An Analysis of Stated and Revealed Preference Cycling Behaviour:
A Case Study of the Regional Municipality of Waterloo

by

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AUTHOR'S DECLARATION

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

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

Abstract

Amongst transportation professionals there is a motivation to increase the use of active transportation to achieve contemporary transportation engineering goals. This research describes a year-long GPS cycling study conducted in partnership by the University of Waterloo and the Region of Waterloo Ontario. Data were collected from 415 self-selected cyclists, using two distinct data collection mechanisms. Data collected from GPS units revealed trip origins, destinations, and routes; the data also contain time stamps from which travel speeds can be computed. An online survey was administered to gather cyclists' socio-economic information and household composition. The survey also collected responses to questions regarding preferences for cycling infrastructure and overall satisfaction.

The trip data allow for several important conclusions. The average trip length observed in the study was 6.96 kilometers; utilitarian trips (i.e. non-recreational) constitute 92% of the observed trips. This suggests that cyclists are able to complete daily activities – commuting, shopping, etc. – with less overall travel than the general population. The trip data also suggests relationships between the propensity to cycle and land use patterns. Strong positive correlations are demonstrated between higher land use density and the number of cycling trips; moreover, cycling trips tend to be more direct in areas with traditional neighbourhood design. The time at which the trips were taken – predominantly the am or pm peaks – suggest that the cyclists' mode choice results in lowering peak demand and, therefore, reducing regional congestion. Fewer and typically shorter cycling trips were observed during winter months, presumably as a result of less favorable climate.

Participants in the study are typically higher-than-average earners and mirror the overall regional age distribution, although seniors and children were underrepresented. The cyclists in the study are predominantly male which may reflect an overall higher propensity to cycle amongst men compared to women. Cyclists' households are more likely than the general population to own fewer cars than licensed drivers which may be interpreted as a cost saving opportunities for these households. Finally, the survey data suggests that the single largest impediment to increased cycling is a perception of poor safety for cyclists, particularly in terms of interactions with automobiles.

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Dedication

To my loving parents George and Oksana Rewa

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Chapter 1
INTRODUCTION

Contemporary transportation planning and engineering professionals have in many cases identified the need to achieve a greater balance between travel modes. Concerns over health, congestion and continued urban sprawl have led efforts towards increased Transportation Demand Management (TDM), where travel behaviour and increased transportation system efficiencies are achieved through the promotion of improved transportation options, land-use management, and accessibility (Transport Canada, 2010).

Within TDM, there has arisen an increased emphasis on promoting a diversity of modes, particularly more sustainable (non-motorized) travel modes with less capital investments; low to no operating cost; lower maintenance cost; decreased space consumption; increased energy-efficiency; and minimal to no environmental impacts. These non-motorized modes, which have long been precluded by the force of the automobile, support TDM with the creation of a balanced multimodal transportation system.

Specifically, increased emphasis is placed on walking and cycling, as these modes play a unique role in the efficiency of transportation systems. Walking and cycling provide a bridge between various modes, as parking lots, downtowns, and other attractions are all dependent on the circulation and connection of destinations by pedestrian and cycle travel (VTPI, 2009). Many of these environments that were built to cater to motorized travel rely on non-motorized modes for final destination arrival and in "*improving non-motorized conditions [we can] improve access by other modes"* (VTPI, 2009, p. 2).

This thesis shall present research that aims to give guidance to planners and engineers in promoting cycling, by building upon data gathered by the Regional Municipality of Waterloo's and University of Waterloo's joint cycling study. Data collection efforts offer a means to better understand cyclists, their relative motivations and obstacles to cycling, and their role in the development of a balanced transportation system. The objective of this thesis is to capture an understanding of cyclists and cycling by gathering and analyzing data on:

I. Who the cyclists are, to where do they travel, and for what purposes;
II. How their household composition influences and is influenced by their cycling activity;
III. What are motivations and obstacles to bicycling;
IV. The benefits of cycling to the overall transportation system performance
V. The influence of land-use and land-use density on mode choice behaviour;
VI. The steps that can be taken to increase the attractiveness of cycling within urban forms; and
VII. Future investment, policies, education, and program implementation strategies.

Current literature attempts to investigate cyclists and cycling from a multitude of directions. Often, focus is placed on stated preference data relating to travel behaviour characteristics, cycling demographics, perceptions of safety, level of service and infrastructure, as well as understanding the increasingly larger mode share of cycling. As illustrated in the table below, research and data collected on cycling are largely divided into two distinct categories, cyclists and physical networks.

Table 1 Typical Data Collection in Contemporary Cycling Literature

Cyclist	Physical Network
Age	Infrastructure
Auto ownership	Diversity of facilities
Physical well-being	Ubiquity and connectivity of network
Household composition	Integration with other modes
Income	Climate
Perception of safety	Surface conditions and Grade
Motivations	Parking and other facilities
Travel Behaviour	

Existing literature has played a vital role in understanding these factors individually; however there exists a gap in the literature, where these factors are holistically analyzed.

Greater focus is needed on generating meaningful answers to:

- *Who are cyclists, what are their demographic profiles, what are their travel characteristics?*
- *What is the potential 'upperbound' on cycling mode share, and how can we aid in achieving this – who do we target?*
- *For what purpose, and what frequency and time of day do cycling trips occur?*
- *What influences the propensity to cycle, and how?*
- *How can we better predict future cycling demands?*

With this in mind, the Regional Municipality of Waterloo comprised of the tri-cities - Waterloo, Kitchener, and Cambridge (see Chapter 3 for more details) – partnered with the University of Waterloo to study cycling activity within the Region. Ultimately, the study will inform the Region's Cycling Master Plan. The study was developed to bring a stronger voice and understanding of bicycling activities within the Region, as well as to link stated preference data with revealed preference data. This study, facilitated by the Travel Wise Transportation Demand Management Department of the Region, is the foundation of the research presented in this thesis.

Data obtained by this study were gathered by three sources of data collection (Figure 1). They include mobile GPS tracking loggers, an online administered survey, and an online one-time travel diary. Results from this study will help shape future transportation policies regarding cycling activities in the Region.

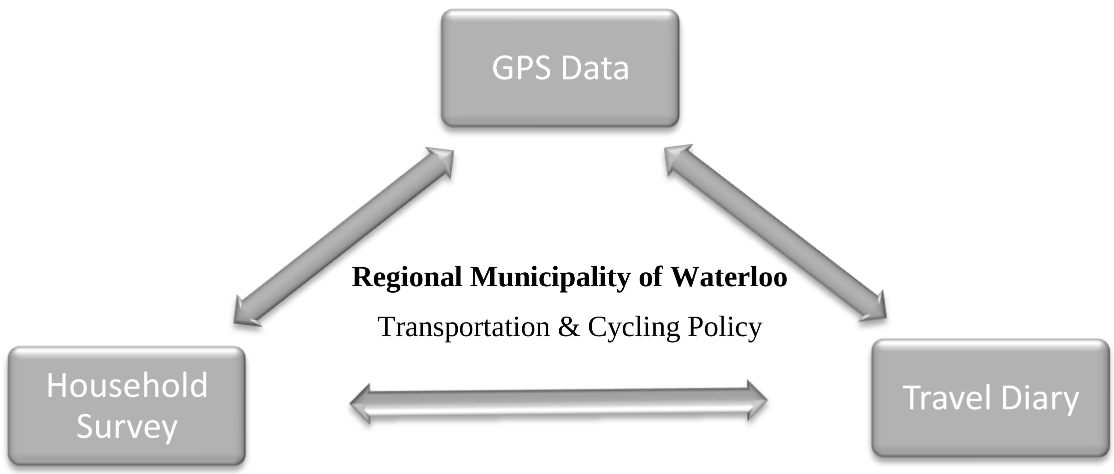


Figure 1: Data Collection Methods

Given the data collected, and the results and analysis conducted, this thesis shall contribute to the literature by expanding the current understanding of cyclists and the physical network by:

- Gathering data on cyclists: bridging existing gaps in the literature;
- Gathering stated preference data relating to obstacles to cycling, both in terms of physical infrastructure and household demographics;
- Gathering revealed preference data, through global positioning systems (GPS), which allows for the evaluation of stated preference data, cyclist behaviour, analysis of trip lengths, speeds, path choice, origins and destinations, etc.

With this increased understanding of cyclists, and their relationship with the physical transportation network, outcomes of this work include:

- Better-informed decision making for the Regional Municipality of Waterloo, and other similar municipalities on cycling investments, policies, education, program implementation, etc.
- Reduced gaps in the literature from the linking of demographic profiles, physical networks, and revealed preference data together;
- Development of data collection standards;
- Formation of a Generalized Cost model, which may be used in the longer term to generate truly multi-modal mode choice models. A generalized cost model considers the variables that influence and discourage a trip by bicycle, formalized into a monetary cost for a given trip.

This thesis is structured as follows. First, literature relating to cycling use is examined and presented in a literature review. Second, the study context of the Regional Municipality of Waterloo is offered as means to better understand the environment in which the research has taken place. Third, the study methodology is described, and steps taken to obtain the data in this research are presented. Fourth, results from distributed GPS units, as well as both the survey and travel diary are explored, and combined together to link travel patterns and households compositions. Fifth, using the understanding that we have of cyclists, and their behaviour, a generalized cost model is considered to help predict and plan for future cycling demand. Lastly, findings and recommendations are put forth and discussed.

Chapter 2
LITERATURE REVIEW

2.1 HISTORY OF URBAN FORM & CYCLING

Prior to the early 20th century, many cities were monocentric settlements. This layout (Figure 2) was a direct result of existing transportation options (Müller, 1995). Within this era, travel was limited to non-motorized modes such as walking, and animal assisted travel (i.e. horse-drawn carriages), which encouraged intra-city travel (McNeil, 2010). In 1817, 'le vélocipède', known as the Pedestrian Accelerator (nicknamed Hobby Horse, as it did not require constant care like live horses) was noted in German newspapers, and introduced the world to a novel human power transportation mode, the early bicycle (Wilson, 2004). Due primarily to initial skepticism and high costs, le vélocipède became a page in history and was never widely constructed (Wilson, 2004). Given this, and the availability of existing transportation options, typical cities were restricted to 30 – 45 minute walking distances from the core, where a concentration of activities congregated creating a central business district – CBD (Müller, 1995). Surrounding these 'walking cities', rural lands provided natural resources, which were transported by horsecars to the core along roads and eventually on tracks. Horsecars operating on tracks allowed for higher volumes (as larger bus-like carriages could be pulled), and enabled travel during poor weather conditions (Müller, 1995).

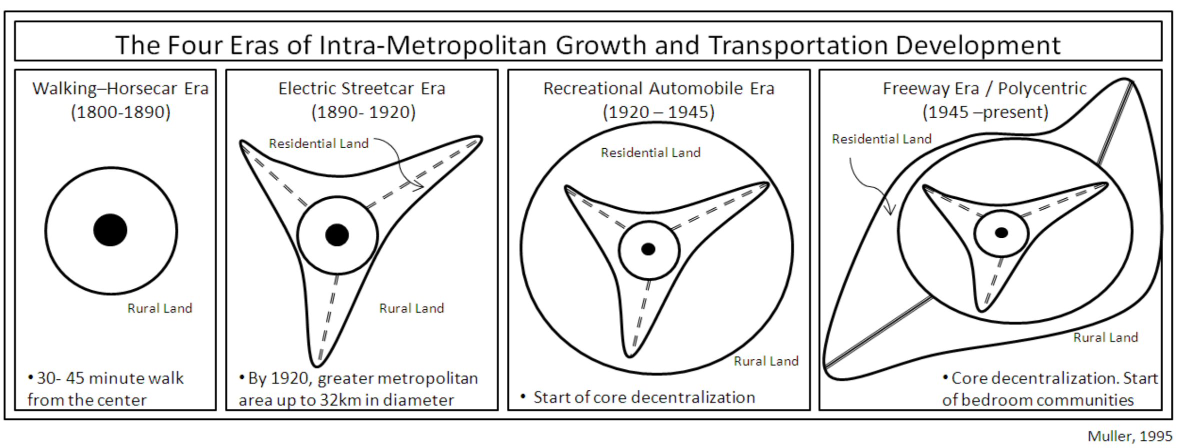


Figure 2 Progression of Monocentric Settlements

By the late 1800s James Starley patented the tangent-tension method of spoking (1874), which allowed for much lighter and larger wheels and the introduction of the high-wheeler or 'ordinary'

(*Figure 3*) (Wilson, 2004). Built to fit a rider's inside leg length (reaching to about 1.5m in diameter) the ordinary was characterized with a large front spoked wheel, decreased weight, and greater traveling speeds (Wilson, 2004). All the same, overshadowed by the emerging (motorized) streetcar, the ordinary and the bicycle boom it created was short-lived. By the end of the 1800s, motorized streetcars permitted greater travel distances and further outward growth followed (Müller, 1995).

Figure 3 High-Wheeler

In the early 20th century, the introduction of automobiles drastically changed the landscape of cities worldwide. Known as the 'Recreational Automobile Era', greater distances could be achieved, with increased efficiency (i.e. greater speeds, decreased energy and consumption, and increased safety), and decreased travel time (Müller, 1995). Nevertheless, mid-century events stimulated a second cycling boom; gas rations imposed by World War II created a need for affordable transportation. The arrival of pneumatic-tired, direct-steering bicycles equipped with shifting-chain gears (derailleurs) allowed for increased comfort and ease of use (Wilson, 2004). Paralleled with lower production costs and advancement in production, cycling became an attractive option. As a result, cycling was no longer exclusively reserved for the rich, and became available to a larger cohort of the population (Wilson, 2004).

Like the previous cycling experience, this war-time growth of cycling was also temporary. By the post World War II Era (early 1950s) affordable automobiles emerged, and *"quickly became a necessity for commuting, shopping, socializing..."* (Müller, 1995, p.42). Out of this reliance on private automobiles spawn the start of urban decentralization, known as the 'Freeway Era'. The Freeway Era removed past travel boundaries, and gave way to suburban growth. Bedroom communities (also known as Suburban "Centers") started to appear on the outskirts of cities, leading to the development of the polycentric layout (Figure 4). This layout further emphasized the need for auto travel (Casello, 2007).

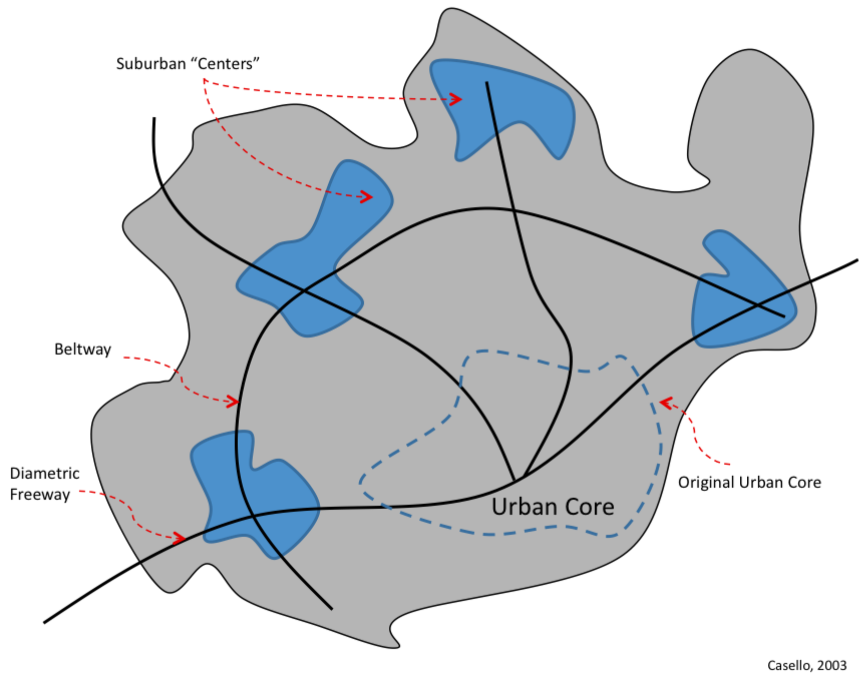


Figure 4 Polycentric City and Suburban Centers

The polycentric layout was enabled by advancements in automobile production, post-war growth, and increased suburban development (McNeil, 2010). Along with the rise of the polycentric city, increased automobile oriented design followed, and the make-up of urban landscapes began to significantly change. Non-motorized transportation modes (such as bicycling and walking) were no longer a natural side-effect of urban development, and had to be planned by local officials (McNeil, 2010, p.4). Cities and communities were divided by high volume arterial roads and freeways, and an ever-increasing dependency on automobiles left many urban cores matted in asphalt.

