, and decreased travel time, energy consumption, and vehicle emissions. This has generated considerable enthusiasm for transit travelers (Barth, 2005).

However, the following questions arise: what are the primary attributes of public transportation that if improved, may attract auto trip-makers? For example, are travelers most sensitive to travel time reductions, improvements in convenience, enhanced safety or lowering cost of travel? In addition, what is the magnitude of the impact of a shift from auto-based modes to public transportation systems on the reduction of GHG emissions? Also, what is the impact of improved transit systems and new technologies regarding the fuel consumption of transit buses? Can they provide a significant reduction in energy consumption and benefits to the environment?

1.2 Motivation

The Region Municipality of Waterloo (RMOW), located 100 km west of Toronto, is a medium-size region of three cities. The Region has consistently ranked as one of the fastest growing communities in Canada. In the last five years, the Region's population has increased by approximately 8% or over 6,300 people per year (Region of Waterloo, 2006b). The Region currently demonstrates high auto dependency; the market share of the "drive alone by auto" option for journey-to-work trips in this area is over 80%, resulting in damaging environmental impacts, particularly in the creation of GHG emissions (Hellinga et al, 2007). This rapid growth and the problem of auto dependency are the main motivations to improve public transportation of the RMOW. The experience of the RMOW is transferable to many growing regions in Canada and throughout North America. While data from the Region provide the case study utilized in this research, the results have applications in many areas.

The RMOW's Grand River Transit (GRT) has initiated an express bus service called *iXpress*, serving trips between northern and southern limits of the region with 13 bus stops along a 37 kilometer route. This service was introduced in September 2005 with funding from the Canadian Government's Urban Transportation Showcase Program to provide a higher order transit in the rapidly growing RMOW (Region of Waterloo, 2005). The objectives are to improve the quality of service by a higher travel speed and an improved use of technology to increase transit ridership, reducing transit's fuel consumption and GHG emissions.

In evaluating potential system improvements, a transit agency assesses the benefits of new investments particularly on achieving reduced travel time, fewer delays, and higher average speeds. An equally important consideration is how these improvements in service translate to increased ridership (and, therefore, greater fare revenue). This is a primary focus of this research: to evaluate how changes in travel cost are reflected in increased transit ridership.

By attracting greater ridership, significant environmental improvements can also be achieved. However, measuring ridership can not directly capture the environmental impacts (Delucchi, 1996). Simulations of vehicular traffic are conducted often to assess fuel consumption and emissions. It is essential to gather information about the various types of vehicles and to provide a realistic network of traffic conditions which, most of the time is challenging. Moreover, less effort is devoted to provide an empirical Heavy-Duty Diesel (HDD) fuel consumption model due to the numerous variables that affect fuel consumption. A second motivation for this research is to determine the improved environmental performance of express service relative to local bus services.

The magnitude of the transit service quality on attracting passengers from different modes varies from case to case, and depends on the type of users, trips, and geographic conditions. None of the previous studies in evaluation of new technologies has accounted for the importance of reducing travel time by public transportation to attract more passengers. Also, there is a lack of HDD fuel consumption models to represent transit fuel consumption as a function of route characteristics such as the number of bus stops and intersections which enables transit analyzers to capture the fuel consumption savings on line by utilizing new technology systems (BRT[1] and TSP).

Due to the necessity of a new *iXpress* service evaluation in RMOW for advanced technology installations, this research has been conducted to examine an example of new transit service

[1] Bus Rapid Transit

to determine the impacts on ridership, GHG emissions and operational efficiency of the *iXpress* service.

1.3 Scope and Objective

The objective of this thesis is to provide an empirical evaluation of the impacts of GRT's *iXpress* service in the RMOW with emphasis on the following.

1. Passenger attraction as a result of decreased total travel time. The impacts of the *iXpress* service on user costs are analyzed to correlate the reduction in travel time to passenger attraction.
2. RMOW's air quality, particularly the reduction of GHG emissions, as a result of auto travelers shifting to public transportation. Estimates are made on the basis of an *iXpress* rider survey data. GRT's *iXpress* service reduces GHG emissions in the RMOW by eliminating the emissions associated with the auto-trips that are no longer made because the trip-makers have switched to the use of *iXpress*.
3. Operational efficiency as a result of a lower fuel consumption rate per unit of transportation work. The fuel consumption ratio is computed for the entire GRT fleet on data collected over a 1 week period to model the transit fuel consumption as a function of the number of bus stops and intersections, as well as the vehicle characteristics in order to capture the impact of the *iXpress* service on fuel consumption savings.

1.4 Content of Thesis

This thesis is organized into six chapters. **Chapter 2** is divided into three parts to review the research on passenger behavior as a function of the quality of transit services, several fuel consumption models, and transport emissions. **Chapter 3** presents the analysis of travel costs reductions and passenger attraction associated with enhanced transit service in the RMOW. **Chapter 4** describes the development of the transit fuel consumption model as a function of the route and vehicle characteristics. **Chapter 5** evaluates the enhanced transit service impact on the change of GHG emissions in the RMOW. **Chapter 6** summarizes the research and provides some recommendation for future work.

2. Literature Review

Prior to post-industrial urbanization, populations were able to make their trips on foot, and goods were moved by simple means of transport. However, as cities grew, such basic transportation no longer met society's needs. The growth of auto ownership in the late 20th century and its relevant problems such as congested traffic and pollution has motivated transit agencies to improve public transportation and the consumer-based transit level of service (Fan, 2002). Certain demographic groups, including people with low incomes, non-drivers, people with disabilities, students, and the elderly people, tend to be more transit dependent (Litman, 2004). Transit companies should be able to provide a service which at least meets the needs of these groups. Overall, the objective for service improvements is to reduce waiting and/or in-vehicle time for transit users in order to provide a level of service that is competitive with that of the private auto (Bowman, 1980).

The first section of this chapter introduces the quality of transit service fundamentals and describes several competing factors for selecting transit vs. the private auto. In the second section, the importance of travel time elasticities is explored for several cases. The third and fourth sections review several fuel consumption models, and urban transport emissions respectively. The final section summarizes the concepts and identifies the need for further research.

2.1 Quality of Transit Service Fundamentals

Quality of service focuses on those aspects of transit service that directly influence how passengers perceive the quality of a particular transit trip (Kittelson & Associates, 2003). Availability is the first fundamental of service quality. Transit service is an option for a trip when the service is available at or near the locations and times that one wants to travel. If it does not exist for a particular trip, transit will not be an option for that trip, and other aspects of transit service quality will not matter to the passenger for that trip. When transit becomes an option for a given trip, passengers weigh the other factors of transit against competing modes such as reliability, travel time, safety and security and travel cost. These factors are described briefly.

2.1.1 Reliability

Reliability affects the amount of time that a passenger must wait at a transit stop for a transit vehicle to arrive, and the consistency of a passenger's daily arrival time. Woodhull (1987) has classified the causes of unreliable services according to whether they are internal or external to the system. External causes include such factors as traffic congestion, incidents, and traffic signalization; internal causes include such factors as driver behavior, improper scheduling, varying passenger demand, and inter-bus effects (Woodhull, 1987).

There are three basic methods to improve transit service reliability, categorized as priority, control, and operational (Strathman et al, 2000). Priority methods involve the special treatment of transit vehicles apart from general vehicular traffic that at least partially offset traffic effects on transit operations. Examples of this type of strategy are exclusive bus lanes and conditional traffic signal priority. Operational methods take place over a longer period of time and include such strategies as schedule modification, route restructuring, and driver training. Control methods take place in real-time and include vehicle holding, short-turning, stop skipping, and speed modification (Strathman, 2000). Transit Signal Priority (TSP) technology allows the presence of a transit vehicle to influence traffic controllers, adjusting cycle and phase timings to reduce transit delays.

2.1.2 Total Travel Time

Total trip time includes the travel time from a passenger's origin to a transit stop, waiting time for a transit vehicle, travel time on-board a vehicle, travel time from a transit stop to the destination, and any time required for transfers between routes during the trip as illustrated in Figure 2-1.

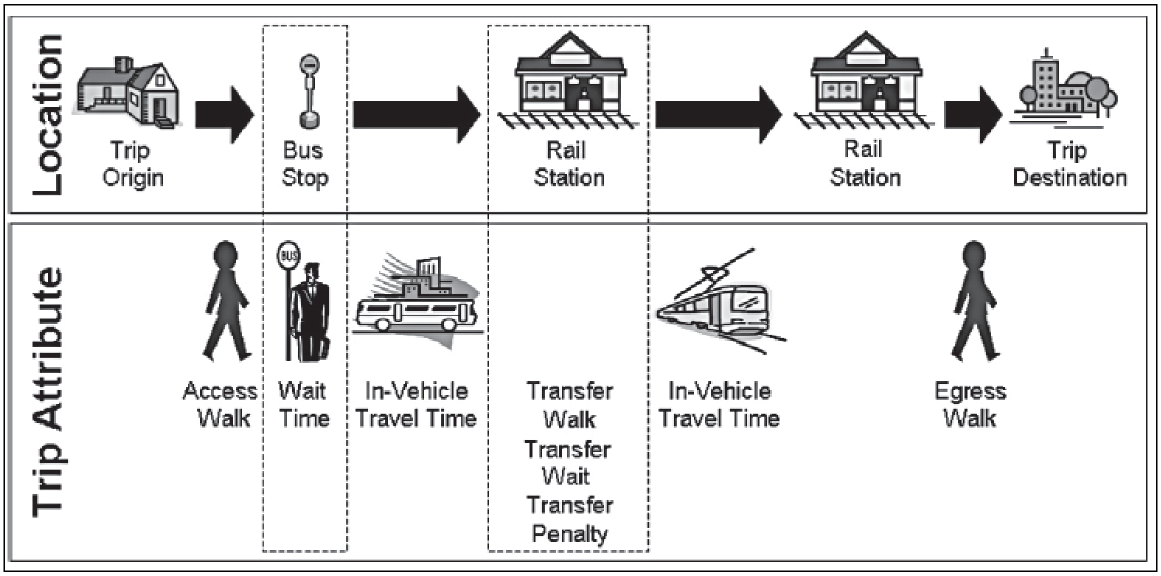

Figure 2-1: Transit Attributes in a Typical Transit Journey (Currie, 2005)

The importance of each of these factors varies from person to a person. Some persons will view the trip as an opportunity for exercise during the walk to transit and for catching up on reading or work while aboard a vehicle. Other persons will compare the overall door-to-door travel time of a trip by transit with the time for the same trip by private automobile (Currie, 2005). Total trip time is influenced by a number of factors, including the route and stop spacing (affecting the distance required for walking to a bus stop), the service frequency (affects the waiting time), traffic congestion, signal timing, and the fare-collection system (affecting the travel time while on a transit vehicle) (Kittelson &Associates, 2003). Next, a description of each attribute is provided.

2.1.2.1 Access and Egress Time

Access time is the time that an individual passenger requires to arrive at a transit stop and egress time is the time from a stop to the final destination for a given trip. The maximum distance people will walk to transit varies depending on the situation. The results of several studies of walking distances to transit in North American cities are shown in Figure 2-2.Although there is some variation between cities and income groups among the studies represented in the exhibit, it can be seen that most passengers (75 to 80% on average) walk 400 meters or less to bus stops. At an average walking speed of 5 km/h, this is equivalent to a maximum walking time of 5 minutes (Sullivan, 1996).

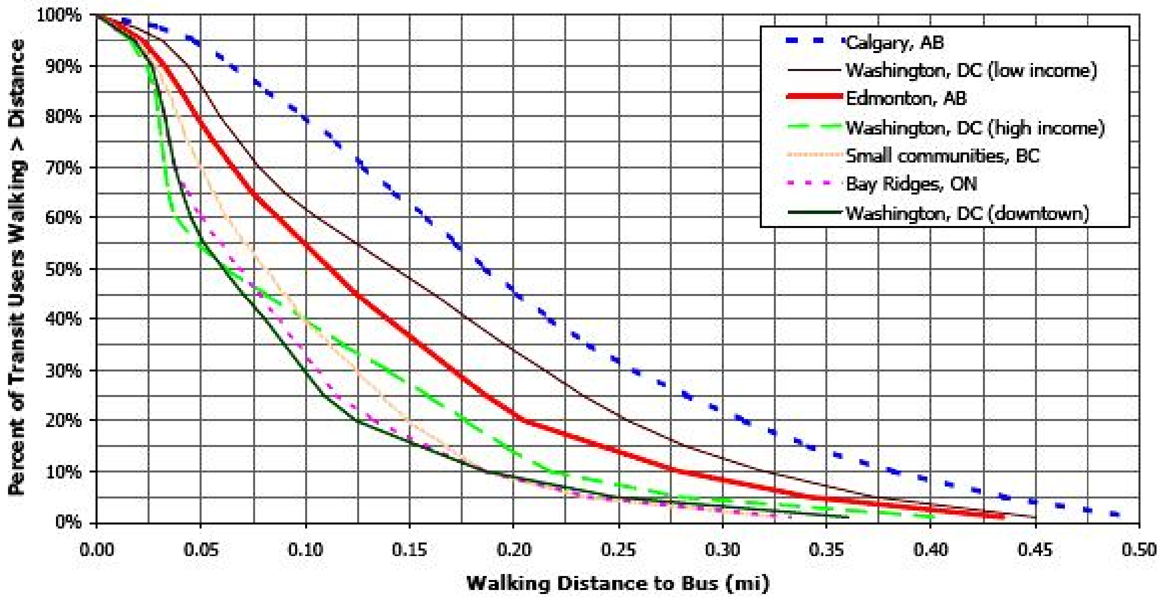

Figure 2-2: Walking Distance to Bus Stops (Kittleson & Associates, 2003)

If access distances are longer than standard walking distance (around 500 meters), passengers use other mode of travel such as bicycle, auto, taxi, etc. Typical bicycling speeds are approximately 20 to 25 km/h, or about four to five times higher than walking speeds. This speed advantage allows transit users to access routes much farther away from their origin or destination than they could if they walked. Typical bicycle trip lengths are approximately 3.5 to 7 km for casual riders and 7 to 10 km and longer for experienced riders (Federal Highway Administration, 1998).

Walking and biking are not the primary access mode to the stations for certain types of transit services, particularly express bus and commuter rail services. For these modes, automobile access via park and ride lots is the primary means of passenger access (Kittelson &Associates, 2003).

2.1.2.2 Waiting time

Waiting time is the time between passenger arrival at a stop and the time of departure for the transit unit. The expected passenger waiting time is related to both the distribution of passenger arrival times at a transit stop, and to the distribution of deviations from schedule in bus arrival times at that stop (Bowman, 1981.) With the simple assumption of passenger arrival at random instants, independent of the schedule of bus arrivals, the expected passenger wait time has been derived by a number of authors (Welding, 1975; Holyord,1966; and Osuna,1972) as follows:

$$E(w) = \frac{H}{2}[1 + C_v^2] \qquad (2\text{-}1)$$

Where,

E (w) : average length of time users must wait before a bus arrive (minutes)

H : mean bus headway (minutes)

C_v : coefficient of the variation in headways (standard deviation/mean).

By assuming that no noticeable variations in bus headways exist, the mean waiting time is equal to half of the bus headway, and in several studies this assumption has been used (Furth et al., 1981; Bakker, 1987; Avineri, 2004).

For longer headways (H>6 or 10 minutes) passengers begin to use a time-table and adjust their arrivals to the schedule (Vuchic, 2004.)

2.1.2.3 In-Vehicle Travel Time

In-vehicle travel time is the time duration of passenger travel in a transit unit for a given trip. In-vehicle travel time can be mitigated by technologies such as TSP, stop skipping, and exclusive transit lanes.

Signal priority is a mechanism for reducing delays to transit vehicles at signalized intersections. A number of researchers have found that signalized intersections are an important contributor to unreliable service (Abkowitz et al, 1983; Smith, 2005). Signal priority typically involves changing the phase of a signal to green or extending the duration of the green phase when a bus approaches an intersection. Signal prioritization reduces running times and decreases delay for all bus passengers (Khasnabis et al., 1999). An optimal signal timing control system would incorporate real-time information on transit operations and general traffic conditions, and would be able to respond to changing operating conditions while minimizing disruptions to traffic flow (Lin et al, 1995).

Right of way category and guidance technology are the most fundamental transit system elements, which strongly influence a mode's performance (Vuchic, 2004), and is grouped in three categories.

1. Right of way C- Street with mixed traffic
2. Right of way B- partially separated system
3. Right of way A- fully separated system

A Matrix of the three ROW categories and three groups of technology is presented in Table 2-1.

Table 2-1: Classification of Transit Modes by ROW Category and Guidance Technology (Vuchic, 2004)

Guidance / **RMOW Category**	**Driver-Steered**	**Rubber Tire Guided**	**Rail Guided**
C	Express bus on streets Regular bus	Trolleybus	Streetcar
B	Bus Rapid Transit (BRT)	Guided bus	Light Rail Transit (LRT)
A	Bus on bus way on entire line	Rubber-tired rapid transit Automated guided transit	Light Rail Rapid Transit Monorail

An express service (like *iXpress*) is the combination of right of way C and a steered vehicle. While this system has the problem of operating on a mixed use urban road network (i.e., congested traffic, and accidents), by extending the stop spacing the running time can be reduced for the vehicle. BRT is any bus line that has partial separation of lanes, new buses, or distinctive line designation as a transit system with ROW category B

2.1.2.4 Transfer Time

Transfer time is the waiting time experienced when transferring from one line or mode to another. Passenger transfers between bus lines occur where two or more transit lines intersect or terminate at one point. Transfers can make service more efficient for the operators, but less convenient for the passenger, depending on the circumstances (Kittelson & Associates, 2003.) In the *Traveler Response to Transportation System Change Handbook* (Pratt et al, 2005), it is reported that the transfer wait is usually perceived as more onerous than the overall initial wait. If the transit service is reasonably reliable, passengers can reduce the impact of the initial wait time by adjusting their time of arrival to more closely match the transit schedule, but transfer waits, in contrast, cannot be controlled by the passenger (Kittelson & Associates, 2003).

The transfer time between lines based on the duration of time headways on the origin and destination lines can be classified into four categories (Vuchic, 2004) (Table 2-2).

Table 2-2: Transfer Times Between Lines with Short and Long Headways

Destination Line / **Origin Line**	**Short Headway (<10 min)**	**Long Headway (>10 min)**
Short headway (<10 min)	Always short, convenient	Varies greatly Information about connection runs required
Long headway (>10 min)	Always short, convenient	Variable depending on headways: 1.Equal and simultaneous: all transfers convenient 2.Equal but not simultaneous: convenient in one direction 3. Different: impossible to coordinate

2.1.3 Cost

Potential passengers weigh the cost and value of using transit versus the out-of-pocket costs and value of using other modes. Out-of-pocket transit costs consist of the cost of the fare for each trip or the cost of a monthly pass (and possibly the cost of parking at a station), while out-of-pocket automobile costs include road and bridge tolls and parking charges (Kittelson, 2003). Other automobile costs, such as fuel, maintenance, insurance, taxes, and the cost of buying an automobile generally do not occur for individual trips and thus usually do not enter into a person's consideration for a particular trip. Thus, if a person does not pay a toll to drive someplace and free parking is provided at the destination, transit will be at a disadvantage because there will be no immediate out-of-pocket cost for driving, while there will be for transit.

2.2 Utility Function

Urban transport involves many travel decisions and a change in one trip criterion (i.e., travel time), can affect a passenger's decision and number of transit rides. To represent the attractiveness of the alternatives, the concept of utility is used to show how travelers combine their perceptions of trip attributes into preferences. The utility function is a convenient theoretical construct, tautologically defined as what the individual seeks to maximize (Ortuzar et al, 2001).

Utility functions are usually defined as a linear combination of variables where each variable represents an attribute of the option. The relative influence of each attribute, in terms of contribution to the overall satisfaction produced by the alternatives, is given by its coefficients (Dios Ortuzar et al, 2001). In many applications, coefficients of variables are presented as importance weights of trip attributes which are captured based on passengers' perception (Wilkie et al, 1973.) However, in some cases a regression is used to fit a utility function to stated preferences by specifying the location of an ideal point based on the assumption of a utility function (Carroll, 1972). A utility function is used in section 3.4.4 to estimate the saving of travel time and cost for passengers who select an *iXpress* service versus local services.

2.3 Elasticity

In economics, there is a rule called “law of demand”, when prices decline consumption increases, and when prices increase consumption declines, all else being equal (Litman, 2004). In transportation, elasticity of demand to price is defined as how changes in travel price (cost) influence changes in transit ridership. Price is a factor that directly affects consumers’ purchase decision. This can include both monetary costs and non-market costs such as travel time and reliability. Demand elasticity is the percentage of change in demand resulting from a one-percent change in price, all else held constant (Litman, 2004.) Mathematically, elasticity of demand with respect to price is expressed as Equation 2-2.

$$Elasticity = \frac{\Delta Quantity \quad (Demand)}{\Delta(\mathrm{Pr}ice, Quality, etc)} \tag{2-2}$$

A low elasticity value means that prices have relatively little effect on consumption. The degree of price sensitivity refers to the absolute elasticity value, that is, regardless of whether it is positive or negative. For example, if the elasticity of transit ridership with respect to transit fares is –0.5, this means that each 1.0% increase in transit fares causes a 0.5% reduction in ridership, so a 10% fare increase will cause ridership to decline by about 5%.

Price elasticities have many applications in transportation planning. They are used in modeling to predict how changes in transit service will affect vehicle traffic volumes and pollution emissions; and they can help evaluate the impacts and benefits of mobility management strategies such as new transit services, road tolls and parking fees.

Several factors can affect public transit elasticities as follow (Litman, 2006):

- **User Type:** Transit dependent riders are generally less price sensitive than choice riders (people who have the option of using an automobile for that trip).
- **Trip Type:** Non-commute trips tend to be more price sensitive than commute trips.
- **Geography:** Large cities tend to have lower price elasticities than suburbs and smaller cities, because they have a greater portion of transit-dependent users.
- **Type of price:** Change in service quality (service speed, frequency, coverage and comfort) tends to have a greater impact on transit ridership than transit fares and fuel price.
- **Time Period:** Impacts can be categorized in three time periods: Short-run (less than two years), medium-run (within five years) and long-run (more than five years). Elasticities increase over time, as consumers take price changes into account in longer-term decisions (i.e., where to live or work).
- **Transit Type:** Bus and rail have different elasticities because they serve different markets.

2.3.1 Travel Time Elasticities

Typically, the increased relative speed for a particular mode attracts passengers from other modes along a corridor (Litman, 2006). *iXpress* service by providing higher speed of travel and shorter delay, can attract passengers from other modes including local services and auto-vehicles to take this service. The change of in-vehicle travel time, waiting time and transfer time which provides faster and shorter trip for *iXpress* passengers cause the change of demand for this service. In this section, the elasticity of demand with respect to transit travel time, especially in-vehicle travel time and waiting time of past research is investigated.

TRACE (1999), has considered the elasticity of various types of travel with respect to car travel times. Long-term car travel time elasticities in areas with a high vehicle ownership (more than 450 vehicles per 1,000 population) are summarized in Table 2-3.

Table 2-3: Long Term Travel Elasticities with Respect to Car Travel Time (TRACE, 1999)

Purpose	Car Driver	Car Passenger	Public Transport	Slow Modes
Commuting	-0.96	-1.02	+0.70	+0.50
Business	-0.12	-2.37	+1.05	+0.94
Education	-0.78	-0.25	+0.03	+0.03
Other	-0.83	-0.52	+0.27	+0.21
Total	-0.76	-0.60	+0.39	+0.19

Slow Mode=Walking and Cycling

TRACE has found that a total of a 1% increase in car travel time causes a 0.39% increase in public transportation travel and a 0.19% increase in walking or cycling travels.

Booz Allen Hamilton (2003) used stated preference survey data to estimate elasticity for various costs (fares, travel time, waiting time, transit service, frequency, parking fees), modes (automobile, transit, taxi) and trip types (peak, off-peak, work, education, other) in the Canberra (Australia) region. Demand was measured in trips (number of single journeys). Table 2-4 shows the estimated fare, in-vehicle, walk and wait time elasticities.

Table 2-4: Australian Bus Users Travel Demand Elasticities (Booz, Allen, Hamilton, 2003)

Mode	Time-of -Day		
	Peak	**Off-Peak**	**Total**
Fare	-0.18	-0.22	-0.20
In-vehicle time	-0.37	-0.37	-0.37
Wait time	-0.10	-0.24	-0.17
Walk time	-0.19	-0.32	-0.25

Table 2-4 indicates that bus users have a greatest elasticity for in-vehicle travel time. For example, a 1% increase in transit fares causes a 0.2% reduction in demand; however a 1% increase in in-vehicle travel time causes a 0.37% reduction in transit ridership.

A review of in-vehicle travel time elasticities are presented in Table 2-5 which was provided by Booz Allen Hamilton (2003).

Table 2-5: Review of Public Transport in-Vehicle Time Elasticities (Booz, Allen, Hamiton, 2003)

City	Elasticity Estimates	Comments and Source
Various	-0.29 - -0.83	Literature review of non-experimental data (bus) (Lago et al, 1981)
Sydney	-0.44 Peak -0.34 Off-peak -0.48 Overall	Sydney Rail (Douglas and Parrish,1990)
Stockholm	-0.36 Off-peak -0.31 Peak	Transportation Model (Algers et al, 1995)
Brisbane	-0.45 all-day -0.52 Off-peak -0.37 Peak	(Booz ,Allen and Hamilton, 2001)
Australia	-0.30 - -0.50	Literature review of Australian examples (Bray, 1995)

One of the most comprehensive reviews is the earlier work by Lago et al (1981), which found values ranged from around –0.30 to –0.80 depending on the mode, market segment and study type.

Litman (2006) lists transit elasticities with respect to fares and transit service from various researchers as presented in Table 2-6.

Table 2-6: Transit Elasticity Values (Litman, 2006)

	Market Segment	Short Term	Long Term
Transit ridership WRT transit fares	Overall	-0.2 to -0.5	-0.6 to -0.9
Transit ridership WRT transit fares	Peak	-0.15 to -0.3	-0.4 to -0.6
Transit ridership WRT transit fares	Off-peak	-0.3 to -0.6	-0.8 to -1.0
Transit ridership WRT transit service	Overall	0.50 to 0.7	0.7 to 1.1

WRT: With Respect To

As indicated, a total of a 10% increase in transit fares results in a 6% to 9% reduction in transit ridership demand in long term situations, and an improvement of 10% in service quality causes a 7% to 11% increase in transit ridership demand.
Obviously, no single elasticity value applies in all situations. Various factors affect price sensitivities including the type of user and of trip, geographic conditions, and time period. Overall, transit passengers are more responsive to service quality (speed, frequency, vehicle travel time and comfort) than to fares. Also, they are more sensitive to in-vehicle travel time than other transit time components. So, *iXpress* service with providing shorter in-vehicle travel time might have more impact on attracting passengers from taking auto-vehicles to public transportation.

2.4 Fuel Consumption Models

Fuel consumption models are mathematical relationships that relate fuel consumption to a number of input variables including: the number of trips; the vehicle miles traveled; the number of stops; vehicle moving forces such as propulsion[1] or rolling resistance[2], and gradient resistance[3]. The input variables are estimated based on several mathematical relationships, simulation results, or field data collected from empirical cases.

To date, most efforts have focused on developing fuel consumption models for light-duty vehicles, not HDD (Heavy-Duty Diesel) vehicles including transit buses or trucks (the California Air resource board has categorized all school and urban buses as HDD vehicles) due to the lack of second- by-second emissions data (Barth, 2005). However, buses are major contributors to the emission inventory, accounting for over 50% of NO_X (Nitrogen Oxides) and PM (Particulate Matter) in many locations (Lloyd, 2001). HDD vehicles compared to light-duty vehicles, have much larger aerodynamic drag coefficients, as well as

[1] The force to overcome the resistance to motion and to accelerate in vehicles.
[2] Total of all resistances, apart from aerodynamic drag.
[3] The force required to overcome grades

much lower power-to-weight ratios which may change the fuel consumption ratios of this group of vehicles from light duty ones (Barth, 2005).

Comprehensive research has been conducted on the available fuel consumption models for light duty vehicles and urban buses, several of which are described in the following section. Many studies of fuel consumption models are based solely on the driving cycle. However the purpose of this research is developing a fuel consumption model as a function of route and vehicle characteristics. In the following section, several fuel consumption models are presented for completeness and their deficiencies are indicated.

Post et al. (1984) developed the original power-based model as the first analytical fuel consumption model. It represents a fuel consumption ratio according to the instantaneous power demand of a vehicle, which has been developed from chassis dynamometer experiments on 177 in-use Australian vehicles.

$$f_t = \alpha + \beta P \qquad (2\text{-}3)$$

where

f_t : instantaneous fuel consumption rate (ml/min)

α : idle fuel consumption rate, estimated to be 39.2 ml/min.

β : average efficiency factor, which is estimated to be 9.2 ml /minKW.

p : total power required (KW)

This model provides aggregate fuel consumption estimates for on-road driving within 2% of the actual measured fuel usage.

Akcelik et al. (1989) has improved power-based model, and found that an average value does not give accurate results since the value varies as a function of the speed and acceleration rate. As a result, he has selected two efficiency parameters for the constant speed and acceleration modes of driving such that

$$f_t = \alpha + \beta_1 P_c + \beta_2 P_a \tag{2-4}$$

where

P_c : $P_D + P_{ec}$

P_a : $P_L + P_{ea}$

P_D, P_L : coast-down drag and inertia powers (KW)

P_{ec}, P_{ea} : power associated with engine/internal drag during constant speed driving and acceleration (Kw).

f_t : instantaneous fuel consumption rate (ml/s)

α : vehicle parameter, idle fuel consumption rate (ml/s)

β_1, β_2 : vehicle parameter (ml/s/KW)

P_c : total drag power during constant-speed driving (KW)

P_a : total engine/inertia drag power (KW)

Due to the disaggregate characteristic of the fuel consumption data, the power-based models are usually implemented to evaluate individual transportation projects such as single intersections, and highway sections, and are not suitable for modeling the entire network of the region routes (Ahn, 1998).

Barth et al. (2005) have developed a model which includes power-demand and instantaneous truck fuel consumption, referred to the comprehensive modal emissions modeling (CMEM) framework. This model is a function of the power demand and engine speed. The engine speed has been determined according to vehicle velocity, gear shift schedule, and the power demand of six categories of trucks.

The basic diesel fuel consumption rate is estimated as follows:

$$FR \approx (KNV + \frac{P}{\eta}) \frac{1}{43.2} \times (1 + b_1 \left(N - 30 \sqrt{\frac{3}{V}} \right))^2 \tag{2-5}$$

$$K = K_0 \left[1 + C \left(N - 30 \sqrt{\frac{3}{V}} \right) \right]$$

where

FR : fuel use rate (grams/second)

P : engine power output (Kw)

K : engine friction factor

N : engine speed (revolutions per second)

V : engine displacement (litre)

η : 0.45 is a measure of indicated efficiency for diesel engines

b_1 : 10^{-4}

C : 0.00125

The model has been validated by the comparison of engine fuel rate measurements from a truck's Engine Control Unit (ECU) on a second-by-second basis with the one in Equation 2-5. This comparison shows that the model under predicts the measured values by approximately 5%. The resulting fuel consumption and emission model has been successfully integrated with the PARAMICS simulator (Barth, 2005).

However, this fuel consumption model has been developed for trucks, based on measured parameters including engine power, and transmission, and may not be representative of the fuel consumption characteristics of diesel transit buses.

Zargari and Khan (2002) have developed a fuel consumption model for the buses in the Ottawa-Carlton Transit way, where access is restricted to buses, emergency and maintenance vehicles. In this model, bus fuel consumption is developed for each of the four phases of bus operation: acceleration, cruise, deceleration and idling; moreover, the transit way section distance, cruise speed, stopped time, average grade, and the total mass of vehicle are inputs to the models for each phase. The acceleration fuel consumption rate per unit time is equal to multiply of the total power required to overcome the forces resisting the vehicle motion (external and internal) into a fuel-to-power efficiency factor from an initial speed of zero to a cruise speed of *V*. The deceleration fuel consumption is estimated similarly to that of acceleration. In this case, the fuel is estimated from the cruise speed to a final speed of zero. The cruise fuel consumption rate is estimated for each kilometer of travel from the end of an acceleration process beginning from a stopped position to the initiation of the next deceleration.

The fuel consumption is also a function of power accessories such as heating or cooling the bus while the passengers board at terminals. This idling fuel consumption is assumed to be constant value of 0.399 ml/s for standard buses on the basis of the computations by Zargari. To validate the model, the results of the bus fuel model were compared with those of the 1994 Ottawa-Carleton Regional Transit Commission (OC Transpo) average bus fuel consumption data which is presented in Table 2-7.

Table 2-7: Comparison of Actual Fuel consumption and Zargari's Model Outputs

	Standard Bus (litres/km)
OC Transport Estimate	0.591
Model Estimate	0.578
% Difference	2.2%

In this model, a separate right of way from the other lanes (BRT) is considered however; in RMOW case *iXpress* buses share the same lanes as other vehicles. Also, in this model, the time spent idling assumed to be constant; however, in reality the number of passengers for each boarding and alighting can change the idle time and fuel consumption. Moreover, according to this model, it is difficult to introduce any difference in driver's behaviour such as the acceleration and deceleration maneuvers of the different drivers, or difference in vehicle characteristics such as age and vehicle type. Primaring due to the model approach that buses operate on an exclusive right-of-way, this model is unsuitable for application to the iXpress services.

Rakha et al. (2002) have presented a fuel consumption and emission model as a function of the vehicle's instantaneous speed and acceleration rates by using the Oak Ridge National Laboratory (ORNL) data from a total of eight light duty vehicles of various weights and engine sizes as follows:

$$Logf_t = \sum_{i=0}^{3} \sum_{j=0}^{3} B_{ij}^{k} u^{i} a^{j} \qquad (2\text{-}6)$$

where

f_t : instantaneous fuel consumption or emission rate (l/s or mg/s)

B_{ij}^{K} : constant for speed degree *i*, acceleration degree *j*, and MOE *k*

u : instantaneous vehicle speed (km/h)

a : instantaneous vehicle acceleration (m/s^2)

The model was found to be highly accurate with the coefficient of determination ranging from 0.92 to 0.99. The eight typical vehicles included five light-duty automobiles and three light-duty trucks which were driven in the field in order to verify their engine parameters as functions of vehicle speed and acceleration. Following the road testing, the vehicle fuel consumption and emission rates were measured in a laboratory on a chassis dynamometer within the vehicle's feasible speed and acceleration capabilities. The study has indicated that vehicle fuel consumption and emission rates increased considerably as each vehicle stop was introduced, especially at high cruising speeds. However, the vehicle fuel consumption was more sensitive to the constant cruise speed levels than it was to the vehicle stops. The constant speed case shows a fuel consumption rate of 0.53 litres per km at a constant speed of 25 km/h and a rate of only 0.35 litres per km at a constant speed of 75 km/h. The variable speed case shows that fuel consumed by a vehicle with a constant average speed of 37 km/h, is lower than that experienced by the same vehicle, if the average speed involves some level of acceleration and deceleration. Though, this research demonstrates the impact of the introduction of stops for light duty vehicles. It does not provide the impact of multiple stops for transit buses as HDD vehicles.

Hellinga et al. (2000) have investigated the fuel consumption and vehicle emissions at signalized intersections by using aggregate analytical models, and generated emissions data from INTEGRATION(a traffic simulator model) . The single 4-leg signalized intersection was modeled with INTEGRATION with a 2-phase fixed time signal and a cycle length of 100 seconds. The authors have developed two classes of regression models: one that directly estimates the fuel consumption from the signal timing parameters (Equation 2-7) and one that estimates the fuel consumption on the basis of the number of stops and stopped delays (Equation 2-8).

$$\text{Fuel(liter)} = e^{-0.610-5.81\times10^{-2}S_f+3.919\times X+1.714\times10^{-2}S_c+1.146\times10^{-3}C+2.47\times10^{-1}g/c} \quad (2\text{-}7)$$

where

S_f : free flow speed (Km/h)

X : degree of saturation

S_c : speed at capacity (Km/h)

C : cycle length (Sec)

g/c : effective green to cycle length

$$\text{Fuel(liter)} = e^{0.641+3.061\times10^{-2}S_f-0.939\times10^{-2}S_c+10.91\times10^{-4}N_s+16.88\times10^{-6}D_s} \quad (2\text{-}8)$$

where

S_f : free flow speed (Km/h)

S_c : speed at capacity (Km/h)

N_s : number of stops

D_s : stopped delay (Sec)

The results imply that the direct estimation regression models are preferred over the indirect estimation models. However, this model is based on the characteristics of light duty vehicles and can not be applied successfully to modeling transit buses.

The review of the literatures has identified a number of fuel consumption models; however none of these are suitable in estimating fuel consumption of transit buses as a function of route and vehicle characteristics. This research presents the development of such a model to investigate the impact of stop spacing changes and other factors on fuel consumption.

2.5 Transport Energy and Emissions

In recent years, transport's use of energy has risen significantly. However, over the past 35 years, air quality impacts of public transport have improved dramatically as a result of increasingly stiff regulations and advances in technology in developed countries (Puchalsky, 2005). In the previous section, the principal criteria of public transport services for attracting more passengers was explained. In this section, first, the key emissions of urban public transport that affect air quality are introduced; next these emissions for different public modes and the auto are compared.

2.5.1 Urban Public Transport Vehicles Emissions

The first significant legislation to recognize the harmful effects of air pollution on public health was the Clean Air Act (CAA) in 1970. The CAA established air quality standards for six pollutants: Carbon Monoxide (CO), Lead (pb), Nitrogen Oxides (NO_x), ozone (O_3), particulate matter (PM_{10}) and Sulfur dioxides (SO_2) (Ahn,1998). In 1990, the new clean air act legislated further reductions in HC (Hydrocarbons), CO, NO_x, and particulate emissions.

Urban public transport vehicles are powered predominantly by diesel or electricity. Buses and many trains are diesel powered, whereas electrification is widespread for urban railway lines and is standard for metro and tram systems. For diesel-powered buses and trains, the key emissions that affect air quality (Potter, 2003; Ahn, 1998) are as follows:

Carbon Monoxide (CO) – Highly toxic gases which reduce the flow of oxygen in the bloodstream and are harmful to every living organism. Transport is the major source of carbon monoxide with 90% coming from cars.

Nitrogen Oxides (NO_x) – Formed by the reaction of nitrogen and oxygen atoms during high pressure and temperature, these cause respiratory problems and contribute to low level ozone formation and acid rain. Transport produces about half of NOx emissions. Diesel vehicles (buses and diesel cars) are an important source.

Hydro Carbon (HC) – These emissions result from fuel that does not burn completely in the engine. Hydrocarbons emitted by vehicle exhaust systems are also toxic and are known to cause cancer in the long term.

Particulate matter (PM) –this emission is complex mixture of extremely small particles and liquid droplets. This pollution is made up of a number of components including acids, organic chemicals, metals and soil particles. About half of all particulates come from diesel vehicles.

2.5.2 Emissions from Different Transport Modes

A comparison of GHG emissions for the public transportation modes has been conducted in several studies (Delucchi et al. 1996; Potter, 2003; and Puchalsky, 2005). Comprehensive analysis of emissions by Delucchi used a lifecycle emission model to estimate the percentage change in emissions of door-to-door auto trips switching to public transportation. The change in emissions is calculated as:

$$100 \times \frac{(T_r - A_d)}{A_d} \tag{2-9}$$

where,

T_r : grams emitted per passenger trip involving transit

A_d : grams emitted per direct door-to-door auto trip.

The distinguishing feature of a life cycle emissions analysis is that it estimates emissions associated with the entire life cycle of a particular product, as opposed to emissions from just consumer end use (Delucchi, 2005). A life cycle analysis (LCA) of emissions formally characterizes the inputs, outputs, and emissions for each stage of the lifecycle, links the stages together, and aggregates the emission results over all of the linked stages.

Six locations with different transit modes and diverse fuel categories were selected for the analysis.

The fuel cycle emission of CO_2 is a function of the amount and kind of energy consumed by cars, buses, and trains. Delucchi et al. modeled this energy consumption by using a detailed engineering model by Ross and An (Ross, 1994; An and Ross, 1993) to calculate the energy use of passenger cars and vans as a function of the characteristics of the trip (average speed, maximum speed, number of stops per mile, number of cold starts, and more) and the characteristics of the vehicles (empty weight, number of passengers, rolling-resistance coefficients, frontal area, drag coefficient, component efficiencies, energy use by accessories, use of regenerative braking, and other factors). The fuel consumption rates are presented in Table 2-8.

Table 2-8: Fuel Use (L/km) by light Duty Cars and Vans (Delucchi, 1996)

Area / Fuel Use	Sacramento (USA)	San Francisco (USA)
L/km of two passengers in car	0.13	0.096

The data for the energy use of buses are provided from real energy use data that was reported by the transit agencies to the U.S Federal Transit Administration of the U.S Department of Transportation. These data are shown in Table 2-9.

Table 2-9: Fuel Use (L/km) by Diesel Buses (U.S Federal Transit Administration, 1990)

Area	**Sacramento**	**San Francisco**	**Los Angeles**	**San Diego**	**Boston**	**Washington D.C**
Fuel Use	0.75	0.99	0.84	0.73	0.68	0.95

The final total-trip average gram/km emission factors are estimated, based on different levels of emissions (e.g., exhaust and evaporative). The estimated factors for Sacramento are given in Table 2-10, and the final emission factors for the other cities are derived identically, and are very similar to those for Sacramento.

Table 2-10 Calculated Modal Emission Factors, Corrected for Local Temperature (Delucchi, 1996)

Mode / **Pollutants**	**Light Duty Automobiles**	**Light Duty Trucks**	**Buses**
CO (gram/Km)	2.95	3.96	12.48
NO_x (gram/Km)	0.24	0.35	11.36
PM_{10} (gram/Km)	1.54	1.77	12.11

Delucchi study implies that the use of transit causes an increase in the fuel cycle GHG in some places and a decrease in others compared with those of direct automobile trips, because the key parameters assume vastly different values from one place or policy to another (weather, fuel type, vehicle type and assembly). Therefore, the effect of transit must be analyzed case-by-case. For each scenario, several parameters are important in the comparison of emissions from transit trips with emissions from direct-drive automobile trips:

- Energy consumption per vehicle kilometer;
- Vehicle occupancy;
- Type of fuel used by cars, vans, or buses;
- Mix of fuels used to generate electricity;
- Mode of access to transit.

This research conducted in the U.S using lifecycle emission model demonstrates that the effect of transit use can range from almost a complete elimination of all emissions per passenger trip to a substantial increase in all the emissions per passenger trips, and depends on several assumed parameters. However, this model is not used for estimating of GHG emissions reduction in RMOW, because the model needs an extensive detailed inputs which comprises all of the physical and economic process involved directly or indirectly in the life of the GHG emission production, and collection of all these data for RMOW case is not possible.

2.6 Chapter Summary

This chapter begins with an investigation of the quality of transit services, and describes the competing factors such as travel time, cost, and reliability in selecting public transit instead of automobiles. Then the chapter provides a literature review of the elasticities to ascertain how changes in transit criteria (e.g., reduction or increase of travel time) affect a number of transit riders. Next, fuel consumption of light and heavy duty diesel vehicles is introduced.

Also, urban vehicle emission components and various factors for increasing these emissions are investigated. A comparison of the vehicle emissions for different modes of transportation indicates the tremendous difference of GHG emissions between public transit vehicles and private cars.

However, none of the research on fuel consumption and GHG emissions covers the real effect of transit improvement in energy consumption and regional air quality. Moreover, due to lack of specific fuel consumption models for basic transit buses, there is a need for further research to evaluate the impact of operational efficiency and regional air quality on enhanced public transportation systems.

The following chapters outline such an evaluation procedure, by using collected fuel consumption data and ridership data to investigate the impact of express bus service (high-order service) in a mid-sized Canadian region.

3. Enhanced Transit Service Impact on Passenger Attraction

The description of transit quality of service and its fundamentals in section 2.1 conveyed the importance of transit travel time for trip-makers for several case studies. In this chapter, the Regional Municipality of Waterloo (RMOW) and its transit services are introduced. The costs of transit travel before and after the introduction of express bus service are computed and correlated to changes in ridership. The analysis is carried out to determine the success of the new express service to attract passengers.

3.1 Study Area Description

The RMOW is located in southern Ontario, approximately 100 km west of Toronto. The Region consists of the cities of Kitchener, Waterloo, and Cambridge, as well as four townships. Figure 3-1 shows the location and configuration of the Regional Municipality.

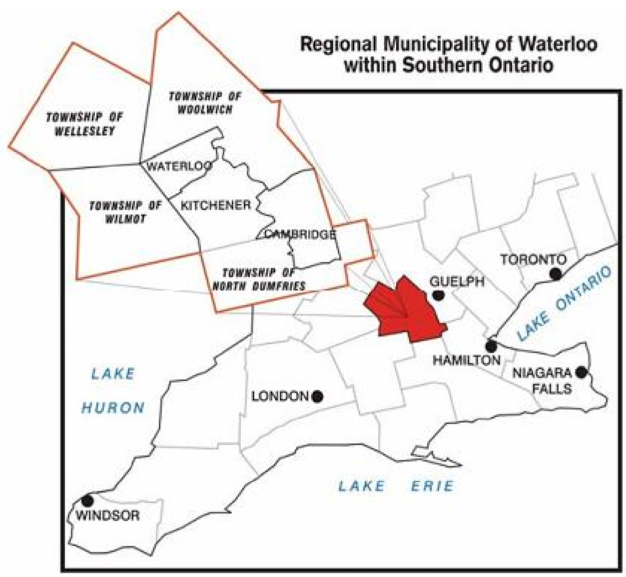

Figure 3-1: Location of the Region of Waterloo

The population of the Region is nearly half a million people, which makes it the tenth largest municipality in Canada, and fourth largest in Ontario (Statistics Canada, 2005). It is a mid-sized Canadian urban area, which has recently undergone rapid growth, and is expected to have 700,000 people by 2031 (Region of Waterloo, 2002). Such growth is a concern for politicians, planners and the general public as the growth has the potential to negatively impact mobility, environmental protection, public health, and air quality. Accommodating this growth is a major challenge for the region (Region of Waterloo, 2003). A major initiative for the Region is to accommodate the growing transportation demand with an enhanced public transportation system.

Since January, 2000, the RMOW has operated Grand River Transit (GRT), a transit network of 50 fixed bus routes. Current GRT service consists of 480 employees, 181 transit buses, 21 Mobility PLUS services[1], 2 multi-modal bus terminals, and 9 transfer terminals (Region of Waterloo, 2006). Table 3-1 shows the distribution of the GRT routes and terminals.

Table 3-1: Distribution of Bus Routes and Terminals in GRT Coverage Area (2006)

Area	No. Routes	Multi-Modal Terminals	Transfer Terminals
Waterloo	6		2
Kitchener	17	1 (Charles Street Terminal)	4
Cambridge	18	1 (Ainslie Street Terminal)	3
Kitchener-Waterloo	5		
Cambridge-Kitchener	3		
Waterloo-Kitchener-Cambridge	1		
Total	50	2	9

As shown in Figure 3-2, GRT covers most of the areas of three urban centers. Ridership in the region totals more than 12 million trips annually (Region of Waterloo, 2005)

[1] This is a service for disabled persons which is a demand responsive, non-fixed route service.

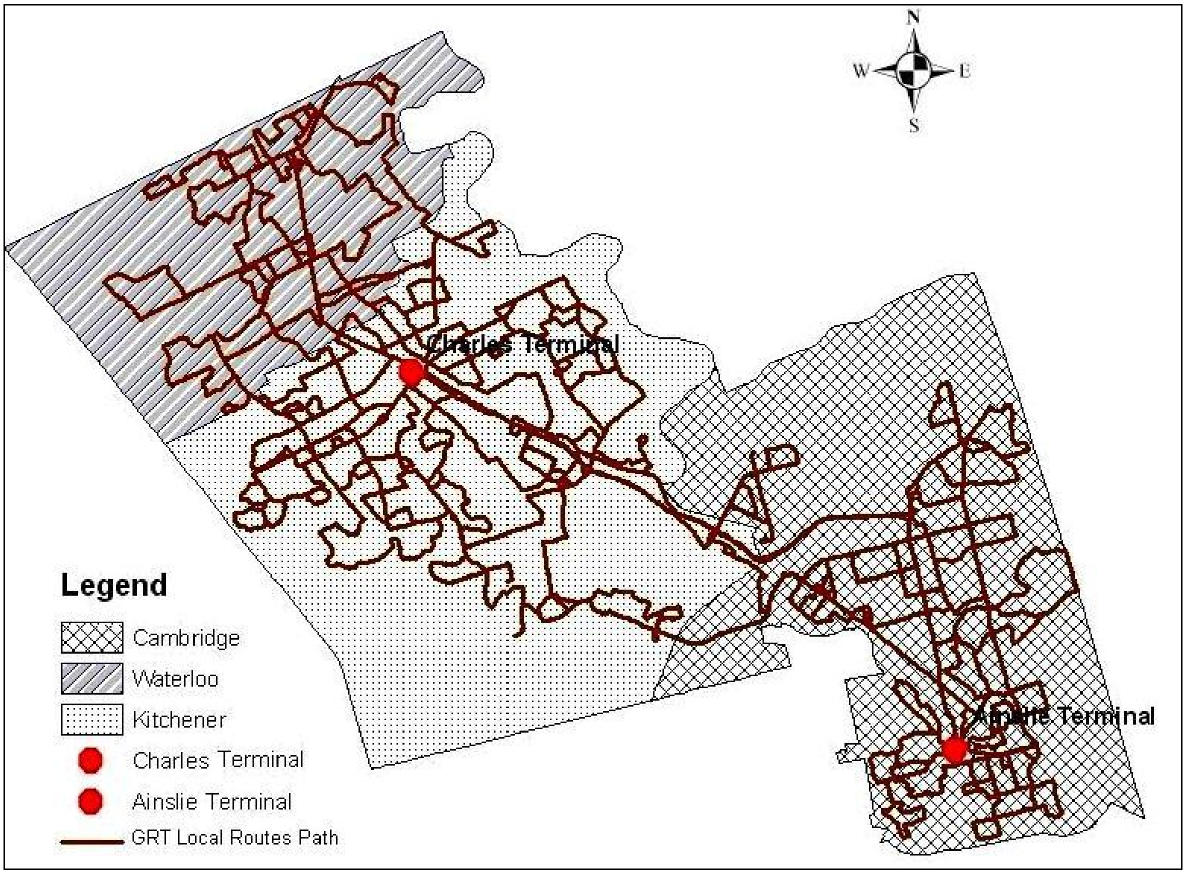

Figure 3-2: Grand River Transit Network in Waterloo Region

Despite this ridership, the Region can still be considered heavily "auto-dependent." Over 80% of commuters drive alone for their journey to work trips in RMOW (Region of Waterloo, 2003). High auto dependency has been caused by several reasons including: low traffic congestion, free parking, proper road infrastructure, and favorable auto travel times (Hellinga et al., 2007)

The problems of auto-dependency are well documented (Delucchi et al, 1996). One major issue of particular importance in the Region is air quality. The collective impacts of auto-dominated urban transportation result in conditions which cause climate change. On the national level, Canada's National Climate Change monitors the environmental aspect of life and allocates a portion of government funding to improve the environment (Region of Waterloo, 2003). In 2004, the RMOW was selected to receive funding through the Urban Transportation Showcase Program (UTSP) (Region of Waterloo, 2006a). UTSP was designed to evaluate strategies to reduce the GHG emission caused by urban transportation. The Region of Waterloo launched a higher order transit service, branded as the *iXpress*, to attract auto trip-makers to public transportation and to decrease GHG emissions.

3.2 Express Service (*iXpress*)

The express bus service, *iXpress*, in the RMOW began operation in September 2005. It connects the city of Waterloo in the north to the city of Kitchener and to the city of Cambridge in the south. The alignment is 37 kilometers in length and has 13 stops. The locations of the bus stops along the *iXpress* route were selected in relation to the major activity centers, which are identified in terms of the land use and network connectivity (Region of Waterloo, 2003). The major portion of the *iXpress* alignment is along King Street, a major arterial in the RMOW, which connects the cities of Waterloo, Kitchener, and Cambridge, passing two universities, two major shopping centers, a central hospital, and two transit terminals. Figure 3-3 portrays the *iXpress* route alignment along the three cities in the RMOW, while Table 3-2 presents the stop spacings for the route.

This service operates Monday to Friday, 6 a.m. to 7 p.m. with time headway of 15 minutes in the morning and afternoon peak periods and 30 minutes in the mid-day. In 2007, weekend service was initiated. The *iXpress* service is provided by year 2004 NOVA buses which differ from buses serving the local routes. These 40 foot-low floor buses provide easy and immediate access to the bus interior by wide doors, facilitating fast, efficient passenger boarding and exiting.

More reliable and convenient service with a shorter travel time has resulted in a steady increase in boardings, as the communities have become more aware of the service and its benefits. The total monthly boardings have risen from 47,796 in September 2005 to 77,873 in March 2006 (Region of Waterloo, 2006b). Data suggest that 81% of trips are home or work based trips and 57% of trip makers are under the age of 25.

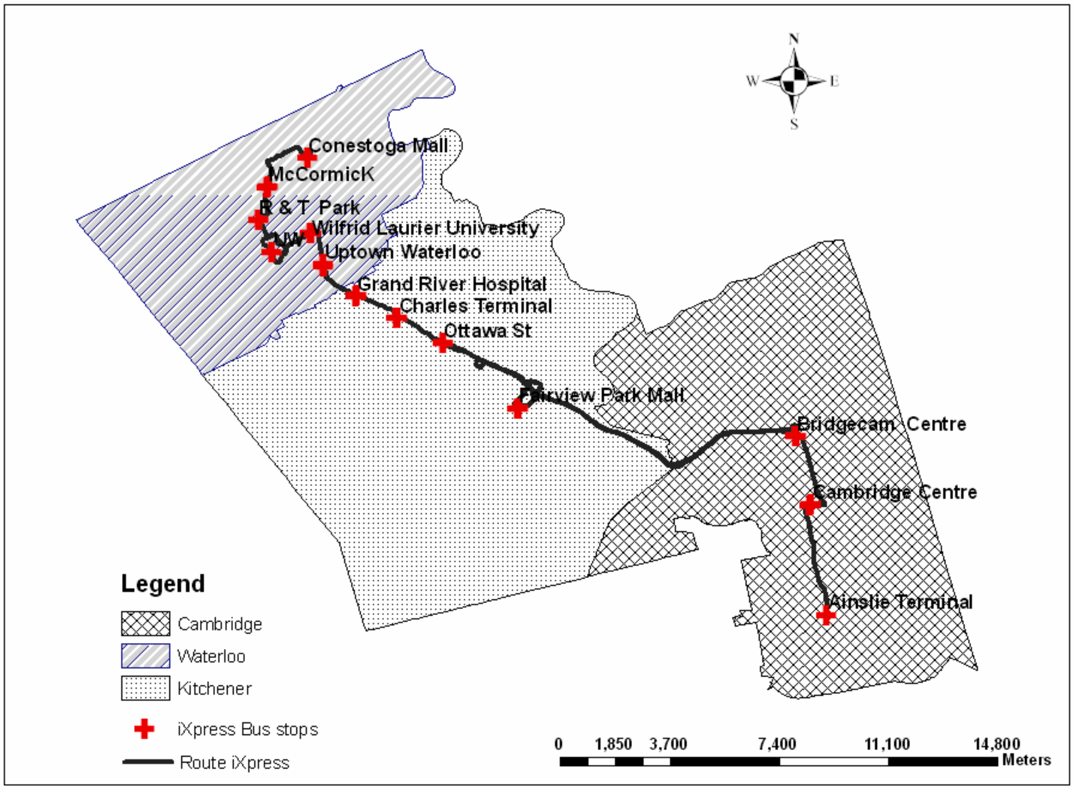

Figure 3-3: *iXpress* Route and Stations

Table 3-2: Stop Spacing of *iXpress* Stations

Stop Space	1 Conestoga Mall	2	3	4	5	6	7	8	9	10	11	12 Ainslie Terminal
Inter Stop Spacing (Km)	2.66	1.40	1.29	2.18	1.65	1.22	1.96	1.83	4.38	12.9	3.00	4.08

Table 3-3 illustrates the land use and network connectivity of the main 8 stations along the *iXpress* route. The RMOW was subdivided into 11 major activity centers (Xin, 2004), and the *iXpress* service stops at 8 of these.

Table 3-3: Main *iXpress* Stations Land Use and Network Connectivity (Region of Waterloo, 2003)

Express Bus stops	Land Use	Network Connectivity
Conestoga Mall	Regional Shopping Centre- 500,000 square feet existing Can expand to 775,000 square feet	8 routes including busPLUS van service
University of Waterloo(UW)	25,000 students 3,500 employees	4 routes
Wilfred Laurier University	9,500 students 1,000 employees	4 routes
Uptown Waterloo	4,000 employees	2 routes
Grand River Hospital	5,500 employees	1 route
Charles Street Terminal	10,000 employees	15 routes
Fairview Park mall	Regional Shopping Centre - 720,000 square feet planned expansion – 830,000 square feet	10 routes
Ainslie Street Terminal	5,000 employees	11 routes

3.3 *iXpress* and System Ridership

The impacts of the *iXpress* service on system ridership can be quantified by comparing the change in boardings along routes serving the *iXpress* corridor prior to, and after the introduction of *iXpress* services. Prior to the introduction of *iXpress*, local route 7 was the only service operated between Fairview Mall and Conestoga mall ("northern corridor.") Service between Fairview Mall and Ainslie terminal (the "southern corridor") was limited to local routes 51 and 52. The alignments of these routes are shown in Figure 3-4.Average daily ridership (boardings) on 2005 for the northern corridor was 15,941, while the boardings on the southern corridor (routes 51 and 52 combined) were 2,213 (Region of Waterloo, 2005).

To determine the impacts of new service in these corridors, the actual growth in ridership on the *iXpress* corridor is compared to the system-wide growth in ridership. GRT as a whole experienced a 7% increase in boardings in the period considered (2005-2006). If the *iXpress* corridor ridership grew at the system rate, the average daily boardings in the corridor without *iXpress* would be 17,057 for the north corridor (i.e.15941×1.07) and 2,368 (i.e.2213×1.07) for the south corridor.

Actual boardings were counted on existing local and *iXpress* routes in April of 2006, six months after the introduction of *iXpress*. Route 7 boardings grew to 16,528, while routes 51 and 52 grew to 1,913 and 982 respectively making the total for the southern corridor 2,895.

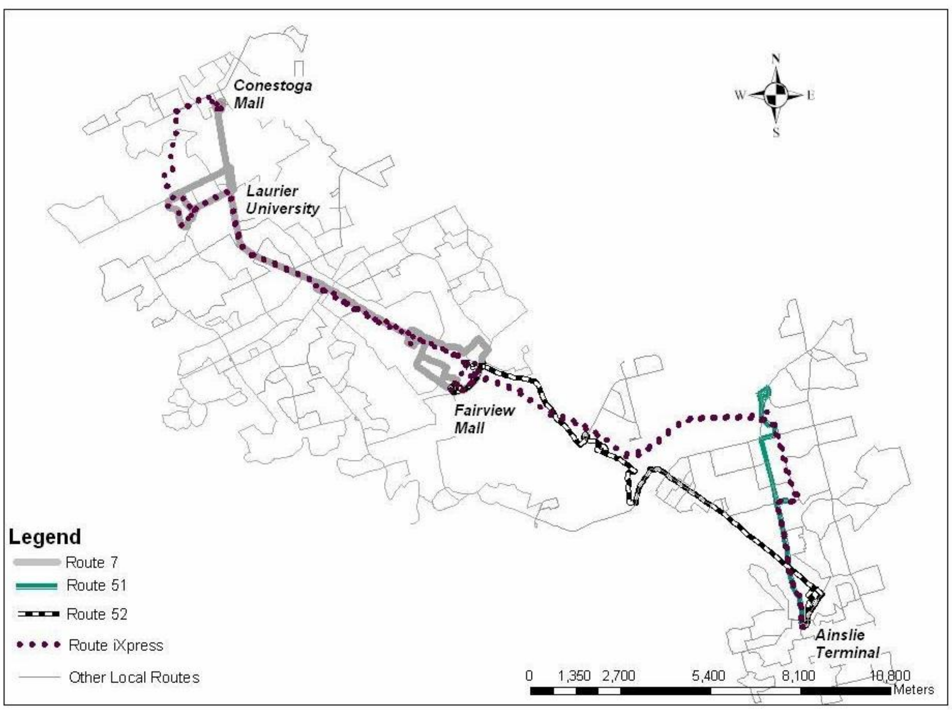

Figure 3-4: Route *iXpress*, and Routes 7, 51, and 52 paths

Total ridership in the northern and southern corridor also includes trips made on *iXpress*. The average number of *iXpress* daily boardings in April of 2006 was 3,500. The percentage of trips contained in the northern and southern corridors is estimated using passenger survey data. An origin-destination survey conducted in the same month suggests that of all the respondents, 64% make trips that begin and end within the northern corridor; 16% of riders make trips that begin and end in the southern corridor, 8.9% begin in northern corridor and end in southern corridor, 11.1% begins in southern corridor and end in northern corridor. To compute the number of *iXpress* trips within the northern and southern corridors, 64%+8.9% and 16%+11.1% of total trips is computed respectively. Thus, we can estimate that *iXpress* had 2555 boardings (3500*0.73) in the northern corridor and 945 boardings in the southern corridor.

The total number of trips served in the northern corridor after the introduction of *iXpress* is the sum of 16528 (on route 7) and 2555 on *iXpress*, or 18840 daily boardings. Similarly, the total number of transit trips carried in the southern corridor after the introduction of *iXpress* is the sum of 1,913 (on route 51), 982 (on route 52) and 945 (on *iXpress*), or 3,840. Table 3-4 summarizes these results.

Table 3-4: Influence of *iXpress* on Ridership (Daily Boarding)

Route	**Average Daily Ridership**			**Difference (actual counts – expected)**	**Increase (%)**
	Prior to iXpress	**Expected Post iXpress**	**Actual Post iXpress**		
Route 7	15491	17057	16528	-528	
iXpress (north corridor)	-	-	2555	2555	
Northern corridor total	**15491**	**17057**	**18840**	**2027**	**19%**
51	1289	1379	1913	534	
52	924	989	982	-7	
iXpress (south corridor)	-	-	945	945	
Southern corridor total	**2213**	**2368**	**3840**	**1472**	**62.1%**

Comparing these values to the expected number of trips (assuming average system growth of 7%) demonstrates the impacts of *iXpress* in generating new riders. In the northern corridor, while the Route 7 service grew slightly slower than the system as a whole, the total number of trips (route 7 plus *iXpress*) observed after the introduction of the *iXpress* exceeded the projected number of riders by 2,027, or 19.1%. In the southern corridor, route 51 ridership grew much faster than the system as a whole, exceeding the expected ridership total by 534. Route 52 grew at about the system average. When *iXpress* is considered, the total number of observed riders in the southern corridor exceeded the expected by 1,472 or 62.1%.

Questions arise as to the motivation for this growth in ridership as a result of the *iXpress* service. In the next section, a comparison of the travel time of route *iXpress* and routes 7, 51, and 52 attempts to explain these observed changes.

3.4 Travel Time Analysis

To quantify the impacts of adding *iXpress* service the following approach is taken. The generalized travel costs for trips between all O-D pairs served by *iXpress* are computed with only local service and with local service supplemented by *iXpress*. The generalized cost of travel is computed as a linear, weighted sum of out of pocket expenses (fares), access time, waiting time, in-vehicle time, transfer times (as necessary), and egress time.

Fares are equal for the two services; similarly, because the *iXpress* and local routes share the same alignment, it is assumed that access and egress times are also equal. These variables are excluded from the generalized cost calculations. Thus, the generalized cost comparisons are based on the sum of only waiting time, in-vehicle time, and transfer times. Each of these cost components is computed in the following sections for local service only and for local and *iXpress* service.

3.4.1 In-vehicle Travel Times

As Table 3-5 indicates, *iXpress* provides shorter travel time compared to local routes which serve the same alignment (Figure 3-4). This time comparison is derived from the printed schedule travel time of routes 7, 51, and 52 between stations (incrementally and cumulatively) and the travel times of the *iXpress* service between the same stations. “Number of Bus Stops” in Table 3-5 shows the number of stops between *iXpress* stations when traveling by local routes.

Table 3-5: Travel Time Comparisons: Local versus *iXpress* service

North Bound Direction					
Station	**Local routes travel time (Minutes)**			***iXpress* travel time (Minutes)**	
	Incremental	**Cumulative**	**Number of Bus Stops**	**Incremental**	**Cumulative**
1-Ainslie Terminal	-	-	-	-	-
2-Cambridge Centre	15	15	11	10	10
3-Bridgecam Centre	13	28	8	6	16
4-Fairview Mall(est)	25	53	-	18	34
5-Ottawa	11	64	18	7	41
6-Charles Terminal	8	72	12	6	47
7-Grand River Hospital	5	77	9	4	51
8-Uptown Waterloo	4	81	6	3	54
9-Wilfred Laurier University	5	86	7	5	59
10-UW	10	96	5	3	62
11-R & T Park(est)	3	99	-	3	65
12-McCormick(est)	5	104	-	3	68
13-Conestoga Mall(est)	10	114	-	6	74
Total		**114**	76		**74**

est: Estimated

The travel time between Bridgecam and Fairview Mall, and the University of Waterloo (UW) to Conestoga Mall is estimated for local routes because there is no local route alignment between these stations (Region of Waterloo, 2003).

As illustrated in Table 3-5, travel from Ainslie St .Terminal to Conestoga Mall via *iXpress* is 35% shorter (40 minutes) than the same trip using local routes. Even for short trips, the *iXpress* provides considerable travel time savings. The primary reason for savings compared with those of local routes is fewer bus stops. It is observed that trip makers who take local routes must delay their travel due to time spent at 76 stations compared with the *iXpress* which stops at 13 stations along the same path. Moreover, the timed-transfer between route 52 and route 7 does not occur, and the passengers who make travel between two corridors face an additional 15 to 30 minute transfer wait (Region of Waterloo, 2003).

From Table 3-5, a matrix of travel time savings can be developed to show the reduction of in-vehicle travel times for all O-D pairs served in the *iXpress* corridor. Table 3-6 shows the in-vehicle travel time savings with the introduction of *iXpress* service.

Table 3-6: In-Vehicle Travel Time saving with the Introduction of *iXpress* Service

	Ainslie Terminal	Cambridge Center	Bridgecam centre	Fairview Mall	Ottawa	Charles St. Terminal	Grand River Hospital	Up-town Waterloo	Laurier	U of W	R&T Park	McCormick	Conestoga Mall
Ainslie	0	5	12	19	23	25	26	27	27	34	34	36	40
Cambridge Center	5	0	7	14	18	20	21	22	22	29	29	31	35
Bridgecam centre	12	7	0	7	11	13	14	15	15	22	22	24	28
Fairview	19	14	7	0	4	6	7	8	8	15	15	17	21
Ottawa	23	18	11	4	0	2	3	4	4	11	11	13	17
Charles St.	25	20	13	6	2	0	1	2	2	9	9	11	15
Grand River	26	21	14	7	3	1	0	1	1	8	8	10	14
Uptown	27	22	15	8	4	2	1	0	0	7	7	9	13
Laurier	27	22	15	8	4	2	1	0	0	7	7	9	13
U of W	34	29	22	15	11	9	8	7	7	0	0	2	6
R & T park	34	29	22	15	11	9	8	7	7	0	0	2	6
McCormick	36	31	24	17	13	11	10	9	9	2	2	0	4
Conestoga	40	35	28	21	17	15	14	13	13	6	6	4	0

3.4.2 Waiting Times

Equation 2-1 expresses expected waiting time at a transit stop as half the headway (minutes) between successive transit units) of the route servicing that stop. For stops serviced by multiple routes, expected waiting time is one half of the net headway, h_{net}, or the time between arrivals of successive transit units from all routes. Expected waiting time is computed from the sum of all route frequencies, f_i as shown in Equation 3-1.

$$E(w) = \frac{h_{net}}{2} = \frac{60}{2 \cdot \sum_i f_i} = \frac{30}{\sum_i f_i} \tag{3-1}$$

The introduction of *iXpress* service increases frequencies by four departures per hour in peak periods, and two departures per hour in the off-peak. The reduction of expected waiting time, $\Delta E(w)$ as a result of *iXpress* service can be computed using the following equations:

$$\Delta E(w) = \frac{30}{\sum f_{local}} - \frac{30}{\sum f_{local\ \&\ iXpress}} \tag{3-2}$$

$$\Delta E(w) = \frac{30}{\sum f_{local}} - \frac{30}{\sum f_{iXpress}} \tag{3-3}$$

Equation 3-2 applies for trips when there was required to make transfer between local routes and *iXpress* (positive values in Table 3-7), and Equation 3-3 applies for trips that did not require to make transfer (negative values in Table 3-7).

Table 3-7 shows the reduction in waiting time (minutes), $\Delta E(w)$, for travel between all O-D pairs.

Table 3-7: Reduction in Waiting Time (minutes)

	Ainslie Terminal	Cambridge Center	Bridgecam centre	Fairview Mall	Ottawa	Charles St. Terminal	Grand River Hospital	Up-town Waterloo	Laurier	U of W	R&T Park	McCormick	Conestoga Mall
Ainslie	0.00	3.75	3.75	10.00	7.50	7.50	7.50	7.50	7.50	7.50	7.50	7.50	7.50
Cambridge Center	3.75	0.00	3.75	10.00	7.50	7.50	7.50	7.50	7.50	7.50	7.50	7.50	7.50
Bridgecam centre	3.75	3.75	0.00	10.00	7.50	7.50	7.50	7.50	7.50	7.50	7.50	7.50	7.50
Fairview	10.00	10.00	10.00	0.00	2.00	2.00	2.00	2.00	2.00	3.75	10.00	10.00	10.00
Ottawa	-2.50	-2.50	-2.50	2.00	0.00	1.76	1.76	1.76	1.76	1.76	7.38	7.38	7.38
Charles St.	-2.50	-2.50	-2.50	2.00	1.76	0.00	1.25	1.25	1.25	3.75	3.75	3.75	3.75
Grand River	-2.50	-2.50	-2.50	2.00	1.76	1.25	0.00	1.25	1.25	3.75	3.75	3.75	3.75
Uptown	-2.50	-2.50	-2.50	2.00	1.76	1.25	1.25	0.00	1.25	3.75	3.75	3.75	3.75
Laurier	-2.50	-2.50	-2.50	2.00	1.76	1.25	1.25	1.25	0.00	3.75	3.75	3.75	3.75
U of W	0.00	0.00	0.00	3.75	1.76	3.75	3.75	3.75	3.75	0.00	3.75	3.75	3.75
R & T park	7.50	7.50	7.50	10.00	7.38	3.75	3.75	3.75	3.75	3.75	0.00	3.75	3.75
Mc Cormick	7.50	7.50	7.50	10.00	7.38	3.75	3.75	3.75	3.75	3.75	3.75	0.00	3.75
Conestoga	7.50	7.50	7.50	10.00	7.38	3.75	3.75	3.75	3.75	3.75	3.75	3.75	0.00

It is interesting to note that in some cases, the introduction of *iXpress* actually increases waiting time. For example, passengers traveling between Charles St. terminal and any of the southern stations (Ainslie, Cambridge Centre, etc.) will bypass local service, and wait longer for *iXpress* to avoid the transfer at Fairview mall.

3.4.3 Transfer Times

To estimate transfer times between two lines with headways h_1 and h_2, the method presented by Vuchic (2005) is written as Equation 3-4.

$$TT = \min\left\{\frac{h_1}{2}, \frac{h_2}{2}\right\} \tag{3-4}$$

Where,

TT :transfer time (min)

h_1 :time headway of origin line (min)

h_2 :time headway of destination line (min)

Passengers who take *iXpress* do not need to make any transfers for travel between any of the 13 stations and, therefore, do not have any transfer penalty. However, passengers who utilize local services have to make transfers, most commonly at Fairview mall to connect the northern and southern corridors. A second common transfer is eliminated by *iXpress*. Prior to *iXpress*, all northbound trips departing from the University of Waterloo would use local service to the intersection of King and University where a transfer would be made to a northbound route 7. *iXpress* offers direct service from the campus to these northbound destinations. Table 3-8 shows the transfer times (minutes), *TT*, eliminated by the introduction of *iXpress*.

Table 3-8: Transfer Time (minutes) Eliminated by the Introduction of *iXpress*

	Ainslie Terminal	Cambridge Center	Bridgecam centre	Fairview Mall	Ottawa	Charles St. Terminal	Grand River Hospital	Up-town Waterloo	Laurier	U of W	R&T Park	McCormick	Conestoga Mall
Ainslie	0	0	0	0	5	5	5	5	5	6	15	15	15
Cambridge Center	0	0	0	0	5	5	5	5	5	6	15	15	15
Bridgecam centre	0	0	0	0	5	5	5	5	5	6	15	15	15
Fairview	0	0	0	0	0	0	0	0	0	0	0	0	0
Ottawa	5	5	5	0	0	0	0	0	0	0	0	0	0
Charles St.	5	5	5	0	0	0	0	0	0	0	0	0	0
Grand River	5	5	5	0	0	0	0	0	0	0	0	0	0
Uptown	5	5	5	0	0	0	0	0	0	0	0	0	0
Laurier	5	5	5	0	0	0	0	0	0	0	0	0	0
U of W	7.5	7.5	7.5	0	0	0	0	0	0	0	7.5	7.5	7.5
R & T park	15	15	15	0	0	0	0	0	0	7.5	0	0	0
Mc Cormick	15	15	15	0	0	0	0	0	0	7.5	0	0	0
Conestoga	15	15	15	0	0	0	0	0	0	7.5	0	0	0

3.4.4 Reduction in Generalized Cost

Having computed the changes in each cost component (in-vehicle, waiting and transfer times), the change in generalized cost for all O-D pairs can now be calculated. As was discussed in section 2.1.2, passengers perceive the passage of time differently for each portion of their trip (i.e. wait time at the stop, in-vehicle time, and transfer time). *Transit Capacity and Quality of Service Manual* (Kittelson et al, 2003) documents the results of a number of studies of the relative importance of travel time. In all cases, in-vehicle time is considered least onerous, while waiting time and transfer times are considered to be greater penalties.