More recently, government officials and planning agencies have struggled to keep pace with the rise of the automobile, and many roads, freeways, and downtown cores have become flooded with congestion. Government spending on roadway infrastructure has increased from 4.3 billion to 7.3 billion (approximately 70% increase) from 1998 to 2005 (StatsCan, 2011), and congestion has kept pace. As such, many transportation professionals have advocated for Transportation Demand Management (TDM) and the promotion and development of active transportation modes such as walking and cycling to alleviate the ever-growing impact of motorized travel.

To better understand the function of TDM and active transportation, the following section reviews past research with specific focus on cycling and how cycling can help shape TDM strategies.

2.2 LITERATURE REVIEW

In an effort to better understand the research outlined in this paper, and the role of cycling within urban landscapes, a literature review is presented. Literature has been selected primarily from sources originating from North America, as climate, behaviour, and perceptions reviewed are to provide the foundations upon which this thesis shall build. Specifically, case studies from the Cities of Toronto and Ottawa will be discussed and evaluated. Photos used to illustrate infrastructure interventions in the subsequent section are open source citations retrieved from the internet.

Current literature presents two main facets of cycling: factors influencing the propensity to cycle and the benefits of cycling. Each of these topics is described below.

2.2.1 Factors Influencing the Propensity to Cycle

Factors that influence the propensity to cycle are fundamental to understand as both positive and negative influences help to shape current mode shares and cycling behaviours. The review of the literature is divided into three distinct categories that help to frame influences to cycling:

1. Physical attributes – the role of infrastructure;
2. Motorized and non-motorized interactions;
3. Travel costs

2.2.1.1 Physical Attributes – The role of Infrastructure

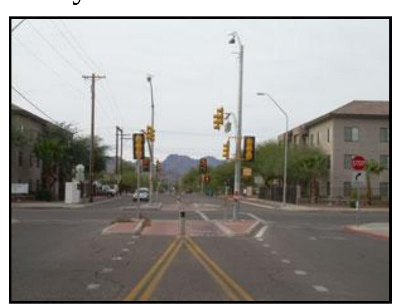
Reflected in Section 2.1, *History of Urban Form & Cycling*, we are able to trace the development of the contemporary city with the evolution of transportation options. Cities and their respective transportation networks have in larger part been designed to accommodate existing travel options. With the rise of private motorized travel in the mid 1950s, continued outward growth resulted in higher volumes on existing transportation systems, and larger travel distances and times. With vehicle stocks expected to increase by 2.5 times by 2030 (Dargay, 2002), the make-up of cities, and their physical attributes will need to adapt and existing systems will need to be revisited.

Within the literature, the role of infrastructure has been identified as a key intervention in the promotion of balanced, sustainable transportation systems (Vuchic, 1999). Infrastructure has proven to have the ability to influence travel behaviour and increase attractiveness of transportation options. Although there is no indication of a direct cause-effect relationship between infrastructure and increased modal shares of cycling, Dill (2003) notes "*higher levels of bicycling infrastructure are positively and significantly correlated with higher rates of bicycling commuting"* (p.122). With consideration on cycling transportation, it is important to reflect on what infrastructure interventions have been shown to help increase modal shares, while providing safe and inviting environments for cyclists. Interventions illustrated below, when planned and implemented correctly, have the ability to influence travel behaviour, and significantly increase the propensity to cycle.

Cycling Interventions

Bicycle Routes: bicycle routes (also known as paved shoulders) are roads that are particularly suitable for cycling and cyclists. Routes are appropriate for streets with low traffic speeds and volumes, and are typically applied along lightly travelled residential roadways, which require no extra construction or specific infrastructure (Litman, et al., 2006 and NCDT, 2010). Routes are generally marked with signs and in some instances with pavement markings.

Bicycle Boulevards: bicycle boulevards are signed bike routes usually located on low-traffic urban and suburban streets. Typically, traffic-calming features such as speed humps and raised medians are included to discourage motorized through-traffic. These features decrease motorized traffic, and encourage increased mobility for active modes such a walking and cycling (Litman, et al., 2006 and



Pucher, et al., 2010). Bicycling boulevards have originated in European cities, however boulevards have started to appear in North America.

Bicycle Lanes: bicycle lanes are a portion of the roadway designated by striping, signing, and pavement marking for the preferential and exclusive use of bicyclists (Pucher et al., 2010). Lanes can be bidirectional, located on right side of traffic or either side of a roadways (NCDT, 2010). Bicycles lanes are most effective mid-block and separate cyclists from overtaking vehicles (NCDT, 2010). Typical lanes vary from 1.2 to 2 meters in width.

Bicycle Boxes and Advanced Stop Lines: Bicycle boxes (also known as advanced stop lines) are marked spaces at intersections where cyclists can skip queues, and wait in adavance of vehicles at red lights. Bicycle boxes grant cyclists greater visibility at intersections, as motorized users can clearly see cyclists as they wait and prepare to move through the intersection (City of Guelph, 2010). These boxes also enable cyclists to safely proceed first through intersections which lends to increased safety, and decreased travel times.

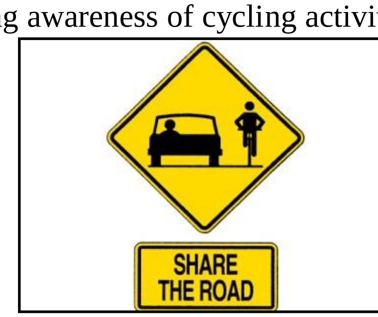
Shared-Use Paths: shared-use paths (also known as mixed-use paths) are non-motorized facilities with an exclusive right-of-way that are generally designated to accommodate two-way traffic. Typically, paths are developed in numerous locations, including; railway and utility corridors, parks, waterfronts and community trails (AASHTO, 1999). Users of share-use paths include cyclists, pedestrians, and other non-motorized modes (AASHTO, 1999).

Bicycle Parking: bicycle parking and storage have been identified as "*the basic physical elements needed to make extentise bicycle use feasible*" (Vuchic, 1999 p.310). Among parking, there exists both long-term and short-term parking. Long-term parking typically consists of single or multi level racks in a controlled, sheltered secured access areas. Short-term parking is more readily available, and consists of on-street racks (both sheltered and open) and is typically unsecured. Many short-term facilities are accessible for public use, however they do not provide protection from theft or vandalism (City of Toronto, 2008).

Connectivity and Number of Street Crossings: Connectivity and number of street crossings are characteristics found in most routes, and play contradictory roles. Connectivity within a route is established primilarly on level of comfort (or safety) and directness of route. As connectivity increases, the propensity to chose a route increases. On the other hand, as the number of street crossings increase, the less desireable a route is for potential cyclists.

Grade and Surface Condition: On any route, there exists a multitude of grades and surface conditions. Typically, routes are chosen to minimize physical effort, while providing a safe environment (Geelong Bikeplan, 1978). The presence of steep terrain is an influential impedance factor that can discourage a route, or trip for commute cycling (Cervero and Duncan, 2003). This notion is reversed for recreational trips, where grade and resulting physical exertion are more sought after. In both cases, quality of surface condition can play an important role in motivating cyclists.

Signage: Given any number of the interventions proposed, creating awareness of cycling activity (to other modes) and availability of infrastructure (to cyclists) is vital. Signage provides a cost effect method of promoting multimodal transportation within a network. Interventions can take shape in terms of pavement marking (bicycle icons, lanes, chevrons, etc), or as sign (designations of lanes, trails, icons,



parking, etc).

End-of-Trip Amenities: Workplace lockers, showers, parking and repair stations encourage higher rates of cycling by providing facilities cater to cyclists and cycling (Dill et al., 2003). These amenities help to diminish common perceptions that active modes, such as cycling do not fit into the fabric of professional workplaces.

Research has also shown that end of trip or non-transportation facilities can play a strong role in influencing the mode share of cycling. Facilities such as indoor and outdoor storage space (as shown in Figure 5), short and long-term parking, work place showers and bus bike racks help to create bikeable communities. "Lack of facilities" has been identified as a key factor for not commuting to work by bicycle (Dill et al., 2003 p.116), and increased facilities, especially work place lockers have been cited as to having the potential to increased bicycle commute rates (Jackson et al., 1998).

Given their flexibility to be applied to various scenarios, and the scope of possible interventions, when applied injunction with Transportation Demand Management strategies, infrastructure interventions have the capacity to help increase the propensity of cycling (Jackson et al., 1998).

Figure 5 Bicycle Parking - Frieburg, Germany

Casello, 2011

Canadian Examples

Given the diversity of implementation strategies, these interventions may be applied to a variety of scenarios. However, in every case it is important to identify the objectives of the intervention, where upon planning can consider current state, application, intervention type, and budget. This is well illustrated when assessing the City of Toronto and the City of Ottawa, where varying degrees of interventions have recently taken place.

In 2010, the City of Toronto undertook a lower cost approach, and introduced bicycle boxes and advanced stop lines within the core (City of Toronto, 2011). This was a reaction to recent incidents involving motorists and cyclists, where motorists were unaware of cyclists on the roadways. The objective of this intervention was to increase the visibility of cyclists within the core district. In planning this intervention, consideration was placed on availability of space within the core, which application would be best suited, and what would be the most cost effective solution. As a result of limited space and a restrictive budget, bicycle boxes were proposed, which allowed cyclists to jump queues at traffic lights, ultimately increasing their relative visibility to motorists.

In contrast, the City of Ottawa in 2011 introduced a more costly set of interventions to help introduce cycling to novice cyclists within the core. The objectives of these interventions were to create a safer environment for cyclists and to promote increased active transportation within the core. In planning, consideration was placed on choosing the appropriate street to introduce the proposed intervention, as well as which application would be most appropriate. It was proposed to build a segregated bicycle lane along Laurier Avenue, which runs across the core of the City (City of Ottawa, 2011). In addition to the segregated lane, bike boxes, turning restrictions, planters, and additional paint marking were added (City of Ottawa, 2011). This ultimately established a safer environment (OO, 2011), while decreasing motorized vehicles interactions and increased attractiveness for current and prospective cyclists. This outcome is evident by assessing cycling rates along the Laurier corridor, where approximately 2,000 cyclists are recorded daily, resulting in more than triple the cycling rate prior to the introduction of these interventions (OO, 2011).

Though these two case studies do not highlight all of the mentioned interventions, it is clear that the level and application of these interventions can be catered to specific applications and budgets.

2.2.1.2 Motorized and Non-Motorized Interactions

With the majority of travel time spent on shared roadways, cyclists rely on many networks built for motorized vehicles, and are exposed to a variety motorized and non-motorized interactions. These interactions play an increasingly larger role in influencing the propensity to cycle as safety is one of the largest concerns facing cyclists in North America (Casello, et al., 2010). With a cycling mode share of l.3% (of employed workers in 2006), Canadian cyclists are outnumbered on transportation network (StatsCan, 2006). Perception of safety plays an influential part in this low percentage of commute cyclists, as urban forms, network standards, and historical development catered to motorized travel have created unattractive environments for cyclists.

Early research by the Geelong Bikeplan (1978) examined the importance of a bicyclist's perspective, a concept known as the *bicycle stress level*, and used this to define roadway bikeability from a cyclist's viewpoint. Bicycle stress levels were based on the assumption that routes were often chosen based on minimizing both physical effort, and mental effort, or stress. Stress, defined as a "*conflict with motor vehicles, interaction with heavy vehicles, and having to concentrate for long periods of time while riding on high-volume and high speed roadways"* (p. 4), was found to be most considerably influenced by curb lane width, vehicle speeds, and traffic volumes.

Cycling and motorized traffic more often than not must share existing roadways and infrastructure. Given this, Forester proposes the concept of "vehicular cycling", which suggests that "*cyclists should practice and obey traffic laws applicable to drivers of vehicles, and also be treated by other drivers and by law as drivers of vehicles*" (Pucher et al., 1999, p.632). Nevertheless, roadways are frequently considered as 'stressful' environments for cyclists and often "vehicular cycling", which is mandated by law in Ontario (as bicycles are considered vehicles (MTO, 2011)) is not always adhered to.

Data from the City of Toronto, with a cycling mode share of 2% indicated that 2% of all vehicle collisions within Toronto involve cyclists. Of these, a 2001 study found that 75% collisions were considered vehicle error (City of Toronto, 2001). Interestingly, over 30% of cyclists reported in collisions were found to have been riding on the sidewalk prior to the incident (City of Toronto, 2001). This is an alarming figure, and this relates directly back to 'vehicular cycling', where a cyclists' perception of safety is to shift from shared networks –roadways, to grade separate infrastructure – sidewalks.

It has also been found that cyclists alter their route based on traffic speeds, signals, and volumes (Sener et al., 2009). Recently, Montreal cyclists were surveyed and asked questions focusing on examining factors that affect route choices. General findings from this study suggest that cyclists would travel an additional distance to use separated facilities rather than shared roadways (Larsen et al., 2010). The authors indicated that cyclists would alter their routes according to perceived dangers, and as skill levels increased, use of shared facilities increased (Larsen et al., 2010). This once again reinforces the impact of motor-vehicle interactions on shared roadways, and the obstacles and motivations they result in.