To develop a utility fuction of generalized cost, a linear, weighted model of travel time components is applied. The model utilizes weightings which are in the ranges suggested by TCRP. The generalized cost, *GC*, is calculated as shown in Equation 3-5.

$$GC = \left[1.5W + inVT + 2TT\right]VOTT \qquad (3\text{-}5)$$

Where

GC	:generalized cost ($)
W	:waiting time (min)
$inVT$	:in-vehicle travel time (min)
TT	:transfer time (min)
$VOTT$	:value of time which is a typical value of $8

The reduction in generalized cost is computed as the difference of local only costs and local and *iXpress* costs. The cost savings ($) are shown in Table 3-9.

Table 3-9: Reduction in Generalized Cost ($)

	Ainslie Terminal	Cambridge Center	Bridgecam centre	Fairview Mall	Ottawa	Charles St. Terminal	Grand River Hospital	Up-town Waterloo	Laurier	U of W	R&T Park	McCormick	Conestoga Mall
Ainslie	0.00	1.67	2.60	5.20	7.07	7.33	7.47	7.60	7.60	8.93	12.53	12.80	13.33
Cambridge Center	1.67	0.00	1.93	4.53	6.40	6.67	6.80	6.93	6.93	8.27	11.87	12.13	12.67
Bridgecam centre	2.60	1.93	0.00	3.60	5.47	5.73	5.87	6.00	6.00	7.33	10.93	11.20	11.73
Fairview	5.20	4.53	3.60	0.00	1.07	1.33	1.47	1.60	1.60	3.00	4.67	4.93	5.47
Ottawa	4.40	3.73	2.80	1.07	0.00	0.74	0.87	1.00	1.00	1.94	3.44	3.70	4.24
Charles St.	4.67	4.00	3.07	1.33	0.74	0.00	0.47	0.60	0.60	2.20	2.20	2.47	3.00
Grand River	4.80	4.13	3.20	1.47	0.87	0.47	0.00	0.47	0.47	2.07	2.07	2.33	2.87
Uptown	4.93	4.27	3.33	1.60	1.00	0.60	0.47	0.00	0.33	1.93	1.93	2.20	2.73
Laurier	4.93	4.27	3.33	1.60	1.00	0.60	0.47	0.33	0.00	1.93	1.93	2.20	2.73
U of W	7.53	6.87	5.93	3.00	1.94	2.20	2.07	1.93	1.93	0.00	4.00	4.27	4.80
R & T park	12.53	11.87	10.93	4.67	3.44	2.20	2.07	1.93	1.93	4.00	0.00	1.27	1.80
Mc Cormick	12.80	12.13	11.20	4.93	3.70	2.47	2.33	2.20	2.20	4.27	1.27	0.00	1.53
Conestoga	13.33	12.67	11.73	5.47	4.24	3.00	2.87	2.73	2.73	4.80	1.80	1.53	0.00

As Table 3-9 demonstrates, the introduction of *iXpress* service provides tremendous generalized cost saving (>$10) for passengers who travel between the southern and northern corridors. Similarly, trips originating at the University of Waterloo also experience larger than expected generalized cost savings (>$4).

3.4.5 Generalized Cost Savings and Elasticity

As discussed in Chapter 2, elasticity of demand with respect to price attempts to predict or explain customer response to changes in cost for a given service or product. In the preceding sections, both the change in ridership (demand) and change in generalized cost (price) have been presented. From this data, it is possible to comment on the value of elasticity models in predicting transit customer behavior.

Recall that elasticities are defined in terms of percent changes in demand and price. Table 3-10 presents the change in generalized cost in terms of a percent reduction from the original cost of travel (i.e. without *iXpress*).

Table 3-10: Percent Reduction in Generalized Cost due to Introduction of *iXpress*

	Ainslie Terminal	Cambridge Center	Bridgecam centre	Fairview Mall	Ottawa	Charles St. Terminal	Grand River Hospital	Up-town Waterloo	Laurier	U of W	R&T Park	McCormick	Conestoga Mall
Ainslie	-	31%	36%	42%	44%	43%	42%	42%	40%	43%	51%	51%	50%
Cambridge Center	31%	-	38%	43%	46%	44%	43%	43%	41%	44%	53%	52%	51%
Bridgecam centre	36%	38%	-	41%	45%	43%	42%	41%	40%	43%	52%	52%	51%
Fairview	42%	43%	41%	-	25%	25%	25%	25%	22%	33%	40%	40%	40%
Ottawa	33%	33%	29%	25%	-	20%	20%	20%	18%	28%	37%	37%	38%
Charles St.	33%	32%	29%	25%	20%	-	15%	17%	14%	33%	31%	32%	33%
Grand River	32%	32%	28%	25%	20%	15%	-	16%	13%	35%	33%	33%	34%
Uptown	32%	32%	28%	25%	20%	17%	16%	-	11%	36%	33%	34%	35%
Laurier	30%	30%	27%	22%	18%	14%	13%	11%	-	41%	38%	38%	38%
U of W	39%	40%	38%	33%	28%	33%	35%	36%	41%	-	59%	57%	55%
R & T park	51%	53%	52%	40%	37%	31%	33%	33%	38%	59%	-	31%	33%
Mc Cormick	51%	52%	52%	40%	37%	32%	33%	34%	38%	57%	31%	-	32%
Conestoga	50%	51%	51%	40%	38%	33%	34%	35%	38%	55%	33%	32%	-

The growth in ridership presented in section 3-3 focuses on changes in boardings for trips within the northern (19%) and southern corridors (62%). The percent changes in travel cost for the northern corridor can be seen in the lower right shaded area in Table 3-10 (between Fairview and Conestoga); the changes in travel cost for the southern corridor can be seen in the upper left shaded area in Table 3-10 (between Ainslie and Fairview).

To calculate the elasticity of demand with respect to generalized cost, the average cost reduction is computed over all O-D pairs in the northern and southern corridors. From Table

3-10, the average cost reduction in the northern corridor is 31% and 39% in southern corridor. Table 3-11 summarizes the inputs into the elasticity equation (Equation 2-2).

Table 3-11: Estimated Elasticity of Demand versus Price for North and South Corridors

Route Section	Observed Change in Demand	Observed Change in Cost	Implied Elasticity of demand WRT Cost
Northern corridor	19%	-31.3%	-0.61
Southern corridor	62%	-38.5%	-1.61

The data suggests that ridership in the southern corridor is much more sensitive to the travel cost savings than are those traveling in the northern corridor. Possible reasons for this include: (1) Route 7 as a parallel route to *iXpress* in the north corridor, provides less than 10 minutes headway, while may reduce the sensitivity of riders to time spend waiting for *iXpress*. (2) Stops are spaced farther apart on the *iXpress* route in the southern corridor than in the northern corridor, and consequently most passengers use both local and *iXpress* services to arrive to their destinations, and therefore are counted as boardings twice in the corridor (one on *iXpress* and one in local route)

The following section describes an *iXpress* transit ridership survey that was conducted to analyze the travel patterns of such route trip-makers.

The survey questions are divided into four groups which asked riders about their: (1) personal information (age, gender) to determine the age and gender distribution of *iXpress* users; (2) Origin and destination address and trip purposes to figure out the start and end locations of trips. (3) Modes that were used to arrive to or leave the *iXpress* stations and (4) the mode which used before *iXpress* to make the same trip. Survey responses from parts 2 through 4 provide the further analysis in continue and chapter 5.

3.5 Transit Ridership Survey

The survey was conducted on Wednesday February 15, 2006 to analyze the *iXpress* ridership. Because of a limited number of surveyors available to conduct the survey, the survey was scheduled to be done on two successive days with surveyors on half of the *iXpress* buses on each day. Unfortunately, on the second day of the survey period (Feb.16) a winter storm resulted in the closure of all public elementary and high schools in the RMOW, University of Waterloo, Wilfred Laurier University, in addition to many day care centers, offices, and other businesses. Noticeably, this event has changed travel patterns, including the use of *iXpress* service, and accordingly the survey was cancelled.

On February 15, data were collected from 5:30 a.m. to 6:00 p.m. (service hours of *iXpress*) for approximately half of the *iXpress* fleet. In this survey, riders were provided with a questionnaire which contained 15 questions (Appendix A) when they boarded the bus, asked to complete the questionnaire, and asked to return it before leaving the bus. From this survey, a total of 1146 questionnaires were returned and the analysis of the survey is based on the data collected from these 1146 cases.

The actual number of *iXpress* riders during the survey period is not known, however average daily boardings obtained from the fare box system indicates approximately 3500 boarding for the survey day.

3.6 Data Analysis

In this section, some findings about the use of the *iXpress* service are given based on survey and fare box systems data collection to show the impact of the *iXpress* on transit ridership and the change of the travel patterns for trip-makers. Then, a comparison of the local, *iXpress*, and auto travel time for a group of trip-makers is conducted to investigate the impact that reduced travel times provided by the *iXpress* service had on attracting passengers to the *iXpress* service.

3.6.1 Use of Service

The impact of the *iXpress* on the use of the service is analyzed based on the increase of average daily boarding during the *iXpress* service operation, the success in attracting passengers who travel to work or school for several days, and in attracting passengers from other modes to switch their travel to the *iXpress* especially those who used auto-based modes previously.

The average daily boarding of the *iXpress* service for each month between September, 2005 and December, 2006, is graphed in Figure 3-5 based on the fare box data collection system.

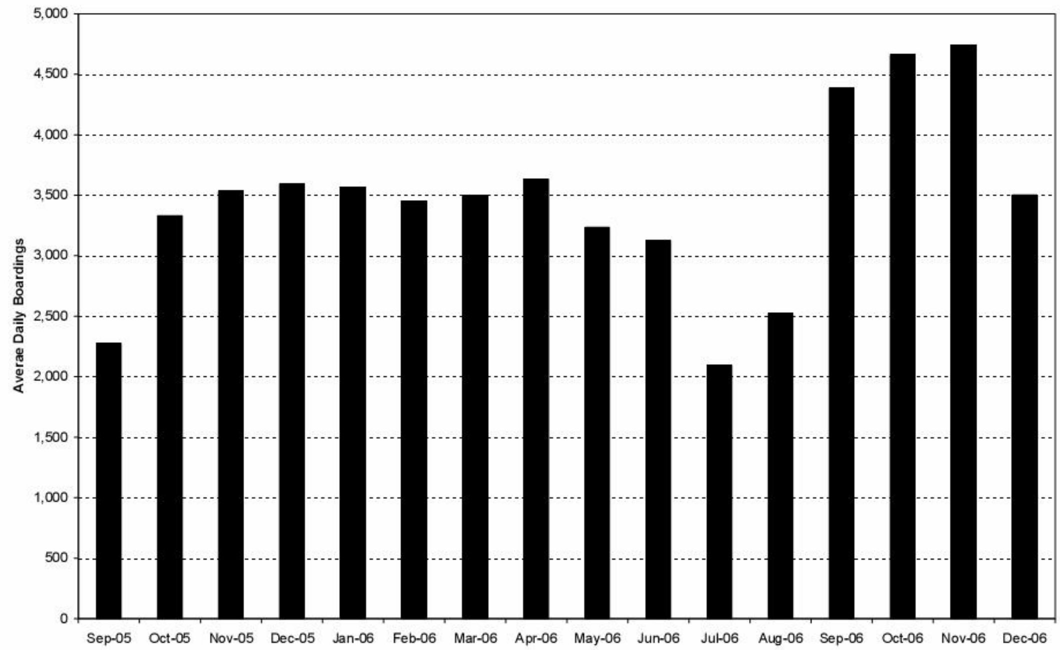

Figure 3-5: Average Daily Boarding for the *iXpress* service

Several observations can be made based on this figure:

- The low average daily boarding in the first month of *iXpress* service (Sep-2005) in comparison to the next months reflects the lag time from beginning of operation which passengers need to change their traveler behavior, and to start taking *iXpress* service.

- In the summer months, July and August, the closure of schools and universities decreases the travel demand, and obviously significant seasonal variation is evident in the data.
- The significant increase in average boarding for September, October, November, and December 2006 in comparison to corresponding months in 2005 can be explained by an increasing awareness of the service by the community.

The forecast of *iXpress* transit riderships that was made in the original UTSP project proposal predicted an average daily ridership of 3,800 passengers in 2005. Based on the monthly *iXpress* ridership data during 16 months of operation, the average daily boarding is approximately 3,500 passengers, which is 92% of the proposed forecast.

Questions 3 and 8 of the survey questionnaire asked about the origin and destination, and purpose of the trip, and are used to analyze the proposed category of trip makers (Figure 3-6 and Figure 3-7) .Note that the total number of responses for each question varies as not all respondents completed each question.

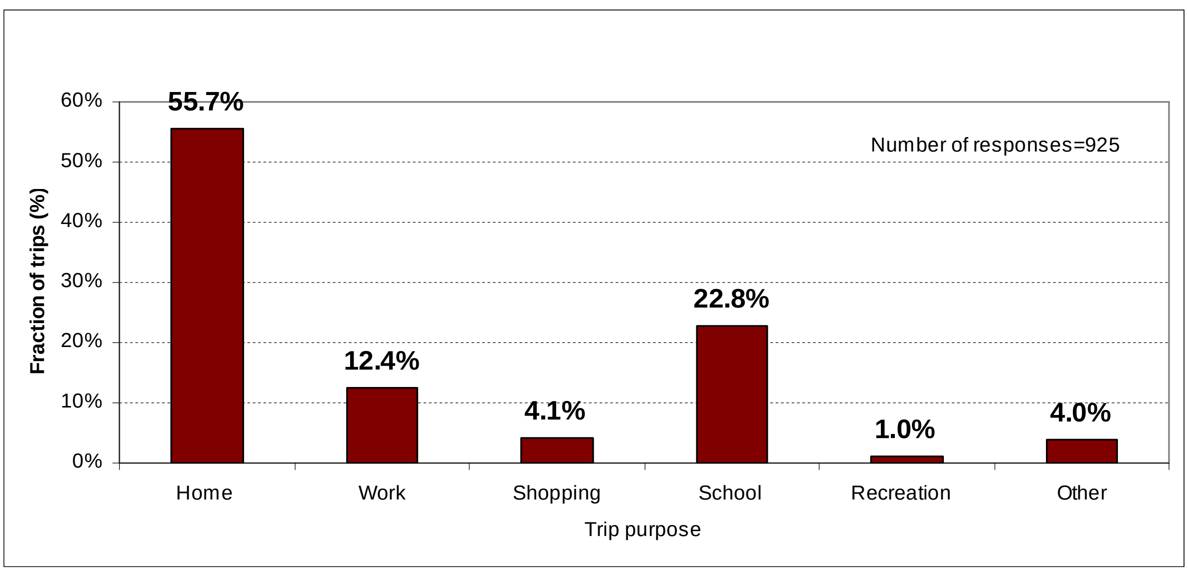

Figure 3-6: Distribution of Category of Origin

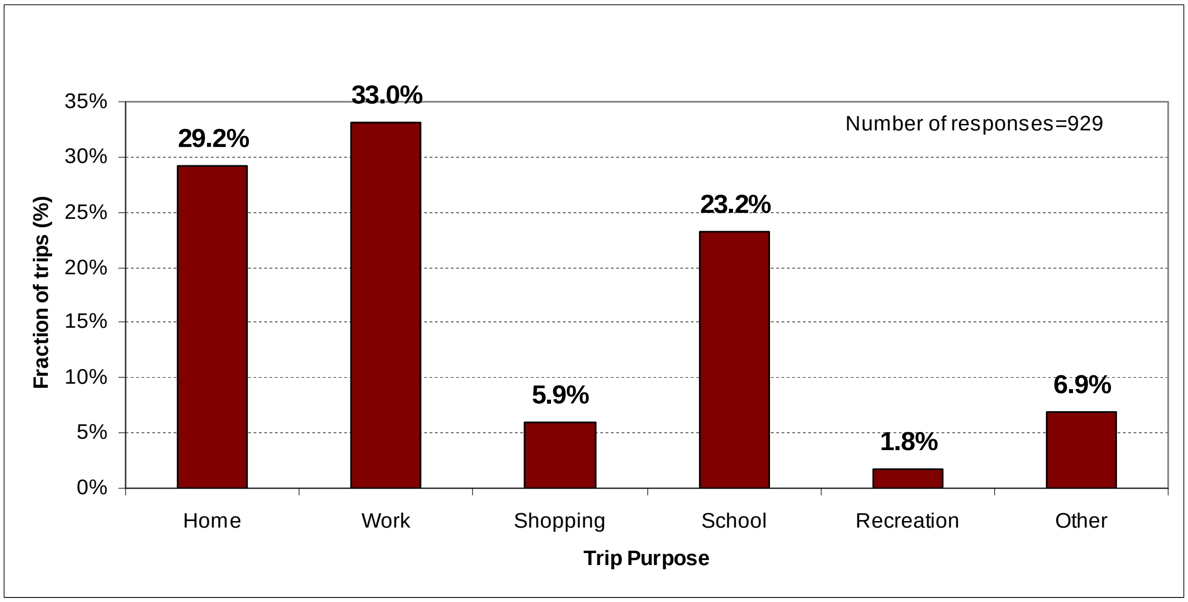

Figure 3-7: Distribution of Category of Destination

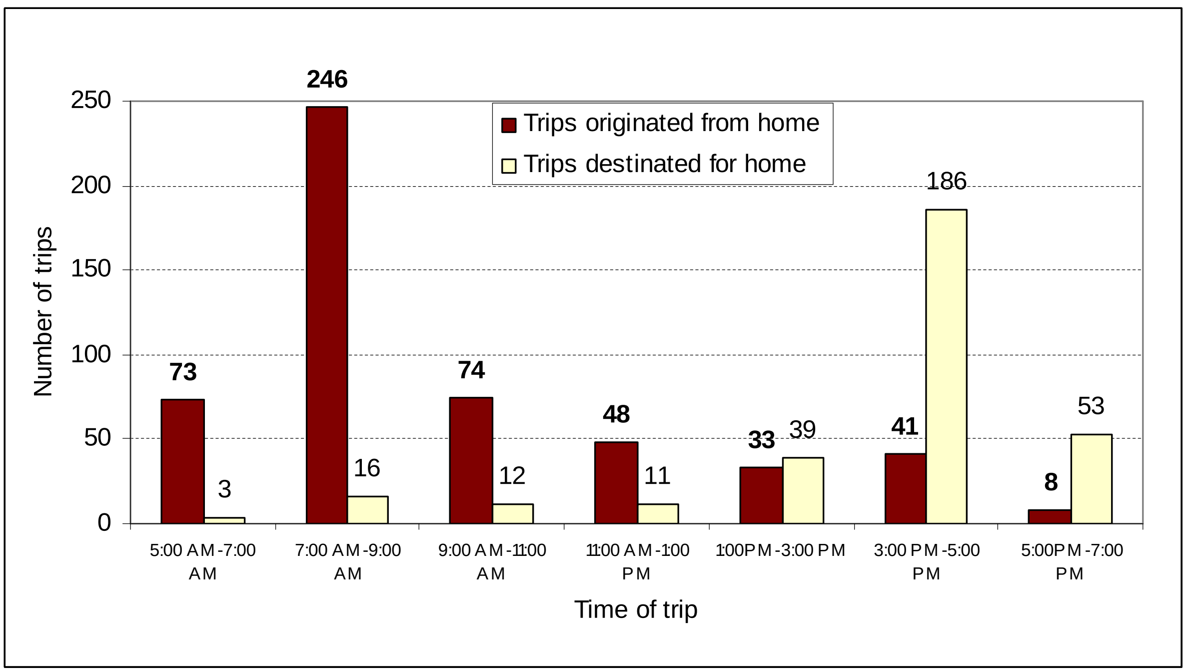

Figure 3-8: Number of Trips Originated from and Destined for Home

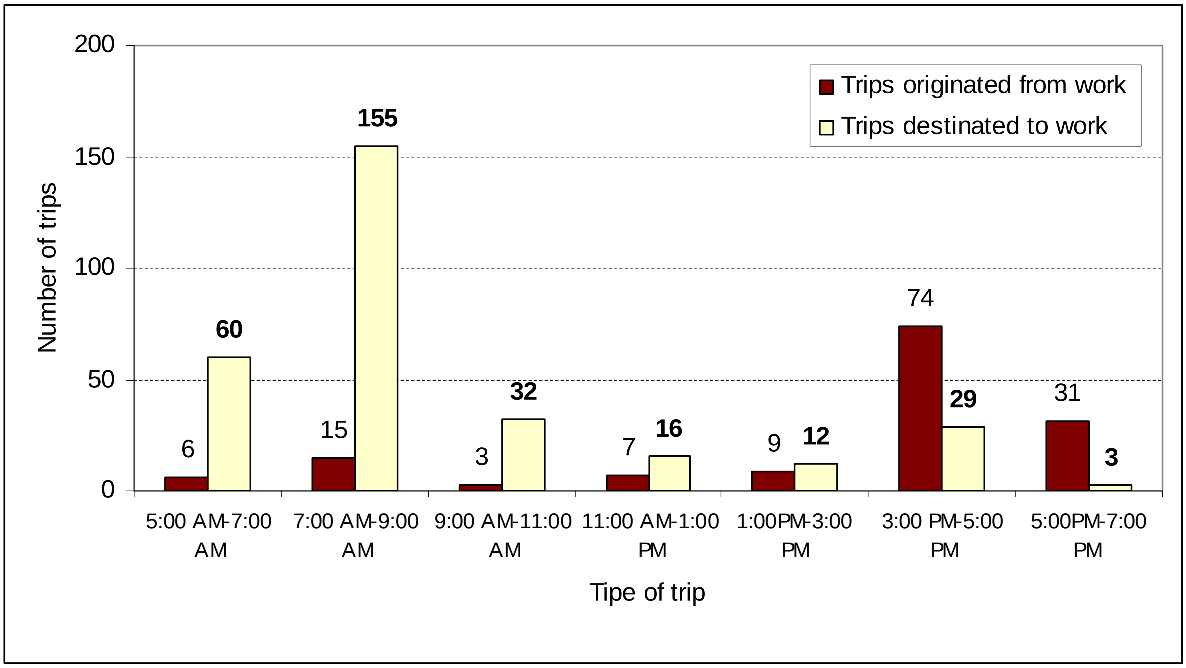

Figure 3-9: Number of Trips Originated from and Destined to Work

The survey data shows that 55% of the trips on the *iXpress* originated from home, and 29% of the trips ended at home. It should be noted that almost twice as many trips originated at home than end at home. Also, approximately 3 times as many trips originated at work as are destined to work. These disparities are counter intuitive as it would be expected that approximately same number of trips originated and end at home or work. There are several possible explanations for these observed inconsistencies.

1. The survey sample may be biased. For example the survey sample return may have been much higher in the morning (when it expected to observe more trips originating from home and destined to work) than in the afternoon(when trips originating from work and trips destined to home are more likely).
2. trip chaining describes travel patterns in which travel does not consist of a simple sequence of trips from origin A to destination B and then sometime late a return trip from B back to A. trip which are more likely to consist of travel from A to B, then B to C and then C to A. for example, students may travel from home to school morning

and then from school to work in the afternoon, and then work to home late in the evening. Given that *iXpress* service hours were from 5:30 am to 7:00 pm, some of the later trips in the chain may not have been captured in the survey.

Figure 3-10 illustrates the distributed of survey respondents to question #3 as a function of the time of day. As it is seen 40% of survey questionnaires are completed during morning peak time (5:00 AM-9:00 AM) and 31% are returned during the evening peak time (3:00PM-7:00 PM). This suggests that there are approximately 10% more responses obtained during the morning period than the evening period. Unfortunately, the distribution of ridership by time of day on *iXpress* is not known and therefore it is not possible to make conclusions about biases in the survey sampling rate. Therefore near to 9% of passengers who filled the form in the morning and reported their trips from home, are not reported their return trips in the evening time period.

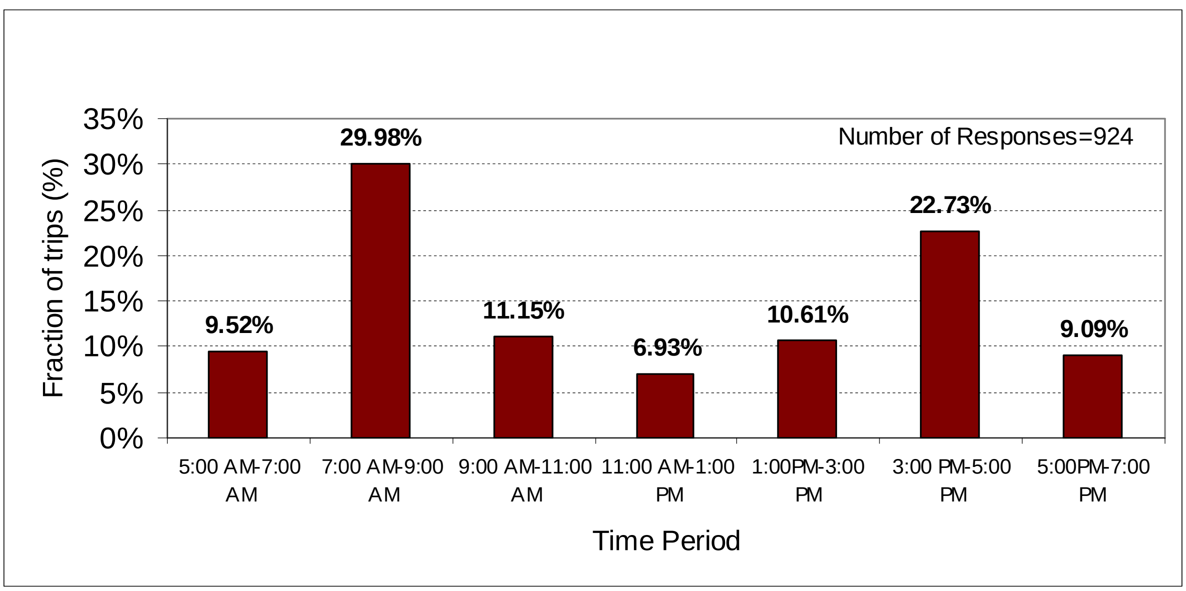

Figure 3-10: Ridership Time Period Range

The age distribution of survey respondents in Figure 3-11 indicates that more than half of the passengers are between 17 to 25 years old, and more than 50% of them are home-to-school or school-to-home trip generators (ridership survey). It is possible that probably they as students need to stay longer evening at school for their classes or studying.

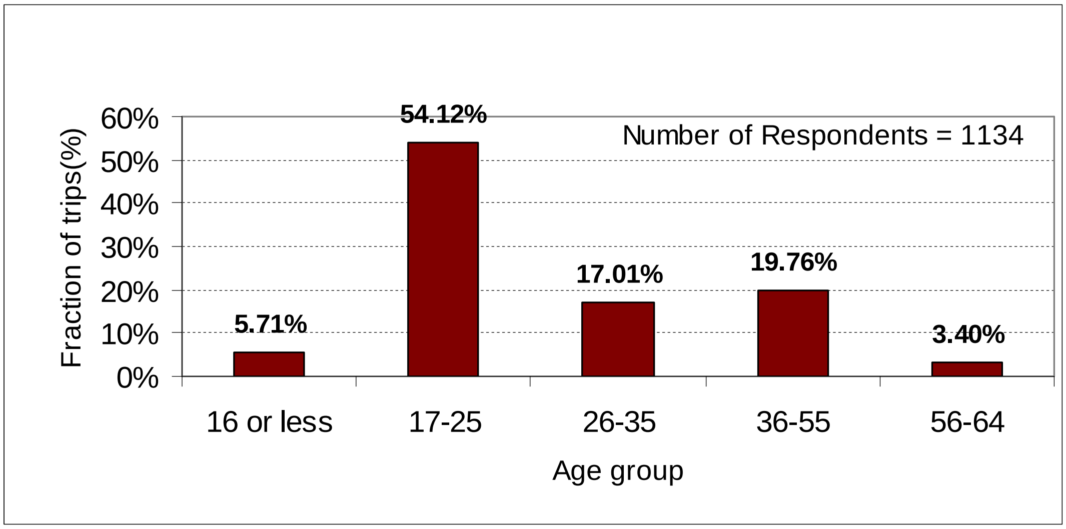

Figure 3-11: Ridership Age Range

The data collected from question 14 which asked about the mode used before the *iXpress* was operating, are presented in Figure 3-12. From this figure it can be observed that 73%, 8.2%, and 7.5% of the passengers shifted from using local routes, driving a car, and had not previously made the trip. A more specific analysis of each of these three groups is conducted in sections 3.6.2 through 3.6.4.

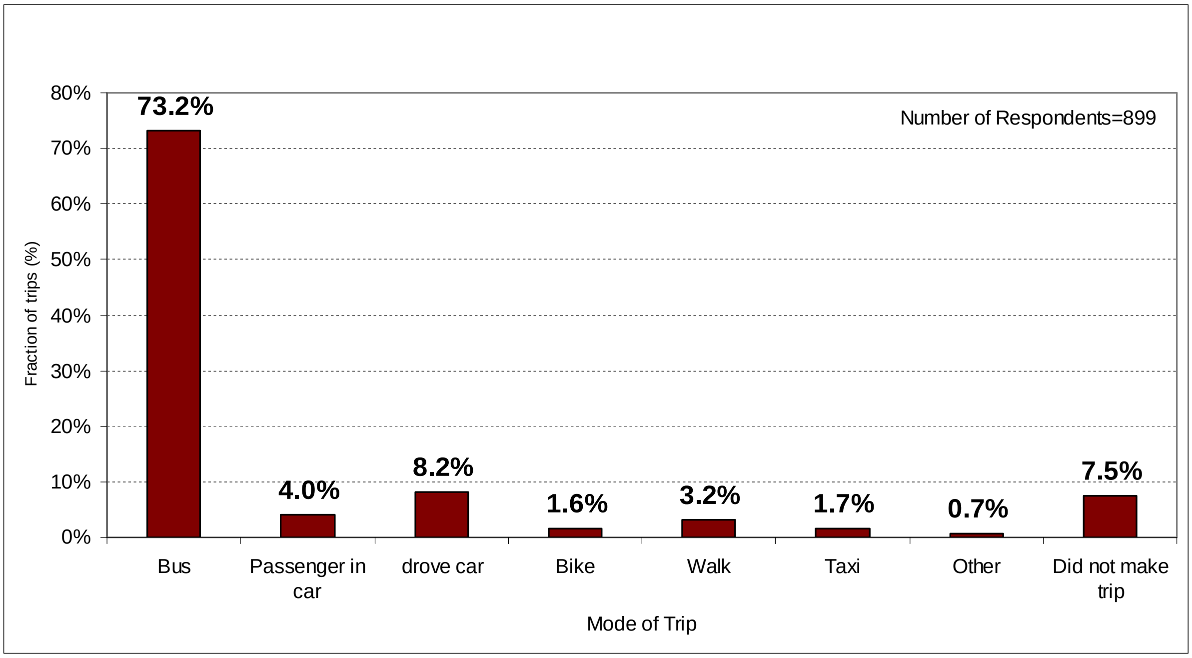

Figure 3-12: Mode Taken prior to Using *iXpress*

It is interesting to notice that approximately 76% of survey respondents indicate that their household had 1 or more vehicles (Figure 3-13). However, only 15% of respondents had a vehicle available to home for their trip (Figure 3-14). These trip makers are choice riders.

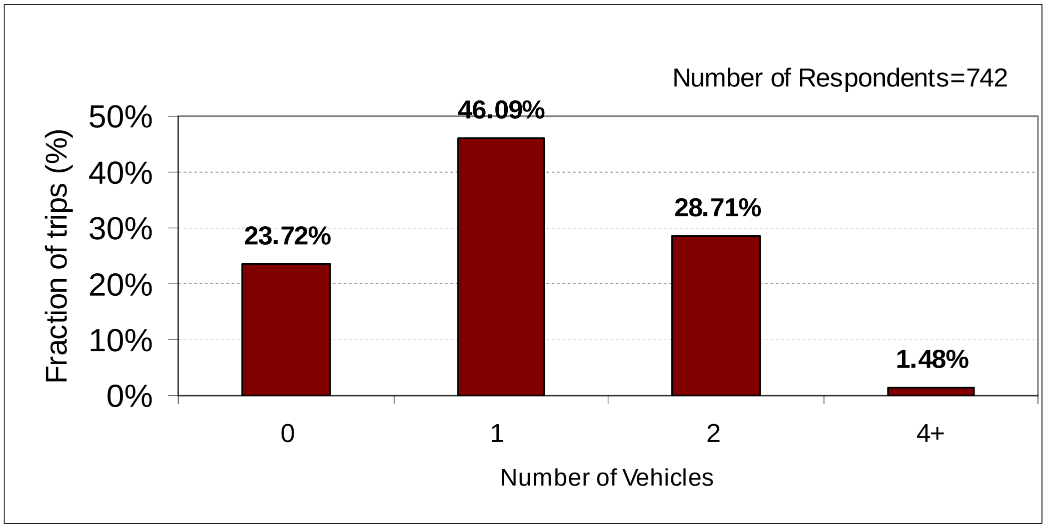

Figure 3-13: Number of Vehicles Available in household

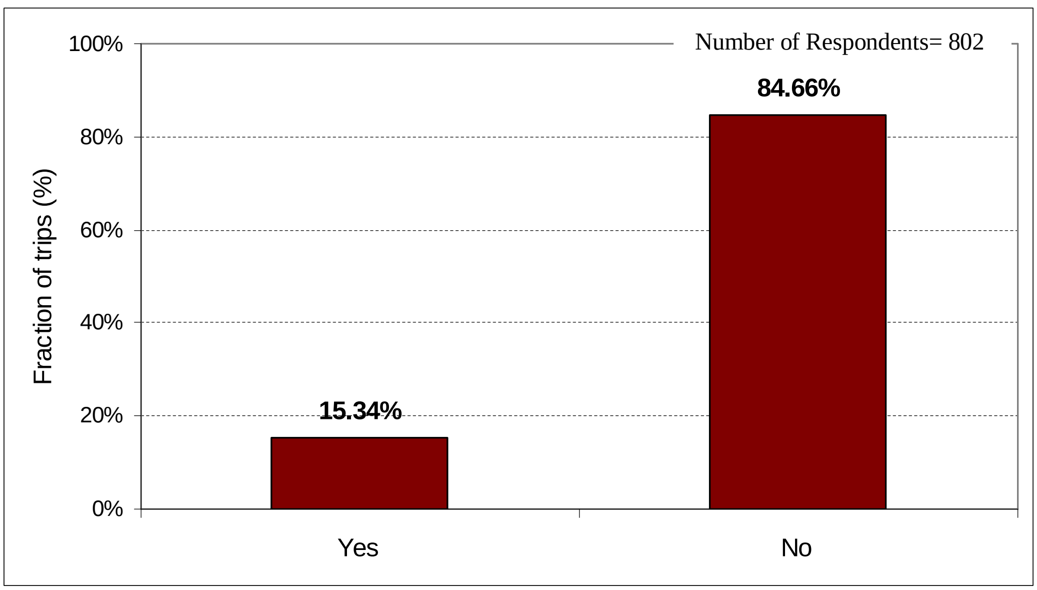

Figure 3-14: Number of Passengers who had or had not Vehicle Available for the Trip

3.6.2 Switch of Passengers from Local Routes to iXpress

A more detailed examination was conducted for those survey respondents who took local transit routes prior to using the *iXpress* (i.e. 73.2% of survey respondents), which showed that 64.2% of them switched from routes 7, 52, and 51.

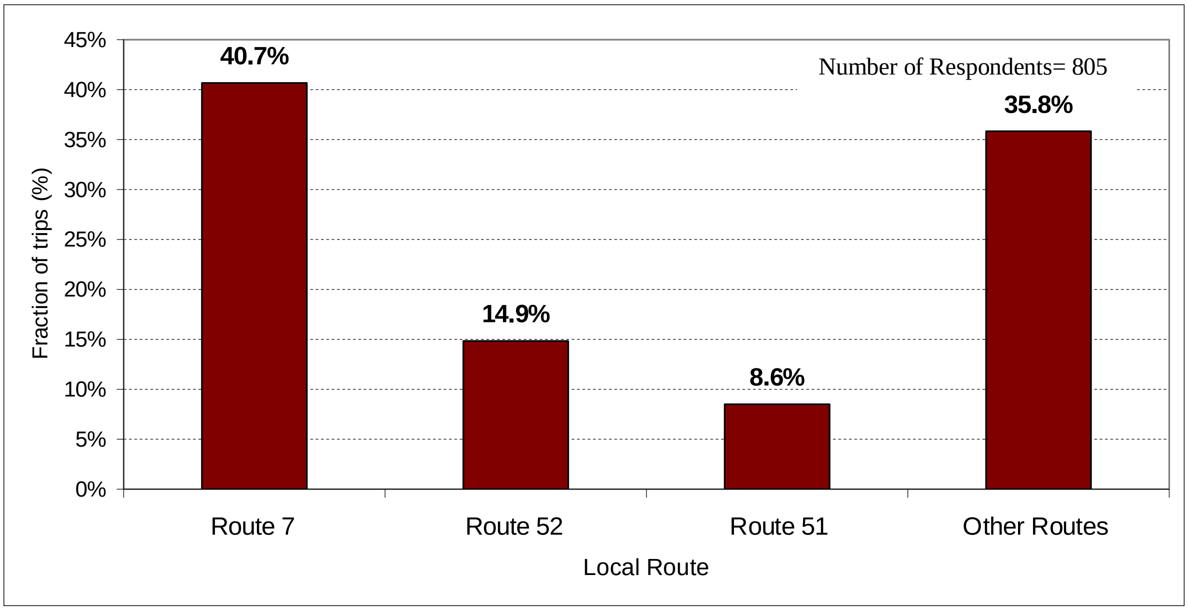

Figure 3-15: Percentage of Passengers Switching from Local Routes

As investigated in Figure 3-4, the *iXpress* route parallels the majority of route 7 from Wilfred Laurier University to Fairview Mall, and routes 51 and 52 from Fairview Mall to Ainslie terminal. The *iXpress* has attracted some riders by providing more reliable service, and a shorter travel time.

Route 7 which fully serves King Street and most commercial and residential area of Kitchener and Waterloo, is regarded as a main route, and is usually filled with overload of passengers at peak times (Region of Waterloo, 2005). This high load of passengers reduces the comfort level of the on-board portion of the transit trip in terms of being able to find a seat and in the overall crowding levels within the vehicle. Since the introduction of the *iXpress* service along route 7, the overloading of passengers has decreased and the comfort and convenience for passengers who used to take this route has increased (Region of Waterloo, 2005), and it can attract more trip makers from other modes to make their travel by route 7. Based on Table 3-4, and percentage of trips switched from route 7 to *iXpress* bus (Figure 3-15), in overall 30% of *iXpress* riders came from route 7. Considering 2555 riders for *iXpress* who made their travel in the northern corridor (Table 3-4), 766 riders have switched from route 7 to iXpress (30% of 2555 riders). The comparison of 766 riders to the difference of actual and expected ridership for route 7 from Table 3-4 (17057-16528=529 riders) suggests route 7 has experienced an additional increase.

3.6.3 Switch of Passengers from "Drove Car" to "*iXpress*"

Survey results reveal that almost 8% of the passengers have switched from traveling by a personal auto to traveling by transit. Also, of all the survey respondents, 59 persons (5.14%) used to complete their trip as a driver of a private auto and still have access to the vehicle for their trip, but they have switched to make their trip by the *iXpress*. The investigation to the change of this group's behavior is described in section 3.6.5 to determine the magnitude of the reduction of travel time that is necessary to attract passengers to the *iXpress* service. The answer to this question determines the importance of travel time for people who live in the mid-sized RMOW.

3.6.4 Passengers who did not Make Trip

Figure 3-12 indicates that 7.5% of the passengers did not make the reported trip prior to the implementation of the *iXpress* service (i.e. 5 months prior). Unfortunately, there is no information from the survey that provides a clear understanding of why these trips were not previously made. Possible explanations include: the trip maker is a new resident; a change in the trip maker's life style such as a new job or admission to university has resulted a new need for travel; OR this trip took so long prior to the availability of the *iXpress* service. Out of 899 survey respondents who answered all the relevant questions, there were 18 (1.70%) who did not have cars available, did not previously make the trip but now make the trip at least four times per week, and are traveling to work or school.

3.6.5 Estimation of Trip Travel Time by Modes

Usually passengers weigh several factors in choosing between personal auto and public transportation to travel. Some factors are categorized as out-of-pocket or vehicle operation costs, including fuel, parking fees, road tolls and transit fare. In addition to out-of-pocket expenses, passengers weigh other factors of transit such as travel time, convenience, and safety as opposed to those of auto-vehicle.

Several studies have illustrated the importance of travel time for trip makers and identified the elasticity of travel time for different peak periods (Goodwin, 1996; TRACE, 1999, and Litman, 2006). However, none have examined the importance of the reduction of travel time by public transportation to attract more passengers.

In this section, a comparison of the travel time of the *iXpress*, local routes and auto modes for the portion of survey respondents who previous to the start of the *iXpress* service, completed their trip as a driver of a private auto, and then switched to using the *iXpress* ,and still had an auto available to them to make the trip. For estimating the local transit travel time for trip-makers, it is supposed they previously traveled by determining the best combination of local routes instead of taking private auto.

From all survey questionnaires, 59 persons have selected answers to the following questions.

Question 13: Did you have a vehicle available to use for this trip?

- ✓ Yes
- o No

Question 14: Before the *iXpress*, how did you make this trip?

- o Local route#
- o Passenger in car
- ✓ Drove car
- o Bike
- o Walk
- o Taxi
- o Other
- o Did not make the trip

Question 15: How many vehicles are at your home?

- o 0
- ✓ 1 or more

From these 59 cases, 42 provided complete information about their origin, and destination postal codes (questions 4 and 9), the mode to and from the boarding and alighting *iXpress* (questions 6, 10, and 11), and the name of the boarding and alighting stations (questions 5 and 7). The analysis of the travel time estimation is based on this sample of 42 cases.

In addition, the following assumptions are made for the estimation of the travel time component.

- The centre points of the origin and destination postal code areas are considered as the trip origin and destination points to estimate the distance of travel. (postal code area is approximately of o.2 Km in diameter)
- The average waiting time of one half of the headway (Avineri, 2004 and Equation 2-1) is considered for both the *iXpress* and local services.
- An average walking speed of 5 km/h or 83.3 meter/min (Sullivan, 1996) is consumed for estimating the walking time.
- One minute of walking time is assumed for the passengers who reached the *iXpress* bus by being dropped off at the station or arrived at their final destinations by being picked up at the stations.

In the next section, the methodology for the estimation of the travel times for each of the three modes is proposed, followed by the results of the analysis.

3.6.5.1 iXpress Travel Time

Overall, transit travel time consists of several components such as in-vehicle travel time, walking, waiting and transfer time which is described in section 2.1.2. This section presents the computed travel time attributes for the *iXpress* service in the RMOW.

In-Vehicle Travel Time

On the day of the survey, the surveyors were requested to record the boarding and alighting time for each passenger who completed the travel survey questionnaire. The *iXpress* in-vehicle travel time is estimated by subtracting the alighting time from the boarding time (minutes), and later it was checked manually by the *iXpress* route schedule sheet.

Waiting Time

Using the assumption of including half of the headway for the waiting time, the waiting times are computed as 15/2= 7.5 minutes for the morning and afternoon peak-time, and 30/2=15 minutes for the mid-day.

Access and Egress Time

From the 42 cases in the sample, 16 passengers walked, 12 transferred from other routes, 10 were dropped off at the boarding *iXpress* stations, and 3 were picked up from the alighting to iXpress stations.

The access distance for the passengers who walked is the distance from his/her origin postal code to the transit stop, where the first boarding accrued (*iXpress* or local route stations), and the egress distance is the distance from the last transit stop of the passengers' trip (*iXpress* station or local route station) to the destination postal code.

If the passenger did not transfer between *iXpress* and the other local routes, the walking distance is estimated from the Origin or Destination (OD) postal codes to the *iXpress* stations. But, if the passenger had transferred from other routes to an *iXpress* bus or transferred to other routes for the final destination, the walking distance is estimated from the OD postal codes to the local routes' nearest bus stops.

For instance, consider a trip made by survey respondent No.1007 (Figure 3-16). The trip maker walked from his trip origin to a bus stop of route 58, took the bus to the Ainslie street terminal, transferred to *iXpress*, exited the *iXpress* bus at the Charles street terminal and walked to the trip destination. Total walking distance from *iXpress* station to the trip destination (egress distance) is estimated to be 548 meters.

Both the access and egress distance are calculated by using the shortest path method in ArcGIS[1].

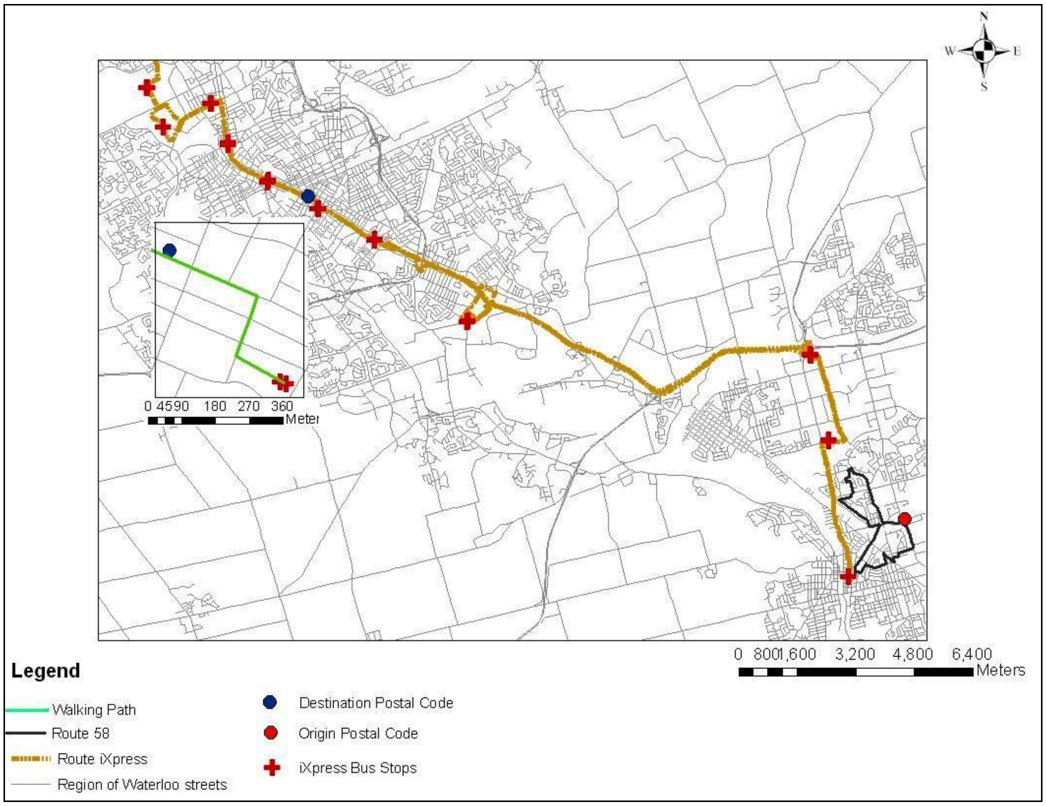

Figure 3-16: An Example of Walking Distance Computation for Survey Respondent No. 1007

Transfer Time

Of the 42 cases, 19 (45%) made one or more transfers between the *iXpress* and local services. 8 passengers transferred from a local route to catch the *iXpress* service, 7 arrived at their final destination by transferring to a local route from the *iXpress* services, and 4 made 2 transfers, the first transfer from a local route to the *iXpress* bus and the second from the *iXpress* to a local route.

[1] ArcGIS Is the name of a Geographic Information System software produced by ESRI, which enables the analyzing, storing, capturing, and managing of geographical data in a computer based system.

The transfer time for each case is determined by matching three criteria: the *iXpress* boarding and alighting time, the timetable of the *iXpress* route, and the timetable of the local route to/from which the transfer was made. The *iXpress* boarding and alighting time provides an approximate time when the transfer took place. The timetable of the *iXpress* and the local route was examined for that time period, and the transfer time was estimated based on the time schedule.

For example, according to the reported boarding time, survey respondent No.1007 boarded the *iXpress* bus at the Ainslie terminal at 7:15 a.m. Examination of the timetable for route 58 revealed that the closest time prior to 7:15 a.m. for the bus to arrive at the Ainslie Terminal is 7:12 a.m. Therefore, the passenger waited approximately 3 minutes at the station to transfer from a bus on route 58 to the *iXpress* bus as illustrated in Figure 3-17.

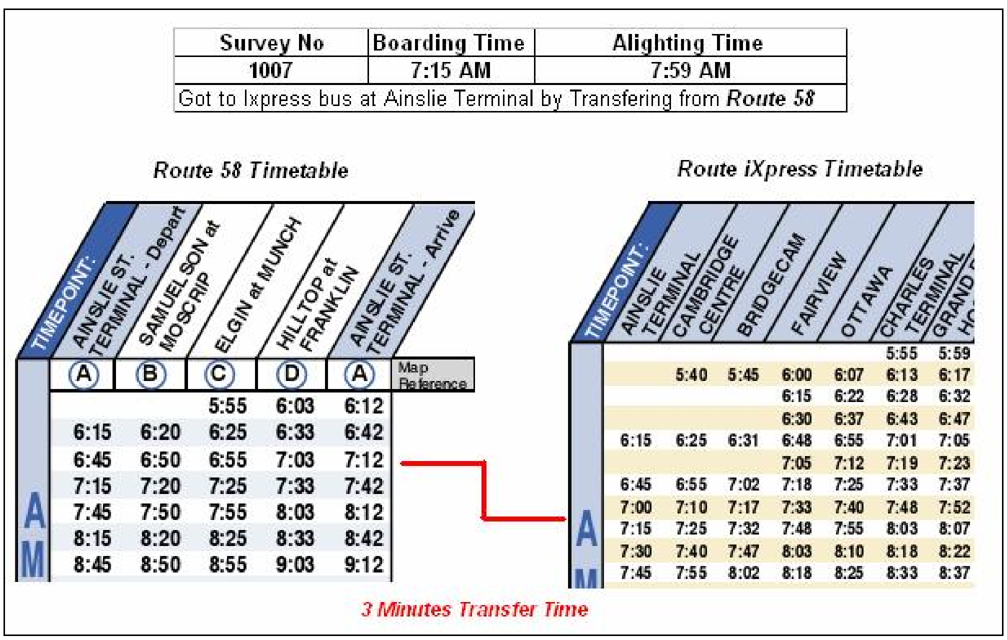

Figure 3-17: An Example of Transfer Time Computation for Survey No. 1007

The transfer point is determined according to the information that the passengers provided in questions 5 or 7, regarding the stations where the passengers boarded or departed from the *iXpress* bus, and matching that point to the closest station of the transferring route. Then, the in-vehicle travel time is estimated by matching the closest station of the local route to the OD postal codes from the map in ARCGIS, and the time period of traveling from that point to the transfer point from the route timetable.

Finally, total travel trip time for each passenger is estimated by computing

$$Ti_j = Twt_j + Tin_j + Ta_j + Te_j + \sum_{K=1}^{K}(Ttr_{kj} + Tin_{kj}) \tag{3-6}$$

where

Ti_j : total *iXpress* travel time for passenger *j*

Twt_j : waiting time for passenger *j*

Tin_j : *iXpress* in-vehicle travel time for passenger *j*

Ta_j : access time for passenger *j*

Ttr_{kj} : transfer time for passenger *j* for the *k*th transfer

k : number of transfers k={0,1,2,3}

Tin_{kj} : in-vehicle travel time for passenger *j* for the *k*th transfer

Te_j : egress time for passenger *j*

For instance, for survey respondent No. 1007, the total *iXpress* travel time is expressed as follows:

Ti_{1007} = 1.2+15+12+3+44+6.57= 81.77 Minutes

Ta_j : access time from Origin postal code to route 58 station is 1.2 minutes.

Twt_j : waiting time for route 58 is 15 minutes.

Tin_{kj} : route 58 in-vehicle travel time is 12 minutes.

Ttr_{kj} : transfer time from route 58 to *iXpress* is 3 minutes.

Tin_j : *iXpress* in-vehicle travel time is 44 minutes.

Te_j : egress travel time is 6.57 minutes.

3.6.5.2 Local Travel Time

In this section, the travel time that the 42 trip-makers, who had used a private auto to complete their trip is estimated.

For this analysis, all the route paths in the RMOW, except the *iXpress*, and 42 trip-makers' OD postal codes are allocated by ARCGIS. Then, for each trip-maker, the best route network (the closest routes' stations to the OD postal codes) is considered as illustrated in Figure 3-18.

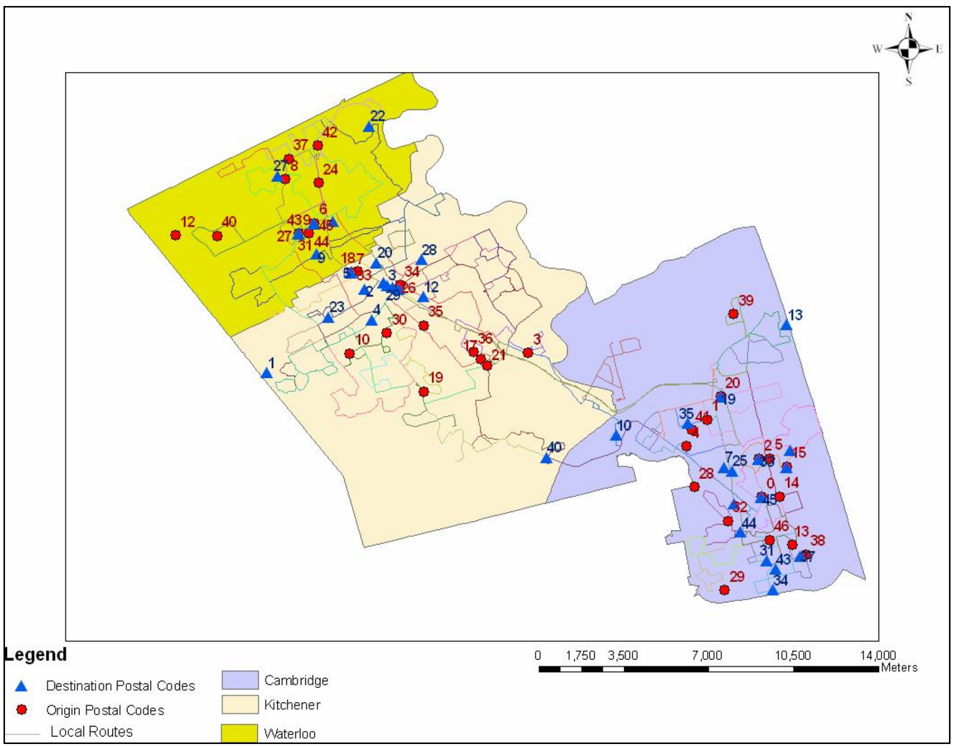

Figure 3-18: Local Routes Path and 42 OD Postal Codes on the ArcGIS Screen

Eighty-five percent of this group of trip-makers must transfer one or more times between the local routes to reach their destinations. The allocation of the postal codes in Figure 3-18 exhibits the distribution of the points in three areas. On these, 66.6% transferred between routes 7 and 52 at the Fairview Mall terminal. This long travel distance was clearly a strong incentive for these trip-makers who travel between Kitchener-Waterloo and Cambridge to use personal auto. However, the implementation of *iXpress* service has significantly reduced the travel time for these trips and this has persuaded the trip makers to change their travel behaviour and use public transit.

The process of the computing the time attributes for the local routes is conducted in the same way as was described for the *iXpress* service.

$$Tl_j = Twt_j + Ta_j + \sum_{K=1}^{K}(Ttr_{kj} + Tin_{kj}) + Te_j \qquad (3\text{-}7)$$

where

- Tl_j : total local travel time for passenger *j*
- Twt_j : travel waiting time for passenger *j*
- Ta_j : access time for passenger *j*
- Ttr_{kj} : transfer time for passenger *j* for the *k*th transfer
- k : number of transfers *K*={0,1,2,3}
- Tin_{kj} : in-vehicle travel time for passenger *j* for the *K*th transfer
- Te_j : egress time for passenger *j*

For example, for survey respondent No.1007 the local route travel time is estimated to be 104.77 minutes (Figure 3-19).

Tl_{1007} =1.2+15+12+3+41+4+22+6.57= 104.77 minutes

Ta_j :access time from Origin postal code to route 58 station is 1.2 minutes

Twt_j : waiting time for route 58 is15 minutes

Tin_{1j} : route 58 in-vehicle travel time is 12 minutes

Ttr_{1j} : transfer time from route 58 to 52 is 3 minutes

Tin_{2j} : route 52 in-vehicle travel time is 41 minutes

Ttr_{2j} : transfer time from route 52 to 7 is 4 minutes

Tin_{3j} : route 7 in-vehicle travel time is 22 minutes

Te_j : egress travel time is 6.57 minutes

Based on the estimated trip times by *iXpress* and local transit for this particular trip, the *iXpress* service has reduced the travel time by 23 minutes. This amount of time saving has induced this particular maker to leave his/her auto at home and take the *iXpress* service.

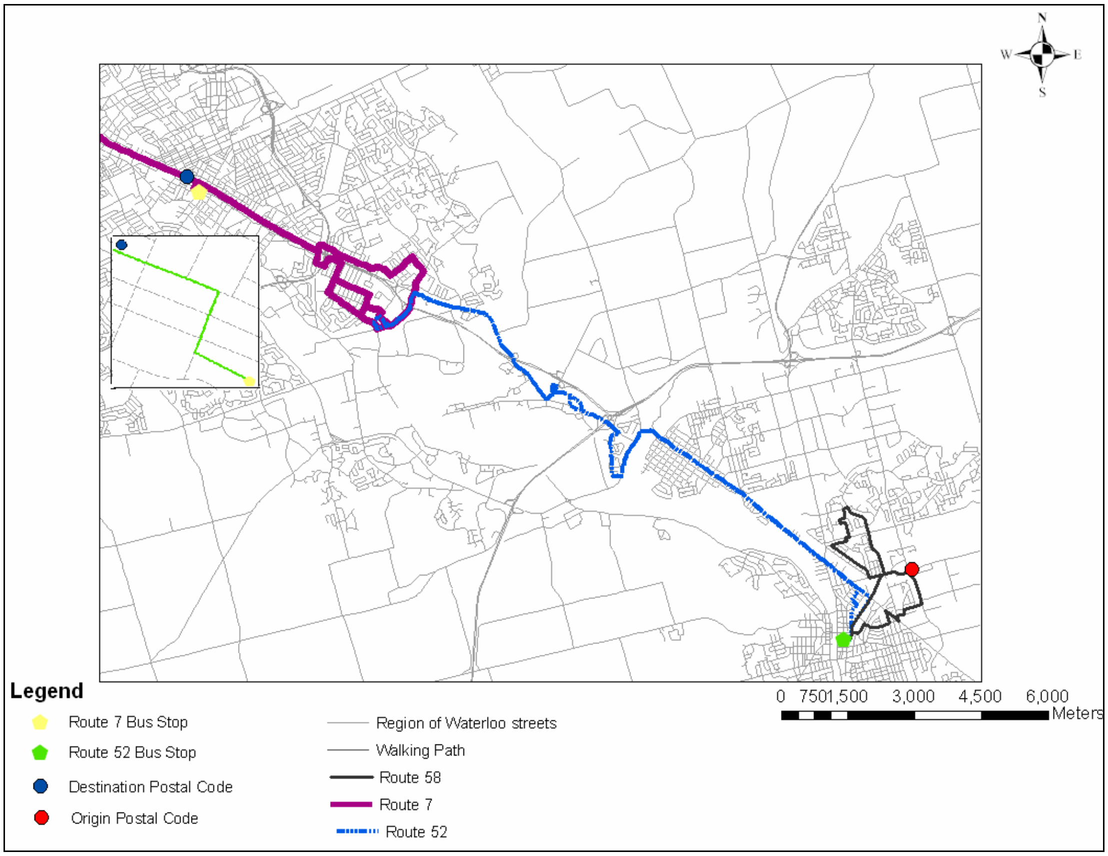

Figure 3-19: An Example of Total Travel Time Computation by Local Buses for Survey No.1007

3.6.5.3 Auto Travel Time

The auto travel time for each OD pair was estimated using Google map to estimate the travel time between two points. For instance, survey No. 1007 traveled 22.3 kilometers between the OD postal codes with an estimated driving time of 22 minutes implying an average speed of 60.8 Km/h (Figure 3-20).

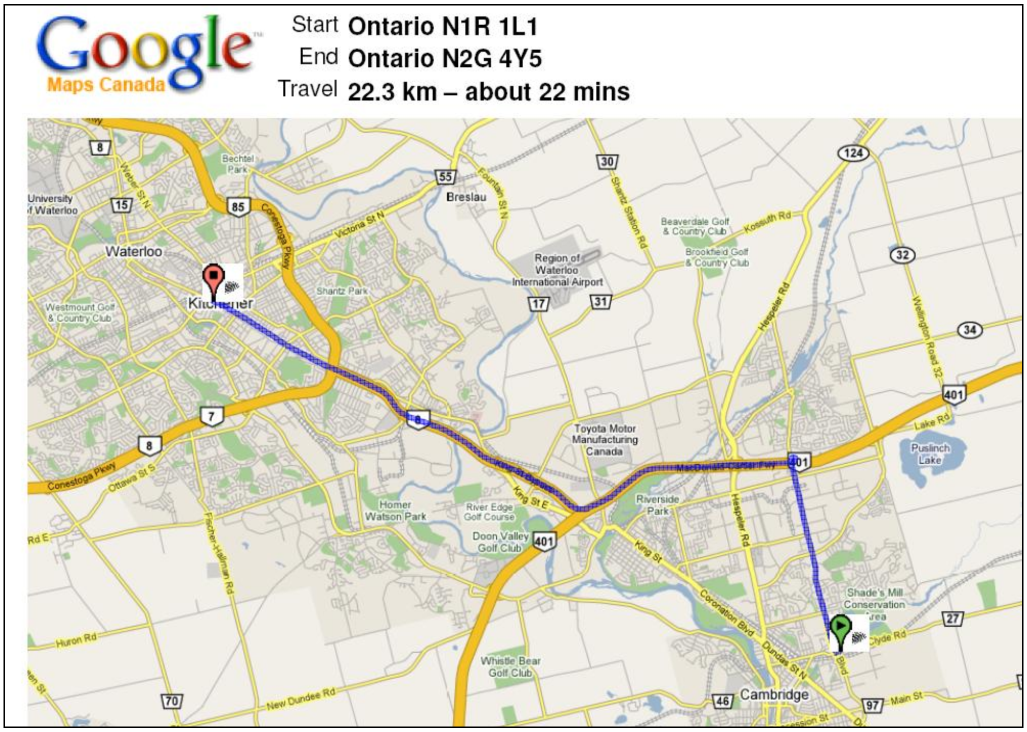

Figure 3-20: An Example of the Total Travel Time Computation by Auto for Survey No. 1007

3.6.6 Comparison of Trip Travel Times by Mode

The three estimated categories of travel time for the 42 trips are provided in Table 3-12.

Table 3-12: Trip Travel Times by Modes

ID	Survey No.	TT_{local} (Minutes)	# Transfers	$TT_{iXpress}$ (Minutes)	TT_{Auto} (Minutes)	Δ_{TT1}	Δ_{TT2}	Δ_{TT3}
1	7	105	1	77	29	48	76	28
2	24	123	2	107	21	86	102	16
3	32	113	1	71	24	47	89	42
4	117	55	1	41	9	32	46	14
5	317	91	2	61	22	39	69	31
6	319	99	2	52	23	29	76	48
7	518	102	1	69	27	42	75	33
8	546	92	1	56	22	34	70	36
9	567	23	0	20	5	15	18	3
10	571	23	0	15	4	11	19	8
11	654	102	2	81	32	49	70	21
12	1007	105	2	82	22	60	83	23
13	1028	84	1	44	22	22	62	41
14	1029	83	1	43	32	11	51	41
15	1031	58	0	40	18	22	40	18
16	1064	19	0	21	7	14	12	-2
17	1227	91	2	70	17	51	74	23
18	1259	106	2	59	18	41	88	47
19	1264	58	0	42	18	24	40	16
20	1292	52	1	50	8	42	44	2
21	1536	125	2	92	24	68	101	33
22	1548	97	1	62	25	37	72	35
23	1554	105	2	69	21	48	84	36
24	1579	54	1	20	7	13	47	35
25	1715	106	2	90	22	68	84	15
26	1717	85	1	54	30	24	55	32
27	1771	52	1	57	14	43	38	-5
28	1906	128	1	97	35	62	93	31
29	1920	111	1	81	28	53	83	30
30	1921	73	1	53	22	31	51	20
31	1944	102	2	80	29	51	73	22
32	2142	90	2	56	17	39	73	34
33	2162	59	1	53	18	35	41	6
34	2202	139	3	106	30	76	109	33
35	2229	111	1	72	32	40	79	40
36	2238	132	3	70	24	46	108	62
37	2619	83	1	66	26	40	57	17
38	2639	111	1	60	25	35	86	51
39	2661	25	0	30	8	22	17	-5
40	2666	104	1	70	34	36	70	34
41	2669	109	1	75	32	43	77	34
42	2914	104	1	64	27	37	77	40
Average		87	-	61	21	40	66	26

Table Legend:

TT_{Local}: Total Travel Time by Local Services

$TT_{iXpress}$: Total Travel Time by the iXpress Service

TT_{Auto}: Total travel Time by a Auto-vehicle

$$\Delta_{TT1} = TT_{iXpress} - TT_{Auto}$$

$$\Delta_{TT2} = TT_{Local} - TT_{Auto}$$

$$\Delta_{TT3} = TT_{Local} - TT_{iXpresso}$$

As it is suspected, people who switched from personal auto to traveling by *iXpress* tend to have an average longer trips than those who previously used another mode, and their travel pattern tend to be aligned with the *iXpress* corridor. This is illustrated in Figure 3-21.

The estimated average trip length for 42 passengers who switch to *iXpress* from drove car previously is 18.64 kilometer which is 76.5% longer than the average trip length of *iXpress* users who previously used local transit routes.

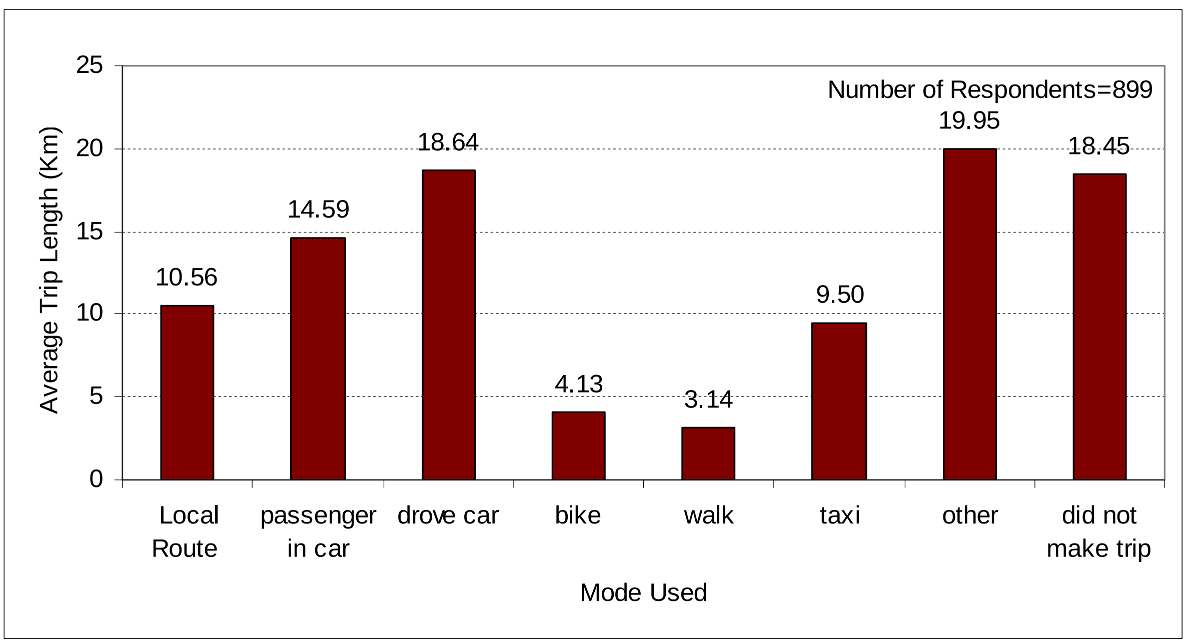

Figure 3-21: Average Trip Length by Previous Mode Used

Figure 3-22 presents the difference between *iXpress* travel time and auto travel time on the horizontal axis versus the difference between local and *iXpress* travel time on the vertical axis.

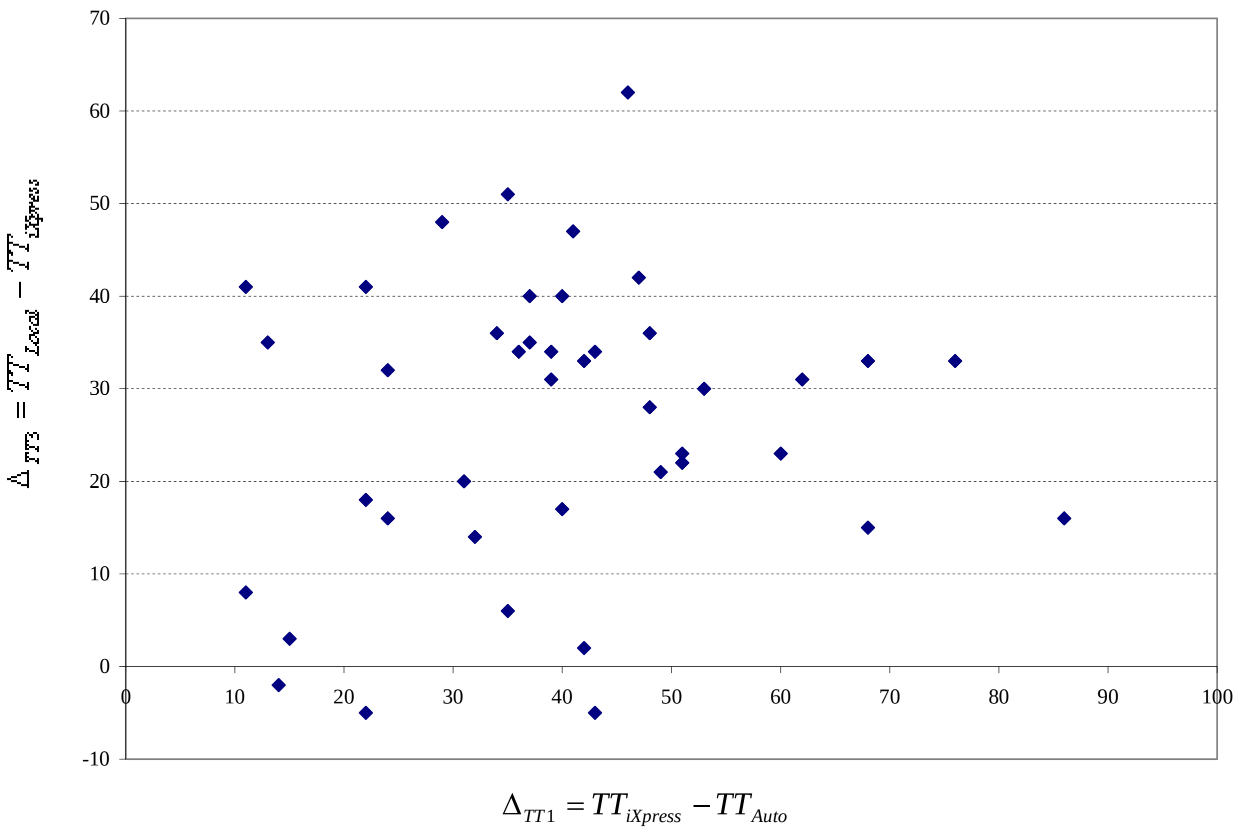

Figure 3-22: Difference between Local and *iXpress* Time versus *iXpress* and Auto Travel Times

Several observations can be made on the basis of based on Figure 3-22.

- The likelihood of choosing the *iXpress* increases as one moves towards 0 along the horizontal axis (there is more time saving by selecting *iXpress* instead of local services) and away from the 0 on the vertical axis. There are some people for whom *iXpress* offers very positive benefits. It saves some travelers about 40 minutes and is now only 10-15 minutes longer than the auto travel time.

- For the sample of 42 passengers, there are three passengers for whom using *iXpress* for their trips takes 2-5 minutes longer than using local transit service (points with negative value on the Y-axis in Figure 3-22. For these passengers route 7 and the *iXpress* provide stop stations at the location where the trip makers boarded and alighted. Because the travel distance is short, there is very little impact to the riders; if they take a local bus or *iXpress* bus. The traveler is likely to take whichever bus arrives first. Also, route 7 provides less in-vehicle travel time (3 minutes) than the *iXpress* for a portion of the route paths from Conestoga Mall to the University of Waterloo.
- Some outliers exist at the lower right corner of the Figure 3-22. For these riders, the *iXpress* route is 60 to 80 minutes longer than auto travel and the change from local service to the *iXpress* only saves 15-30 minutes. This group of passengers travels from Cambridge to Waterloo or in the reverse direction, and the *iXpress* service at least deducts one transfer for them. This suggest that even though the *iXpress* travel time is much longer than auto travel time, the elimination of a transfer and reduction in travel time provided by *iXpress* compared to local route is sufficient to induce these travelers to switch modes.