In order to better understand the interaction of cyclists and motorized vehicles, further examination was taken to relate bicycle stress levels with different street environments. It was found that varying roadway geometry, traffic conditions, and lane widths were highly correlated with comfort, and experienced stress (Sorton et al., 1994). Building upon these assumptions, further research was taken to develop the first Bicycle Level of Service (Landis et al., 1997). The Bicycle Level of Service (BLOS) distinguishes itself from traditional automotive Level of Service, as traffic flow properties such as vehicle density and delay are exchanged for bicycle facility properties (Klobucar, 2006). The BLOS model evaluates a network based on individual link attributes and the perceived hazards of a shared environment (Klobucar, 2006). Factors inclusive to the BLOS are depicted in Equation 1.

$$BLOS = a_1 \ln\left(\frac{Vol_{15}}{L}\right) + a_2 \ln\left[SPD_p(1 + HV\%)\right] + a_3 \ln(COM_{15} * NCA) + a_4(PC_5)^{-2} + a_5(W_e)^2 + C \quad (1)$$

Where;

BLOS = perceived hazard of the shared-roadway environment
a_i = calibration coefficients
Vol_{15} = volume of directional traffic in 15-min time period
L = total number of through lanes
SPD_p = posted speed limit
HV% = percentage of heavy vehicles (as defined in the *Highway Capacity Manual*)
COM_{15} = trip generation intensity of the land use adjoining the road segment (stratified to a commercial trip generation of 15, multiplied by the percentage of the segment with adjoining commercial land development)
NCA = effective frequency per mile of uncontrolled vehicular access (e.g. driveway and on-street parking spaces)
PC_5 = FAWA's 5-point pavement surface condition rating
W_e = average effective width of outside through lane ($W_e = W_t + W_l - W_r$, where W_t= total width of outside lane pavement, W_l= width of paving between outside lane stripe and edge of pavement, and W_r= effective width (reduction) of encroachments in the outside lane).
C = constant

Klobucar, 2006

Concurrent with the previous research, the Highway Safety Research Center at the University of North Carolina developed a Bicycle Compatibility Index (Harkey et al., 1998). The Bicycle Compatibility Index (BCI) considers similar characteristics to the BLOS; however it differentiates itself by rating the perceived safety of roadway segments, rather than hazards (Klobucar, 2006). Characteristic of the BCI are illustrated in Equation 2.

$$BCI = C - a_1 BL - a_2 * BLW - a_3 CLW + a_4 CLV + a_5 OLV + a_6 SPD + a_7 PKG - a_8 AREA + AF \quad (2)$$

Where;

BCI = perceived safety of roadway segments
C = constant
a_i = calibration coefficients
BL = presence of a bicycle lane or paved shoulder
BLW = bicycle lane or paved shoulder width
CLW = curb lane width
CLV = curb lane volume
OLV = other lane volume
SPD = 85^{th} percentile speed of traffic
PKG = presence of a parking lane with more than 30% occupancy
$AREA$ = presence of residential roadside development
AF = (f_t+ f_p+f_n), where f_t= adjustment factor for truck volumes, f_p= adjustment factor for parking turnover, and f_n= adjustment factor for right turn volumes.

Harkey et al., 1998

Both of these models have been widely accepted and applied, however, limitations have been found. Most notably, these models require considerable information about link attributes, increasing the difficulty of network wide implementation, and lessening their relative applicability (Klobucar, 2006). Given this, Klobucar 2006, developed a Bicycle Network Analysis Tool, which focused on aiding investment decisions based on a primary factor of safety. Increased safety has been shown offer increase bicycle commute rates (Dill et al., 2003) and Klobucar suggests that perceived safety (modeled by the BCI) and travel distance are the two key factors that cyclists base their decisions on (Klobucar, 2006). Other variables such as grade, surface conditions, and aesthetics are noted as influential factors, however, safety and travel time are deemed as most important and related back to roadway interactions (Klobucar, 2006).

According to his developed Bicycle Network Analysis tool, a cyclist's "*perceived cost of each link in the network can be defined as the product of the link length and its BCI"*, where, "*long,* *unsafe links are less attractive than short, safe links"*(Klobucar, 2006, p.20). In other words, the shorter the interaction - the safer and the more bikeable it is.

2.2.1.3 Travel costs

While many transportation modes have an associated cost with travel, cycling "*offers the most economical type of vehicular travel and is especially convenient for trips in neigbourhoods, small towns, or high-density areas*" (Vuchic, 1999, p. 307). Typically, given the same set of origin and destination, cycling travel time is significantly higher (especially as distances increase), than competing motorized modes and this extra time spent cycling is an additional cost carried by cyclists (Bicycling Life, 1999). The cost of time relates directly to travel time, which is a function of the distance from a given pair of origins and destinations. The cost associated with time spent traveling is an important measure for cycling, as when travel time increases, motivations for cycling decrease.

2.2.2 Cycling Benefits

Cycling has been shown to offer a variety of benefits that are often categorized as household (personal) or transportation system performance benefits. Household benefits refer to a benefit derived by cyclists as a result of cycling instead of utilizing other modes. These typically include physical health, mental health, and direct economic costs savings. Transportation system performance and operational benefits are typically a by-product of cycling (however in recent times TDM strategies have supported increased cycling), and result in greater efficiencies in overall transportation operation. These include lower vehicular volumes (especially during peak periods), decreased environmental impacts, and increased urban vibrancy.

Household (personal) Benefits

Households (cyclists) attain benefits from cycling through increased physical activity and the benefits of exercise. As a source of physical activity, cycling has been linked to increased physical health and exercise at home, and "*can attractively combine travel and physical activity*" (Moudon et al., 2005, p. 259). Recent literature has also drawn connections between physical activity and mental health. Specifically, active lifestyles have been shown to help cope with stress, depression, and low self-esteem (Landers, 2007).

Beyond health benefits, cycling derives monetary savings. Cost savings may be found in reduced automotive use, where savings in terms of fuel, insurance, auto ownership, maintenance and repair, and parking are attained (Litman et al., 2006).

Transportation System Performance

Cycling offers transportation system performance benefits in creating a balanced network, and reducing the impact of motorized modes. Specifically, increased cycling activity (especially commute based trips) has the ability to reduce vehicular volumes during peak periods. In turn, travel times are reduced for motorized modes, and the need for further infrastructure development can be lessened. This is increasingly more of a concern as, "*we can no longer build our way out of congestion*" (Moritz, 1997 p91), and need to approach current congestion with alternative solutions. By reducing motorized volumes and travel, the environmental degradation imposed by paved surfaces can be mitigated, and increased urban vibrancy can be attained. Urban vibrancy, which can be defined as 'liveable' communities, encompasses the notion of addressing economic inefficiencies, environmental deterioration, and unsatisfactory quality of life (Vuchic, 1999).

Politically, increased investments in active transportation have the potential to generate greater efficiencies within current transportation systems at a much lower cost to users. This is best illustrated when comparing construction costs, where cycling infrastructure is estimated at $\frac{1}{500}$ of the cost of auto.

Literature has shown that there exists a great wealth of information on cycling and cyclists, however gaps lie in linking cycling activity to demographic information (cyclists). Increased infrastructure interventions have the potential to increase cycling mode shares. This in turn benefits the transportation system as a whole through greater efficiencies and increased performance. Politically, investments in cycling infrastructure are much lower than those posed by motorized modes; however they are not as widely accepted by the public. With increased cycling it is vital to consider the interactions placed between cyclists and motorized modes. Interactions with motorized modes have long been considered a barrier to cycling and need to be addressed.

Chapter 3
STUDY CONTEXT

The Regional Municipality of Waterloo, comprised of the tri-cities, Waterloo, Kitchener, and Cambridge, and the Townships of North Dumfries, Wellesley, Wilmot and Woolwich, is one of the fastest growing regions within Ontario (ROW, 2010). Located approximately 110km west of the City of Toronto, Waterloo Region regularly experiences temperatures ranging from -15°C to 30°C, with annual snow and rainfall of over 125cm and 500mm respectfully (WPL, 2009). Originally planned according to past harvesting and cattle trails, Waterloo Region lacks strong arterial connections, which are typically found in traditional grid-pattern street layouts. As a result, transportation and planning initiatives must be specifically tailored to Waterloo Region's unique layout.

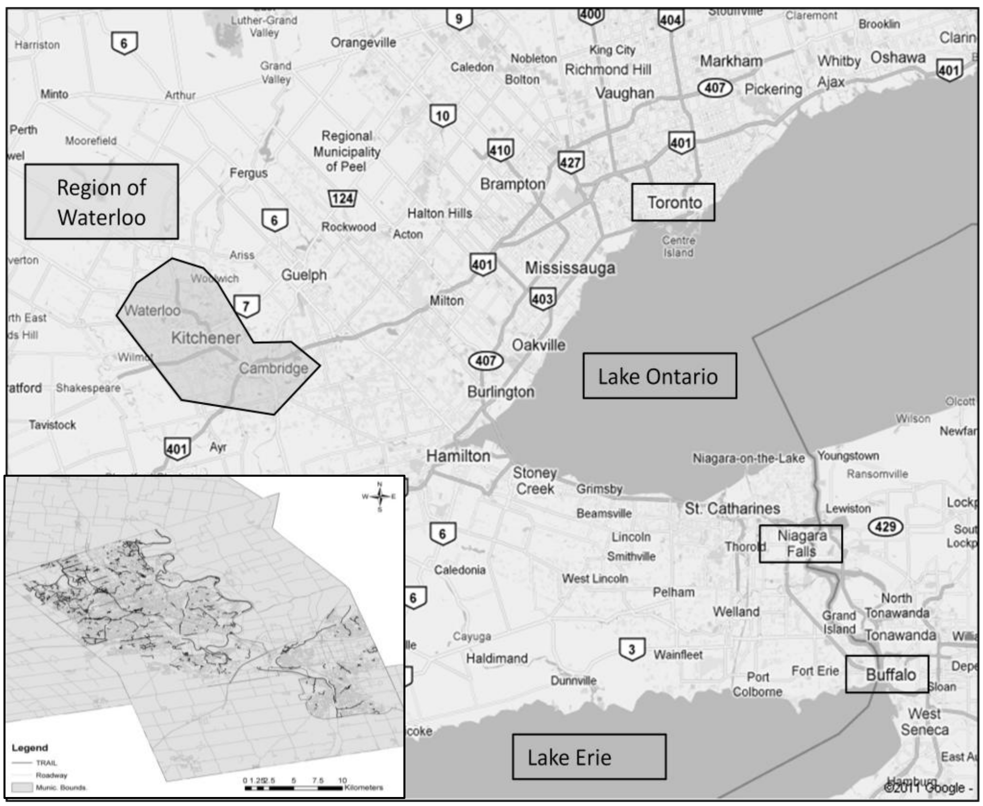


Figure 6 Waterloo Region Context Map

Adhering to several legislative documents such as the Ontario Places to Grow Plan 2006, the Provincial Policy Statement 2005, and the Greenbelt Act 2005 (Figure 7), the Region of

Waterloo has been progressing towards the intensification of urban cores, and the protection of vital agricultural lands. Located within the boundaries of the Greater Golden Horseshoe (GGH) (Figure 7), Kitchener, Waterloo, Cambridge, and Guelph have been designated by the province as Urban Growth Centres, with an estimated GGH population increase of four million people, and two million more jobs by 2031(PtG, 2006).

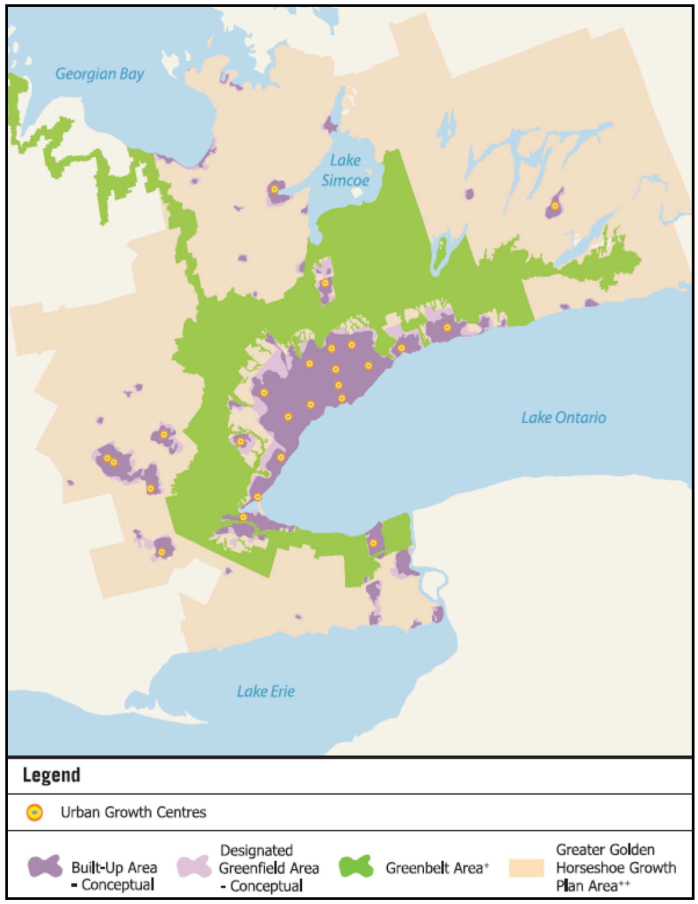


Figure 7 Greater Golden Horseshoe Plan

Places to Grow, 2006

Occupying a land area of 1,368 km^2 and a population density of 370 residents per square kilometer, the Region of Waterloo's current population of approximately 550,000 is expected to grow to 730,000 by 2031 (StatCan, 2006). During this period, the Region's economy is also expected to add 50% more jobs, ultimately challenging regional staff to accommodate increased housing and employment lands without diminishing local agricultural lands. As a result of forecasted population and economic increases, "Growth Management Strategies" (RoW, 2003) have been undertaken by the Region. These strategies include: strict growth boundaries that have been imposed around core areas; increased development and intensification (higher density) of existing built environments; and major investments in both current transit operations and introduction of combined Light Rail Transit (LRT) and adapted Bus Rapid Transit (aBRT) system along the central core corridor of the Region (Figure 8).