Figure 3-23 represents the ratio of *iXpress* to auto travel time versus ratio of local to *iXpress* trip travel time. The majority of data fall within iXpress to auto travel time rates of 2 to 4. This seems to suggest that it is necessary for transit trip travel times to be within this range in order to transit be sufficiently attractive to induce a shift from auto modes.

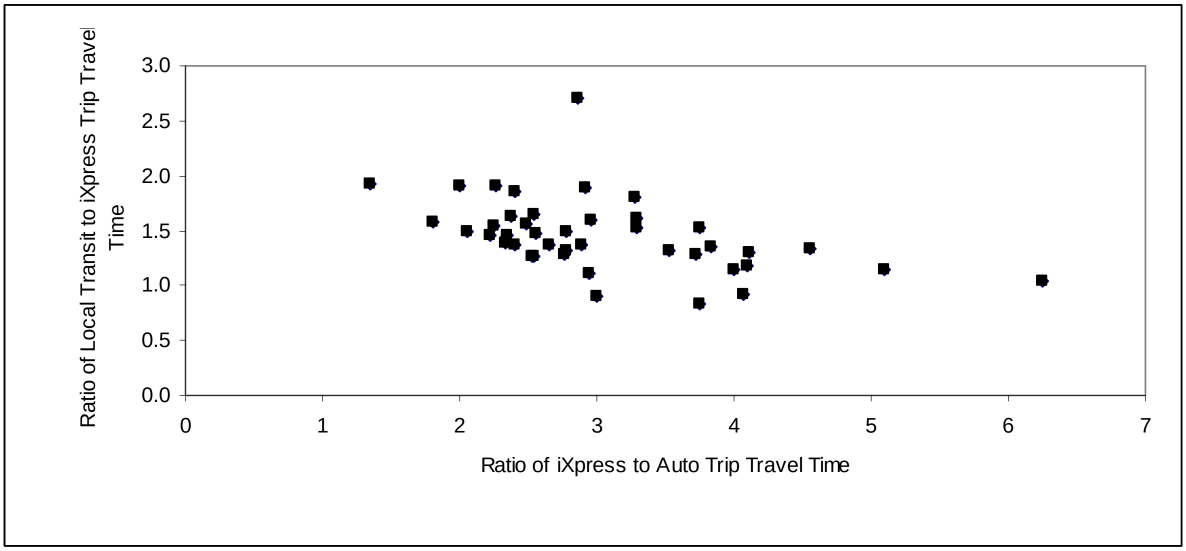

Figure 3-23: Ratio of *iXpress* to Auto Trip Travel Time versus Ratio of Local Transit to *iXpress* Trip Travel Time

3.7 Chapter Summary

This chapter relates the success of the *iXpress* service to attract passengers in the RMOW. This impact is investigated using data that were collected from the transit ridership survey in 2006 and fare box data.

The analysis reflects that:

- Six months after service implementation, the *iXpress* service experienced approximately 3500 boardings per day.
- In the northern corridor, the observed number of transit riders after the introduction of the *iXpress* exceeded by 19% and 62% for southern corridor.
- The estimated elasticity of transit demand with respect to average in the generalized cost for the northern and southern corridors, suggest that ridership in the southern corridor is much more sensitive to the travel cost savings than are those traveling in the northern corridor.

- After 6 months of operation, approximately 73% of *iXpress* users had previously used local transit routes, 14% had used auto to complete their trips and 7.5 % had not made the trip.
- Approximately 64% of *iXpress* riders who had switched from local transit routes had previously used one or more of three local routes (Routes 7, 51, and 52).The *iXpress* service provides considerable travel time savings (31% for trips in the southern corridor and 39% for trips in the northern corridor) which appears to be a significant determination in travelers' modes choices.
- Approximately 5% of *iXpress* riders previously made their trips by driving personal automobiles and still have vehicle available to make their trips. However, after the introduction of the *iXpress* service, these riders have chosen to use transit. Moreover, approximately 75% of *iXpress* users have 1 or more vehicles in their household.
- An examination of the estimated trip time for these 5% of passengers (42 passengers) showed that on average, the availability of *iXpress* reduced the trip time via local transit routes by 30% (26 minutes). It is apparent that these travel time savings were sufficiently large to induce these trip makers to switch modes. However, it is important to state that, even with these savings, the average trip time by *iXpress* is much longer than by car (61 minutes versus 22 minutes). It was also observed that there is significant variability about these average values, indicating that factors other than travel time (i.e. availability of service) may be significant in the mode choice decision.

4. Fuel Consumption Modeling and Analysis of GRT Buses

As discussed in the introduction, an improvement in the GRT services can reduce fuel consumption and resultant GHG emissions. However, there are no appropriate models to represent the fuel consumption savings of buses as HDD vehicles as a function of transit service improvements.

In this chapter, the process of modeling the fuel consumption of the GRT buses is developed as a function of the route and bus characteristics. A comparison of the fuel consumption of the *iXpress* with that of route 7, a parallel local route is presented to check the significance of the difference in fuel consumption rates of the two routes.

4.1 Data Collection

The fuel consumption data were collected on five days from Monday, April 24, 2006 to Friday, April, 28, 2006 at the north (Kitchener, Waterloo) and south depot (Cambridge) buses.

The odometer readings for 167 buses at the north depot and 43 buses at the south depot were recorded; the readings for the five days provide the kilometers traveled for each bus for four days.

The buses were fueled to a full tank by the GRT staff each night, and the amount of fuel was recorded from the fuel pump's pulse meter. This method of collecting the distance and fuel consumption data results in four potential sources of errors as follows:

1. Incorrect odometer data entries.
2. Incorrect pumped gas data entries.
3. Inaccurate fuel pump pulse meter.
4. Failure to fill fuel tank to the same level each night.

Errors have the effect of introducing additional variability in the data, and only some of the errors, associated with incorrect odometer reading, could be identified and eliminated.

4.2 Data Preparation

The five-day survey, from April, 24 to 28, 2006, resulted in a database containing 789 observations. However, approximately 18% of the south depot data (22 of 125) and 16% (100 of 664) of the north depot data were removed from the data set due to missing or incorrect data entries (i.e. an unreasonably large value for volume of fuel or a recorded odometer reading that was smaller than the reading recorded on the previous day.

Routes 72-75 at the north and south depots serve as Mobility plus services, where vans are used instead of conventional buses due to the low demand of passengers. The data from these routes are not considered for modeling purpose, because of the different kinds of vehicles. Moreover, in some cases, buses service more than one route during a day (i.e. bus number 2422 served routes 12 and 20 on Friday, April 28). Because there is no information available from the survey about the portion of fuel consumed on each of the routes the bus serviced on the single day, this event has caused a problem for dividing the consumed fuel among different routes with different criteria (i.e., the number of bus stops and intersections). Thus, the data of the buses that served more than one route, which is 243 cases or 31% of the collected data, were not considered in modeling.

Overall, the data for the fuel consumption modeling of GRT's conventional diesel buses are 311 cases (38% of the collected data), of which 29% is from the south depot and 71% is from the north depot. The table of the collected data is provided in Appendix B.

4.3 Development of a General Bus Fuel Consumption Model

In this analysis, the regression model of bus fuel consumption and route-based variables (i.e., the number of bus stops, number of signalized intersections along the route), and vehicle-based variables (i.e., bus age, and type of floor) is investigated.

A regression analysis can explore the mathematical relationship between several variables and the effects that some variables exert on a specific variable. The regression analysis involves two types of variables, called predictor or independent variables, and response or dependent variables (Smith, 1981).

The general format of the proposed regression model for bus fuel consumption is

$$Y = a + \sum_{i=1}^{n} b_i V_i + \varepsilon \qquad (4\text{-}1)$$

where

- Y :fuel Consumption (Liter)
- a :constant value
- n :number of independent variables included in model
- b_i :coefficient of independent variable i
- V_i :independent variable i
- ε :random error term, which is assumed to be normally and independently distributed

4.3.1 Description of the Factors Affecting Transit's Fuel Consumption

Based on previous studies in transportation energy consumption (Rakha et al., 2000; Hellinga et al., 2005; Kishi et al., 1995) several factors impact the vehicle fuel consumption as summarized in Table 4-1. These factors are classified into four groups; travel, driver, route, and vehicle related factors. Table 4-1 presents the factors for each category. All of these factors have the direct relationship by energy consumption which means an increase in the specific factor causes an increase in the fuel consumption rates.

The possibility of analyzing each factor is determined by the YES or NO expressions based on availability of data and methods for the GRT case.

Table 4-1: Supposed Criteria Which Can Affect the Fuel Consumption of Urban Buses

Group of Factors	Factors	Analysis Possibility for GRT case
Route-Related Factors	Distance	Yes
	Bus Stops	Yes
	Signalized Intersections	Yes
	Unsignalized Intersections	Yes
Travel-Related Factors	Travel Demand (Number of Loaded Passengers)	Yes
	Traffic Flow (i.e. Congested or Uncongested conditions)	No
Vehicle-Related Factors	Bus Floor Type (Low Floor-High floor)	Yes
	Vehicle Age	Yes
Driver-Related Factor	Driver Behavior(i.e., Aggressive Behavior	No
Other Factors	Air conditioning	No
	Climate (i.e., low Temperature and High Wind)	Yes
	Tire Pressure	No
	Measurement Error	Yes

4.3.1.1 Distance

Vehicles convert fuel as a source of energy to Kinetic energy in order to move the vehicle. The greater the distance that the vehicle travels, the more energy is consumed. Therefore, there should be a strong positive correlation between energy consumption and distance.

4.3.1.2 Vehicle Stops

Transit buses are required to stop for one of four reasons; bus stops, signalized intersections, unsignalized intersections or traffic congestion. The idling duration in these four stop types can be different, but each stop event can be represented by three components, acceleration (V_a), idling (V_0), and deceleration (V_b) (Figure 4-1). Most of the studies on fuel consumption are presented based on these speed (section 2-4), however in this research the average bus speed is considered for developing fuel consumption model as a function of several criteria.

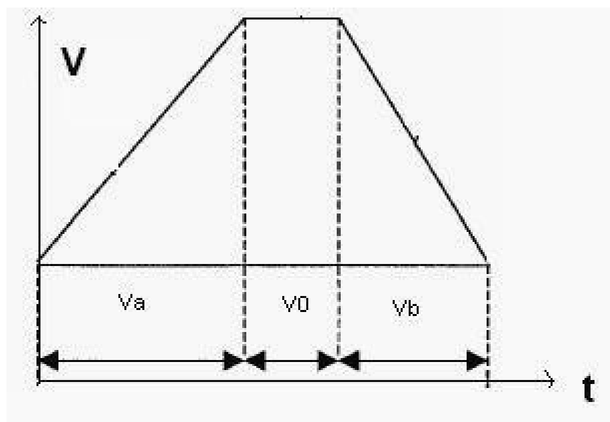

Figure 4-1: Speed of Vehicles at Each Stop (Rakha et al, 2003)

Based on the literature review in Chapter 2, the impact of a single stop and a single intersection on light-duty vehicle's fuel consumption and GHG emissions has been analyzed by Hellinga et al. (2005) and Rakha et al. (2002) who showed that there is an increase in fuel consumption as a result of the introduction of a bus stop or intersection. However, none of these analyses have included the impact of the stops for HDD vehicles, especially urban transit buses. The fuel consumption data of the RMOW for conventional buses provides an opportunity to analyse impact of stops on bus fuel consumption.

4.3.1.3 Travel Demand

An increase in passengers or travel demand means more boarding and alighting, implying an increase in the frequency of stops at bus stops and an increase in duration of idling at these stops. The increase in idling time and increased number of stops can increase the fuel consumption and GHG emissions. The ridership of the GRT routes for April, 25 to 28, 2006 enables the analysis of the fuel consumption and travel demand relationship.

4.3.1.4 Traffic Flow

It is apparent that the increase in the number of motor vehicles on the roads results in a serious impact on the global environment. In some cases, the road system does not accommodate traffic demand, and the resulting congestion condition results in increasing GHG emissions. The TTI Annual Mobility Study estimates that billions of gallons of fuel are wasted every year because of congestion (Schrank et al, 2005).

Kishi et al. (1996) have investigated the impact of traffic flow on fuel consumption for two types of vehicles (light and heavy duty vehicles). They use a micro model in which the behaviour of independent vehicles is considered, and the resultant fuel consumption rate per second for each vehicle due to the individual movement of vehicles, is estimated.

For the GRT case, no information is available about the traffic flow of the RMOW's network during the fuel consumption collection data period. Therefore, the impact of this criterion can not be analyzed.

4.3.1.5 Type of Bus Floor (High and Low Floor)

The goal of low floor is to improve access to transit service for all customers, including those with canes, crutches, wheelchairs, or young children. In low floor buses, there are no steps at the front and rear doors, allowing faster boarding and alighting. A decrease in the boarding and alighting time; that is decreasing the vehicle's dwell time can result in a decrease of the fuel consumption rates for transit buses. The data available from the RMOW provides an opportunity to use the type of bus (i.e. floor type as one of the independent variables in the fuel consumption modeling.

4.3.1.6 Vehicle Age

It is hypnotized that new vehicles consume less fuel due to improvements in vehicle and engine technologies. Research conducted by Natural Resources of Canada shows that each additional year of vehicle age means an increase in the fuel consumption ratio of 0.3 L/100 km (Natural Resource of Canada, 2005).

4.3.1.7 Driver Performance

Driver behaviour such as accelerations, braking, and gear shifting affects fuel economy, aggressive behaviours, sharp acceleration and braking, negatively affect fuel economy compared with cruise-type driving (Ahn, 1996).

European research has shown that changing drivers behavioural can produce fuel savings in the range of 5-12%.

In one case, Mercedes-Benz offered driving courses which resulted in a fuel consumption reduction of 5 to 10 percent for drivers who followed the strategies. Switzerland showed an average decrease in fuel consumption of 12%, following the training courses (Europe Environment Group, 2006). However, there is no precise available database on transit drivers' names and the characteristics for GRT, and so, modeling these characteristics is not possible.

Nevertheless, variations in driver characteristics exist within the data and contribute to unexplained variations in the models.

4.3.1.8 Type of Fuel, Climate, Air Conditioner

Some criteria were almost constant during the 5 day survey and are not being considered in this modeling, including weather and the kind of fuel consumed. The weather was almost constant at 10^{o}C, without any rain, no wind or sun (Weather Network, Archive 2006), and air conditioners were not on at that time.

4.3.1.9 Tire Pressure

There is a high possibility that improper inflation pressure has a negative effect not only on safety, but also on fuel consumption (Toyo Tire Group, 2005). This concept was tested by the Toyo Company in Japan. It tested two identical vehicles, where the tire vehicle inflation pressure of one vehicle was recommended by the vehicle manufacturer, and tire inflation pressure of the other one was reduced by different amounts, below that of the first vehicle. They found that when the tire pressures are reduced by 1.0 kg/cm^2, the fuel consumption is increased by 10% - 15%.

4.3.1.10 Measurement Error

As described in section 4.1, the method of collecting the distance and fuel consumption data results in four sources of measurement errors, and only a portion of them are associated with incorrect odometer data is determined. These measurement errors and the fact that some features influencing fuel consumption were neither measured not controlled be in the data collection effort (i.e., driver behavior), contributes to unexplained variation in the observed data.

4.3.2 Dependent Variable of a Fuel Consumption Model

It is suspected that there is a strong correlation between consumed fuel (x_1) and distance traveled (x_2). This expectation is confirmed by computing the correlation coefficient between these two variables.

The correlation coefficient indicates the strength of the relationship between two variables, and Pearson's correlation coefficient is a measure of the linear association (SPSS).

As expected, there is a strong positive linear correlation coefficient (r =0.93 close to 1) between two variables which is statistically significant at the 0.01 level (Figure 4-2).

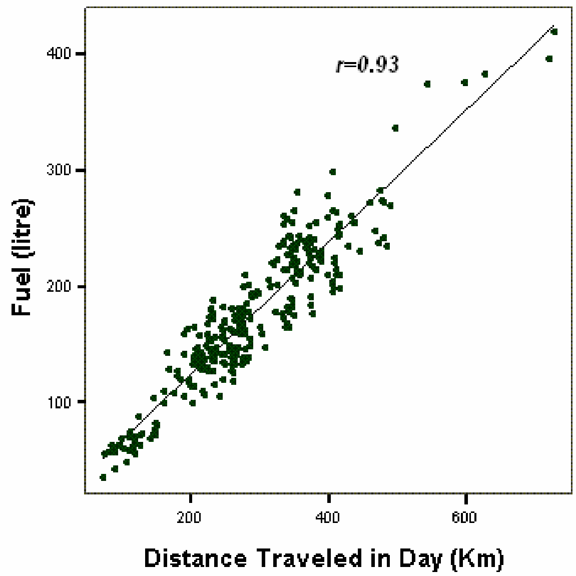

Figure 4-2: Scatter Diagram of Consumed Fuel versus Distance Traveled in a Day

However, we are interested in developing a model that relates fuel consumption to route characteristics such as number of bus stops and number of intersections, etc. To explain these impacts, we consider fuel consumption rate (L/Km) as the dependent variable rather than simply volume of fuel consumed.

The fuel consumption in litres and distance traveled for each conventional diesel bus which served only a single route during an entire day provide a L/Km ratio as a dependent variable of the model. Table 4-2 presents the descriptive estimated statistics of fuel consumption ratio for each day.

Table 4-2: Estimated Statistical Measures of Fuel Consumption Rate

Day	No. observation	Minimum (L/Km)	Maximum (L/Km)	Average (L/Km)	Standard deviation (L/Km)	Coefficient of variation (std/mean)
Tuesday	73	0.48	0.86	0.60	0.078	0.130
Wednesday	74	0.49	0.84	0.62	0.083	0.134
Thursday	84	0.44	0.84	0.61	0.092	0.151
Friday	80	0.47	0.79	0.61	0.076	0.124

Computed fuel consumption ratios demonstrate considerable variation due to measurement errors, uncontrolled factors such as driver behavior, tire pressure, climate and measured factors such as bus and route characteristics. Consequently, the fuel consumption rate can be represented as a random variable that follows a continuous distribution.

Several continuous distributions such as Normal, Lognormal, Poisson, and Beta frequently arise in applications. However, the most widely used model for the distribution of random variables is a normal distribution, because many statistical techniques are appropriate only when the population is (at least, approximately) Normal (Montgomery, 2006).

There are two methods to explore whether a Normal distribution is an appropriate distribution for the data: the Normal probability plot[1], and goodness of fit.

Figure 4-3 shows the Normal probability plot of the fuel consumption rate data (L/Km). The plot follows approximately a straight line indicating that these data can be considered to be Normally distributed.

[1] The Normal probability plot provides a graphical method for determining whether the sample data conform to a normal distribution, based on the subjective visual examination of the data.

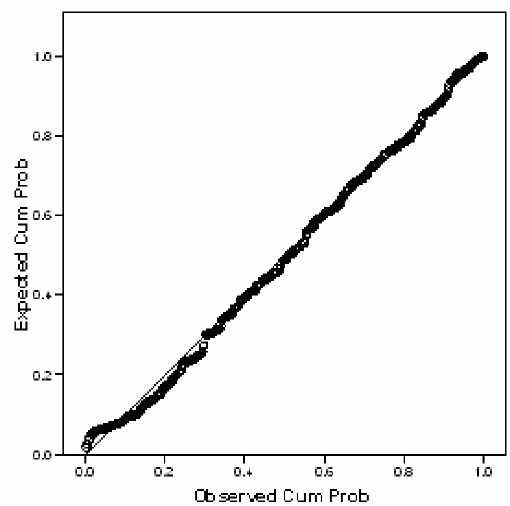

Figure 4-3: Normal Probability Plot of Fuel Consumption Ratio (L/Km)

Moreover, the Normal distribution of random variable Y is tested by a formal goodness of fit test procedure, based on the calculated test statistic χ_0^2 and following the hypothesis statement, as charted in Figure 4-4.

H_0: The form of the distribution is Normal

H_1: The form of the distribution is nonNormal

Test Statistic based on chi-square=15.7

Since two parameters (the mean and standard deviation) can be estimated based on the data, the chi- square statistic has a 11-2-1=8 (11 number of intervals) degrees of freedom[1]. The null hypothesis H_0 is rejected if $\chi_{\alpha,8}{}^2 < 15.7$.The corresponding p-value or α for this unequal function is equal to 0.0482.

[1] The number of observations which are freely available to vary given the additional parameters estimated.

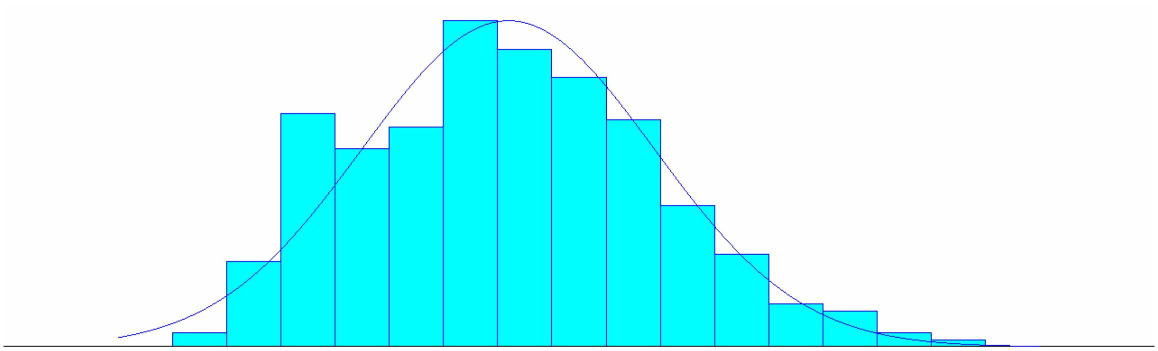

Figure 4-4: Normal Histogram Plot of Fuel Consumption Rate (L/Km)

The p-value or significance of the test is the smallest level of significance that would lead to rejection of the null hypothesis H_0 with the given data and is ranged from 0 to 1 (Montgomery, 2006). The amount of evidence for rejecting the null hypothesis is given according to the guidelines in Table 4-3 (Duever, 2006):

Table 4-3: P-Value guideline for Rejecting Null Hypothesis (Duever, 2006)

P-Value Range	Guideline
$P < 0.01$	Very strong evidence against null hypothesis
$0.01 < P < 0.025$	Strong evidence against null hypothesis
$0.025 < P < 0.05$	Moderate evidence against null hypothesis
$0.05 < P < 0.1$	Weak evidence against null hypothesis
$P > 0.1$	Data are consistent with the null hypothesis

The p-value of Normality test of data is adequate enough to indicate that variable Y or the ratio of consumed fuel (liter) to distance (km) is Normally distributed with mean μ =0.61 L/km and variance σ^2 = 0.0068 $(L/Km)^2$.

4.3.3 Independent Variables of a Fuel Consumption Model

The potential independent variables are identified by including: (1) the ratio of the number of bus stops to route length; (2) of the number of signalized intersections to the route length, (3) the ratio of the number of unsignalized intersections to the route length; (4) travel demand on the route; (5) bus age; (6) vehicle floor type; and (7) average speed of movement on each route. The construction of the data set for each of independent variables is explained in the following sections.

4.3.3.1 Number of Bus Stops/Route Length

By using ArcGIS features and the available computer-based geographic information of all the bus stops in the RMOW, the number of bus stops along each route was computed and is provided in Appendix C.

Some routes have different alignments during peak time and off-peak time (i.e., Route 5 in Appendix D), and the number of bus stops and length of route can change for two or more alignments. In this case, the average of the number of bus stops and that of the lengths have been considered to compute the ratio of the bus stops to the route distances.

In other cases, a portion of some routes is a loop in one direction (i.e., route 13 in Appendix E). For these routes, the ratio of the bus stops to the route length for the loop and line path is estimated separately, and the average of bus stops to the kilometer length is estimated establishing the coefficient of the length to each ratio.

4.3.3.2 Number of Signalized Intersections/Route Length

By using the available map of signalized intersections, provided by the RMOW in 2004, the number of signalized intersections along each route is accounted for manually, and the division of number of signalized intersections to the length of the route is computed and shown in Appendix F.

4.3.3.3 Number of Unsignalized Intersections/Route Length

The overall number of intersections, along each route, is computed using the analysis feature of Arcview. The number of unsignalized intersections is estimated by the reduction of the signalized intersections from the overall route intersections, which is shown in Appendix F. However, this method of determining the number of unsignalized intersections does not distinguish between intersections at which the bus is required to stop (due to a stop sign) and those at which the bus does not need to stop (i.e. bus is on the major street on a two-way stop controlled intersection).

4.3.3.4 Route Travel Demand

Daily ridership data were obtained from GRT for each route for the same period which the fuel consumption survey was conducted (i.e. April 25-28, 2006) and are presented in Appendix G. These data provide an aggregate measure of passenger demands and may be useful in the regression analysis to capture number and duration of dwell times.

4.3.3.5 Bus Floor Type and Age

The age range of 2 to 22 years old for GRT buses gives the data for investigating the age factor as an independent variable in the regression analysis in relating to the bus fuel consumption. The vehicle characteristics data such as the vehicle model, year, and floor type for each bus with 4 digit code number, provided by GRT, is denoted in Appendix H.

4.3.3.6 Route Average Speed

Considering the estimated route length which is presented in Appendix C, and calculating the total travel time of each route in peak and off-peak time based on available GRT schedule sheets, the average speed for each route is estimated and presented in Appendix I.

4.3.4 Linear Regression Model of Fuel Consumption Ratios

By considering all independent variables in section 4.3.3, a regression model is developed as follows:

$$Y_{n,d} = a + b_1 V_{1,n,d} + b_2 V_{2,n,d} + b_3 V_{3,n,d} + b_4 V_{4,n,d} + b_5 V_{5,n,d} + b_6 V_{6,n,d} + b_7 V_{7,n,d} \quad (4\text{-}2)$$

where

$Y_{n,d}$: fuel consumption ratio for bus number *n* on day *d* (L/Km) *a* : constant value

b_i : coefficient of independent variable *i*

$V_{1,n,d}$: number of bus stops per route km for route than bus *n* traveled on day *d*

$V_{2,n,d}$: number of unsignalized intersections per route km for route that bus *n* traveled on day *d*

$V_{3,n,d}$: number of signalized intersections per route km for route that bus *n* traveled on day *d*

$V_{4,n,d}$: average daily ridership for the route that bus number *n* served on day *d*

$V_{5,n,d}$: age (between 2 to 21 years old) of bus number *n* served on day *d*

$V_{6,n,d}$: floor type of bus number *n* served on day *d* (1= high floor;0= low floor)

$V_{7,n,d}$: average speed of the route that bus number *n* served on day *d* (Km/h)

SPSS software provides four methods of developing the regression model, including Enter, Stepwise, Forward, and Backward.

In the first step, the enter method is used in which all the variables V_1 to V_7 are entered in a single step. The fitted regression model is presented in Equation 4-3.

$$Y = 0.557 + 0.016V_1 + 0.005V_2 - 0.015V_3 + 1.6*10^{-5}V_4 - 0.001V_5 + 0.006V_6 - 0.001V_7 \qquad (4\text{-}3)$$

Based on the description provided in 4.3.1, we expect the coefficients of variables V_1, V_2, V_3, V_4, V_5, and V_6 to be positive and V_7 to be negative, however the sign of coefficients b_3 and b_5 are not consistent with this expectation.

Table 4-4 shows the regression results in terms of the contributed coefficients and their significant.

Table 4-4: Significance of Independent Variables in the Developed Model

Independent Variables	Coefficient	p-value (Significance)
Constant	0.557	0.000
V_1	0.016	0.000
V_2	0.005	0.097
V_3	-0.015	0.024
V_4	$1.6*10^{-5}$	0.000
V_5	-0.001	0.362
V_6	0.006	0.709
V_7	-0.001	0.208

Dependent Variable: Y

As Table 4-4 presents, variables age (V_5) and floor type (V_6) show high p-value which indicates that the coefficients of these two variables are not significant in the developed model. For examining the adequacy of the model three methods are used.

4.3.4.1 Hypothesis Test in the Developed Model

To test the hypothesis of the model, it is assumed that the error term ε in the regression model is normally and independently distributed with mean zero and variance. The test for the significance of regression is to determine whether a linear relationship exists between the dependent variable Y and a subset of the independent variables V_1, V_2, V_3, V_4, V_5, V_6 and V_7. The appropriate hypotheses are

H_0: $V_1=V_2=V_3=V_4=V_5=V_6= V_7=0$

H_1: $V_i \neq 0$ for at least one i

Test Statistic: $F_0= \dfrac{MS_R}{MS_E}$ (4-4)

where

MS_R : Mean Square Regression

MS_E : Mean Square Residual

Rejection Criterion: $f_0 > f_{\alpha, p-1, n-p}$ (4-5)

where

p = 8   : number of parameters in the model

n = 310   : number of observations

The rejection of null hypothesis implies that at least one of the independent variables contribute significantly to the model.

The provided ANOVA table of the model (Table 4-5) shows a p-value of test equal to 0 which is very strong evidence against null hypothesis. Therefore, at least one of the independent variables contributes significantly to the model.

Table 4-5: Analysis of Variance for Testing Significance of Multiple Linear Regression Model

Source of Variation	Sum of Squares	Degree of freedom	Mean Square(MS)	F_0	P-Value
Regression (R)	0.492	p-1=7	0.070	13.126	0
Residual (E)	1.616	n-p=302	0.005		
Total	2.107	n-1=309			

4.3.4.2 Residual Analysis

The residuals from the regression model are $e_i = Y_i - \hat{Y}_i$, i=1, 2,…, n

where

Y_i : actual observation

$\hat{Y}_i$: corresponding fitted value from the regression model

The analysis of the residuals helps to check the assumption that the errors are approximately Normally distributed with a constant variance. Figure 4-5 shows the plot of residuals in terms of the dependent variable Y and Figure 4-6 shows the Normal probability plot of regression residuals. The plot shows that the residuals are not Normally distributed and variation appears not to be constant.

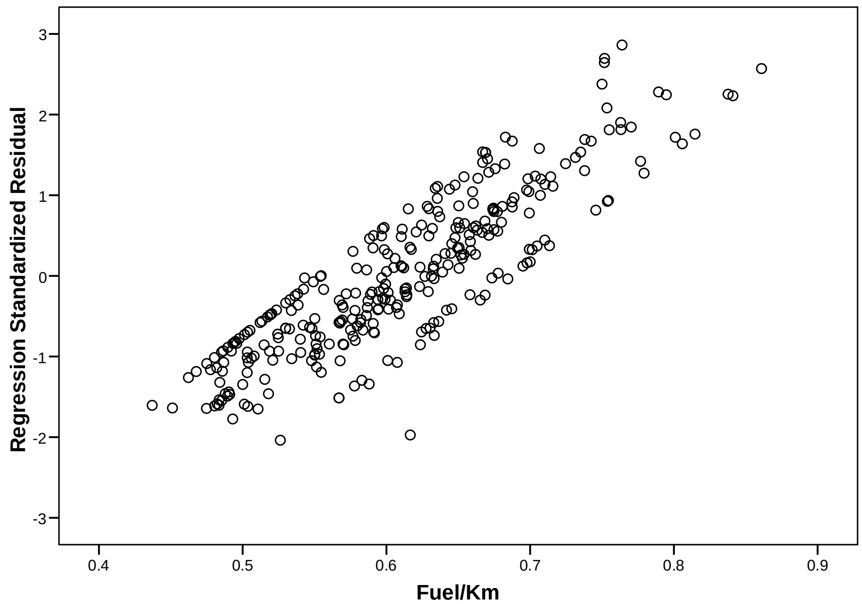

Figure 4-5: Regression Model Residuals

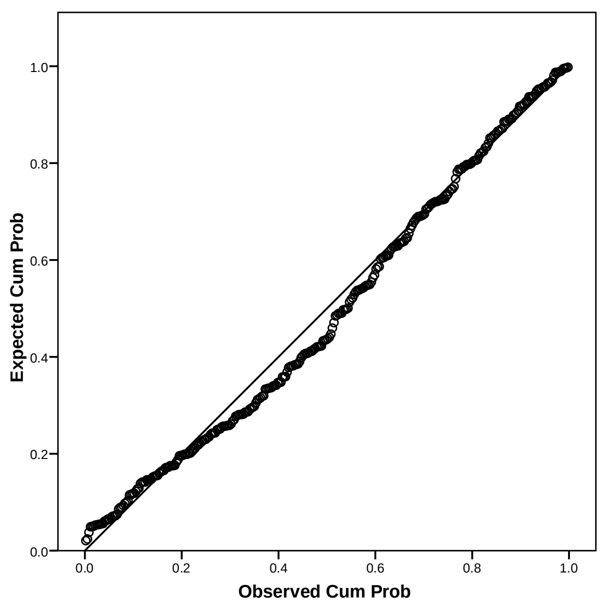

Figure 4-6: Normal Probability Plot of Regression Residuals

4.3.4.3 Coefficient of Determination (R^2)

A widely used measure of the explanatory power of a regression model is a ratio of the sum of squares or R^2 which is between 0 and 1. This ratio indicates what percentage of the variation in the data is accounted for by the model; so, the closer the ratio is to 1, the better the model is for explaining the data. The resultant R^2 for the equation is equal to 0.233, demonstrating the model accounts for only a modest amount of the variability in the data.
In terms of the three regression model evaluation methods, the regression model in equation 4-2 is not suitable.

Using a stepwise method to develop a regression model shows that the significant independent variables of the model are V_1 and V_4. However, the resulting R^2 value is only 0.208 and examination of residuals show non-Normal distribution and non-constant variation.

4.3.5 Investigation of the Significance of Bus Age and Floor Type

In this part, we test to determine if age and floor type influence the mean fuel consumption rate.

4.3.5.1 Hypothesis Test on the Bus Age

If the GRT buses are classified into two groups of old and new buses, the hypothesis is that the average of the fuel consumption for old buses will be higher than that of new ones. This statement is investigated by developing a hypothesis test on the mean of two samples. Table 4-6 conveys the statistical inferences for the two groups of buses.

Table 4-6: Impact of Bus Age on Mean Fuel Consumption Rate

Group	Age Range	Sample Size	Average Fuel Consumption Rate (L/Km)	Standard Deviation(l/Km)
Old Buses(X_1)	[14-21]	49	0.63	0.095
New Buses (X_2)	[2-4]	147	0.61	0.081

As it is seen in Table 4-6, old buses consume 0.02 litres more fuel per kilometer traveled than newer buses. However, these two samples from a normal distribution have a *t* distribution with *n-1* degrees of freedom (v), and the hypothesis test on mean of two samples should be investigated with respect to the sample size and inferences.

The hypothesis statement, test statistic, and degree of freedom functions are expressed in the following equations.

Null hypothesis: $H_0 : \mu_1 - \mu_2 = 0$ (4-6)

Test statistic: $T = \dfrac{\overline{X}_1 - \overline{X}_2 - 0}{\sqrt{\dfrac{S_1^2}{n_1} + \dfrac{S_2^2}{n_2}}}$ (4-7)

$$v = \frac{\left(\dfrac{S_1^2}{n_1} + \dfrac{S_2^2}{n_2}\right)^2}{\dfrac{(S_1^2 / n_1)^2}{n_1 - 1} + \dfrac{(S_2^2 / n_2)^2}{n_2 - 1}} \quad (4\text{-}8)$$

Where,

n_i : Sample *i* size

S_i : Sample *i* variance

Rejection Criteria: $T_0 > T_{\alpha/2}, v$ or $T_0 < -T_{\alpha/2}, v$ (4-9)

The estimated test statistic for a two-tailed alternate is T_0 = 1.33 based on 72 degrees of freedom, and the P-value = 0.14, which means $H_0 : \mu_1 = \mu_2$, is not rejected at any significant level of $\alpha < 0.14$ .This null acceptance means that there is no evident to conclude that bus age impacts average fuel consumption rate.

4.3.5.2 Impact of Bus Floor Type

For the low floor buses, there are no steps at the front and rear doors, facilitating faster boarding and alighting for riders and decreasing dwell time. In this section we examine if floor type impacts fuel consumption rate. Table 4-7 provides descriptive statistics for the two groups of buses.

Table 4-7: Fuel Consumption Rate Statistics for High and Low Floor Buses

Group	Sample Size	Average Fuel Consumption Rate (L/Km)	Standard Deviation(L/Km)
High Floor Buses(X_1)	40	0.57	0.069
Low Floor Buses(X_2)	229	0.60	0.078

Table 4-7 indicates that the low floor buses consume 0.03 liters more fuel for each kilometer of travel than high floor buses.

Based on Equations 4-7 to 4-9, the T-value for the floor type hypothesis test is equal to -0.72 with 68 degrees of freedom, and the corresponding p-value of 0.38 which shows that the hypothesis test is not rejected at $\alpha < 0.38$. The high level of test significance implies that there is insufficient evidence to suggest that high and low floor buses have statistically different fuel consumption rates.

The results of the analysis described in section 4.3.5 suggest that bus age and floor type do not have a significant impact on bus fuel consumption rate. Therefore these variables have been removed from consideration in the model. The next section investigates the explanatory capabilities of a linear regression model based on route characteristics. considering the independent variable to be the mean fuel consumption rate computed from buses operating on each route in four days instead of the fuel consumption rate for each bus individually.

4.3.6 Multiple Linear Regression Model Based on Route Characteristics

By considering all route variables, a regression model is developed as follows.

$$Y_r = a + b_1 V_{1,r} + b_2 V_{2,r} + b_3 V_{3,r} + b_4 V_{4,r} + b_5 V_{5,r} \tag{4-10}$$

where

- Y_r : mean fuel consumption rate for route r (L/Km)
- a : constant value
- b_i : coefficient of independent variable i
- $V_{1,r}$: number of bus stops per route km for route r
- $V_{2,r}$: number of unsignalized intersections per route km for route r
- $V_{3,r}$: number of signalized intersections per route km for route r
- $V_{4,r}$: average daily ridership of route r
- $V_{5,r}$: average speed of buses operating route r (Km/h)

Figure 4-7 shows the average fuel consumption rate computed for each route. Note that the iXpress has the lowest fuel consumption rate. Table 4-8 lists the average of the fuel consumption for each day plus the relevant input variables V_1 to V_5.

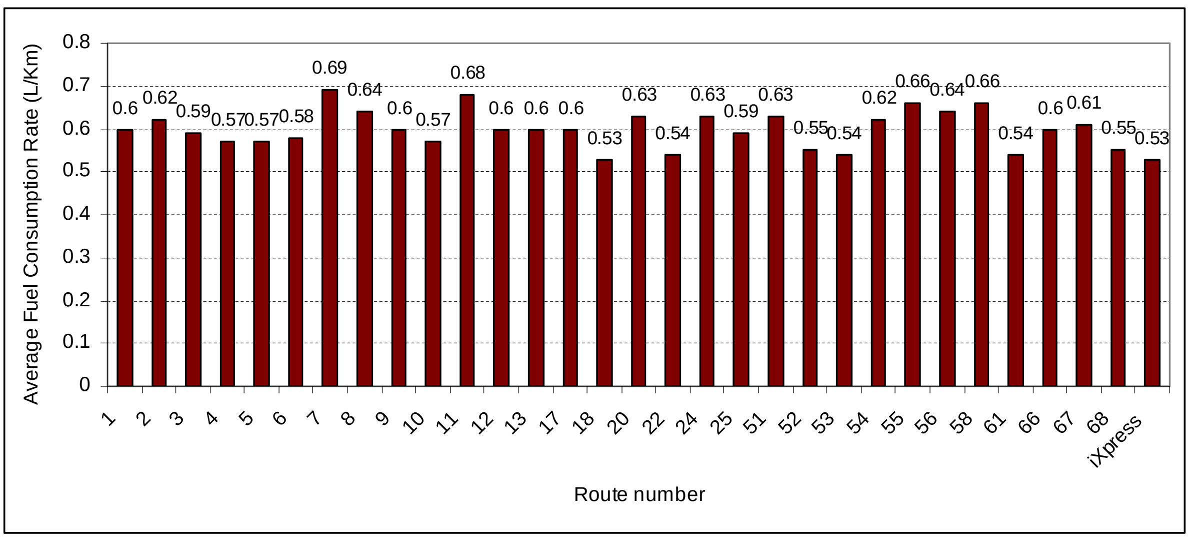

Figure 4-7: Average Fuel Consumption for each route

Table 4-8: Average Fuel Consumption vs. Route Number

Route	Y	V_1	V_2	V_3	V_4	V_5
1	0.6	4.01	5.36	1.56	652	22.94
2	0.62	3.43	2.98	1.69	337	25.01
3	0.59	3.33	2.95	1.52	1029	22.72
4	0.57	4.11	4.06	1.8	416	23.77
5	0.57	3.06	6.13	1.12	767	36.54
6	0.58	3.88	5.13	1.97	428	22.52
7	0.69	3.78	2.83	6.58	9695	19.51
8	0.64	2.96	5.31	2.12	3104	19.92
9	0.6	3.48	6.01	1.41	1014	23.01
10	0.57	3	3.64	0.6	1089	64.17
11	0.68	4	7.74	1.33	1263	20.43
12	0.6	2.7	2.37	1.22	3309	23.48
13	0.6	3	3.49	1	286	26.33
17	0.6	2.89	3.51	1.79	465	17.46
18	0.53	4.38	5.47	2.34	175	23.25
20	0.63	3.35	6.06	3.35	450	16.16
22	0.54	3.25	3.71	1.56	1154	22.73
24	0.63	4.18	6.68	1.81	607	19.83
25	0.59	4.66	5.42	1.15	980	19.21
51	0.63	1.07	0.75	1.39	1913	38.69
52	0.55	2.71	4.08	0.98	982	25.65
53	0.54	2.75	2.43	1.38	677	25.98
54	0.62	3.68	6.04	1.13	334	23.56
55	0.66	3.06	7.02	0.57	563	24.32
56	0.64	3.95	5.2	1.07	579	25.73
58	0.66	3.22	3.5	1.1	532	24.11
61	0.54	1.66	3.18	0.58	74	31.96
66	0.6	2.87	5.73	0.34	96	22.75
67	0.61	2.46	0.59	0.93	101	30.68
68	0.55	2.33	4.85	1.94	90	19.94
iXpress	0.53	0.35	2.98	1.41	1570	30.17

Figure 4-8 represents a matrix of the two-dimensional scatter plots of the data. This display helps to visualize the relationships among the variables in a multivariable data set. For example, the first row in Figure 4-8 shows the relationship between *Y* as a dependent variable and V_1 to V_5 as independent variables of the model. These figures indicate that the clear relationship between *Y* and any of the variables V_1 to V_5 does not exist.

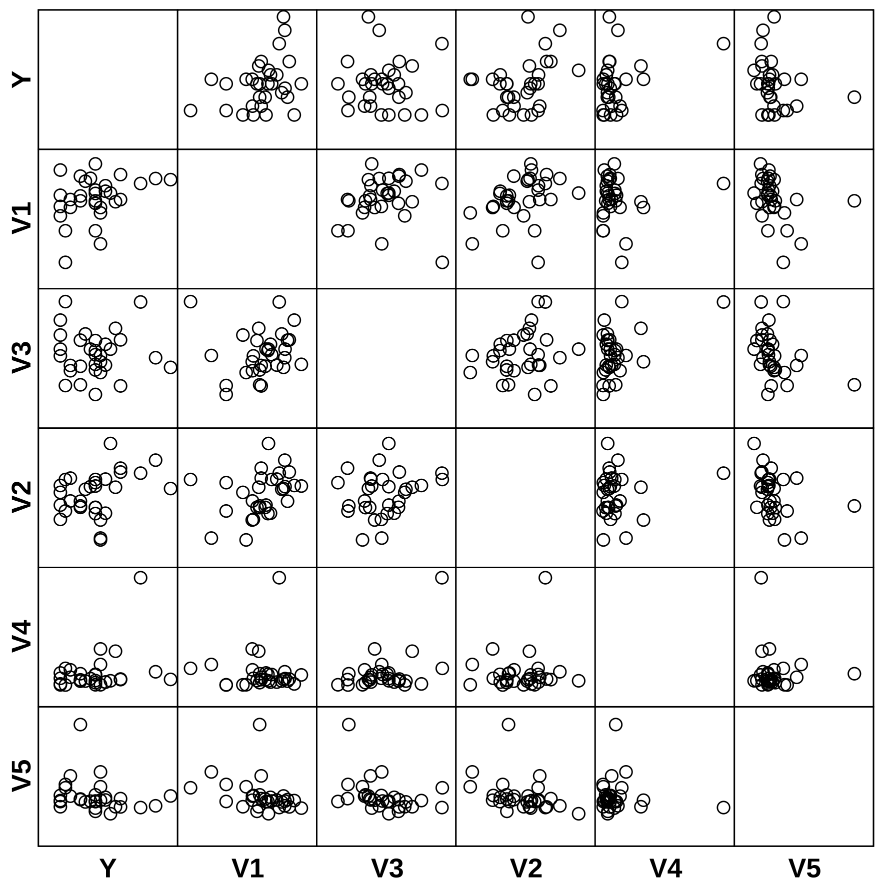

Figure 4-8: Matrix of Scatter Plot of Model Input Variables

Any regression model that is linear in parameters is a linear regression model, regardless of the function of the independent variables (Montgomery, 2006), so five different functions of each variable are tested to determine which function can present the best relationship of fuel consumption rate and the independent variables in order to develop the most appropriate regression model structure.

Tables 4-9 to 4-13 provide the R-square value and significance of the regression (p-value) for each independent variable V_1 to V_5 for five different functional forms of the regression model.

The hypothesis relates to the significance of the regression for each independent variable is

$H_0 : \beta_i = 0$

$H_1 : \beta_i \neq 0$

Where β_i is the coefficient of independent variable V_i in the supposed function (i.e. Linear, Inverse).

The failure to reject the null hypothesis ($\beta_i = 0$) is equivalent to concluding that the coefficient is zero and there is no relationship between the independent variable V_i and Y. Avoiding the failure of rejection null hypothesis; the least significance value (based on description in Table 4-3) for each equation in the tables is selected which is identified by an arrow.

Table 4-9: Examining Y as several functions of V_1

Equation	R Square	P-value
Linear	0.118	0.059
Inverse	0.082	0.118
Quadratic	0.122	0.163
Cubic	0.169	0.166
Power	0.111	0.067

Table 4-10: Examining Y as several functions of V_2

Equation	R Square	P-value
Linear	0.093	0.096
Inverse	0.001	0.885
Quadratic	0.044	0.201
Cubic	0.054	0.456
Power	0.024	0.409

Table 4-11: Examining Y as several functions of V_3

Equation	R Square	P-value
Linear	0.058	0.191
Inverse	0.013	0.543
Quadratic	0.079	0.316
Cubic	0.082	0.501
Power	0.027	0.381

Table 4-12: Examining Y as several functions of V_4

Equation	R Square	P-value
Linear	0.092	0.097
Inverse	0.100	0.083
Quadratic	0.092	0.258
Cubic	0.093	0.442
Power	0.092	0.098

Table 4-13: Examining Y as several functions of V_5

Equation	R Square	P-value
Linear	0.087	0.011
Inverse	0.055	0.020
Quadratic	0.090	0.265
Cubic	0.095	0.432
Power	0.077	0.131

Based on the significance of regression for each equation of independent variables, the linear function is the best function for variables V_1, V_2, V_3, and V_5. And the inverse function is the best for variable V_4.

As a first step, a regression model is considered including all 5 independent variables. The fitted regression model is presented in Equation 4-11.

$$Y = 0.621 + 0.007 \times V_1 + 0.006 \times V_2 - 0.022 \times V_3 - \frac{4.22}{V_4} - 0.001V_5 \tag{4-11}$$

The adequacy of the model is checked using three methods described in section 4.3.4.

The regression has a F_0 value of 1.69 (p-value=0.173) indicating that no significant linear relationship exists between *Y* and the independent variables. Also, examining of the residual indicated that data were not Normally distributed and did not have constant variances.

The resultant R^2 for the equation is equal to 0.253, indicating that the model accounts for only 25.3% of the variability in the data.

As a result of the three mentioned criteria, the regression model in equation 4-11 is not acceptable for explaining the observed fuel consumption rate variations. Moreover, the use of the other techniques (Stepwise, Forward, and Backward) of the linear regression development does not provide a better model.

The inability to develop a statistically significant regression models likely results from two sources.

1. Errors in the data (error measurements and an imprecise data collection process)
2. Lack of specificity in the independent variables

The relative contribution of these sources is not known.

4.4 Fuel Consumption Comparison for *iXpress* and Route Seven

The investigation in fuel consumption data for developing a linear regression model has not shown any significant change in the fuel consumption as a function of the number of bus stops/Km (i.e. variable V_1). However, one of the goals of developing the *iXpress* route in the region was to reduce energy consumption and associated GHG emissions.

In overall, the comparison of average fuel consumption rate for all local buses (0.62 L/Km) to the *iXpress* one (0.52 L/Km) shows that local buses consumed 10 L/Km more fuel. However, the different alignment of local routes and variety in bus characteristics which served on these routes a hinder a direct comparison between *iXpress* and local routes.
Between all local routes, Route 7 has the most similar route alignment to the *iXpress*, at least for the portion of the *iXpress* in Kitchener, Waterloo. Along this section of the route, most attributes such as travel demand, traffic conditions, number of signalized intersections, and number of unsignalized intersections are constant. The most noticeable difference between the route 7 and *iXpress* route is the number of bus stops.

This section presents a comparison of the fuel consumption rate for route *iXpress* and route 7, which is parallel to *ixpress* in the congested area of the city (Figure 4-9). The objective is to discern the impact that number of bus stops has on bus fuel consumption.

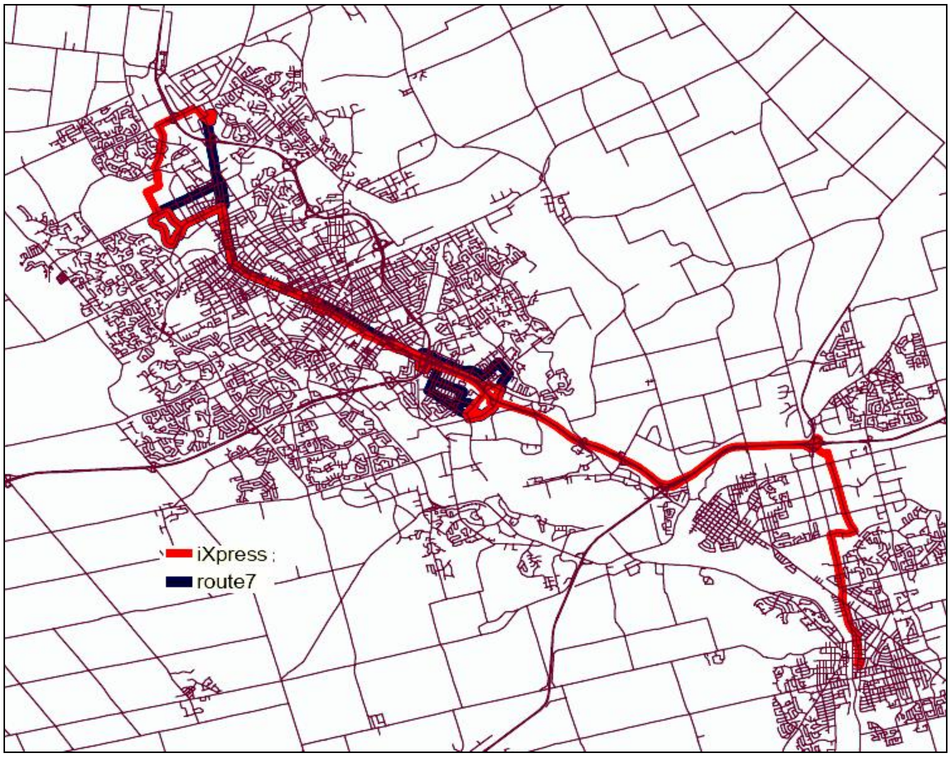

Figure 4-9: Route *iXpress* and 7 Paths in the RMOW

Table 4-14 summarizes the attributes of route 7 and the *iXpress*. Route 7 follows the same alignment as *iXpress* for approximately half of the *iXpress* route, but buses operating on route 7 consumed 14 liters/km more fuel. First, the significance of this difference is tested, and then the reasons for this difference are investigated.

Table 4-14: Route 7 and *iXpress* Attributes and Fuel Consumption Ratios (L/Km)

	No. Bus Stops	No. Signalized Intersections	No. Unsignalized Intersections	Route Length(Km)	Mean Fuel Consumption Rate	Median Fuel Consumption Rate	Standard Deviation
Route 7	123	214	92	32.52	0.68	0.68	0.083
iXpress	26	106	224	75.17	0.54	0.52	0.070

By using Equations 4-2 to 4-5, the two-tailed t-test is equal to 8.35, based on 80 degrees of freedom. The corresponding p-value for this t-test is $1.11*10^{-12} \sim 0$, indicating significant evidence against the null hypothesis that fuel consumption rate for route 7 and *iXpress* is equal. On average, buses on route 7 consume 21% more fuel per km travel than buses on the *iXpress* route. The *iXpress* route is served by all 2-year old buses; however route 7 is served by buses that range in age from 2 to 14 years old. Though the previous analysis indicated there has no evidence that bus age impacted bus fuel consumption rate, we compare the average fuel consumption rate of bus on *iXpress* route to buses aged 2-3 years old serving route 7. The comparison of the mean of fuel consumption for the buses in aged of 2-3 years old for route 7 (0.67 L/Km) with that of the route *iXpress* (0.54 L/Km), again shows the significance of higher fuel consumption ratio for route 7.

Several reasons can be identified to explore why buses on the *iXpress* route have a statistically significant lower fuel consumption rate than similarly aged buses serving route 7. first, there are fewer bus stops on the iXpress route alignment (7) versus the route 7 (51); second , in the south corridor, i*Xpress* buses travel on highways 8, and 401 on which the average speed and traffic demand is quite different than arterial streets. However, the relative contribution of these two reasons on *iXpress* fuel consumption saving can not be determined from the available data and both may have an important role.

4.5 Chapter Summary

In this chapter, the development of a multiple linear regression model of fuel consumption as a function of several routes and vehicle characteristics was described. The three methods to determine the adequacy of the model indicates the absence of any significant linear relationship between the fuel consumption rate and independent variables of route and bus characteristics.

However, the comparison of average fuel consumption rate for local routes and *iXpress*, shows that on average, buses serving the *iXpress* route consume 19% less fuel than buses serving local routes.

5. Impact of *iXpress* Service on GHG Emissions

The rise in transport's use of energy has primarily come from the increased use of the private car for personal transport, especially in North America (Potter, 2003). Therefore, there is a growing concern in the RMOW for improving the quality of the GRT service to transfer travel from private cars to public transport and reduce GHG emissions from private cars.

As described in section 3.6.3, the *iXpress* service provides an improved public transportation service with respect to improve convenience and reduced travel time, and therefore has attracted passengers who have switched to this service from auto-based modes.

This chapter presents the impact of the *iXpress* service on the reduction of GHG emissions in the RMOW area.

5.1 Emissions Estimation Methodology

The impact of the new *iXpress* service on GHG emissions arises from four different sources, namely;

1. The elimination of the emissions associated with auto trips that are no longer made, since the trip makers have switched to the *iXpress* route.
2. The elimination of emissions from route 101, since the *iXpress* service replaced the route.
3. The emissions created by new *iXpress* service.
4. The attraction of new passengers, who did not make trip previously, but now they have to make a trip and choose *iXpress* service instead of auto-vehicle.

The method for estimating the GHG impacts of these sources is described in the following sections.

5.1.1 Elimination of Emissions Associated with the Auto-Based Mode

The method for estimating the quantity of auto-based mode emissions eliminated as a result of a mode change is based on data obtained from the ridership survey conducted on February 15, 2006, described in section 3.5.

Of the 1146 returned survey questionnaires, 802 contain completed answers for the following 8 questions which are relevant for the purposes of estimating the impact of the *iXpress* on GHG emissions; therefore, only these responses constitute the survey sample that is used for quantity the GHG impact.

Question 4: On this bus, I am coming from a place which is located at:
Address:
OR
Closest Intersection:
OR
Postal Code:
Question 5: I got on this bus at: < *iXpress* stop name>
Question 6: I got to this bus by:

- Transfer from route…
- Walking
- Dropped off
- Bike
- Other

Question 7: I am getting off this bus at: <*iXpress* stop name>
Question 9: My final destination for this bus trip is located at….
Address:
OR
Closest Intersection:
OR
Postal Code:
Question 11: I will arrive at my final destination by:

- By transferring to route #
- Walking
- Being picked up
- Riding my bike
- Other

Question 12: I take this trip: times per week
Question 14: Before *iXpress*, how would you have made this trip?

- Local route#
- Passenger in car

- Drove car
- Bike
- Walk
- Taxi
- Other
- Did not make trip

For survey respondent *i*, the Origin (*O*) and Destination (*D*) postal codes reflect exact OD points where the trip was started and ended. The distance (d_i) from the origin postal code (O_i) to the destination postal code (D_i) is estimated for the auto-based modes (M_i) (where *M* is the mode of travel), including passengers in car, drove car, and took taxi.

From those data the total trip distance and associated GHG emission by autos is computed. In answer to question 14, which asked about the mode of travel prior to the availability of *iXpress* (M_i), a few respondents listed multiple modes. For these respondents, a fractional trip is assigned to each listed mode. For example, if a respondent listed “bus”, and “drove car” as the previous modes, 0.5 trips are allocated to each mode.

For all trips reported in the survey data base the number of automobile kilometers of travel that have been eliminated as a result of the trip maker taking transit (*iXpress*) is estimated. This is accomplished by estimating the trip length (from the reported trip origin and destination location) and then the multiplying by a factor. The value of this factor reflects the fraction of the trip length that is no longer made by personal auto. For all trips which the mode previously used was not auto-based (i.e. walk, bike, transit), the factor = 0 is used. For trips previously made by personal auto (either as a driver of personal auto or passenger of a taxi), a factor value of 1 is used. For trips previously made as a passenger in auto, the factor value ≤ 1 is used, to reflect these assumptions that some portion on the vehicle kilometer are still being made by the driver of the auto for some other purpose. There is no data from the intercept survey that permits direct empirical calibration of an appropriate value for the facts. Furthermore, no suitable values were discovered within the literatures. Consequently, the value used within this research is based on engineering judgment and not empirical evidence.

Some *iXpress* riders continue to use personal auto for a ratio of their trip by being dropped off or picked up at an *iXpress* station.

For people who were dropped off at the *iXpress* stations, the auto trip length was computed as the shortest path through the road network from the trip origin (O_i) to the *iXpress* station where the survey respondent embarked on a bus. For those who were picked up at the *iXpress* station, the auto distance computed as the shortest path distance from the *iXpress* station at which the passenger alighted from the bus to the destination (Di).

For example, consider respondent No. 412, which reflects a trip previously made by the traveler as a passenger in a personal auto (Figure 5-1). The traveler now made the trip using *iXpress* but was dropped off and picked up at the *iXpress* stations as illustrated in Figure 5-2. Therefore, traveler decides to switch mode (i.e. to use *iXpress*) has reduced auto use for only a fraction of the total trip length. In this case, the fraction is computed as $1-(\frac{1415+2116meter}{24412meter}) = 0.85$ of the total trip length.

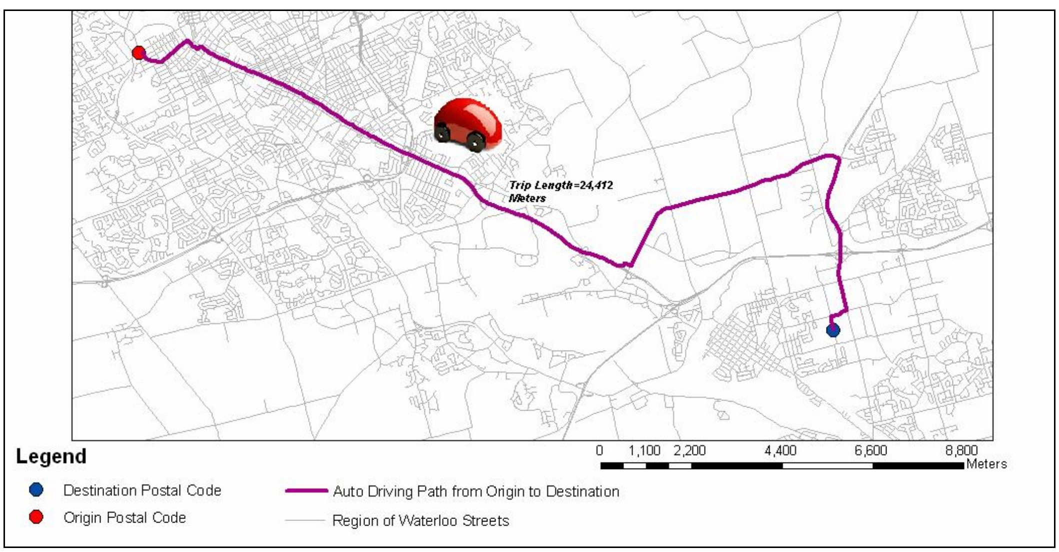

Figure 5-1: Estimated Auto Trip Path and Length for Trip Previously Made Using Auto (Survey No. 412)

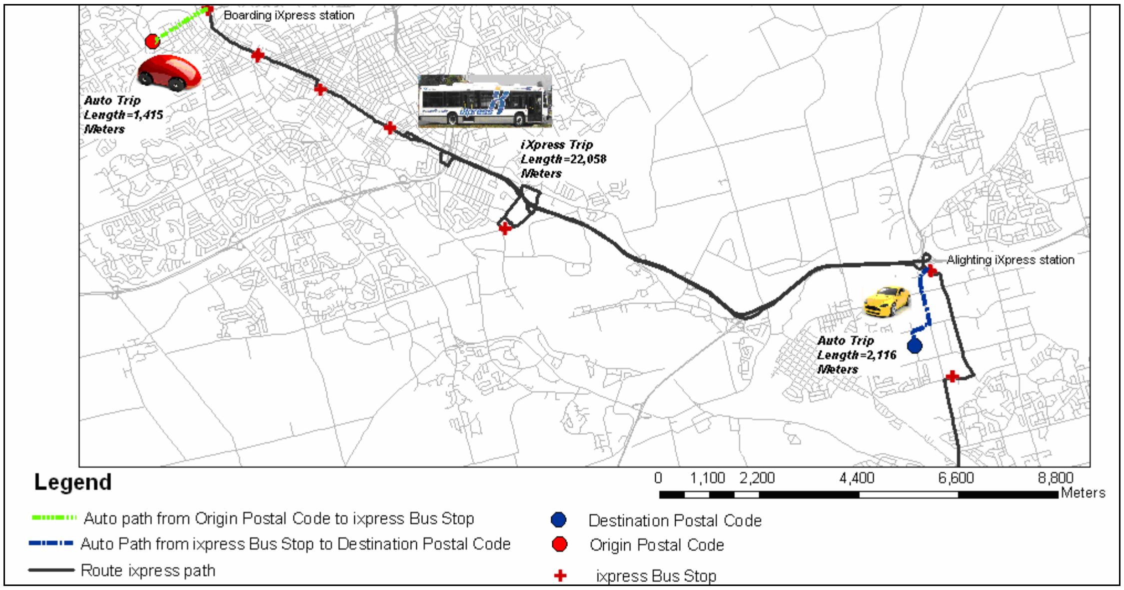

Figure 5-2: Auto Trip Length and *iXpress* Trip Length by using *iXpress* Service (Survey No. 412)

With the trip length (d_i), and the related factor for each respondent i who had used an auto-based mode previously, the average distance for each category is estimated, and the total distance is calculated as the product of the average trip distance and number of trips for each group of auto-based modes. Consequently, the annual fuel saving (in Litres) is calculated as the trip length $\times$ average fuel consumption rate $\times$ average trip frequency per week $\times$ number of weeks per year. With a constant conversion rate, the fuel is converted to the mass of GHG emissions saved (E).

Survey Responses **Calculations**

Respondent (i)	Origin (O_i)	Destination (D_i)	Mode M_i	Frequency (f_i)
1 2 3 . . N				

Trip Length (d_i)	Factor

Total Fuel	T
Total GHG	E

Figure 5-3: Emission Calculation Methodology for Auto-Based Modes

The trip length, frequency, and factor numbers of 102 respondents who had used auto-based modes previously are given in Appendix J, and Table 5-1 lists the average trip length and total distance for each group of auto-based modes previously used.

Table 5-1: Average Trip Length and Total Distance For each Group of Auto-Based Modes

Previous Mode	**Number of Respondents**	**Average Trip Length (km)**	**Total Distance (km) per day**
Passenger in car	31	14.65	454.15
Passenger in taxi	9	9.39	84.51
Driver of car	62	21.78	1350.4

5.1.2 The Elimination of Emissions Associated with Route 101

When the *iXpress* was implemented, an existing express route, route 101, was discontinued. Route 101 ran from Fairview Mall Terminal to the University of Waterloo, along a route of approximately 13 km. The service provided 20 runs per weekday in each direction for a total daily service distance of 528.4 km. The service ran during the school year for approximately 41 weeks. Thus, the total fuel consumption for a year is computed by multiplying the total annual distance traveled (151,650 km) by the bus fuel consumption rate, and finally the GHG emissions are computed by multiplying the annual fuel consumed by the bus GHG conversion constant rate.

5.1.3 Emissions Created by New *iXpress* Service

The *iXpress* service consists of 38 and 41 runs in the a.m. and p.m. periods respectively, and not all the runs are equal in length. However, the runs were combined for a total daily service distance of 2921.3 km. The *iXpress* service operates on week days only which results in 759,358 km (260×2921.3) annually. Then, by multiplying the annual distance of travel by the bus fuel consumption rate and GHG conversion constant rate, the annual GHG emissions by the *iXpress* service are calculated.

5.1.4 New Passengers, Who did not Make Trip, But now Make the Trip Using *iXpress*

From the ridership survey, it is interesting to note that 7.5% of the respondents had not previously taken the trip. Two possibilities can be identified to explain why these trips were not previously made (Hellinga et al, 2007).

1. These trips might be new because of a change in the trip makers' travel generation circumstances, such as a change in employment location, employment status, or a change in the place of residence.
2. The person might not have made the trip previously because the trip was not sufficiently attractive given the travel modes available to the trip-maker. However, after the *iXpress* was introduced, the trip time and/or costs were sufficiently reduced to make the trip attractive, representing an increase in a trip maker's mobility.

It is difficult to conclude what impact these trips have on GHG emissions. If it is assumed that these trips would have been made by some other mode, if the *iXpress* had not been available (i.e. assuming trips of category 1), then these trips should also be considered in the calculation of the GHG due to the *iXpress*; therefore, two estimates of the annual GHG reduction are provided. One of the estimates is obtained by ignoring the impact of the trips that were not made prior to the implementation of the *iXpress*. This estimate is likely conservative and underestimates the GHG reduction due to mode switching. The second GHG reduction estimate includes the impact of new trips.

The following describes the methodology for estimating the impact of new trips on GHG emissions.

In this analysis, it is assumed that the selection of the mode for the people who had not make the trip previously, would likely have follows the same distribution as that of other modes that respondents selected in question 14 (e.g., Local route #, Passenger in car, Walk, Taxi). This means that if these trips had been made; the total distance traveled by each available mode would have been in the same proportions as observed. The observed proportion of travel by mode can be determined by estimating the trip length for each trip reported in the survey. Trip length has been reported earlier in this thesis by a portion of all trips in the database (i.e. 102 trips for which the traveler previously used auto-based modes, Table 5-1). Due to the level of effort required to determine trip length for all other trips in the same manner, a more efficient, appropriate method was adopted as described below.

The trip length for each respondent is computed on the basis of the distance from the station, at which the trip maker boarded the *iXpress* to the station from which they disembarked the *iXpress*. It is recognized that this distance represents only a portion of the total trip, and likely under estimates the actual trip length. Consequently, a scaling factor was calibrated using the exact and appropriate trip length from the 102 passengers who used an auto-based mode previously.

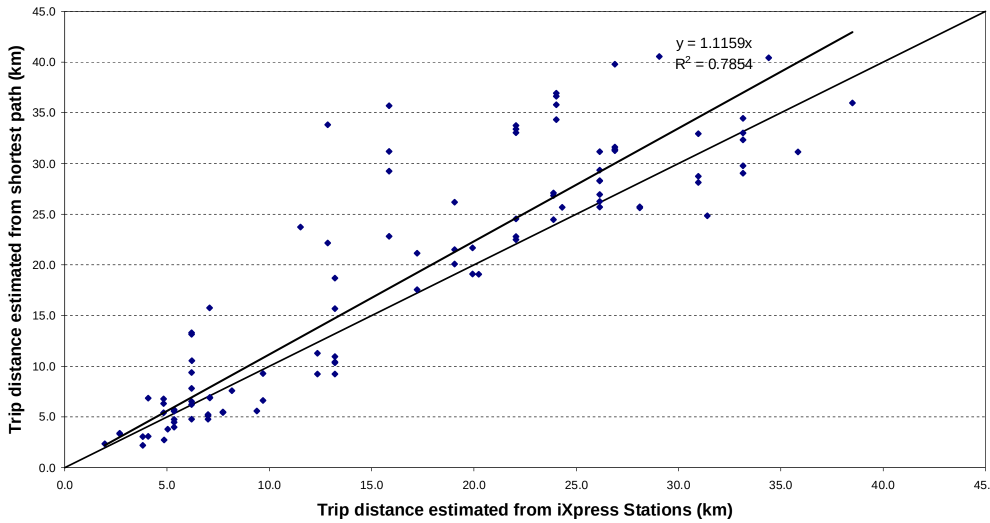

Figure 5-4: Linear Regression of Shortest Path Distance Estimation versus *iXpress* Stations Estimation

Figure 5-4 represents the proposal simple linear regression model between the distance estimated from the shortest path, and the distance estimated from *iXpress* stations, for 102 passengers who had used auto-based modes previously. The resultant R^2 or coefficient of determination, shows that 78% of the variation in the data is accounted for by equation Y=1.12 X where Y= trip distance estimated from shortest path and X= trip distance estimated from *iXpress* stations. The probability of more than 0.99 against the null hypothesis for the equation implies that the estimated coefficient in the equation is accurate enough to capture the data and confirms that the estimated distance from the *iXpress* stations is underestimated by the coefficient 1.12. Moreover, an examination of the residual plot in Figure 5-5 reveals that there is no specific pattern in the residuals (i.e. assumption that error is normally distributed with constant variances is not violated), implying that and the regression model is accurate enough.

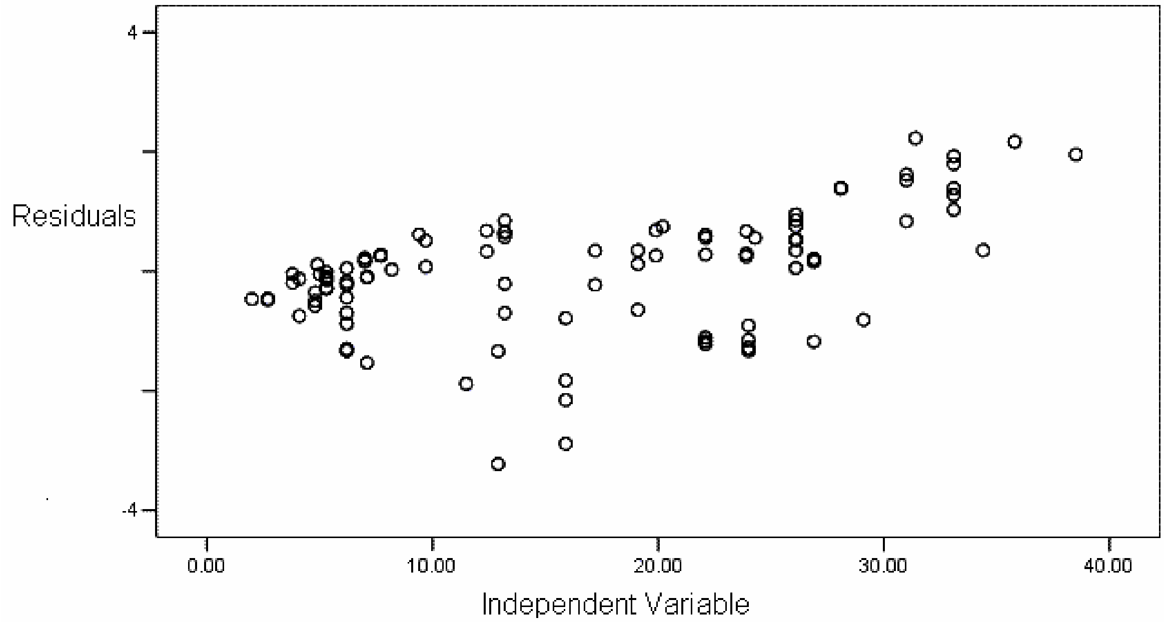

Figure 5-5: Residual Plot of Regression Linear Equation Y=1.12X

Then, the total daily station to station distance for the passengers who did not make their trip previously is 1091.5 km and by multiplying this by coefficient 1.12, the approximate actual distance for this group is 1222.48 km. However, this total distance must be allocated to the six categories of modes (answer of Question. 14 in survey questionnaire), and only the portion of this distance associated with auto-based modes is considered to have impact on the reduction of GHG emissions.

The allocation to each of the six modes is accomplished by first determining the distribution of station to station trip distances by previous mode for survey respondents who previously did make the trip. Table 5-2 provides the average *iXpress* station to station trip length by previous mode, used to make the trip. The total distance, associated with each mode, is computed as the product of the average trip length and the number of trips.

Table 5-2: Average *iXpress* Station to Station Trip Length by Previous Mode Taken

Mode previously Use to make Trip	Number of Trips/day	Average Trip Length (km)	Total Distance per day (km)	Percent of Total
Bus Route #	592	10.7	6334.4	76.2%
Passenger in Car	31	12.9	399.9	4.8%
Driver of Car	66	18.7	1234.2	14.85%
Bike	14	4.6	64.4	0.77%
Walk	26	3.3	85.8	1.03%
Taxi	9	10.0	90.0	1.08%
Other	5	19.9	99.5	1.1%
Total	Average trip length for *iXpress* riders 11.4		8308.2	

The proportion of the trip km associated with auto-based modes is, respectively, 4.8% (399.9 km/8308.2 km) for "Passenger in car", 14.8% for "Driver of car", and 1.08% for "Taxi" modes. Consequently, the addition vehicle kilometer eliminated by multiplying the estimated auto-based trip portion (e.g., 14.8% for the driver of the car) by the mode factor (e.g., 1 for driver of car), and then summed for all auto-based modes which is equal to $0.148\times1+0.011\times1+0.048\times0.92=0.21$ (Note that 0.92 is the average mode factor for a passenger in car from Appendix J).