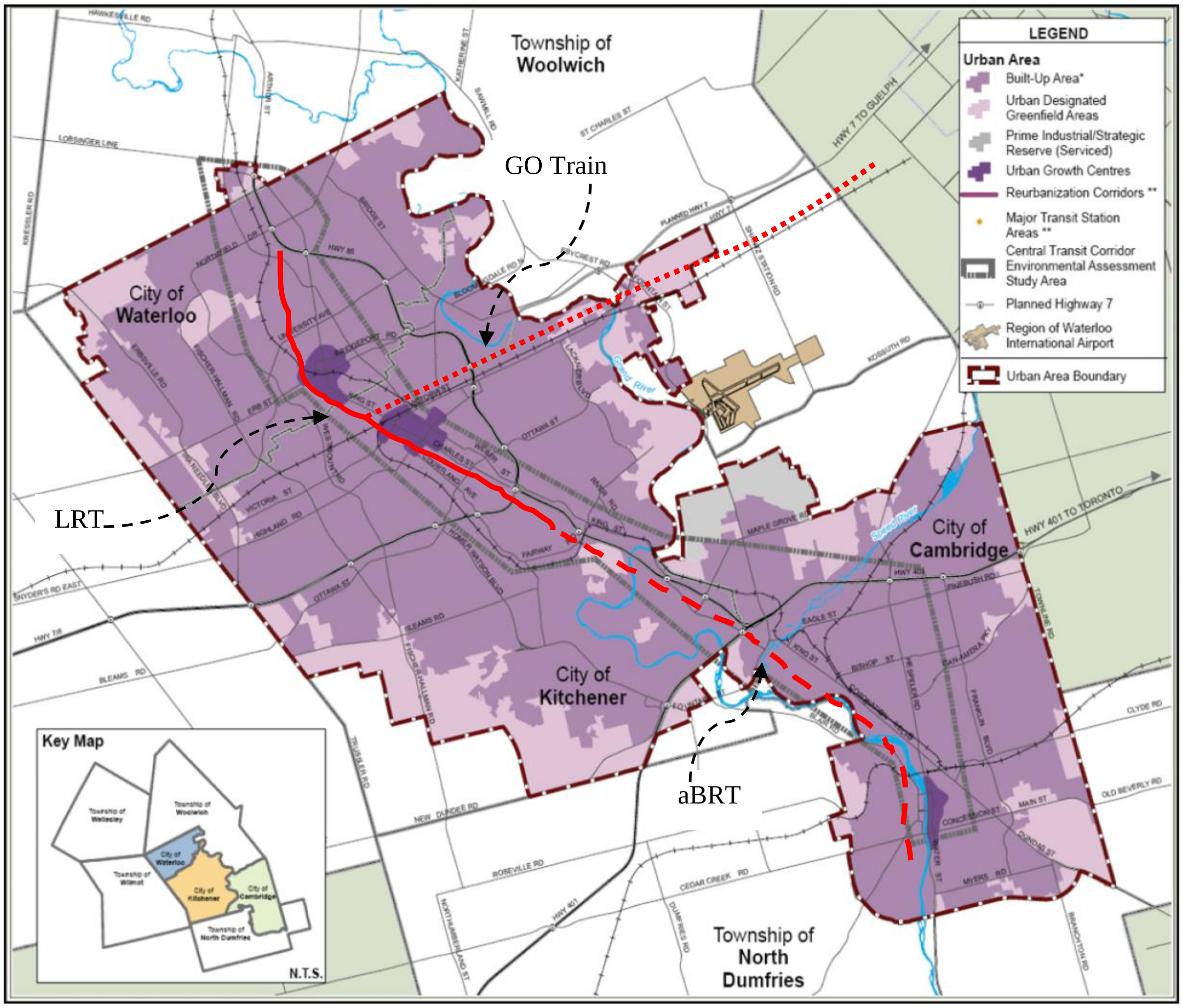


Figure 8 Growth Boundaries and Proposed Rapid Transit Corridor

ROW, 2011

Concurrent with Growth Management Strategies, the Region has launched a "Travel Wise" program to complement the land-use and transportation policies outlined above. The Travel Wise program was initiated as a Transportation Demand Management (TDM) initiative to increase awareness and to advance more sustainable transportation modes such as walking, cycling, and transit. Within this framework, greater emphasis is placed on educating the public about transportation alternatives, while providing economic incentives for the utilization of sustainable transportation (ROW, 2010). One of the primary outcomes of this program is the development of a Cycling Master Plan (ROW Cycling Master Plan, 2004), which places a modal target of 2% of total trips by 2016. This target is supported by the presence of a 'young' population, as several universities and colleges (University of Waterloo, Wilfred Laurier University, Conestoga College, etc) are located in the region and offer a demographic typically associated with higher likelihoods of cycling. Given this potential, the Region has allocated a budget of $33 million towards the construction of new bicycle facilities spanning over 730 km. Table 2 below illustrates current regional characteristics in relation to existing cycling facilities.

Table 2 Current Cycling Facility Characteristics

Regional Municipality of Waterloo	
Population (2011)	507,096
Mean Age	36 years
Employment (2006)	257,655
Area	1,368.94 km^2
Population density	370 prs / km^2
Length of road network	3,342 km
Cycling Data for the Region of Waterloo	
Regional Trails	252 km
Bike Lane	103.2 km
Boulevard Multi-Use Trail	4.3 km
Paved Shoulder	174.8 km
Shared Bike/MV/Parking Lane	33.4 km
Signed Route	53.9 km
Wide Curb Lane	5.8 km
Cycling mode share (commuting - 2006)	1.6%

To assist in the implementation of regional growth strategy objectives, the Region of Waterloo in conjunction with the University of Waterloo began a joint research study to capture data on cyclists and cycling habits within the region. This study commenced as a winter cycling study to improve maintenance and debris removable, and progressed to a year-round study aimed to complement TDM initiatives. The study, its findings and their applications are described in the subsequent sections.

Chapter 4
METHODOLOGY

The University of Waterloo (Waterloo Public Transportation Initiative - WPTI) in conjunction with Regional Municipality of Waterloo (Travel Wise) developed a joint Cycling Research Study to collect data on cyclists and cycling infrastructure. This study aimed to understand the physical environment and socio-economic characteristics of regional cyclists, by identifying:

I. Who the cyclists are, to where do they travel, and for what purpose.
II. How their household composition influences and is influenced by their cycling activity.
III. The motivations and obstacles to bicycling – how these could potentially lead to improved cycling mode choice models;
IV. The benefits of cycling to overall transportation system performance.
V. The influence of land-use and land-use density on mode choice behaviour;
VI. The steps that can be taken to increase the attractiveness of cycling within urban forms;
VII. Future investments, policies, education, program implementation strategies;
VIII. Methods to maximize the value of the data.

Each of these is addressed in subsequent sections.

4.1 Study Structure

Participant Recruitment

In March 2011, regional cyclists where asked to participate in a winter cycling study through media, local newspapers, and word of mouth. Over 100 cyclists registered soon after the announcement. During the recruitment process, no specific procedure was used to reflect diversity in terms of gender, age, geography, skill level, income, etc. Participants were self-selected cyclists, and selected to participant based on their availability.

Data collection

Among the first 100 registered cyclists, two groups of cyclists (of approximately 50 participants each) were given compact GPS loggers/units (Figure 9) for a two-week period. These units recorded origins, destinations, speeds, route, altitude, and time of travel. The units were calibrated to record X,Y,Z (longitude, latitude, altitude) way-points every 3 seconds or 5 meters. Data collected by units were downloaded via USB and stored within an excel database according to group and unit number (Appendix A). Recorded points were overlaid onto a map of the Region using a program supplied by the GPS manufacturer and traces were illustrated individually by colour and date (Figure 10). The software also generated speed and altitude profiles for every trace. Along with gathered GPS data, daily weather conditions were recorded for each group, and stored with the data.

Figure 9 GPS Unit

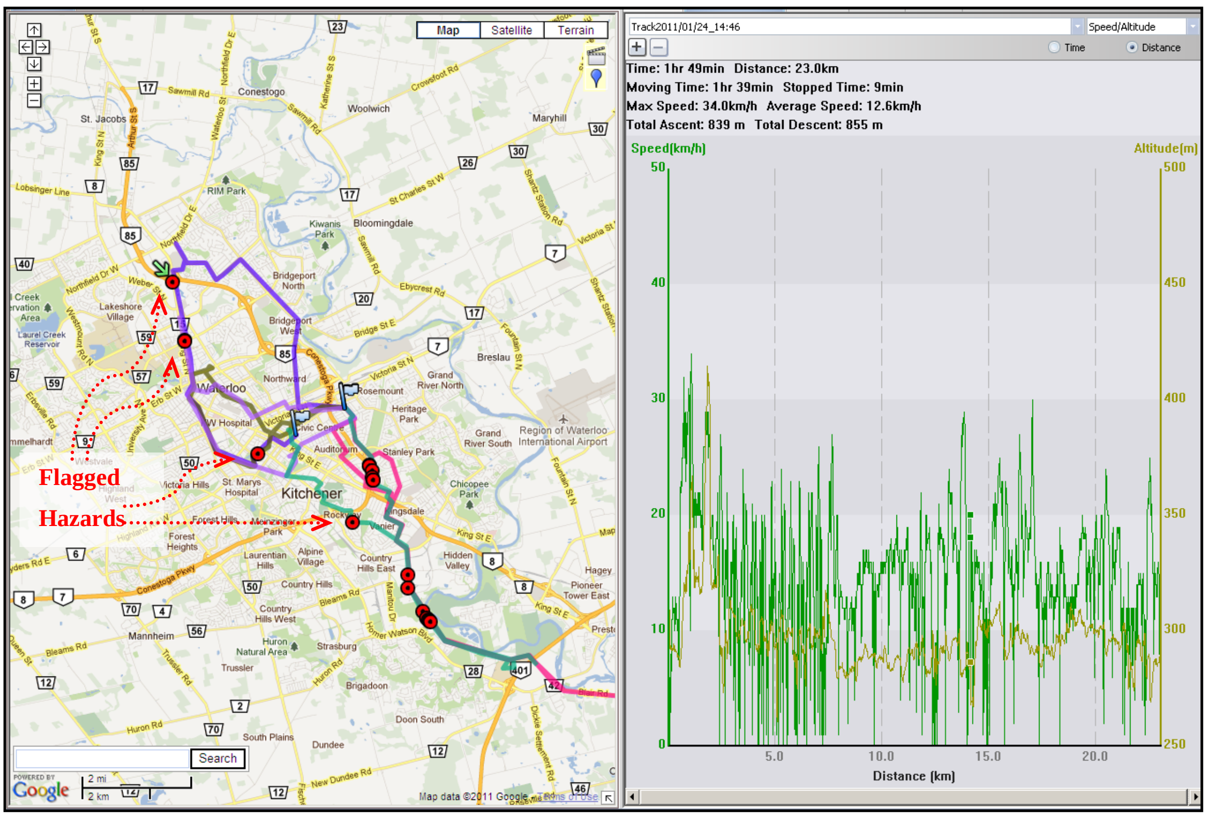


Figure 10 GPS Output

The GPS units are also equipped with a manual location / time recorder. If the user pushes the button on the unit, the unit's x,y,time data are stored with a unique identifier to indicate that this was a manually identified data point. In the research, participants were asked to use this functionality to 'flag' perceived hazards on their daily cycling routine. Hazards, represented as red markers in Figure 10, were defined as any physical obstruction encountered on route. Instructions were given to ensure that hazards experienced be of a physical nature (i.e. intersection geometry, surface condition, disconnectivity, etc) and not behavioural hazards (i.e. poor motorist behaviour). This was specified as such so that flagged hazards could be investigated later.

In parallel with the collection of revealed preference data through GPS loggers, participants were asked to complete an online survey developed to capture household compositions and characteristics. Characteristics of the survey are seen in Table 3 *(full survey in Appendix B)*.

Table 3 Survey Characteristics

Category	Data collected
1. Demographics, auto ownership and vehicle ownership	Respondent's age, gender, income, frequency of cycling by season, frequency of other modes; household # autos owned, # licensed drivers
2. Characteristics of regular cycling route	Satisfaction with current route, assessment of skill level, frequency of bike-transit trips (racks on buses), helmet use
3. Cycling behavior	Factors that motivate to cycle, factors in current route choice, obstacles to increased cycling
4. Specific hazards	Relative importance of various interactions with cars, interaction with other cyclists, road (facility) maintenance, weather
5. Cycling economics	$ spent on annual maintenance, level of investment for new bicycle, and willingness to pay to join a bike-sharing program
6. Necessary cycling infrastructure	Prioritized list amongst: paths (on-road, off-road, boulevard), parking facilities, lighting, shower facilities, bicycle signage and path maintenance.
7. Miscellaneous	Use of GPS / cell phone when cycling; evidence of bicycle theft; bicycle collisions; level of training; opinions on motorized bicycles.

After logging two weeks of cycling data, and with the completion of the survey and trip diary, GPS units were collected, and data were extracted.

GPS Data Validation

As with any data collection exercise, it was important to validate the raw data to ensure subsequent analysis was valid. Challenges specific to GPS data include incorrect data points – in both the x,y and z dimensions – from poor satellite connectivity which result in extreme travel distances and speeds. To eliminate incorrect data points, the following approach was used. Using Visual Basic (VB) code, each point (or series of points) were evaluated based on both altitude and speed thresholds. Invalid data point(s) are defined as those that:

Altitude Thresholds

1. Have an altitude less than 0 metres or greater than 600 metres; this range was used to reflect regional elevations.
2. Have a difference in altitude between two adjacent points (3 seconds) that is greater than 35 metres.

Speed Thresholds

1. Produce an initial speed greater than 10km/hr.
2. Produce an observed speed of greater than 75km/hr.
3. Produce a difference in speed between two consecutive segments that exceeds 16km/hr (Figure 11).
4. Produce a difference in speed between two adjacent segments that exceeds 30km/hr (Figure 11).

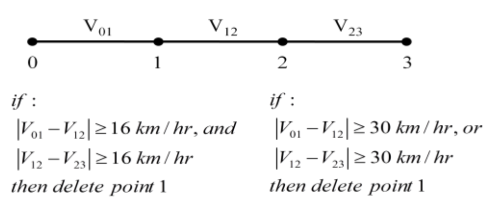


Figure 11 Speed Cleaning Thresholds

An example of data validation and cleaning can be seen in the following figure.

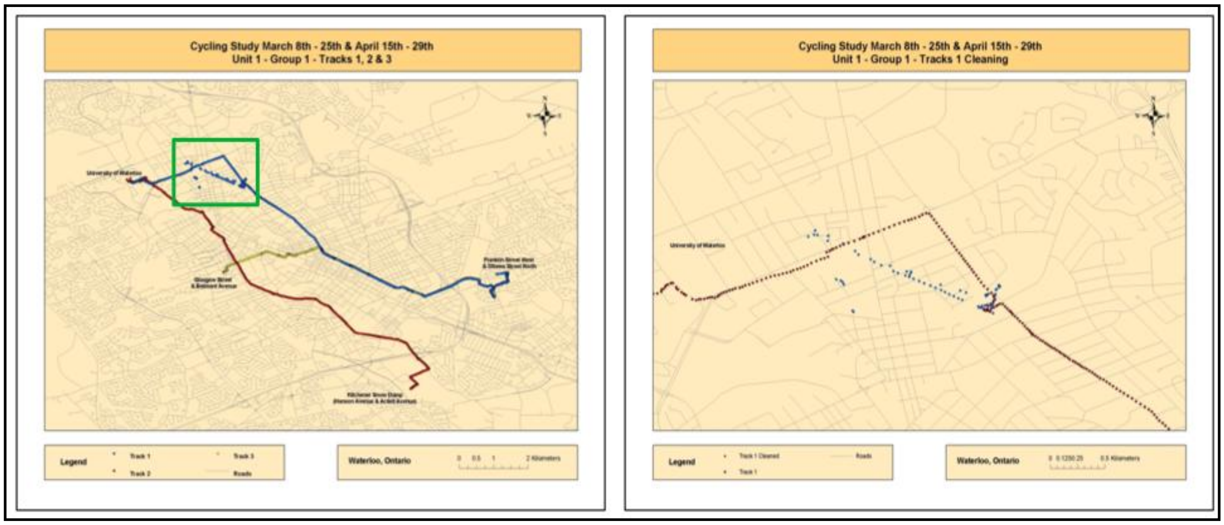


Figure 12 Raw and Cleaned Data

As noted, poor satellite connectivity experienced within the raw data (highlighted on the left, Figure 12) was cleaned using the thresholds outlined above. In cleaning the data, points that were identified as 'poor/incorrect' were removed (blue points on the right map) leaving only points that were identified as representative of cycling activity (red points on the right map).

Concurrent with this, daily regional weather conditions were recorded and matched for each group, and day within the study (Table 4).

As a result of the overwhelming support and number of cyclists registered, the study was extended from its original winter study to a year around study. In total, 11 groups and 415 cyclists registered for this study. Table 4 shows the sequence of data collection efforts. Given the duration of the full study, data on cyclists and cycling both in-season (summer and fall) and off-season (winter) conditions have been collected.