Consequently, the total vehicle kilometer eliminated by the introduction of the *iXpress* for passengers, who did not make the reported trip previously, is 0.21×1222.48 km/day = 256.8 km/day.

5.2 GHG Calculation Results

This section presents the annual GHG emission reduction that the *iXpress* service brought about.

The following constants were used in the GHG emissions calculation.

- The average automobile fuel consumption rate is 0.11 L/ km (Canadian Vehicle Survey, 2001)
- The average *iXpress* bus fuel consumption rate is 0.54 L/km (as computed in chapter 4)

- The average fuel consumption for buses serving local routes rate is 0.62 L/km (as computed in chapter 4)
- The conversion of auto gasoline to the mass of GHG is 2, 503.86 tonnes/million litres of gasoline (Transport Canada, 2006)
- The conversion of diesel bus fuel to mass of the GHG is 2,763.81 tonnes/million litres of diesel fuel (Transport Canada, 2006)

The annual projections for reduced GHG emissions are carried out by computing an average of 3500 boardings per day (the average boarding recorded on the *iXpress* over 16 month period from the beginning of September 2005 to the end of December 2006 (Figure 3-5).Table 5-3 lists the annual GHG reduction due to mode switching. Column two, entitled "Distance (km)", is from Table 5-1. The column entitled "Fuel Consumed/day" is computed as the product of column 2 and the fuel consumption rate constant of 0.11 L/km, and the fourth column "CO_2/day" is computed as the product of column 3 and the auto GHG emissions conversion.

Table 5-3: Annual GHG Reductions due to Mode switching

Previous Mode	Distance (km)	Fuel Consumed/day (litres)	CO_2/day (tonnes)	Average # Trips/week	CO_2/year (tonnes)	
Passenger in car	454.15	49.95	0.125	3.5	22.81	22.81
Passenger in taxi	84.51	9.30	0.023	3.3	3.96	3.96
Driver of car	1350.4	148.54	0.371	4.1	79.31	79.31
Did not make trip	256.8	28.25	0.071	3.9	14.44	
	Total	236.04	0.590		**120.52**	**106.08**

Average daily boarding		3500
Survey Sample Size (# of inter-zonal trips)		794
Scale factor(=average daily boarding/survey sample size)		4.41
Annual CO_2 reduction(tonnes)	Ignoring impact of trips not previously made	467.81
	Considering impact of trips not previously made	531.49

The results from Table 5-3 indicate that the annual GHG reduction resulting from the mode shift, by considering the impact of new trips, is 531.49 tonnes, and by ignoring the impact of new trips is 467.81 tonnes.
Also, the GHG emissions created by the *iXpress* service is computed as the product of the annual distance of travel 759,358 Km, the *iXpress* fuel consumption rate is 0.54 L/km, and the HDD GHG conversion constant is 0.00276 tonnes/L. As a result, it is estimated that the *iXpress* service consumes 410,053 litres of diesel fuel annually, and produces 1,133 metric tonnes of CO_2 equivalent GHG per year.

In addition, the elimination of emissions from route 101 is calculated as the product of the annual distance of travel of 151,650 km; local bus fuel consumption rate of 0.62 L/km, and the same as *iXpress*, heavy duty GHG conversion constant, which results in a saving of 94,023 litres of diesel fuel annually, and 260 tonnes of CO_2 equivalent GHG per year.

The net impact of the *iXpress* in terms of GHG production is represented in Table 5-4. The net annualized impact of the *iXpress* service as of Feb.2006 is estimated as an overall increase in GHG emissions between 342 and 405 metric tonnes of CO_2 equivalent GHG.

It should be noted that, there are several other impacts which we have not been able quantity as part of this analysis. However, these impacts likely act to further reduce of GHG emission as follows :

1. Many *iXpress* riders have switched from local routes. This has fled up capacity on these local routes which may have induced additional mode change (i.e. switching from auto-based mode to local routes).
2. The reduction of personal auto use also reduces congestion on the local area road network which in turn reduces fuel consumption and GHG emissions for all vehicles on the network.

Table 5-4: Net Annualized GHG Reduction

	Total GHG (Tonnes)	
	New Trips Considered	**New Trips Ignored**
iXpress	-1133	-1133
Route101	260	260
Mode shift	531	468
Total	-342	-405

Gross annualized reduction in GHG emissions due to mode change is a function of the number of riders making use of *iXpress* service, and an increase in ridership will increase the GHG emission reductions. An increase of ridership on the *iXpress* over the next few years is predicted, as the more advanced technology components of the *iXpress* services are implemented. Figure 5-6 illustrates the change in annual GHG reductions due to auto mode switch as a function of the average number of daily boarding and Figure 5-7 illustrates the net annualized GHG emission for the RMOW.

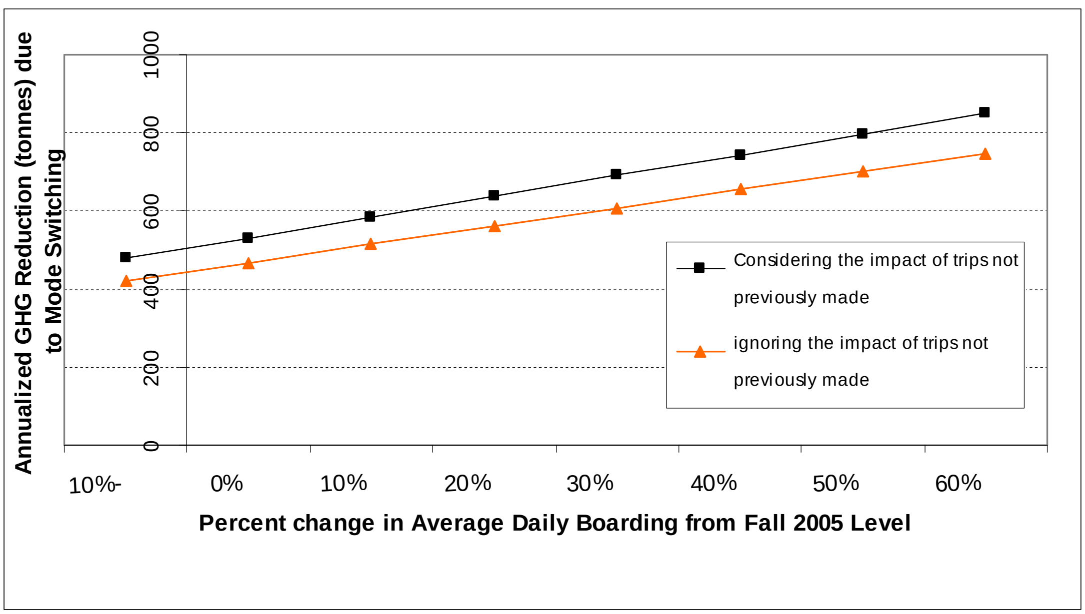

Figure 5-6: Estimate of Annualized Gross Reduction in GHG Emissions due to Auto Mode Shift to *iXpress*

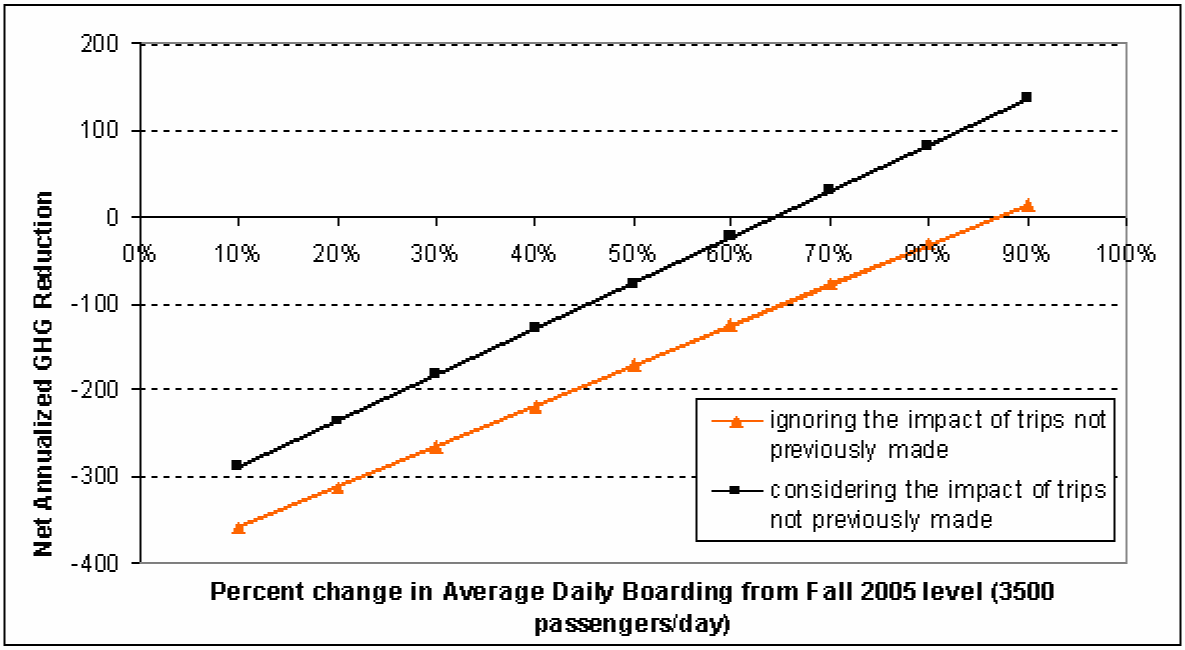

Figure 5-7: Estimate of Net Annualized Reduction in GHG emissions

As Figure 5-6 presents, a 50% increase in *iXpress* ridership, which will expected to be achieved within 2 years of initial service deployment, is expected to produce approximately 800 tonnes reduction in GHG emissions due to mode shift. And as Figure 5-7 presents, the net annualized value will be zero with approximately 60% increase in transit ridership (i.e. total ridership of 3500×1.6 +3500= 5200) with considering the impact of trips not previously made.

Another way to examine the influence of the *iXpress* service with respect to GHG emissions is to compare the GHG reduction of the *iXpress* service to private auto on a per passenger kilometer buses. This comparison (Table 5-5) shows that on average *iXpress* provides less than half the GHG emissions per passenger km as passengers auto.

Table 5-5 : Emissions Estimation per passenger-km for *iXpress* and Auto

Variables	Emissions per passenger-km for *iXpress*	Emissions per passenger-km for Auto
Average trip length for *iXpress* riders	11.4 (Table 5-2)	-
Average boarding per day	3500 (section 3.5)	-
***iXpress* bus distance per day (Km)**	2921 (section 5.1.3)	-
Auto-vehicle occupancy	-	1.1
fuel consumption rate (L/km)	0.54	0.11
Conversion of fuel to GHG (g/L)	2,763.81	2,503.86
Kg GHG-per passenger km	$\frac{2921 \times 0.54}{11.4 \times 3500} \times 2,763.81 = 0.11$	$\frac{1.1}{0.11} \times 2,503.86 = 0.25$

These results suggest that *iXpress* a much more environmentally efficient mode of travel than personal auto.

Furthermore, as ridership of *iXpress* continues to grow, the environmental efficiency of iXpress continues to improve.

5.3 Chapter Summary

In this chapter, the impact of the *iXpress* service on GHG emissions in the RMOW was described.

This impact was investigated using data collected from a transit ridership survey conducted in 2006. This analysis showed that almost 13% of the *iXpress* users had previously used an auto-based mode (either drove a car, were a passenger in car, or took a taxi), results in an annualized reduction of 468 tonnes of GHG emissions. By considering the increase of GHG emissions from the *iXpress* service and the reduction for route 101 which *iXpress* service has replaced, an overall increase in GHG emissions of 342 tonnes is predicted. However, the decrease in GHG emissions is the function of the *iXpress* transit ridership. The increase of the ridership to 60% (i.e. 5600 boardings/day) results the zero net annualized value. However, there are several other impacts which may reduce more GHG emissions but are not quantified in this analysis.

6.Conclusions and Future Work

This research has conducted a systematic study of the impact of the express transit service (*iXpress*) on travel behavior and resulted impact on emissions, fuel consumption. This chapter summarizes conclusions and recommendations achieved from the study.

6.1 Conclusions

Through the studying of *iXpress* service impact on passenger attraction, fuel consumption and GHG emission for RMOW, the following is found:

- Passenger Attraction
    1. The introduction of *iXpress* service resulted in a decrease of 31%, and 38% generalized cost by transit for northern and southern corridors.
    2. The examination of prior to iXpress ridership with expected and actual post iXpress ridership presents 19% and 62% of growth in ridership for northern and southern corridors.
    3. The change in cost and ridership permits the calculation of elasticity of demand to generalized cost which is -0.61 in the northern corridor and -1.61 in the southern corridor. This result suggests that ridership in the southern corridor is much more sensitive to the travel cost savings than are those traveling in the northern corridor.
    4. The iXpress service provides fewer bus stops, fewer transfers, and shorter travel times leading to an increase of 37% in ridership after one year of operation.
- Fuel Consumption
    1. We are unable to confirm statistically significant correlation between expected independent variables (e.g. age, floor type, number of bus stop) and fuel

consumption due to measurement errors and lack of specificity in independent variables.

2. The *iXpress* buses consume 21% less fuel per kilometer than route 7 buses which serve the parallel paths with the same traffic congestion conditions. This may indicate the direct impact of the reduction of bus stops from 51 to 7, along the path, on the energy consumption of the GRT buses.

- GHG Emissions
  1. The impact of *iXpress* service on reduction of GHG emission is estimated considering 4 sources, and determines that mode change of almost 13% of passengers who had previously used an auto-based mode (drove a car, were a passenger in a car, or took taxi), results in an annualized reduction of 467.81(ignoring the impact of trips not previously made) and 532 tonnes (considering the impact of trips not previously made) of GHG emissions.
  2. The increase of the ridership to 60% (i.e. 5600 boardings/day) will result in zero net annualized GHG emission in the region. However, there are several other impacts which may reduce more GHG emissions but are not quantified in this analysis.

6.2 Future Work and Suggestions

This research is limited in several aspects that require further research. The following recommendations have been suggested for future work.

- The RMOW has plans to improve the *iXpress* service by using several advanced technologies, including transit signal priority and automatic bus locating system. Due to fewer efforts devoted to modeling the HDD vehicles fuel consumption as a function of these improvements, it is recommended that efforts be made to develop the HDD fuel consumption model as a function of the reduction of in-vehicle travel time or idling duration at bus stops and intersections, or an increase of transit speed to show the impact of improvements of an Intelligent Transportation System (ITS).

- It is recommended to obtain more recent ridership survey data to model additional impacts of *iXpress* service on travelers in RMOW, considering larger travel behavioural decisions (e.g home location, car purchase decisions, etc).

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APPENDIX A

February 15, 2006 Transit Ridership Questionnaire

GRT
GRAND RIVER TRANSIT

Travel Survey

No: ☐

Complete this survey for a chance to win an iPod!

Name: ____________________

Address: ____ (##) ____________ (Street Name)

Postal Code: __________ Phone #: ______________

☐ Kitchener ☐ Waterloo ☐ Cambridge ☐ Other _______

1. **My age is:** ☐ 16 or less ☐ 17-25 ☐ 26-35 ☐ 36-55 ☐ 56-64 ☐ 65+
2. **My gender is:** ☐ Female ☐ Male
3. **On this bus trip I am coming from:**
   ☐ Home ☐ Work ☐ School ☐ Shopping ☐ Recreation ☐ Other
4. **Which is located at *(please fill out at least one of the categories below)*:**
   Address: ________ (##) ______________________ (Street Name)
   OR
   Closest Intersection: ______________ (Street Name) & ______________ (Street Name)
   OR
   Postal Code ____________
   ☐ Cambridge ☐ Kitchener ☐ Waterloo ☐ Other ________
5. **I got on this bus at:**
   ☐ Conestoga Mall ☐ U Waterloo ☐ Grand River Hospital ☐ Fairview ☐ Bridgecam ☐ McCormick ☐ Laurier ☐ Charles Terminal ☐ Cambridge Centre ☐ R & T Park ☐ Uptown Waterloo ☐ Ottawa ☐ Ainslie Terminal
6. **I got to this bus by:**
   ☐ transfer from Route # _____ ☐ walking ☐ dropped off ☐ bike ☐ other
7. **I am getting off this bus at:**
   ☐ Conestoga Mall ☐ U Waterloo ☐ Grand River Hospital ☐ Fairview ☐ Bridgecam ☐ McCormick ☐ Laurier ☐ Charles Terminal ☐ Cambridge Centre ☐ R & T Park ☐ Uptown Waterloo ☐ Ottawa ☐ Ainslie Terminal

Important! Please Fill Out Back of Form!

Travel Survey

8. **My FINAL destination for this bus trip is:**
   ☐ Home ☐ Work ☐ School ☐ Shopping ☐ Recreation ☐ Other
9. **Which is located at *(please fill out at least one of the categories below)*:**
   Address: ________ (##) ______________________ (Street Name)
   OR
   Closest Intersection: ______________ (Street Name) & ______________ (Street Name)
   OR
   Postal Code ____________
   ☐ Cambridge ☐ Kitchener ☐ Waterloo ☐ Other ________
10. **I will get to my FINAL destination:**
    ☐ on this bus ☐ by transferring to Route # _____
11. **I will arrive at my FINAL destination by:**
    ☐ walking ☐ being picked up ☐ riding my bike ☐ other
12. **I take this trip:**
    ☐ ________ days per week ☐ _______ days per month ☐ other
13. **Did you have a vehicle available to use for this trip?** ☐ Yes ☐ No
14. **Before iXpress, how would you have made this trip?**
    ☐ Bus (Route # ____) ☐ passenger in car ☐ drove car ☐ bike ☐ walk ☐ taxi ☐ other ☐ did not make trip
15. **How many vehicles are at your home?** ☐ 1 ☐ 2 ☐ 3 ☐ 4+

Thank you for completing this survey!

Collection Notice: Personal information requested on this form is collected under the authority of the Municipal Act and will be used to assist Region staff and Regional Committees regarding transit service. All information is confidential. **Region of Waterloo employees or their families are not eligible to win.**

APPENDIX B

Fuel Consumption Collected Data from Tuesday, 25 to Friday, 28 April, 2006

Date	Bus Number	A(Km)	B(Liter)	Fuel Consumption Ratio (B/A)	Route #	Run #
Tuesday, 25	8506	91	59	0.65	9	52
Tuesday, 25	8507	142	69	0.49	10	81
Tuesday, 25	8509	126	73	0.58	10	82
Tuesday, 25	9202	475	283.44	0.60	52	3
Tuesday, 25	9208	335	237	0.71	12	38
Tuesday, 25	9402	373	229	0.61	8	1
Tuesday, 25	9403	246	166	0.67	11	3
Tuesday, 25	9406	473	238	0.50	10	31
Tuesday, 25	9408	347	208	0.60	1	33
Tuesday, 25	9416	352	203	0.58	25	33
Tuesday, 25	9417	336	173	0.51	10	33
Tuesday, 25	9418	354	217	0.61	8	7
Tuesday, 25	9423	391	225.33	0.58	20	31
Tuesday, 25	2203	289	194	0.67	8	4
Tuesday, 25	2206	258	147	0.57	12	32
Tuesday, 25	2207	414	249	0.60	12	37
Tuesday, 25	2310	269	148	0.55	17	1
Tuesday, 25	2311	324	178.43	0.55	6	32
Tuesday, 25	2312	412	264	0.64	9	31
Tuesday, 25	2313	375	208	0.55	25	31
Tuesday, 25	2318	391	223	0.57	12	31
Tuesday, 25	2325	368	233	0.63	8	5
Tuesday, 25	2327	232	177	0.76	24	2
Tuesday, 25	2413	201	114	0.57	10	83
Tuesday, 25	2414	408	196	0.48	80	1
Tuesday, 25	2415	339	166	0.49	80	7
Tuesday, 25	2418	149	78	0.52	80	51
Tuesday, 25	2420	346	190	0.55	80	5
Tuesday, 25	2422	377	218	0.58	8	2
Tuesday, 25	2426	226	131	0.58	24	33
Tuesday, 25	2428	275	173	0.63	25	34
Tuesday, 25	2429	232	143	0.62	2	33
Tuesday, 25	9600	284	139	0.49	22	31
Tuesday, 25	9601	274	163	0.59	1	32
Tuesday, 25	9602	232	128	0.55	20	33
Tuesday, 25	9604	276	167	0.61	4	31
Tuesday, 25	9609	308	148	0.48	22	35

Date	Bus Number	A(Km)	B (Liter)	Fuel Consumption Ratio (B/A)	Route #	Run #
Tuesday, 25	9610	247	135	0.55	3	2
Tuesday, 25	9615	217	129	0.59	12	34
Tuesday, 25	9617	267	145	0.54	80	3
Tuesday, 25	9618	260	148	0.57	1	31
Tuesday, 25	9619	284	178	0.63	8	6
Tuesday, 25	9622	232	136	0.59	2	32
Tuesday, 25	2301	269	181.5	0.67	54	31
Tuesday, 25	2303	279	210.2	0.75	58	32
Tuesday, 25	2305	199	119.2	0.60	56	81
Tuesday, 25	2309	276	200	0.72	55	33
Tuesday, 25	2401	260	138.8	0.53	51	31
Tuesday, 25	2402	228	146.8	0.64	51	34
Tuesday, 25	2403	220	107.1	0.49	51	31
Tuesday, 25	2405	350	175.4	0.50	54	32
Tuesday, 25	2407	216	129	0.60	80	23
Tuesday, 25	2410	236	136.1	0.58	80	21
Tuesday, 25	8319	118	70.4	0.60	61	1
Tuesday, 25	8519	276	138.9	0.50	53	32
Tuesday, 25	8521	246	156.3	0.64	68	31
Tuesday, 25	8525	271	170.6	0.63	68	32
Tuesday, 25	8526	264	134.1	0.51	53	31
Tuesday, 25	8529	349	189.2	0.54	66	31
Tuesday, 25	8532	190	142.8	0.75	51	35
Tuesday, 25	8533	296	196	0.66	55	32
Tuesday, 25	8535	205	138.2	0.67	56	33
Tuesday, 25	9204	167	143.78	0.86	7	15
Tuesday, 25	9400	401	211	0.53	7	3
Tuesday, 25	9404	110	71	0.65	7	58
Tuesday, 25	9405	346	242	0.70	7	11
Tuesday, 25	2316	356	222	0.62	7	7
Tuesday, 25	2317	231	180	0.78	7	31
Tuesday, 25	2326	265	161	0.61	7	8
Tuesday, 25	2423	206	141	0.68	7	14
Tuesday, 25	2430	210	147	0.70	7	9
Tuesday, 25	9616	224	127	0.57	7	6
Tuesday, 25	9620	211	133	0.63	7	12
Wednesday, 26	8907	222	149	0.67	10	32
Wednesday, 26	8908	265	175	0.66	5	32
Wednesday, 26	8913	349	183	0.52	10	33
Wednesday, 26	9002	247	163	0.66	13	1
Wednesday, 26	9202	227	153	0.67	20	34
Wednesday, 26	9204	351	265	0.75	8	1

Date	Bus Number	A(Km)	B (Liter)	Fuel Consumption Ratio (B/A)	Route #	Run #
Wednesday, 26	9208	229	182	0.79	11	3
Wednesday, 26	9400	446	231	0.52	8	7
Wednesday, 26	9401	270	176	0.65	11	1
Wednesday, 26	9402	356	213.64	0.60	22	36
Wednesday, 26	9406	372	242	0.65	8	5
Wednesday, 26	9407	418	245	0.59	12	35
Wednesday, 26	9408	197	121	0.61	25	33
Wednesday, 26	9409	372	221	0.59	8	2
Wednesday, 26	9412	344	243	0.71	3	1
Wednesday, 26	9417	222	150	0.68	2	33
Wednesday, 26	9421	280	162	0.58	6	31
Wednesday, 26	2203	481	273	0.57	52	3
Wednesday, 26	2207	226	158	0.70	24	33
Wednesday, 26	2310	257	150	0.58	12	32
Wednesday, 26	2312	269	170	0.63	17	1
Wednesday, 26	2318	479	274	0.57	10	31
Wednesday, 26	2327	366	239.47	0.65	22	35
Wednesday, 26	2411	148	72	0.49	80	51
Wednesday, 26	2412	343	178	0.52	80	7
Wednesday, 26	2413	148	82	0.55	80	53
Wednesday, 26	2414	334	177	0.53	80	5
Wednesday, 26	2419	412	214	0.52	80	3
Wednesday, 26	2420	119	66	0.55	80	52
Wednesday, 26	2422	418	254	0.61	12	37
Wednesday, 26	2423	438	255	0.58	9	32
Wednesday, 26	2424	160	110	0.69	24	1
Wednesday, 26	2425	356	238	0.67	1	33
Wednesday, 26	2426	381	232	0.61	25	31
Wednesday, 26	2429	391	231	0.59	12	31
Wednesday, 26	2430	391	222	0.57	11	2
Wednesday, 26	9600	260	134	0.52	1	31
Wednesday, 26	9601	232	144	0.62	2	32
Wednesday, 26	9604	278	175	0.63	3	2
Wednesday, 26	9605	271	159	0.59	24	2
Wednesday, 26	9607	206	114	0.55	12	34
Wednesday, 26	9609	277	136	0.49	22	34
Wednesday, 26	9610	274	133	0.49	22	32
Wednesday, 26	9615	286	149	0.52	4	31
Wednesday, 26	9617	288	192	0.67	8	6
Wednesday, 26	9620	249	171.5	0.69	20	33
Wednesday, 26	9622	260	148	0.57	18	31
Wednesday, 26	2300	229	153.5	0.67	51	34

Date	Bus Number	A(Km)	B (Liter)	Fuel Consumption Ratio (B/A)	Route #	Run #
Wednesday, 26	2301	276	181.5	0.66	56	33
Wednesday, 26	2302	351	234.1	0.67	51	31
Wednesday, 26	2304	629	383.8	0.61	58	32
Wednesday, 26	2308	434	260.9	0.60	54	32
Wednesday, 26	2309	325	223.4	0.69	56	32
Wednesday, 26	2400	599	376.4	0.63	51	35
Wednesday, 26	2402	349	255.3	0.73	55	32
Wednesday, 26	2406	375	224.4	0.60	80	22
Wednesday, 26	2409	177	108.9	0.62	80	24
Wednesday, 26	2410	202	100.5	0.50	80	23
Wednesday, 26	8319	87	58.2	0.67	67	1
Wednesday, 26	8522	274	164	0.60	53	32
Wednesday, 26	8525	264	161.3	0.61	68	31
Wednesday, 26	8526	264	140.6	0.53	53	31
Wednesday, 26	8527	343	177.9	0.52	66	31
Wednesday, 26	8529	262	118.2	0.45	68	32
Wednesday, 26	8533	79	58.3	0.74	56	81
Wednesday, 26	8535	260	181.6	0.70	54	31
Wednesday, 26	9207	335	215	0.64	7	5
Wednesday, 26	9423	313	206	0.66	7	13
Wednesday, 26	2314	342	258	0.75	7	11
Wednesday, 26	2317	232	189	0.81	7	31
Wednesday, 26	2326	206	166	0.81	7	9
Wednesday, 26	2329	335	239	0.71	7	3
Wednesday, 26	9603	225	130	0.58	7	6
Wednesday, 26	9619	195	164	0.84	7	15
Thursday, 27	8912	95	63	0.66	12	82
Thursday, 27	8913	102	61	0.60	9	4
Thursday, 27	9002	248	158	0.64	13	1
Thursday, 27	9003	301	165	0.55	5	32
Thursday, 27	9010	237	148	0.62	10	32
Thursday, 27	9202	226	159	0.70	20	33
Thursday, 27	9204	400	279	0.70	12	37
Thursday, 27	9207	224	168	0.75	2	33
Thursday, 27	9212	202	134.05	0.66	10	83
Thursday, 27	9406	429	235.06	0.55	8	7
Thursday, 27	9408	382	214	0.56	12	31
Thursday, 27	9410	486	235	0.48	52	3
Thursday, 27	9413	275	133	0.48	22	34
Thursday, 27	9417	409	221	0.54	9	31
Thursday, 27	9418	468	248	0.53	10	31
Thursday, 27	9421	417	210	0.50	12	38

Date	Bus Number	A(Km)	B (Liter)	Fuel Consumption Ratio (B/A)	Route #	Run #
Thursday, 27	9422	287	173	0.60	8	4
Thursday, 27	2201	248	183	0.74	11	3
Thursday, 27	2202	346	242	0.70	11	1
Thursday, 27	2203	329	235.5	0.72	8	5
Thursday, 27	2204	414	244.24	0.59	5	1
Thursday, 27	2206	360	212	0.59	22	35
Thursday, 27	2314	215	132	0.61	12	9
Thursday, 27	2318	124	89	0.72	19	1
Thursday, 27	2319	229	139	0.61	8	2
Thursday, 27	2322	384	227	0.59	25	31
Thursday, 27	2325	400	260	0.65	3	1
Thursday, 27	2411	116	60	0.52	80	4
Thursday, 27	2412	106	49	0.46	80	6
Thursday, 27	2413	147	74	0.50	80	51
Thursday, 27	2414	340	165	0.49	80	7
Thursday, 27	2415	408	202	0.50	80	3
Thursday, 27	2417	152	81	0.53	80	53
Thursday, 27	2418	411	211	0.51	80	1
Thursday, 27	2419	120	57	0.48	80	52
Thursday, 27	2421	357	211	0.59	80	5
Thursday, 27	2423	350	237	0.68	1	33
Thursday, 27	2424	382	256	0.67	20	31
Thursday, 27	2426	360	213	0.59	25	33
Thursday, 27	2427	372	228	0.61	20	32
Thursday, 27	2432	407	265.71	0.65	8	1
Thursday, 27	2433	263	145	0.55	12	32
Thursday, 27	9600	249	133	0.53	1	32
Thursday, 27	9601	303	159	0.52	2	32
Thursday, 27	9603	282	136	0.48	22	31
Thursday, 27	9607	287	155	0.54	4	31
Thursday, 27	9609	234	139	0.59	24	2
Thursday, 27	9615	281	185	0.66	8	6
Thursday, 27	9616	280	147	0.53	3	2
Thursday, 27	9617	147	105	0.71	12	81
Thursday, 27	9618	276	138	0.50	22	32
Thursday, 27	9619	74	57	0.77	11	51
Thursday, 27	9620	260	144	0.55	1	31
Thursday, 27	9621	259	127	0.49	18	31
Thursday, 27	9622	214	138	0.64	12	34
Thursday, 27	2300	354	231.5	0.65	51	31
Thursday, 27	2303	407	299.2	0.74	55	31
Thursday, 27	2309	212	157.4	0.74	56	32

Date	Bus Number	A(Km)	B (Liter)	Fuel Consumption Ratio (B/A)	Route #	Run #
Thursday, 27	2400	347	219.6	0.63	55	32
Thursday, 27	2403	545	374.7	0.69	51	35
Thursday, 27	2404	729	419.2	0.58	55	33
Thursday, 27	2406	378	176.8	0.47	80	22
Thursday, 27	2407	215	143.4	0.67	80	21
Thursday, 27	2408	169	129.1	0.76	80	24
Thursday, 27	2409	243	106.2	0.44	80	23
Thursday, 27	8319	73	36.2	0.50	67	1
Thursday, 27	8521	322	219.7	0.68	66	31
Thursday, 27	8522	262	141.1	0.54	68	31
Thursday, 27	8525	190	105.7	0.56	68	32
Thursday, 27	8526	264	133.6	0.51	53	31
Thursday, 27	8529	277	134.1	0.48	53	32
Thursday, 27	8530	499	336.6	0.67	56	33
Thursday, 27	9208	191	160	0.84	7	14
Thursday, 27	9401	316	200	0.63	7	13
Thursday, 27	9402	211	143	0.68	7	8
Thursday, 27	9405	206	165	0.80	7	9
Thursday, 27	9412	346	233	0.67	7	11
Thursday, 27	2310	199	117	0.59	7	4
Thursday, 27	2312	232	173	0.75	7	31
Thursday, 27	2313	341	228	0.67	7	3
Thursday, 27	2326	318	221	0.69	7	5
Thursday, 27	9602	207	147	0.71	7	15
Thursday, 27	9605	211	148	0.70	7	12
Thursday, 27	9610	223	130	0.58	7	6
Friday, 28	8909	127	64	0.50	13	1
Friday, 28	8910	128	74	0.58	9	33
Friday, 28	8911	258	164	0.64	10	32
Friday, 28	8913	248	121	0.49	5	32
Friday, 28	8914	268	142	0.53	10	33
Friday, 28	9202	298	194	0.65	9	31
Friday, 28	9204	228	174	0.76	11	3
Friday, 28	9209	375	238	0.63	12	31
Friday, 28	9212	356	281	0.79	8	7
Friday, 28	9403	376	192	0.51	25	31
Friday, 28	9405	436	256	0.59	9	32
Friday, 28	9409	417	198	0.47	5	1
Friday, 28	9410	250	170	0.68	25	33
Friday, 28	9417	409	225	0.55	12	37
Friday, 28	9421	481	242	0.50	3	1
Friday, 28	9422	264	171	0.65	24	33

Date	Bus Number	A(Km)	B (Liter)	Fuel Consumption Ratio (B/A)	Route #	Run #
Friday, 28	2203	250	153	0.61	4	31
Friday, 28	2204	217	137	0.63	12	81
Friday, 28	2206	367	240	0.65	8	1
Friday, 28	2207	352	233	0.66	11	1
Friday, 28	2311	293	193	0.66	8	4
Friday, 28	2316	260	162	0.62	12	32
Friday, 28	2318	186	121	0.65	11	51
Friday, 28	2321	374	239	0.64	8	5
Friday, 28	2322	357	243	0.68	1	33
Friday, 28	2325	350	225	0.64	12	38
Friday, 28	2326	381	241	0.63	20	31
Friday, 28	2411	412	211	0.51	80	1
Friday, 28	2413	340	183	0.54	80	5
Friday, 28	2414	110	59	0.54	80	6
Friday, 28	2415	340	168	0.49	80	7
Friday, 28	2416	407	204	0.50	80	3
Friday, 28	2417	148	77	0.52	80	51
Friday, 28	2418	118	64	0.54	80	4
Friday, 28	2419	119	70	0.59	80	52
Friday, 28	2421	372	252	0.68	8	2
Friday, 28	2423	269	163	0.61	17	1
Friday, 28	2427	326	201	0.62	6	32
Friday, 28	2428	490	270	0.55	52	3
Friday, 28	2432	99	70	0.71	12	85
Friday, 28	9602	250	142	0.57	1	32
Friday, 28	9603	244	142	0.58	12	34
Friday, 28	9604	283	201	0.71	8	6
Friday, 28	9605	279	159	0.57	22	31
Friday, 28	9607	238	143	0.60	2	32
Friday, 28	9610	261	148	0.57	1	31
Friday, 28	9614	231	144	0.62	24	2
Friday, 28	9615	162	100	0.62	3	2
Friday, 28	9618	97	63	0.65	12	83
Friday, 28	9621	236	141	0.60	20	33
Friday, 28	2301	375	184.9	0.49	55	33
Friday, 28	2308	268	173	0.65	54	32
Friday, 28	2401	721	396.7	0.55	56	33
Friday, 28	2402	344	165.8	0.48	51	33
Friday, 28	2403	271	165.5	0.61	58	32
Friday, 28	2404	218	141.2	0.65	51	34
Friday, 28	2405	461	272.3	0.59	51	32
Friday, 28	2406	85	63.9	0.75	80	24

Date	Bus Number	A(Km)	B (Liter)	Fuel Consumption Ratio (B/A)	Route #	Run #
Friday, 28	2407	90	57.2	0.64	80	62
Friday, 28	2408	234	115.4	0.49	80	23
Friday, 28	2409	371	235.2	0.63	80	22
Friday, 28	2410	219	110.6	0.51	80	21
Friday, 28	8317	113	75.6	0.67	67	1
Friday, 28	8319	89	43.8	0.49	61	1
Friday, 28	8519	263	125.6	0.48	68	31
Friday, 28	8522	271	165.4	0.61	53	32
Friday, 28	8526	276	179.5	0.65	66	31
Friday, 28	8530	180	122.9	0.68	51	35
Friday, 28	8533	345	227.9	0.66	55	32
Friday, 28	9207	336	261	0.78	7	3
Friday, 28	9416	221	138	0.62	7	2
Friday, 28	9418	341	214	0.63	7	11
Friday, 28	2312	337	254	0.75	7	7
Friday, 28	2328	182	127	0.70	7	5
Friday, 28	2426	349	221	0.63	7	8
Friday, 28	2433	236	157	0.67	7	31
Friday, 28	9600	218	131	0.60	7	12
Friday, 28	9609	224	127	0.57	7	6
Friday, 28	9616	209	133	0.64	7	14
Friday, 28	9620	210	148	0.70	7	15

Legend:

A: Length of Travel (km)

B: Consumed Fuel (Liter)

APPENDIX C

Number of Bus Stops to Route length Ratios

Route No	A	B	A/B	Description
l	59	14.72	4.01	Two route alignments including ; 17.57 km length (72 bus stops) and 11.87 km (46 Stops)
2	53	15.42	3.43	Two route alignments including ; 16.124 km length for peak time and 14.73 km length for off-peak time
3	70	21.01	3.33	
4	73	17.75	4.11	
5	109	35.56	3.06	Three different paths including; -Erb West:13.94 Km(51 stops) - Lancaster:7.49Km(28stops) -Eastbridge:28.71km(PM only-57 stops)and 28.72km (AM only-57 stops) Buses serve on two different alignment ; one go along Erb west and Lancaster 20.98 Km (79 bus stops) the other go along Er bwet, Lancaster and East bridge 50.14Km (139 bus stops)
6	59	15.2	3.88	
7	123	32.52	3.78	Route 7 is served on 3 alignments of 6 branches with common part from University Avenue to Dixie street in south. Each alignment contains of following bus stops and intersections; - 7F,7D 13.98 km- 130 bus stops - 7A,7E 12.87 km- 118 bus stops - 7B,7C 21.94 km-122 bus stops
8	92	31.04	2.96	One butterfly loop - 30.93(Evening time), 31.16(other time)
9	74	21.28	3.48	
10	61	20.32	3.00	Two route alignments; 17.18 Km length (54 bus stops) and 23.47 Km length (Evening service-68 Stops) and there is Expressway for peak time in the morning and afternoon without any stops.
11	75	18.73	4	
12	166	60.66	2.7	
13	36	12.03	3	
14	57	22.3	2.56	Two connected loops with one in one way direction.
15	56	14.07	3.98	
16	61	21.97	2.77	Two route alignments for AM , PM and Midnight ; Conestogacollage:19.94 Km length (AM-PM, 57stops), Forest Glen: 24 Km(Mid day- 65 stops)
17	42	14.55	2.89	

Route No	A	B	A/B	Description
18	56	12.79	4.38	
19	58	18.54	3.13	
20	42	12.53	3.35	Two different alignments for Peak and Off-peak period ;9.61Km(38 stops-peaks), 15.46 Km(45 stops-off peaks)
21	6	7.08	1.18	
22	112	34.47	3.25	
23	75	22.86	3.28	Two route alignments ; 28.61 Km(peak-93 stops), 17.11Km(off-peak- 56 stops),
24	74	17.67	4.18	
25	85	18.25	4.66	
26	35	10.83	3.23	
27	27	8.31	3.25	
51	40	37.40	1.07	
52	100	36.77	2.71	
53	68	24.68	2.75	
54	39	10.60	3.68	Closed loop in one direction.
55	31	10.54	3.06	Path with a small loop in one direction(3.73 Km- 13 stops) and connected line in two directions (6.81Km- 18 Stops)
56	44	11.15	3.95	Closed loop in one direction.
57	29	10.88	2.66	Closed loop in one direction
58	35	10.85	3.22	Closed loop in one direction.
59	38	10.96	3.47	Closed loop in one direction.
60	27	10.59	2.55	Loop in one direction with connected small link
61	23	13.85	1.66	
62	31	9.97	3.11	One small loop with connected link
63	37	10.04	3.68	Closed loop in one direction.
64	40	11.46	3.49	Closed loop in one direction.
65	29	10.56	2.75	One small loop with connected link
66	25	8.72	2.87	One loop with connected link
67	29	11.76	2.46	Closed loop in one direction.
68	24	10.3	2.33	
71	25	9.52	2.62	One loop with connected link
72-75				Mobility Bus Plus services, ignore them from evaluating because of the difference in kind of vehicle.
iXpress (80)	26	75.17	0.35	Express bus with low bus stops along the route

Legend:

A: Number of bus stops in two-way path

B: Two-way route length (Km)

APPENDIX D

Route 5 Path and Time Schedule

Transit Fares

You may pay your transit fare by:

- **Cash**
- **Ticket**
- **Monthly Pass**
- **Day Pass**
- **Sunday/Holiday Family Pass**

Children under 5 ride for free

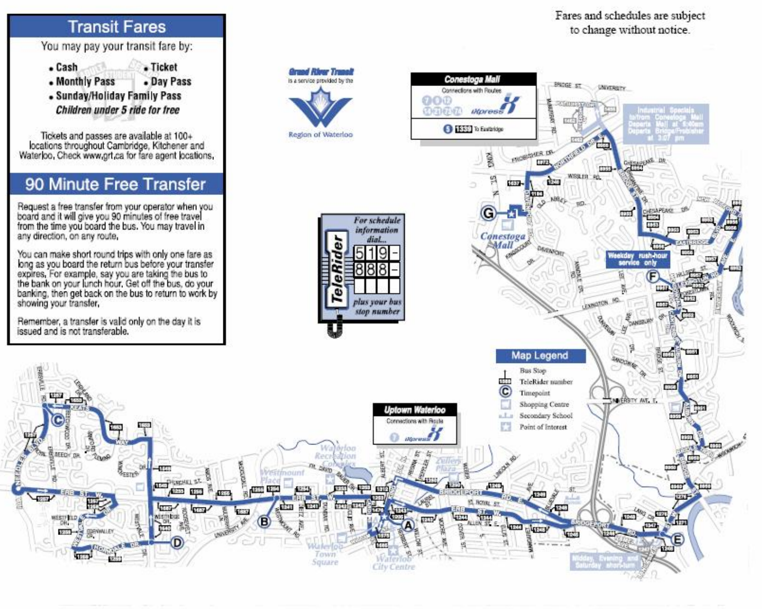
Tickets and passes are available at 100+ locations throughout Cambridge, Kitchener and Waterloo, Check www,grt,ca for fare agent locations,

90 Minute Free Transfer

Request a free transfer from your operator when you board and it will give you 90 minutes of free travel from the time you board the bus. You may travel in any direction, on any route,

You can make short round trips with only one fare as long as you board the return bus before your transfer expires, For example, say you are taking the bus to the bank on your lunch hour, Get off the bus, do your banking, then get back on the bus to return to work by showing your transfer,

Remember, a transfer is valid only on the day it is issued and is not transferable.



MONDAY to FRIDAY SERVICE

TO: Erb West → TO: Uptown

	KING at WATERLOO SQUARE - Depart (A)	ERB at WESTMOUNT (B)	KEATS WAY at ERBSVILLE (C)	THORNDALE at FISCHER-HALLMAN (D)	ERB at WESTMOUNT (B)	KING at WILLIS WAY Arrive (A)	
AM			5:49	5:58	6:04	6:09	
AM	6:20	6:25	6:32	6:41	6:47	6:52	
AM	6:45	6:50	6:58	7:07	7:13	7:19	●
AM	7:15	7:20	7:28	7:37	7:43	7:49	
AM	7:45	7:50	7:58	8:07	8:13	8:19	
AM	8:15	8:20	8:28	8:37	8:43	8:49	
AM	8:45	8:50	8:58	9:07	9:13	9:19	
AM	9:15	9:20	9:28	9:37	9:43	9:49	
AM	9:40	9:45	9:53	10:02	10:08	10:13	
AM	10:10	10:15	10:23	10:32	10:38	10:43	
AM	10:40	10:45	10:53	11:02	11:08	11:13	
AM	11:10	11:15	11:23	11:32	11:38	11:43	
AM	11:40	11:45	11:53	12:02	12:08	12:13	
PM	12:10	12:15	12:23	12:32	12:38	12:43	
PM	12:40	12:45	12:53	1:02	1:08	1:13	
PM	1:10	1:15	1:23	1:32	1:38	1:43	
PM	1:40	1:45	1:54	2:03	2:09	2:14	
PM	2:15	2:20	2:29	2:40	2:46	2:52	
PM	2:55	3:00	3:09	3:20	3:26	3:32	
PM	3:20	3:25	3:34	3:45	3:51	3:57	
PM	3:50	3:55	4:04	4:15	4:21	4:27	●
PM	4:20	4:25	4:34	4:45	4:51	4:57	
PM	4:50	4:55	5:04	5:15	5:21	5:27	
PM	5:20	5:25	5:34	5:45	5:51	5:57	
PM	5:50	5:55	6:04	6:15	6:21	6:27	●
PM	6:20	6:25	6:33	6:42	6:48	6:53	
PM	6:45	6:50	6:58	7:07	bus to garage		
PM	7:15	7:20	7:28	7:37	7:43	7:48	
PM	8:15	8:20	8:28	8:37	8:43	8:48	
PM	9:15	9:20	9:28	9:37	9:43	9:48	
PM	10:15	10:20	10:28	10:37	10:43	10:48	
PM	11:15	11:20	11:28	11:37	11:43	11:48	
PM	11:50	11:54	12:02	12:10			

● Low floor buses are not available for marked trips

TO: Lancaster/Eastbridge → TO: Uptown

	KING at WILLIS WAY Depart (A)	BRIDGEPORT at LANCASTER (E)	LEXINGTON at MEADOWVALE (F)	CONESTOGA MALL Arrive (G)	CONESTOGA MALL Depart (G)	LEXINGTON at MEADOWVALE (F)	BRIDGEPORT at LANCASTER (E)	KING at WATERLOO SQUARE - Arrive (A)	Map Reference
AM							6:07	6:15	
AM					6:10	6:23	6:33	6:42	●
AM	6:10	6:17	6:25	6:38	6:40	6:55	7:05	7:14	
AM					7:10	7:23	7:33	7:42	
AM	6:52	7:01	7:11	7:24	7:35	7:48	7:59	8:12	
AM	7:20	7:28	7:37	7:50 ●	8:10	8:23	8:33	8:42	
AM	7:50	7:58	8:07	8:20	8:40	8:53	9:03	9:12	
AM	8:20	8:28	8:37	8:50	bus to garage				
AM	8:50	8:58	9:07	9:20	bus to garage				
AM	9:20	9:29	—	—	—	—	9:30	9:40	
AM	9:50	9:59	—	—	—	—	10:00	10:10	
AM	10:15	10:24	—	—	—	—	10:25	10:35	
AM	10:45	10:54	—	—	—	—	10:55	11:05	
AM	11:15	11:24	—	Short-turn via		—	11:25	11:35	
AM	11:45	11:54	—	Lancaster and		—	11:55	12:05	
PM	12:15	12:24	—	Hamel		—	12:25	12:35	
PM	12:45	12:54	—	—	—	—	12:55	1:05	
PM	1:15	1:24	—	—	—	—	1:25	1:35	
PM	1:45	1:54	—	—	—	—	1:55	2:05	
PM	2:25	2:34	—	—	—	—	2:35	2:45	
PM					2:40	2:53	3:03	3:13	
PM					3:15	3:28	3:38	3:48	●
PM	3:05	3:15	3:25	3:39	3:45	3:58	4:08	4:18	
PM	3:35	3:45	3:54	4:07	4:15	4:28	4:38	4:48	
PM	4:00	4:10	4:20	4:34	4:45	4:58	5:08	5:18	
PM	4:30	4:40	4:50	5:04 ●	5:15	5:28	5:37	5:46	●
PM	5:00	5:10	5:20	5:34	5:45	5:58	6:07	6:17	
PM	5:30	5:40	5:50	6:04	6:10	6:23	6:32	6:41	
PM	6:00	6:08	6:17	6:30	Rt. 7 Downtown				
PM	6:55	7:03	—	—	—	—	7:03	7:12	
PM	7:55	8:03	—	Short-turn via		—	8:03	8:12	
PM	8:55	9:03	—	Lancaster and		—	9:03	9:12	
PM	9:55	10:03	—	Hamel		—	10:03	10:12	
PM	10:55	11:03	—	—	—	—	11:03	11:12	

SATURDAY SERVICE

TO: Erb West → TO: Uptown

	KING at WATERLOO SQUARE - Depart (A)	ERB at WESTMOUNT (B)	KEATS WAY at ERBSVILLE (C)	THORNDALE at FISCHER-HALLMAN (D)	ERB at WESTMOUNT (B)	KING at WILLIS WAY Arrive (A)
AM			6:28	6:36	6:42	6:48
AM	7:10	7:15	7:23	7:32	7:38	7:44
AM	8:10	8:15	8:23	8:32	8:38	8:44
AM	9:10	9:15	9:23	9:32	9:38	9:44
AM			★9:49	10:02	10:08	10:14
AM	10:10	10:15	10:23	10:32	10:38	10:44
AM	10:40	10:45	10:53	11:02	11:08	11:14
AM	11:10	11:15	11:23	11:32	11:38	11:44
AM	11:40	11:45	11:53	12:02	12:08	12:14
PM	12:10	12:15	12:23	12:32	12:38	12:44
PM	12:40	12:45	12:53	1:02	1:08	1:14
PM	1:10	1:15	1:23	1:32	1:38	1:44
PM	1:40	1:45	1:53	2:02	2:08	2:14
PM	2:10	2:15	2:23	2:32	2:38	2:44
PM	2:40	2:45	2:53	3:02	3:08	3:14
PM	3:10	3:15	3:23	3:32	3:38	3:44
PM	3:40	3:45	3:53	4:02	4:08	4:14
PM	4:10	4:15	4:23	4:32	4:38	4:44
PM	4:40	4:45	4:53	5:02	5:08	5:14
PM	5:10	5:15	5:23	5:32	5:38	5:44
PM	5:40	5:45	5:53	6:02	6:08	6:14
PM	6:10	6:15	6:23	6:32	6:38	6:43
PM	7:15	7:20	7:28	7:37	7:43	7:48
PM	8:15	8:20	8:28	8:37	8:43	8:48
PM	9:15	9:20	9:28	9:37	9:43	9:48
PM	10:15	10:20	10:28	10:37	10:43	10:48
PM	11:15	11:20	11:28	11:37	11:43	11:48
PM	11:50	11:54	12:02	12:10		

TO: Lancaster → TO: Uptown

	KING at WILLIS WAY Depart (A)	BRIDGEPORT at LANCASTER (E)	KING at WATERLOO SQUARE - Arrive (A)	Map Reference
AM	6:50	7:00	7:09	
AM	7:45	7:56	8:05	
AM	8:45	8:56	9:05	
AM	9:45	9:57	10:06	
AM	10:15	10:27	10:36	
AM	10:45	10:57	11:06	
AM	11:15	11:27	11:36	
AM	11:45	11:57	12:06	
PM	12:15	12:27	12:36	
PM	12:45	12:57	1:06	
PM	1:15	1:27	1:36	
PM	1:45	1:57	2:06	
PM	2:15	2:27	2:36	
PM	2:45	2:57	3:06	
PM	3:15	3:27	3:36	
PM	3:45	3:57	4:06	
PM	4:15	4:27	4:36	
PM	4:45	4:57	5:06	
PM	5:15	5:27	5:36	
PM	5:45	5:57	6:06	
PM	bus to garage			
PM	6:55	7:03	7:12	
PM	7:55	8:03	8:12	
PM	8:55	9:03	9:12	
PM	9:55	10:03	10:12	
PM	10:55	11:03	11:12	

★ Trip starts at Fischer-Hallman & Erb

Note: Weather conditions, construction, accidents etc. may cause schedule delays.

How to use this schedule...

Read across for times from beginning to end of route and down for time at a specific bus stop. Bus stop location on map corresponds with circled letter found under bus stop name.

APPENDIX E

Route 13 Path and Time Schedule

MONDAY TO FRIDAY SERVICE

TIMEPOINT:	U of W at Seagram Depart (A)	COLUMBIA at FISCHER-HALLMAN (B)	ERBSVILLE at LAURELWOOD (C)	FISCHER-HALLMAN at COLUMBIA (B)	U of W at Seagram Arrive (A)	Map Reference
AM		5:55	6:00	6:05	6:12	
	6:20	6:28	6:34	6:39	6:46	
	6:50	6:58	7:04	7:09	7:16	
	7:20	7:28	7:34	7:39	7:46	★
	7:50	7:58	8:04	8:09	8:16	
	8:20	8:28	8:34	8:39	8:46	
	8:50	8:58	9:04	9:09	9:16	
	9:20	9:28	9:34	9:39	9:46	
	9:50	9:58	10:04	10:09	10:16	
	10:20	10:28	10:34	10:39	10:46	
	10:50	10:58	11:04	11:09	11:16	
	11:20	11:28	11:34	11:39	11:46	
	11:50	11:58	12:04	12:09	12:16	
	12:20	12:28	12:38	12:42	12:49	
PM	12:50	12:58	1:04	1:09	1:16	
	1:20	1:28	1:34	1:39	1:46	
	2:00	2:08	2:14	2:19	2:26	
	2:30	2:38	2:44	2:49	2:56	
	2:57	3:05	3:13	3:18	3:25	
	3:30	3:40	3:46	3:51	3:58	
	4:00	4:10	4:16	4:21	4:28	
	4:30	4:40	4:46	4:51	4:58	
	5:00	5:10	5:16	5:21	5:28	
	5:30	5:40	5:46	5:51	5:58	
	6:00	6:08	6:13	6:18	6:25	
	6:30	6:38	6:43	6:48	6:55	
	7:05	7:13	7:18	7:23	7:30	
	7:35	7:43	7:48	7:53	8:00	
	8:05	8:13	8:18	8:23	8:30	
	8:35	8:43	8:48	8:53	9:00	
	9:05	9:13	9:18	9:23	9:30	
	9:35	9:43	9:48	9:53	10:00	
	10:05	10:13	10:18	10:23	10:30	

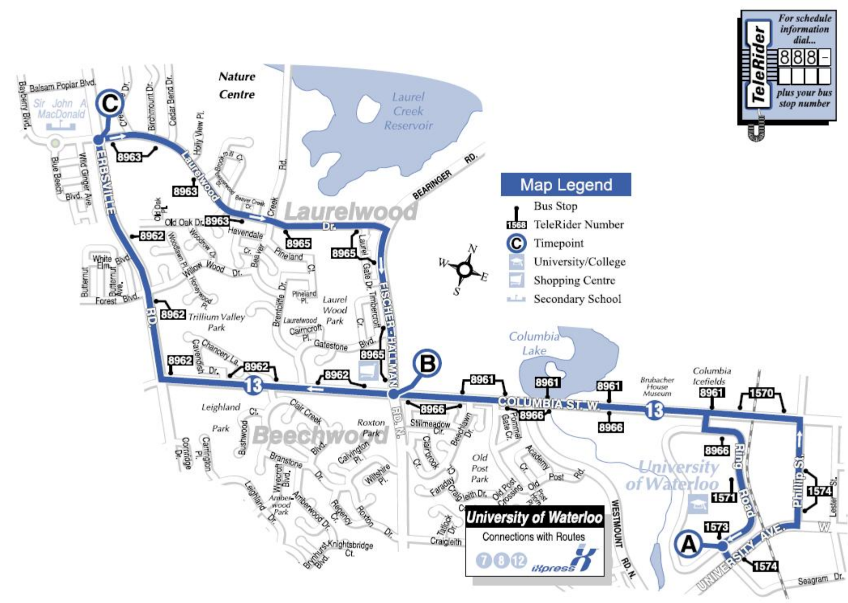
SATURDAY SERVICE

TIMEPOINT:	U of W at Seagram Depart (A)	COLUMBIA at FISCHER-HALLMAN (B)	ERBSVILLE at LAURELWOOD (C)	FISCHER-HALLMAN at COLUMBIA (B)	U of W at Seagram Arrive (A)	Map Reference
AM		8:10	8:15	8:20	8:27	
	8:30	8:38	8:44	8:49	8:56	
	9:00	9:08	9:14	9:19	9:26	
	9:30	9:38	9:44	9:49	9:56	
	10:00	10:08	10:14	10:19	10:26	
	10:30	10:38	10:44	10:49	10:56	
	11:00	11:08	11:14	11:19	11:26	
	11:30	11:38	11:44	11:49	11:56	
PM	12:00	12:08	12:14	12:19	12:26	
	12:30	12:38	12:44	12:49	12:56	
	1:00	1:08	1:14	1:19	1:26	
	1:30	1:38	1:44	1:49	1:56	
	2:00	2:08	2:14	2:19	2:26	
	2:30	2:38	2:44	2:49	2:56	
	3:00	3:08	3:14	3:19	3:26	
	3:30	3:38	3:44	3:49	3:56	
	4:00	4:08	4:14	4:19	4:26	
	4:30	4:38	4:44	4:49	4:56	
	5:00	5:08	5:14	5:19	5:26	
	5:30	5:38	5:44	5:49	5:56	
	6:00	6:08	6:13	6:18	6:25	

★ This trip continues to Conestoga Mall via University and King from September to June

Grand River Transit is a service provided by the Region of Waterloo

How to use this schedule...
Read across for times from beginning to end of route. Read down for time at a specific bus stop. Bus stop location on map corresponds with circled letter found under bus stop name.



APPENDIX F

Number of Signalized and Unsignalized to Route Length Ratios

Route No	A	B	C	A/C	B/C	Description
1	79	23	14.72	5.36	1.56	Two route alignments, shorter one (11.72 km) includes 21 signalized intersections and 63 unsignalized intersections. Longer one (17.57 km) includes 25 signalized intersections and 95 unsignalized intersections
2	46	26	15.42	2.98	1.69	
3	62	32	21.01	2.95	1.52	
4	72	32	17.75	4.06	1.80	
5	218	40	35.56	6.13	1.12	Two route alignments ; - longer line includes 45 Signalized,125 unsignalized intersections and shorter one includes 35 Signalized and 93 un-signalized intersections
6	78	30	15.2	5.13	1.97	
7	92	214	32.52	2.83	6.58	The average number of intersections for three alignments are considered as index of intersections ratio for route 7
8	330	132	62.08	5.31	2.12	72 signalized intersection for upper loop and 60 signalized intersections for lower loop(Overall 132 signalized intersections in two way trip)
9	128	30	21.28	6.01	1.41	
10	74	12	20.32	3.64	0.60	
11	145	25	18.73	7.74	1.33	
12	144	74	60.66	2.37	1.22	
13	42	12	12.03	3.49	1	
14	50	20	22.3	2.24	0.90	
15	90	31	14.07	6.39	2.20	
16	51	9	21.97	2.32	0.41	
17	51	26	14.55	3.51	1.79	
18	70	30	12.79	5.47	2.34	
19	58	52	18.54	3.13	2.80	
20	76	42	12.53	6.06	3.35	38 signals-72 unsignal (Peak time), 46 signals, 80 unsignal (off-peak time)
21	9	8	7.08	1.27	1.13	
22	128	54	34.47	3.71	1.56	
23	140	38	22.86	6.12	1.66	30 signalized, 100 Unsignalized (off-peak time), 46 signalized and 180 Unsignalized (peak time)
24	118	32	17.67	6.68	1.81	
25	99	21	18.25	5.42	1.15	
26	22	5	10.83	2.03	0.46	
27	24	9	8.31	2.89	1.08	

Route No	A	B	C	A/C	B/C	Description
51	28	52	37.40	0.75	1.39	
52	150	36	36.77	4.08	0.98	
53	60	34	24.68	2.43	1.38	
54	64	12	10.60	6.04	1.13	
55	74	6	10.54	7.02	0.57	
56	58	12	11.15	5.20	1.07	
57	46	3	10.88	4.23	0.27	
58	38	12	10.85	3.50	1.10	
59	55	10	10.96	5.01	0.91	
60	36	9	10.59	3.40	0.85	
61	44	8	13.85	318	0.58	
62	60	4	9.97	6.01	0.40	
63	34	11	10.04	3.38	1.09	
64	61	11	11.46	5.32	0.96	
65	46	2	10.56	4.36	0.19	
66	50	3	8.72	5.73	0.34	
67	7	11	11.76	0.59	0.93	
68	50	20	10.3	4.85	1.94	
71	41	3	9.52	4.31	0.31	
iXpress (80)	224	106	75.17	2.98	1.41	

Legend:

A: Number of unsignalized intersections in two-way path

B: Number of signalized intersections in two-way path

C: Two-way route length (Km)

APPENDIX G

GRT Routes Daily Ridership for April, Tuesday 25 to Friday 28, 2006

Route No	Daily Ridership(Persons)			
	Tuesday	Wednesday	Thursday	Friday
1	323	858	883	543
2	181	412	415	340
3	473	1496	1045	1103
4	232	828	373	231
5	804	893	727	645
6	219	493	451	549
7	7967	11605	9767	9442
8	3475	3218	1657	4065
9	554	1233	1225	1043
10	1012	1536	869	938
11	1344	1393	1300	1015
12	3781	3662	2335	3456
13	492	75	276	301
14	139	376	248	216
15	272	268	560	310
16	293	569	537	373
17	678	142	618	423
18	95	321	172	112
19	265	66	294	332
20	404	508	394	494
22	817	1397	1268	1133
23	263	736	624	578
24	650	713	734	330
25	514	1668	919	819
26	21	299	127	281
27	340	309	230	338
51	1780	1885	2055	1932
52	1326	1083	1372	1962
53	842	728	473	666
54	339	305	337	356
55	566	410	394	881
56	491	410	733	681
57	89	92	132	96
58	534	350	600	643
59	217	343	286	183
60	485	464	276	374
61	90	84	55	67
62	125	196	109	102
63	360	517	396	188
64	270	313	152	200
65	285	218	148	320
66	15	153	175	40
67	126	114	85	79
68	150	81	74	56
71	133	211	180	131
iXpress (80)	1471	1849	1350	1610

APPENDIX H

GRT's Bus Attributes

Vehicle Number	Model	Year	Vehicle Style
8504	Classic	1985	High Floor
8505	Classic	1985	High Floor
8506	Classic	1985	High Floor
8507	Classic	1985	High Floor
8509	Classic	1985	High Floor
8510	Classic	1985	High Floor
8801	Classic	1987	High Floor
8802	Classic	1987	High Floor
8803	Classic	1987	High Floor
8804	Classic	1987	High Floor
8805	Classic	1987	High Floor
8806	Classic	1987	High Floor
8901	Orion V	1989	High Floor
8902	Orion V	1989	High Floor
8903	Orion V	1989	High Floor
8904	Orion V	1989	High Floor
8905	Orion V	1989	High Floor
8906	Orion V	1989	High Floor
8907	Orion V	1989	High Floor
8908	Orion V	1989	High Floor
8909	Orion V	1989	High Floor
8910	Orion V	1989	High Floor
8911	Orion V	1989	High Floor
8912	Orion V	1989	High Floor
8913	Orion V	1989	High Floor
8914	Orion V	1989	High Floor
9001	Orion V	1990	High Floor
9002	Orion V	1990	High Floor
9003	Orion V	1990	High Floor
9004	Orion V	1990	High Floor
9005	Orion V	1990	High Floor
9006	Orion V	1990	High Floor
9007	Orion V	1990	High Floor
9008	Orion V	1990	High Floor
9009	Orion V	1990	High Floor
9010	Orion V	1990	High Floor
9011	Orion V	1990	High Floor
9012	Orion V	1990	High Floor
9013	Orion V	1990	High Floor
9200	D40LF	1992	Low Floor
9201	D40LF	1992	Low Floor
9202	D40LF	1992	Low Floor
9203	D40LF	1992	Low Floor
9204	D40LF	1992	Low Floor
9205	D40LF	1992	Low Floor
9206	D40LF	1992	Low Floor
9207	D40LF	1992	Low Floor
9208	D40LF	1992	Low Floor

Vehicle Number	Model	Year	Vehicle Style
9209	D40LF	1992	Low Floor
9210	D40LF	1992	Low Floor
9211	D40LF	1992	Low Floor
9212	D40LF	1992	Low Floor
9213	D40LF	1992	Low Floor
9400	D40LF	1994	Low Floor
9401	D40LF	1994	Low Floor
9402	D40LF	1994	Low Floor
9403	D40LF	1994	Low Floor
9404	D40LF	1994	Low Floor
9405	D40LF	1994	Low Floor
9406	D40LF	1994	Low Floor
9407	D40LF	1994	Low Floor
9408	D40LF	1994	Low Floor
9409	D40LF	1994	Low Floor
9410	D40LF	1994	Low Floor
9411	D40LF	1994	Low Floor
9412	D40LF	1994	Low Floor
9413	D40LF	1994	Low Floor
9414	D40LF	1994	Low Floor
9415	D40LF	1994	Low Floor
9416	D40LF	1994	Low Floor
9417	D40LF	1994	Low Floor
9418	D40LF	1994	Low Floor
9419	D40LF	1994	Low Floor
9420	D40LF	1994	Low Floor
9421	D40LF	1994	Low Floor
9422	D40LF	1994	Low Floor
9423	D40LF	1994	Low Floor
9424	D40LF	1994	Low Floor
9600	C40LF	1996	Low Floor
9601	C40LF	1996	Low Floor
9602	C40LF	1996	Low Floor
9603	C40LF	1996	Low Floor
9604	C40LF	1996	Low Floor
9605	C40LF	1996	Low Floor
9606	C40LF	1996	Low Floor
9607	C40LF	1996	Low Floor
9608	C40LF	1996	Low Floor
9609	C40LF	1996	Low Floor
9610	C40LF	1996	Low Floor
9611	C40LF	1996	Low Floor
9612	C40LF	1996	Low Floor
9613	C40LF	1996	Low Floor
9614	C40LF	1996	Low Floor
9615	C40LF	1996	Low Floor
9616	C40LF	1996	Low Floor
9617	C40LF	1996	Low Floor
9618	C40LF	1996	Low Floor
9619	C40LF	1996	Low Floor
9620	C40LF	1996	Low Floor
9621	C40LF	1996	Low Floor

Vehicle Number	Model	Year	Vehicle Style
9622	C40LF	1996	Low Floor
2200	D40LF	2002	Low Floor
2201	D40LF	2002	Low Floor
2202	D40LF	2002	Low Floor
2203	D40LF	2002	Low Floor
2204	D40LF	2002	Low Floor
2205	D40LF	2002	Low Floor
2206	D40LF	2002	Low Floor
2207	D40LF	2002	Low Floor
2310	Orion VII	2003	Low Floor
2311	Orion VII	2003	Low Floor
2312	Orion VII	2003	Low Floor
2313	Orion VII	2003	Low Floor
2314	Orion VII	2003	Low Floor
2315	Orion VII	2003	Low Floor
2316	Orion VII	2003	Low Floor
2317	Orion VII	2003	Low Floor
2318	Orion VII	2003	Low Floor
2319	Orion VII	2003	Low Floor
2320	Orion VII	2003	Low Floor
2321	Orion VII	2003	Low Floor
2322	Orion VII	2003	Low Floor
2323	Orion VII	2003	Low Floor
2324	Orion VII	2003	Low Floor
2325	Orion VII	2003	Low Floor
2326	Orion VII	2003	Low Floor
2327	Orion VII	2003	Low Floor
2328	Orion VII	2003	Low Floor
2329	Orion VII	2003	Low Floor
2406	LFS	2004	Low Floor
2407	LFS	2004	Low Floor
2408	LFS	2004	Low Floor
2409	LFS	2004	Low Floor
2410	LFS	2004	Low Floor
2411	LFS	2004	Low Floor
2412	LFS	2004	Low Floor
2413	LFS	2004	Low Floor
2414	LFS	2004	Low Floor
2415	LFS	2004	Low Floor
2416	LFS	2004	Low Floor

APPENDIX I

Routes Average Speed

Route Number	Two-way length(Km)	Total Travel time –Peak time(Min)	Total Travel Time-off peak time (min)	Route Speed(Km/h)
l	14.72	39	38	22.94
2	15.42	37	37	25.01
3	21.01	56	55	22.72
4	17.75	48	42	23.77
5	35.56	65	53	36.54
6	15.2	40	41	22.52
7	32.52	101	99	19.51
8	31.04	95	92	19.92
9	21.28	56	55	23.01
10	20.32	19	19	64.17
11	18.73	55	55	20.43
12	60.66	155	155	23.48
13	12.03	26	29	26.33
17	14.55	50	50	17.46
18	12.79	33	33	23.25
20	12.53	38	60	16.16
22	34.47	91	91	22.73
24	17.67	52	55	19.83
25	18.25	57	57	19.21
51	37.4	58	58	38.69
52	36.77	86	86	25.65
53	24.68	57	57	25.98
54	10.6	27	27	23.56
55	10.54	26	26	24.32
56	11.15	26	26	25.73
58	10.85	27	27	24.11
61	13.85	26	26	31.96
66	8.72	23	23	22.75
67	11.76	23	23	30.68
68	10.3	31	31	19.94
iXpress	75.17	150	149	30.17

APPENDIX J

Trip Length, Frequency of Travel, and Factor Number for Passengers who Used Auto-Based Modes Previously

ID	Respondent	Mode	Frequency	Trip Length	Factor
1	7	drove car	3	31.395	1
2	24	drove car	5	26.174	1
3	32	drove car	5	35.79	1
4	101	passenger in car	4	28.125	1
5	113	passenger in car	1	8.1	0.89
6	117	drove car	5	6.533	1
7	119	passenger in car	5	9.391	1
8	303	drove car	5	5.463	1
9	317	drove car	5	22.487	1
10	319	drove car	5	34.334	1
11	401	passenger in car	4	10.546	1
12	409	drove car	5	22.789	1
13	411	passenger in car	5	21.498	1
14	412	passenger in car	5	24.527	0.85
15	423	passenger in car	5	31.197	0.82
16	426	passenger in car	5	21.135	0.75
17	427	passenger in car	5	33.827	0.5
18	446	passenger in car	5	5.557	1
19	470	passenger in car	0	3.086	1
20	485	taxi	7	6.233	1
21	505	passenger in car	3	3.336	1
22	518	drove car	4	31.615	1
23	546	drove car	5	36.921	1
24	562	passenger in car	1	4.482	1
25	567	drove car	3	2.726	1
26	571	drove car	4	2.209	1
27	580	drove car	5	3.064	1
28	588	passenger in car	7	5.583	1
29	596	drove car	3	23.718	1
30	621	drove car	5	11.278	1

ID	Respondent	Mode	Frequency	Trip Length	Factor
31	622	drove car	5	9.239	1
32	654	drove car	2	33.006	1
33	663	drove car	1	21.666	1
34	689	drove car	5	25.693	1
35	698	passenger in car	5	29.243	1
36	1005	passenger in car	1	25.665	1
37	1007	drove car	5	31.152	1
38	1028	drove car	5	33.386	1
39	1029	drove car	2	33.744	1
40	1031	drove car	3	10.432	1
41	1036	passenger in car	2	7.823	1
42	1064	drove car	3	3.791	1
43	1115	drove car	5	5.48	1
44	1191	taxi	1	3.986	1
45	1227	drove car	5	22.164	1
46	1256	drove car	3	22.825	1
47	1259	drove car	5	20.083	1
48	1264	drove car	6	10.944	1
49	1290	taxi	3	6.626	1
50	1292	drove car	5	4.791	1
51	1510	passenger in car	5	17.562	1
52	1511	taxi	3	4.773	1
53	1518	drove car	2	13.147	1
54	1520	passenger in car	3	13.315	1
55	1536	drove car	3	40.433	1
56	1548	drove car	4	39.799	1
57	1549	passenger in car	3	6.786	0.6
58	1554	drove car	5	33.036	1
59	1570	drove car	5	28.741	1
60	1579	drove car	5	3.382	1
61	1707	drove car	5	31.128	1
62	1708	drove car	4	25.635	1
63	1713	passenger in car	5	6.89	1
64	1715	drove car	5	28.284	1
65	1717	drove car	5	26.268	1
66	1771	drove car	4	6.318	1

ID	Respondent	Mode	Frequency	Trip Length	Factor
67	1906	drove car	5	32.317	1
68	1916	passenger in car	1	5.416	1
69	1920	drove car	3	25.714	1
70	1921	drove car	5	36.624	1
71	1944	drove car	5	28.304	1
72	1976	drove car	5	9.271	1
73	2123	passenger in car	1	29.778	1
74	2134	passenger in car	5	26.933	0.95
75	2139	drove car	2	35.681	1
76	2142	drove car	5	19.083	1
77	2145	taxi	5	6.92	1
78	2151	drove car	4	6.85	1
79	2160	drove car	1	15.677	1
80	2162	drove car	5	10.353	1
81	2196	passenger in car	3	5.723	1
82	2202	drove car	5	35.975	1
83	2228	passenger in car	2	9.225	1
84	2229	drove car	4	32.931	1
85	2235	passenger in car	3	40.548	1
86	2238	drove car	3	27.079	1
87	2250	passenger in car	5	5.234	1
88	2602	drove car	5	24.852	1
89	2616	drove car	5	5.446	1
90	2619	drove car	4	18.685	1
91	2639	drove car	5	24.457	1
92	2653	taxi	2	2.359	1
93	2661	drove car	4	4.767	1
94	2666	drove car	4	34.45	1
95	2667	taxi	1	5.134	1
96	2669	drove car	5	29.031	1
97	2675	passenger in car	5	26.827	1
98	2914	drove car	3	31.273	1
99	2921	taxi	4	29.35	1
100	2926	passenger in car	1	15.749	1
101	3002	passenger in car	5	7.579	1
102	3016	taxi	5	19.089	1