Table 4 Cycling Group Characteristics

	Start	Finish	# of Cyclists	Survey	Trip Diary	Weather (°C)	Season
Group 1	08-Mar-10	25-Mar-10	50	42	44	-4.1 to 17.7	Spring
Group 2	15-Apr-10	30-Apr-10	45	39	40	-2.7 to 26.3	
Group 3	15-Jul-10	30-Jul-10	42	40	37	11.6 to 29.6	Summer
Group 4	09-Aug-10	24-Aug-10	40	35	35	9.2 to 30.3	
Group 5	26-Aug-10	10-Sep-10	46	38	38	5 to 33.6	
Group 6	20-Sep-10	04-Oct-10	46	37	43	2.1 to 28.6	Fall
Group 7	28-Sep-10	13-Oct-10	39	36	34	-2.7 to 21.8	
Group 8	20-Oct-10	04-Nov-10	39	35	35	-5.9 to 20.5	
Group 9	03-Nov-10	18-Nov-10	25	20	19	-5.8 to 15	
Group 10	13-Jan-11	27-Jan-11	29	24	24	-28.8 to 1.4	Winter
Group 11	27-Jan-11	11-Feb-11	14	11	10	-23 to -1	
		Totals	415	359	361		

GPS data and survey data were linked together (based on cyclist) and provided insight into answering the research objectives outlined earlier in this thesis. Data were linked together based on recorded group number and unit number (i.e. within group 5, unit 86 was linked to survey group 5, completed by unit 86).

Given the possibility to address past studies limitations identified with the literature review, this structure allowed cyclists, and the physical network to be linked together.

With data gathered, the following methodologies were applied to address the research objectives of this thesis.

Data Analysis

As previously outlined, many objectives have been proposed for this research. These include: who the cyclists are, to where do they travel and for what purpose; how are household composition influenced and are influenced by cycling; what are the motivations and obstacles to cycling; and what are the benefits of cycling to the overall transportation network.

Who the cyclists are?

Cyclists were asked to provide information on demographic characteristics including: age, gender, and income (Table 3). These data were compared to the Regional distribution and used to validate our sample as reflective of the Region as a whole.

Where do they travel to?

With Regional Growth Management Strategies in place, assessment of land use and land use densities has become an important component in Transportation Demand Management (TDM). Specifically, interest lies with understanding how land-use densities help to explain the probability of generating and attracting cyclists' trips. This is of particular interest, as land-use patterns have the potential to influence cycling by:

- Congregating activities – which in turn would provide greater access to a diversity of destinations within a given travel distance;
- Increasing pedestrian traffic and lowering road speeds – which result in safer interactions for cyclists;
- Increasing parking demand – which would result in higher parking charges and limited availability, and increase the competitiveness of cycling relative to autos.

In order to understand the relationship of land-use patterns on cycling behaviour, land-use density (3) as defined by the province of Ontario (Hess, et al., 2007) was computed for each Traffic Analysis Zone (TAZ) within the Region, where:

$$Land\_Use\ Density = \frac{(Population + Employment)}{KM^2} \quad (3)$$

This analysis was applied using observed origins captured by the GPS loggers, which were then spatially joined to a regional TAZ layer. The number of cycling trips originating from and destined for each TAZ was calculated. Trip generation and attraction rates were regressed against land-use density to determine if land-use densities could explain the likelihood to cycle. Results were graphically illustrated allowing for sub-regional and regional analysis.

This methodology and analysis was repeated for recorded destinations.

For what purpose?

In conjunction with demographic and spatial data, GPS data were used to provide information on where and when their trips began (origin) and finished (destination), and which paths were chosen (Figure 10).

It was also possible to assess travel behaviour and identify trip purpose (commute, utilitarian, and recreational trips) based on several rules. These rules were implemented as follows:

I. All trips occurring during the weekend were categorized as recreational trips. In the absence of other information regarding employment (full time, part time, etc.), this appears to be a logical assessment of purpose.

II. All trips occurring on a weekday with an X,Y (linear) distance between origin and destination $\leq$ 0.25km and no intermediate stops (see Figure 13 for the definition of an intermediate stop) were classified as recreational. The assumption here is that if the observed data indicate a complete circuit (i.e. beginning and ending at the same location) with observed stops, then the trip served no utilitarian function and, therefore, is deemed recreational.

III. Any trip that was 'much longer than necessary' was deemed as recreational. Figure 13 illustrates this concept. Consider a cyclist who took a trip from origin A to destination B. Suppose A and B are only 2 km apart, but the cyclist chose a route of 6 km (a difference of 4 km). It is unlikely that the actual path reflects a utilitarian path selection. It is far more likely that the longer than necessary distance – 300% of the shortest path – implies the cyclist sought a longer route, presumably for recreational purposes. However, if a cyclist took a trip from origin C to destination D that are 10 km apart, and chose a route that was 14 km (again a difference of 4 km), that trip has a higher likelihood of being within a range of path choices that would be used for utilitarian purposes.

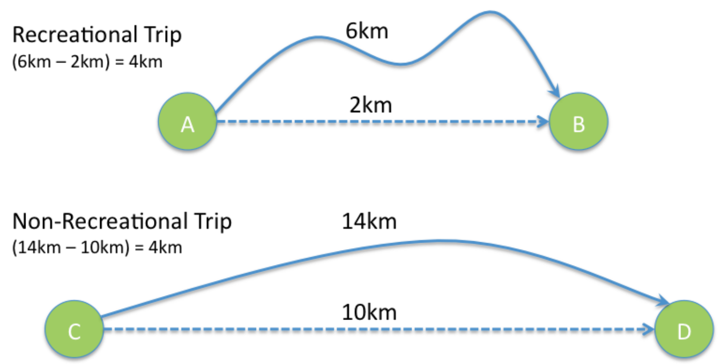


Figure 13 Recreational vs. Non-Recreational Trip

This approach to identifying recreation trips requires that quantitative thresholds for "longer than necessary" are defined. No formal definitions were found in the literature. The approach taken was to try and establish a logical upper bound on the ratio of actual path to shortest path that may be observed for a utilitarian trip. Any ratio exceeding this upper bound was considered to be recreational. The thresholds are determined empirically from the observed data. They are presented graphically in Figure 19 and are summarized in Table 5 in Section 5. All remaining trips were categorized as utilitarian trips.

IV. Among the utilitarian trips, those which occurred during the AM (6:30 to 9:30AM) and PM (4:00 to 7:00PM) peak periods where further categorized as commute trips.

Trip chaining is defined as linking several trips (destinations) and/or trip purposes in series. From a transportation planning perspective, trip chaining is desirable because the traveler can complete a set of activities with less total travel than if each activity were completed as a single trip from the origin. For active transportation, minimizing distance traveled is typically more important than when using motorized travel due to the physical effort required. Trip chaining also provides a break from physical exertion while traveling using an active mode.

Given the importance of trip chaining to cycling, a method was developed and applied to identify GPS data that reflect a trip chain. A trip is defined as continuous movement from an origin with no stops longer than 10 minutes. When the cyclist remains at a location for longer than 10 minutes, we consider this to be a destination.

If the cyclist then begins a second trip within 30 minutes of arriving at the previous location, then the previous location is considered an intermediate stop and the path from origin, to intermediate stop, to final destination is considered a trip chain. This is graphically illustrated in Figure 14.

In the top example, a cyclist departs from point A and arrives at point B. In this case, the cyclist turns the unit off. Fifteen minutes later, the unit is restarted, still at location B, and the cyclist continues from point B to point C. Point B is defined as an intermediate stop and the trip from A to C is a trip chain.

In the second case, the unit remains on and the cyclist is seen to stay at location B, with speeds ≈ 0 for 20 minutes after which she completes the trip to point C. This also reflects a trip chain from point A via point B to the destination, point C.

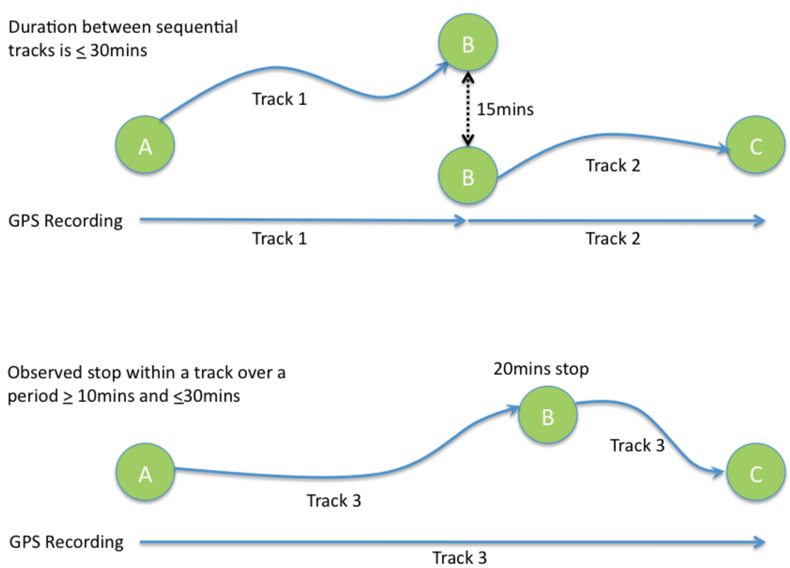


Figure 14 Trip-Chaining

Household demographics

A study of household composition can provide insights into the conditions which favour increased cycling amongst household members and can help understand the impacts of cycling on overall transportation expenditures. This research concentrated on the latter. Research suggests that transportation expenditures can constitute between 15 and 40% of total household expenditures (Center for Clean Air Policy, 2009). A large of this proportion of these costs can be associated with the ownership, operations and maintenance of automobiles. In the case where cycling is a viable substitute for auto ownership, households have the opportunity to reduce total transportation costs.

The expectation is that amongst the general population, households own an equal or greater number of autos than licensed drivers. In this research, the number of licensed drivers in a household is compared to the number of autos owned; a lower ratio suggests less reliance on auto and, as a result, lower transportation costs.

Obstacles to and Motivations for cycling

In order to better plan and design for cycling, cyclists were asked to evaluate several variables that have been shown to influence cycling both positively and negatively. The evaluation included:

- Components of infrastructure that either promote or limit a feeling of safety while cycling;
- Components of infrastructure that enhance or limit the convenience of cycling;
- Interactions with other modes, particularly private auto, that influence cycling safety;
- Other operational parameters;
- The physical environment.

These variables are most often perceived as obstacles to cycling, and their relative rankings help to indicate the study's cyclists' level of agreement and help to prioritize investments which may increase cycling.

Conversely, participants were also asked to express their level of agreement with often-cited motivations for cycling. These include personal health, environmental stewardship, and economic motivations.

In both cases, relative levels of agreement were based on a ranking of 1 to 5, where 1 indicates low agreement, and 5 indicates strong agreement. To rank these variables, an average score is computed for each response and the results are ranked from most to least important.

Benefits of cycling to the transportation network

Recent literature points to the benefits of cycling to the overall transportation system performance by diminishing infrastructure costs, operations and supporting transportation demand management strategies; however, little evidence has been captured to support this claim. In a means to address this, steps were taken to understand the households in which cyclists reside and the impact cycling has on these households.

Data such as the number of vehicles owned per household, number of licensed drivers, departure times (weekend, weekday, peak, and off-peak), route choice, seasonal variation, and distribution of destinations provide insight into benefits of cycling to both households and the overall transportation network performance

Literature has also pointed to the need to create attractive environments, which enable multimodal travel to help manage the increasingly larger demand for travel. Attractive cycling networks have the potential to increase the total mode share of cycling, and broaden current transportation options. Attractiveness, which in general can be attributed to increased safety and greater connectivity, creates a more inviting environment for current and perspective cyclists.

Given this, steps were taken to gather meaningful information on what were perceived as potential hazards for cyclists. While participating in the study, cyclists were asked to flag hazards on their daily cycling trips. This was done through use of the distributed GPS loggers, which had a built in flagging function. Based on hazards that were marked, it was possible to see where cyclists felt unsafe. With this knowledge it was possible to take steps in increasing safety at points identified as hazards or dangerous, as well as applied this knowledge to the entire network to increase safety within the region as a whole.

Investigation also took place to determine if cyclists would travel further to reach attractive (more bikeable) infrastructure. Specifically, how far, and how long would cyclists travel out of their way and why. For each trip, the origin and destination points were recorded and the shortest path was computed using ArcGIS's Network Analyst (applying Dijkstra's algorithm). The shortest path was calculated using two networks layers. The first layer was the regional network of all roadways. The second layer was a regional network with all roadways and multi-use trails. Given the computed shortest paths, we compared the X,Y (linear) distance between same set of origins and destinations, and calculated the experienced *Excess Travel* for each trip along the roadway, roadway and trail networks (4, 5).

$$Excess\ Travel = \frac{(Shortest\ Path - X,Y\ Distance)}{X,Y\ Distance} X\ 100 \qquad (4)$$

$$Excess\ Travel_T = \frac{(Shortest\ Path\ Trails - X,Y\ Distance)}{X,Y\ Distance} X\ 100 \qquad (5)$$

Several interesting observations resulted from this analysis. Equation 4 illustrated the influence of roadway configuration on distance necessary to travel (what is the resulting excess travel by using the roadway network alone). Equation 5 shows the influence of trails in reducing excess travel on the roadway network.

We also compared the shortest calculated paths (with and without trails) to the actual paths taken. This was done to understand the actual excess travel, or extra distance cyclists are willing to travel. Prior to doing so, recreational trips as defined earlier were removed (as typical recreational trips do not offer the same indication of excess travel, where longer, more physically demanding trips might be preferred, compared to shorter A to B utilitarian trips). Results of this examination provide insights into the additional travel costs cyclists are willing to assume to use attractive facilities.

Maximizing the value of the data

To maximize the value of the data, a query-able database is created to allow further investigation into cyclists and their cycling behaviour. The database is composed of revealed (GPS) and stated (survey) preference data, and is broken into two distinct sections. First, a Microsoft Access database stores demographic and cyclist level statistics (i.e. average trip distances, speeds, gender, age, etc). Second, an ArcGIS 10 Geodatabase - with three feature classes – polylines of trips, origin and destination points, and hazards store cyclists' and track level statistics (i.e. track number, date, weekend/weekday, origin, destination, departure time, etc).

The complete database structure is illustrated in Figure 15.

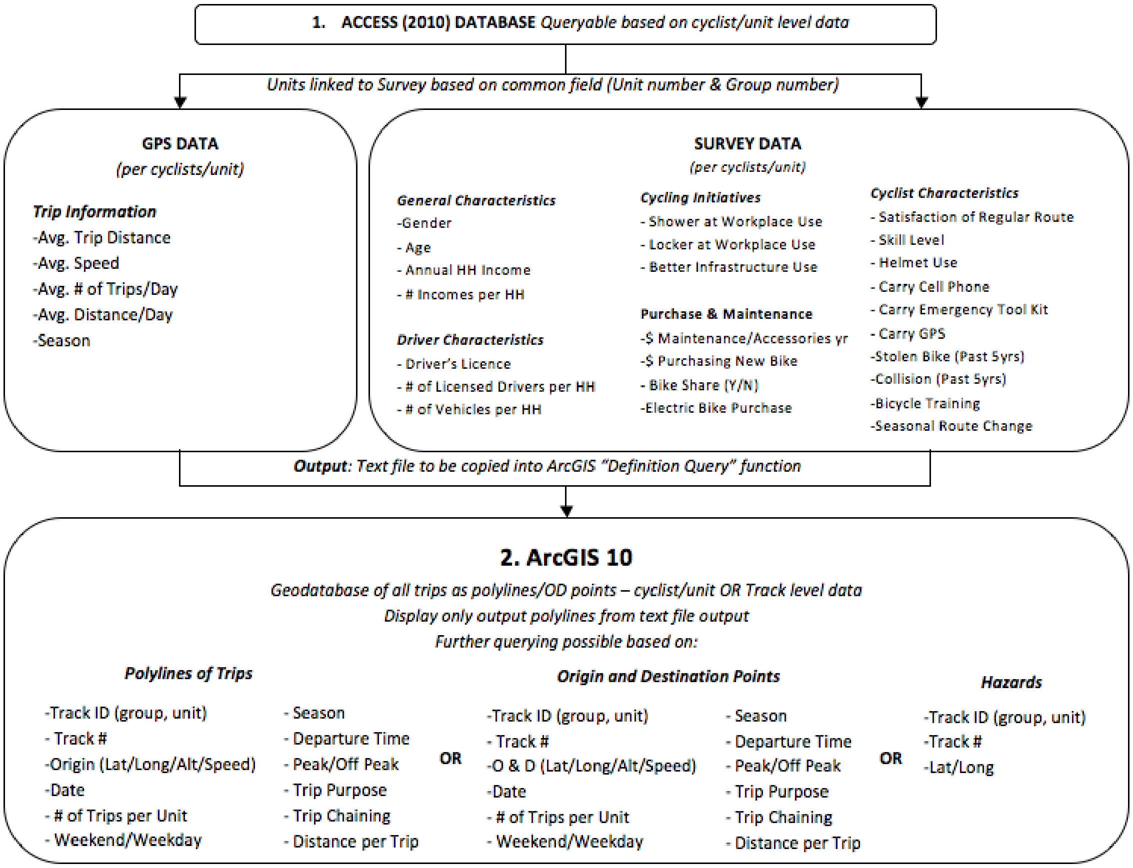


Figure 15 Cycling Database Structure

This structure allows the user to query based on specific characteristics (general, driver, trip, cyclist, cycling and, purchases and maintenance) where upon the corresponding GIS (recorded GPS data) can be extracted and illustrated.

In the following chapter, methodologies presented in this chapter shall be applied to the data, and results shall be discussed.

Chapter 5

RESULTS

The goals of this thesis are to better understand cyclists and cycling in the Region of Waterloo, while contributing to the literature by expanding on current understanding of cyclists and the physical network. Results from this research allow for evidence-based decision making for the Regional Municipality of Waterloo, and other similar municipalities on cycling investments, policies, education and project implementation.

The final outcome of the study yielded approximately 4,800 individual trips (for which GPS data are available), and over 400 completed surveys. As stated previously, seven key objectives have been outlined, and methods to address these objectives have been presented. Results to these objectives are presented in the following sections.

Who the cyclists are?

Variables that have been identified as influential to understanding travel behaviour include, age, income, gender, and auto ownership. Within our study, we were able to capture the following distributions (Figure 16) that help to represent who regional cyclists are.

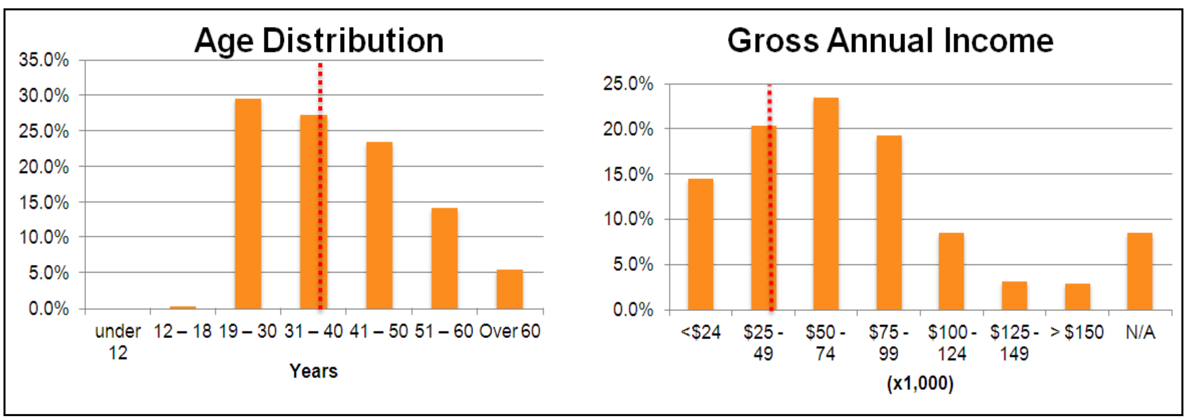


Figure 16 Distribution of Ages & Incomes

We can note from Figure 16 several interesting observations. First, the vertical (red) dashed lines represent the Regional average as reported by Statistics Canada (2006). In evaluating our data with that reported by Statistics Canada, we were able to observe that our sample was representative of the regional mean in terms of age; however, there exists an under representation of children under 18. This outcome is likely a result of the way in which participants were recruited – through local bike shops and through local newspapers – as well as the concentration of activities around universities and regional staff buildings. Finally, the study was not designed to include children, due to the increased liability and the need for a guardian to co-sign the study consent form for those under 18 years of age.

We observe an income distribution that is quite diverse. In comparing participant incomes to that reported by Statistics Canada, we see that our sample represents a segment of the population with incomes that are higher than the regional average. This is of particular interest, as academic research has suggested that households with greater incomes tend to drive more and use more sustainable modes – walking, cycling and transit – less frequently. Of further interest, cyclists have been typically labeled as lower income earners, when, in fact, our results suggest otherwise.

Within our sample we also found an uneven gender representation. 76% of our cyclists were male, and 24% were female. It was also found that 97% of cyclists within our study were licensed drivers, with a mean household auto ownership of 1 vehicle.

To where do they travel?

In conjunction with socio-economic information gathered by our survey, GPS data provided information on when and where trips began (origin) and finished (destination). To determine the impact of land-use on cycling, an assessment of land-use densities was undertaken in relation to the number origins or destinations recorded per Traffic Analysis Zone (TAZ). Figure 17 graphically illustrates the densities of observed origins and destinations as a function of TAZ.

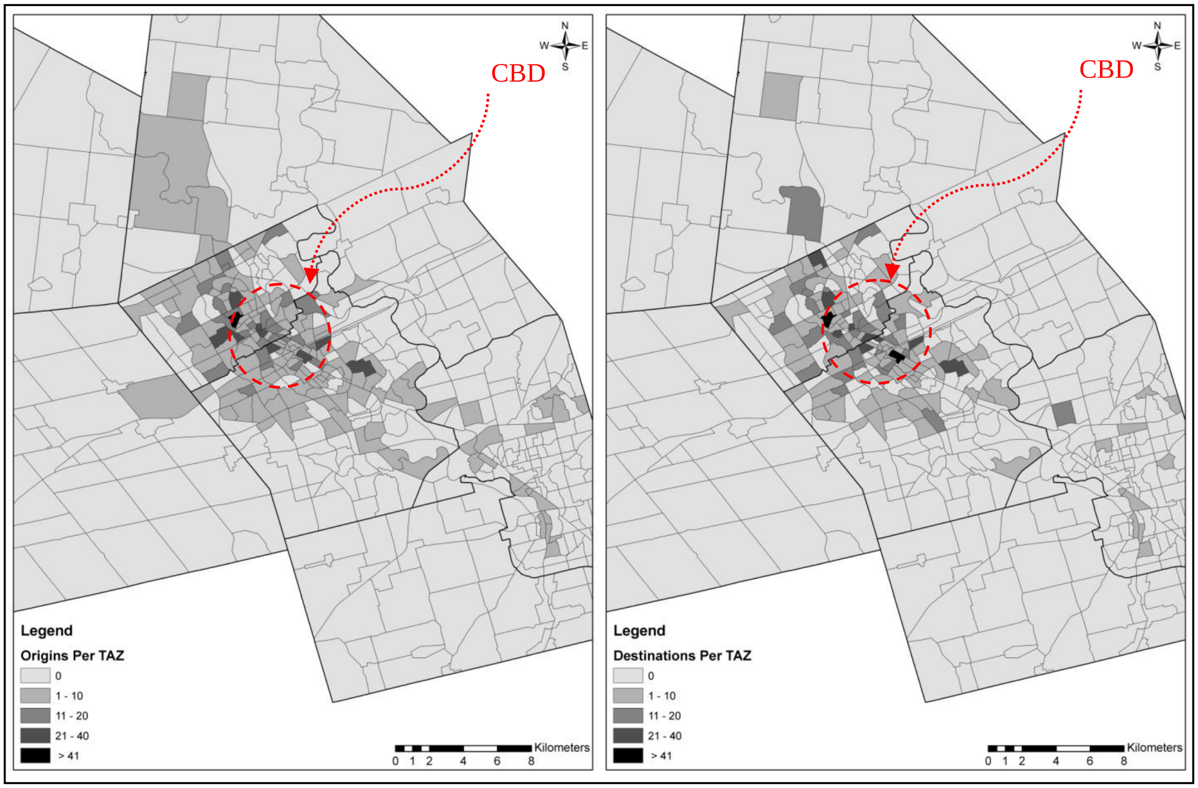


Figure 17 Origins and Destinations per TAZ

We are able to observe that both origins and destinations are highly concentrated within the Region's urban centers; however, a slightly stronger concentration of destinations exists. This suggests that employees are residing outside of the core, and traveling to the Region's CBDs to work.

To further analyze the influence of land use on propensity to cycle, we plotted a normalized trip generation rate as a function of land use density. This is shown in Figure 18.

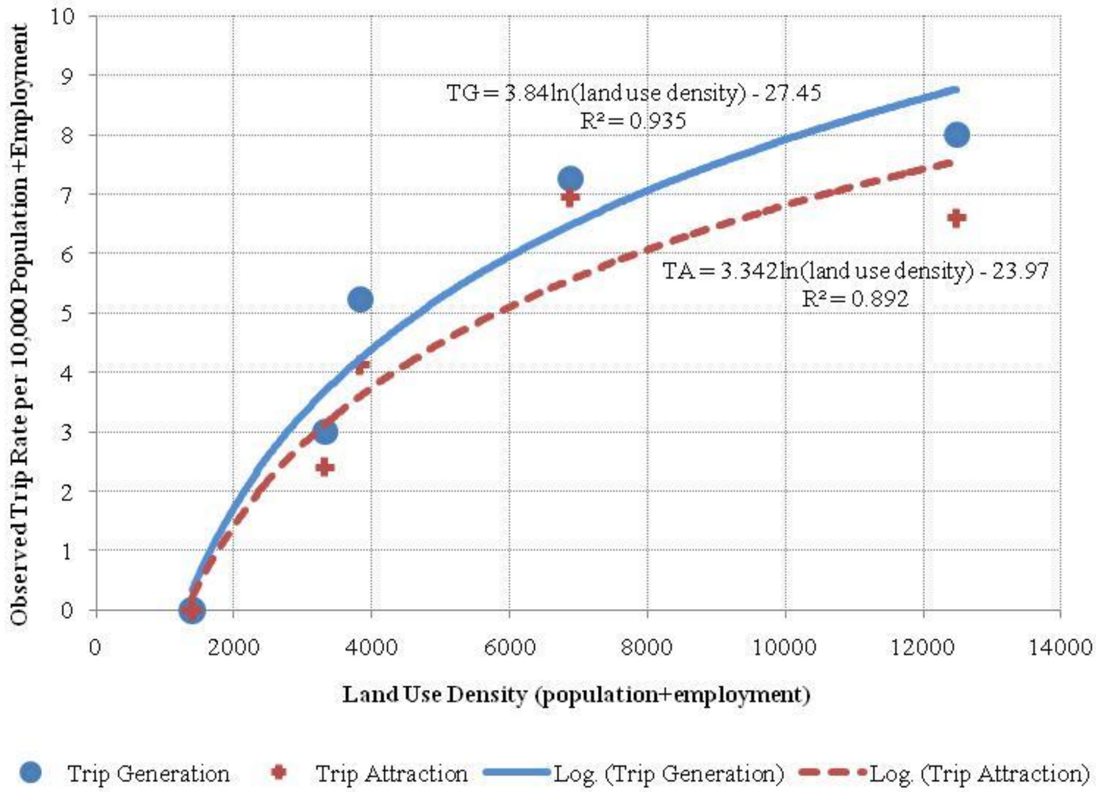


Figure 18 Trip Generation and Attraction as a Function of Land-Use Density

Trip generation and attraction rates are positively correlated with land-use density and exhibit a strong non-linear relationship with R^2 equaling 0.93 and 0.89 respectively. A best fit, non-linear regression also suggests that trip generation and attraction increase with land use density.

1. As land-use density increases, the propensity to start or end a trip in a given TAZ increases;
2. Intensification and reurbanization growth strategies by the Region (which support increase land-use densities) have the ability to increase the rate at which cycling trips are generated; and
3. Higher land-use densities attract cyclists, which in turn provide safer routes (lower total speeds); greater number of destinations (attractions); and increased land value (higher parking charges and decreased available space, resulting in higher costs for motorized users).

For what purpose?

The methodology described earlier to compute the ratio of actual trip length to shortest path was applied with an ultimate goal of identifying utilitarian and recreational trips. In Figure 19, the percentages of trips that exceed a ratio of actual to shortest path are plotted. A set of curves for trips of different lengths are shown to reflect that the ratios represent longer excess travel for longer trips.

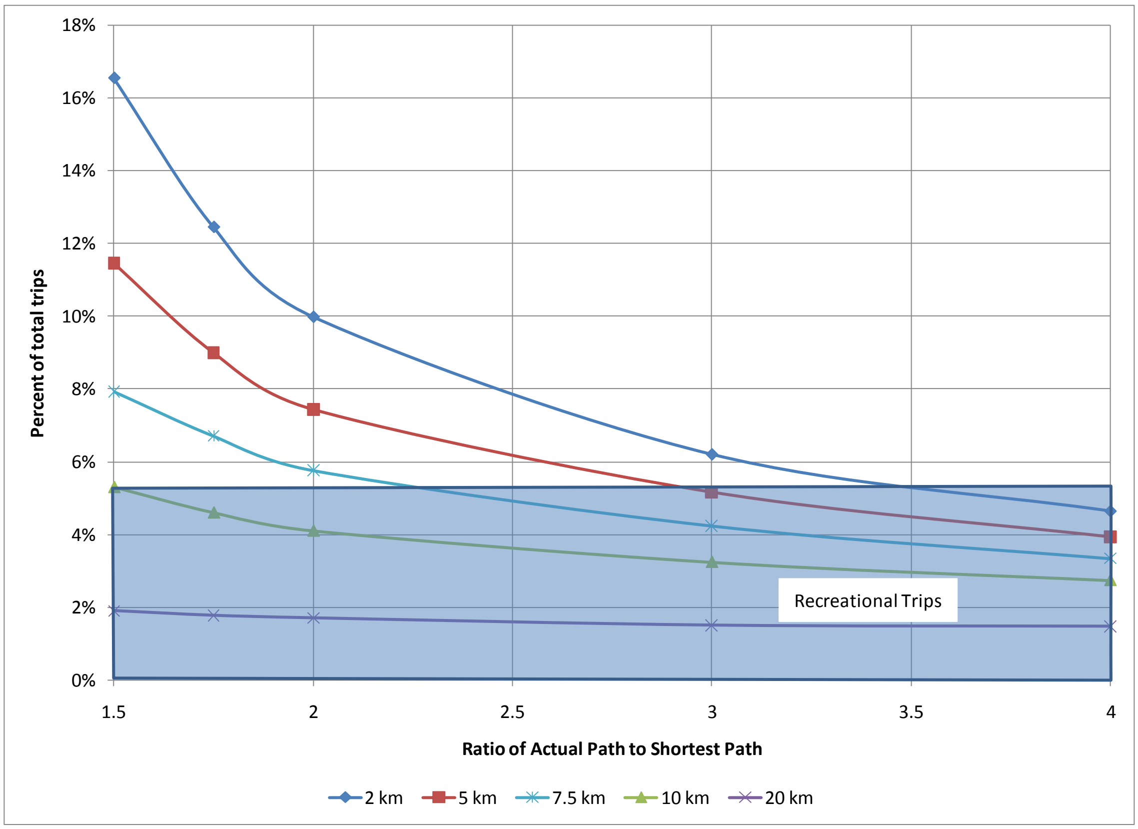


Figure 19 Recreational Thresholds

The data in Figure 19 provide some insights into logical upper bounds for recreational trips. The first assumption is that for long trips – greater than 10 km – any ratio of actual path to shortest path exceeding 1.5 should be considered recreational. Empirically, this reflects about 5.8% of the trips between 10 and 20 km in length. If this percentage of trips in a category is held constant, then for trips in the range of 7.5 km to 10 km, the appropriate ratio threshold is about 2.25. Similarly, the ratio for trips between 5 and 7.5km is 3.0 and for the last category, lengths from 2 to 5 km, the ratio is 3.5.

The interpretation of these results is as follows. A cycling trip between an origin and destination with a shortest path of 3.5 km will only be considered recreational if the cyclist chooses a path that is in excess of (3.5*3.5) 12.25 km – or 8.75 km longer than necessary. This ratio reflects a relatively weak upper bound; as such, the outcome of this technique is to misclassify some recreational trips as utilitarian trips.

Utilizing this technique, 8.4% of total trips were defined as recreational, leaving 91.6% as utilitarian and commute based trips (Table 5). Given the limitations presented above, this value can be considered a lower bound on the number of recreational trips.

Table 5 Recreational Trip Identification

Actual trip length	Ratio	% of trips
2.0 – 5.0 km	≥ 3.5	0.8
5.0 – 7.5 km	≥ 3.0	0.9
7.5 – 10.0 km	≥ 2.25	1.4
> 10.0 km	≥ 1.5	5.3
	Total	8.4

Further investigation into travel patterns revealed the number of daily trips and the average length for each trip (Figure 20). We can note in Figure 20 that the number of daily trips remains consistent with approximately 2 trips per day. The average distance travelled per day was found to be largely influenced by season, where greater distances were covered "in-season", and shorter distances were observed in the off-season.

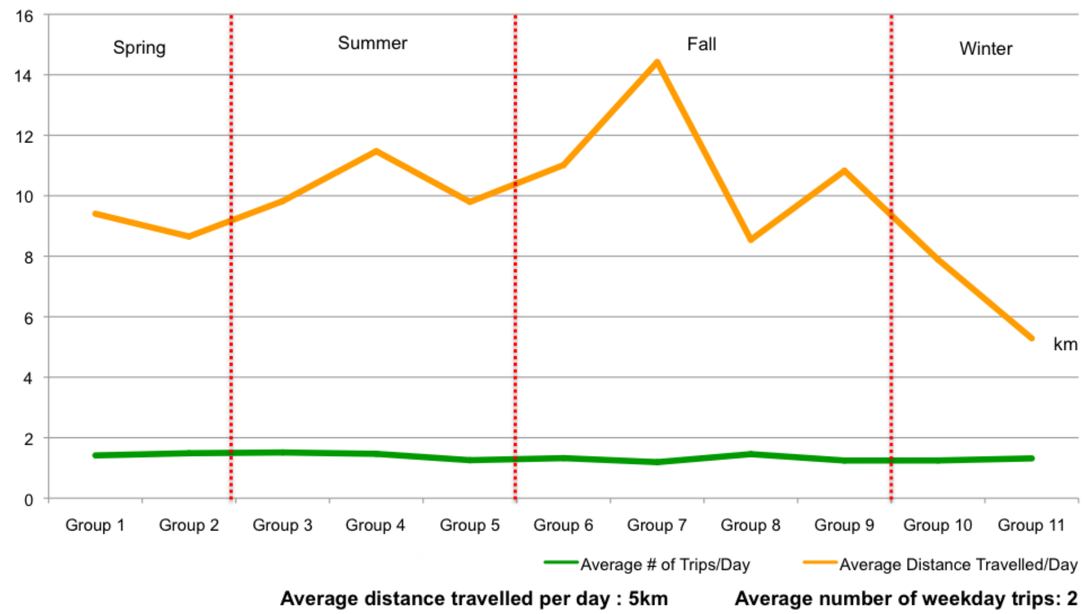


Figure 20 Number of Daily Trips & Average Length per Trip

In evaluating these data, macro-level statistics relating to regional cycling were compiled to understand the behaviour of cyclists within the Region of Waterloo. Specifically, data relating to average trip distance and trip speeds per cyclists were assessed (Figure 21).

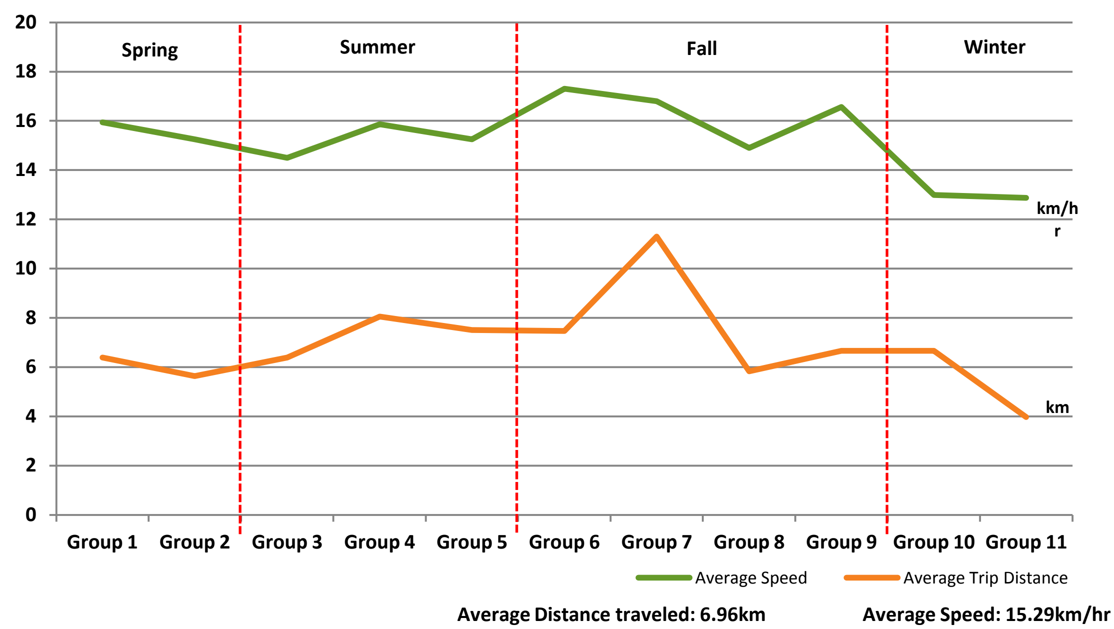


Figure 21 Average Trip Length & Speed

As previously noted in day-level statistics (Figure 20), macro-level data exhibits similar characteristics, where speeds and distances decreased during the off-season (winter). Most interestingly, when overlaying the computed average trip distance of 7 km from Kitchener's City Hall (Figure 22), we are able to note that typical cycling activity (travel distance) provides access to much of the Region.

Figure 22 Distances Accessible within a 7 km Buffer from Kitchener City Hall

It can be interpreted from these results that cycling has the ability to provide necessary transportation access within the Region (and other similar sized municipalities), and offers a feasible alternative to other less sustainable modes.

Household demographics

Academic research has indicated that auto ownership plays an influential part in mode choice. Households with greater access to automobiles have been found to use more sustainable modes less frequently. We were interested in assessing the applicability of these assumptions for our sample.

To this end, participants were asked two questions to understand the role of cycling and their auto ownership.

1. How many licensed drivers live in your household?
2. How many automobiles are owned or leased by members of your household?

Results from these responses where cross-tabulated and summarized in Table 6 below.

Table 6 Number of Licensed Drivers vs. Number of Vehicles Owned per Household

		Number of autos owned by household members				
		0	1	2	3+	Sum
Number of licensed drivers	0	3%	0%	0%	0%	3%
	1	9%	10%	0%	0%	19%
	2	4%	36%	20%	1%	62%
	3+	0%	4%	9%	4%	16%
	Sum	16%	50%	29%	5%	100%

In the table above, cells highlighted in orange show the percentage of households in our study that owned or leased a larger number of vehicles in comparison to the number of licensed drivers. Interestingly, in our sample only 1% (or about 4 households) owned more vehicles than licensed drivers. Cells highlighted in blue represent households in which fewer vehicles are owned than licensed drivers. Within our sample, this accounts for 62% of our households. Cells that have been left unshaded diagonally represent cases in which there are an equal number of vehicles to licensed drivers within a household. This totals to 37% in our sample.

Interpretation of these results indicates that cyclists in our study experience a costs saving by cycling. This is to say, by cycling, cyclists have an opportunity to own fewer vehicles, ultimately reducing household expenditures on transportation. The CAA estimates annual auto ownership costs to be $7,450 (CAA, 2012).

Motivations and obstacles to cycling

In Chapter 2, the literature identified many commonly cited motivations for and obstacles to cycling. The survey asked respondents to rank the relative importance of many of these. A discrete scale from 1 – least important – to 5 – most important – was used. To assess importance, we computed the average score for each motivation for and obstacle to cycling. Results are illustrated in the following tables.

Table 7 Motivations for Cycling

Variable	Importance
Improves health	4.24
Contribution to environment	4.05
Allows for recreation	3.56
Lower cost compared to other modes	3.49
Convenience compared to other modes	3.42

The strongest motivation for cycling is the health benefits attained, followed by environmental implications. Interestingly, costs and convenience compared to other modes were also cited as important. This ranking may arise because:

- Cycling is faster than walking;
- Cycling has the ability to provide greater route choice and directness (building entrances rather than parking facilities, use of trails and roadways) than by auto;
- Urban trips lengths and speeds between auto and bicycle do not produce a significant travel time saving, and hence are comparable; and
- Cycling requires a lower capital and annual investment cost for travel.

Given these results, it can be inferred that increased investments in cycling infrastructure to improve convenience have the potential to accommodate a much larger share of travel.

It is also important to understand what limits cycling activity. By designing to eliminate obstacles to cycling, we can better-understand cycling behaviour and a larger mode share can be attained. To this end, Table 8 reflects the relative strength of often-cited obstacles to cycling. These factors should be noted as identified obstacles to current cyclists (gathered by our study), and not those experienced by prospective cyclists.

Table 8 Obstacles to Cycling

Variable	Importance
Feels unsafe	3.85
High traffic volumes	3.79
Poor motorist behaviour	3.76
Many stops	3.76
Lack of bike parking	3.75
Poor weather	3.53
Poor road conditions	3.50
Travel time is long	2.96
Distance travelled is long	2.69
Route not scenic	2.25

Not surprisingly, the highest ranked factors relate directly to safety and the interactions with motorists. Lower ranked variables such as route not scenic, and travel time and distance suggests that cyclists choose their routes based on safety (their highest concern) and accept longer travel times and distances for this trade off. Recommendations that may be drawn from these results include:

- Multimodal interaction training – both for cyclists and motorists. Understanding travel behaviours and movement patterns for each mode;
- Infrastructure investments to improve cycling safety on corridors that experience high traffic volumes and cycling activity; and
- Maintenance – in terms of cycling facilities (quality and operation) and weather considerations (debris removal and maintenance).

As previously mentioned, there exists a potential to utilize these rankings of obstacles to cycling when assessing the relative importance of variables in the development of mode choice models. Specifically, these data can be used as the calibration constants, a_i in the Bicycle Compatibility equation (Eq. 2). In Table 9, a propose mapping of the stated weights to five BCI variables are put forth.

Table 9 Weighted BCI Variables

	BCI Variables	Study Variables	Weight
1	85th percentile speed of traffic	Feels unsafe	3.85
		Poor motorist behaviour	3.76
2	Curb lane volume	High traffic volumes	3.79
3	Other lane volume		
4	Presence of residential roadside development	Many stops	3.76
5	Presence of a bicycle lane or paved shoulder	Poor road conditions	3.50
		Lack of bike parking	3.75

Benefits of cycling to transportation network

As previously described, households that have one or more regular cyclists have lower ratios of vehicle ownership to licensed drivers. The evidence previously presented also suggests that households in this study are not financially limited to cycling as many households have higher than regional incomes. Many chose to use this mode to derive additional benefits in terms of reduced household expenditures, improved health, and lessened environmental impact. While this analysis explains the benefits to cyclists, the presence of increased cycling also improves the functioning of the overall transportation network. To demonstrate this point, the weekday departure times of cycling trips are plotted in Figure 23.

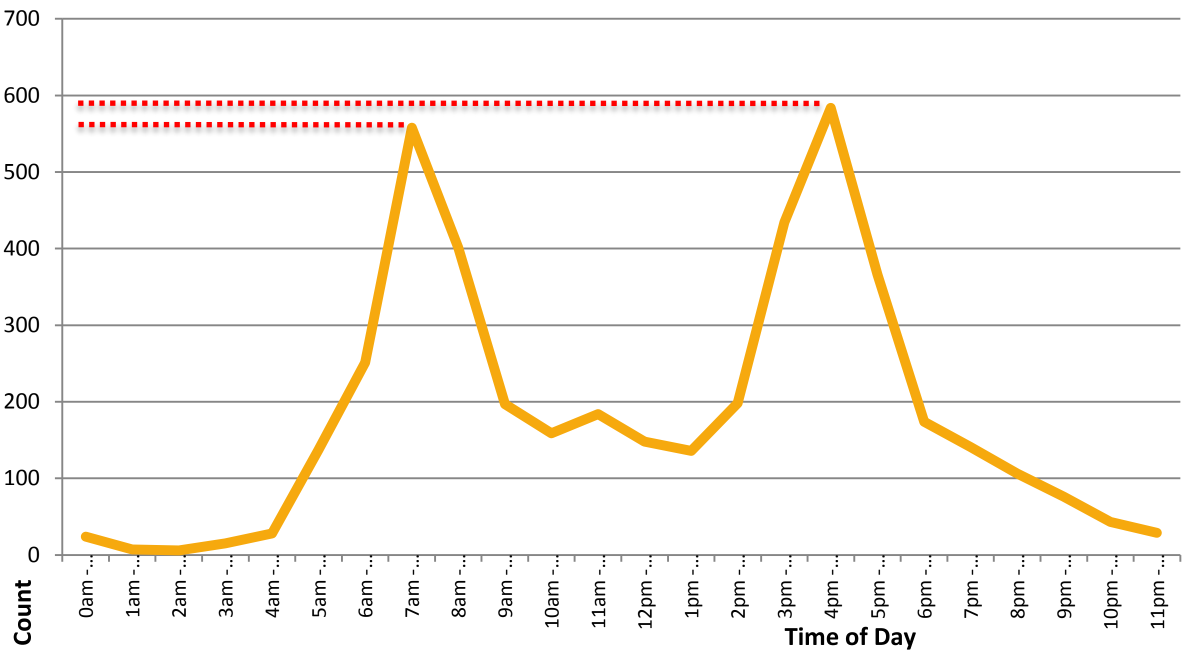


Figure 23 Weekday Departure Times

Two very strong peak periods exist. Departure times for the cyclists in this study coincide with the heaviest travel demand periods – the AM peak (7:00am to 9:00am) and the PM peak (3:30pm to 6:00pm). These peak periods often experience higher volumes, congested traffic, delay, and increased travel time. The relationship between travel volume and travel time is frequently modeled using the "Bureau of Public Roads" (BPR) function (Figure 24), a non-linear relationship, where a small change in volume during peak periods, produces a significant change in total travel time.

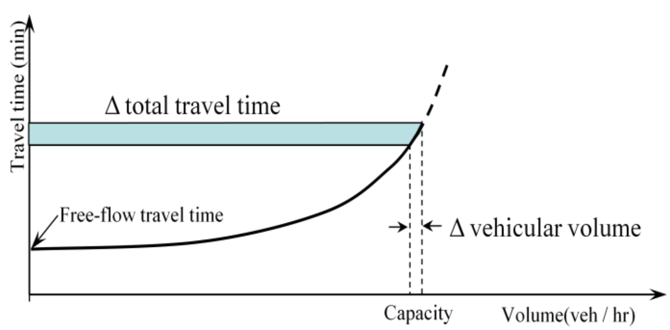


Figure 24 Bureau of Public Roads Function

The data in Figure 24 suggest that if cyclists were to travel by auto in lieu of cycling, the overall transportation system performance would be negatively affected. That is, by having travelers cycle rather than drive in peak periods, significant travel time savings can be attained by motorists.

Cyclists' travel alternatives

One commonly cited obstacle to cycling is climate. The data gathered in this study suggest that fewer people cycle in winter months and the trips made tend to be shorter in distance. These observations imply that cyclists frequently require alternative transportation in periods when weather or other impediments limit the ability to cycle. To understand how cyclists meet their travel demands in periods when cycling is not feasible, we asked cyclists to indicate the percentage of trips they currently make by cycling and other modes "in-season" – in periods with cycling supportive weather – and "out of season" – when weather is likely to dissuade cycling. The results are shown in Figure 25.

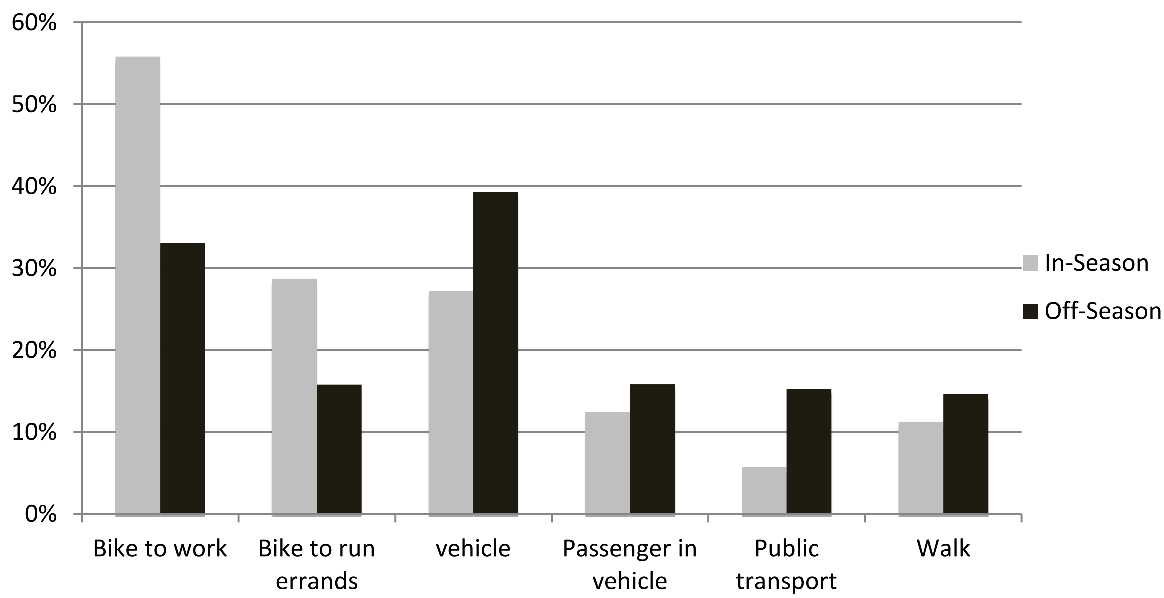


Figure 25 Seasonal Travel Variation

The differences in travel activity between in-season and off-season are shown above, and results suggest that cyclists are approximately half-as-likely to use their bicycles for work and errands during the off-season. During winter periods, the majority of these trips are replaced by increased auto and public transport use, with some growth in walking and as passenger in vehicles. This decrease in off-season cycling activity influences the overall transportation network, as increased volumes and travels times are experienced by all motorized users.

Next cyclists were asked which mode of travel they would use if cycling were not available. These results are shown in Figure 26.

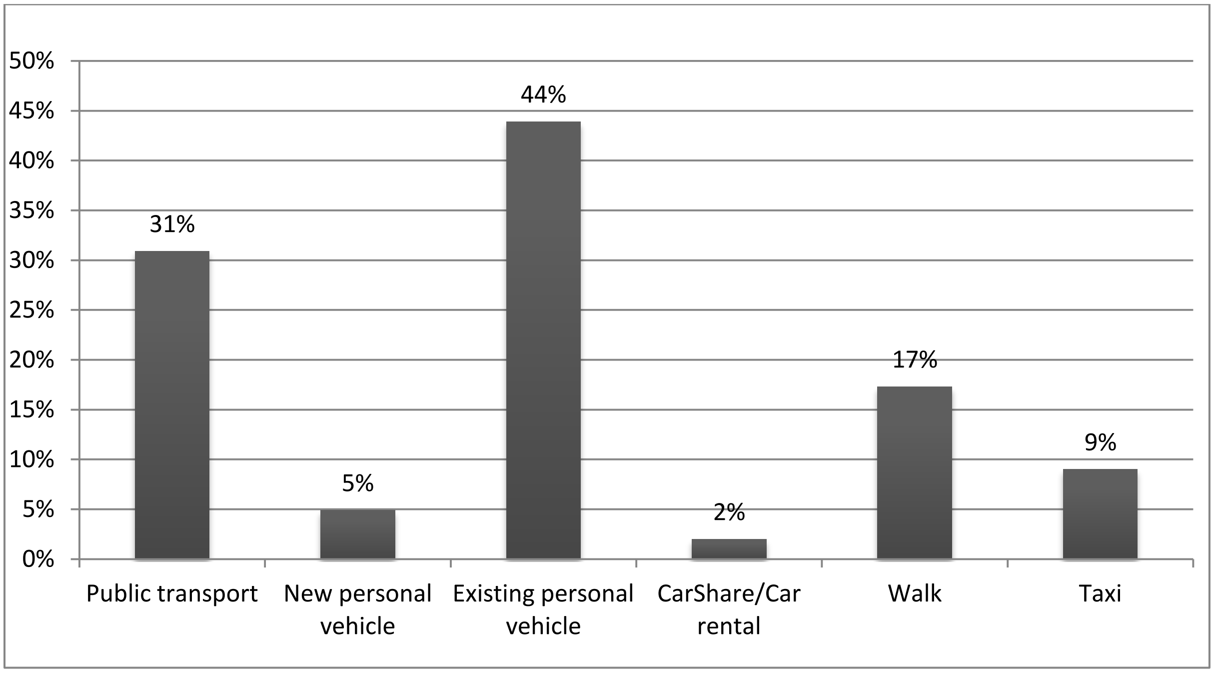


Figure 26 Alternatives to Cycling

Interestingly, these results suggest that 49% of our cyclists (or approximately 200 cyclists) would use a vehicle in the absence of cycling. This result reinforces previously revealed seasonal behaviour, where off-season travel shifts towards motorized modes. Moreover, these data also reinforce the idea that in the absence of cycling, auto use would increase and system performance would degrade.

Increasing cycling attractiveness

It is important to identify what steps can be taken to increase the attractiveness of cycling within urban setting. To better understand these steps hazards and infrastructure utilization are assessed.

Specifically:

- What are potential hazards to cyclists; and
- How is travel behaviour and route choice affected by infrastructure

Participants were asked to flag hazards on their daily cycling journeys using distributed GPS loggers. Figure 27 below shows the distribution of hazards per season. It can be noted that the ratio of hazards to cyclists remains relatively constant throughout the seasons on a per cyclist basis. However, trip lengths are shorter in off-season periods and, as a result, the hazard rate per unit of distance travelled is slightly higher as shown in Figure 27.

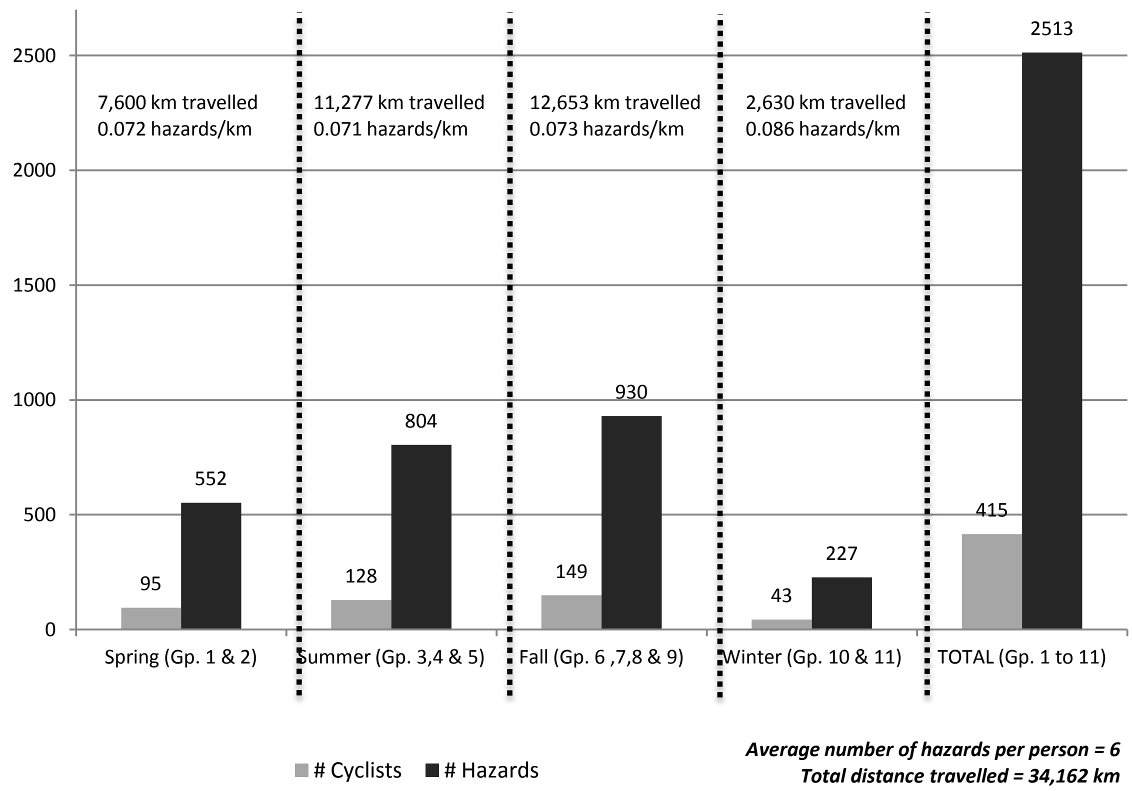


Figure 27 Number of Cyclists and Hazards Recorded per Season

Next, hazards points were extracted from the data, and spatially joined to a map of the Regional road and trail network. Figure 28 illustrates the recorded hazards, and can be interpreted in the following manner. For each segment of the network, unique colours depict the number of recorded hazards. As the number of hazards increase, road and trail segments are sorted into bins, ranging from 0 hazards to over 15.

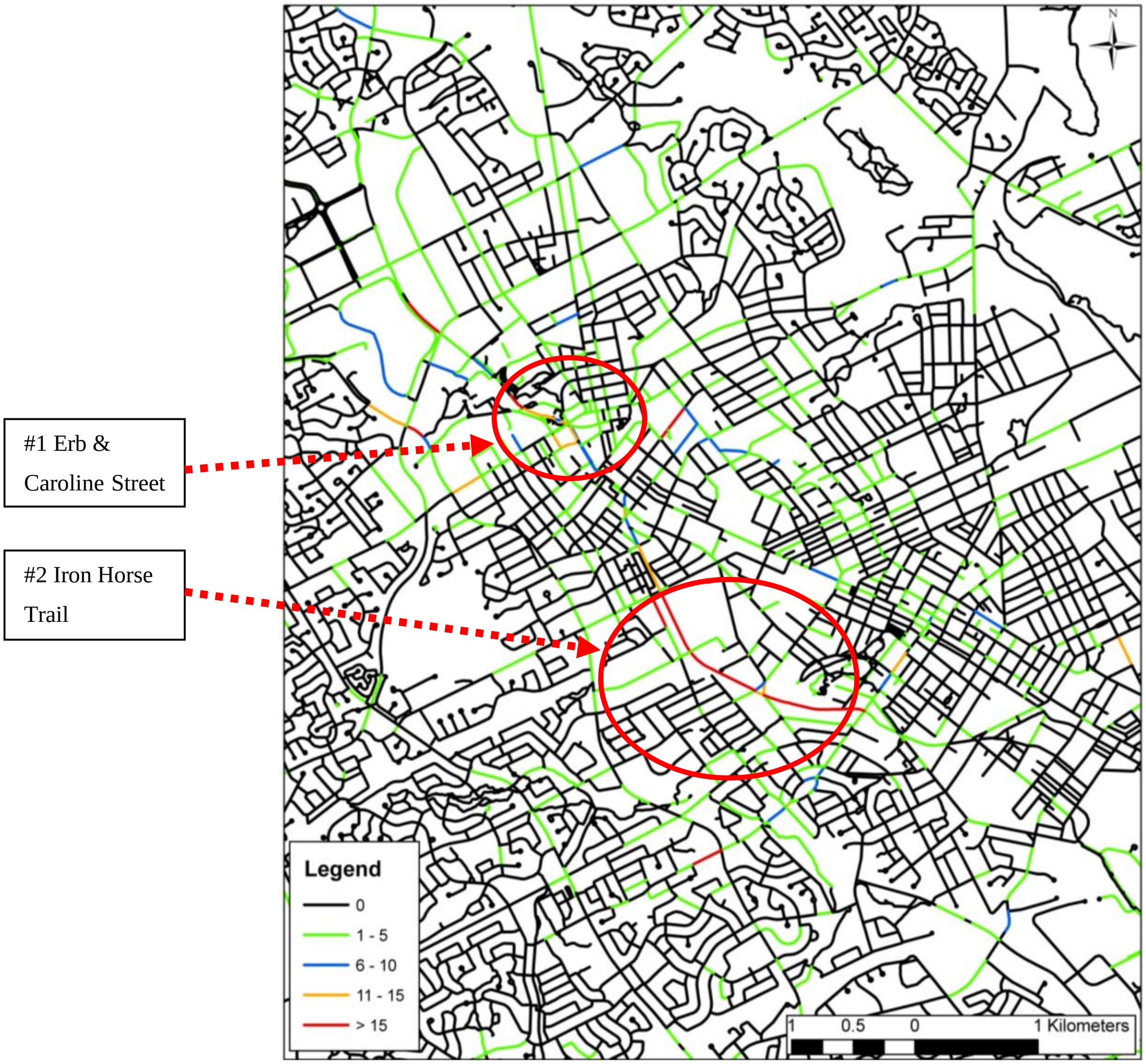
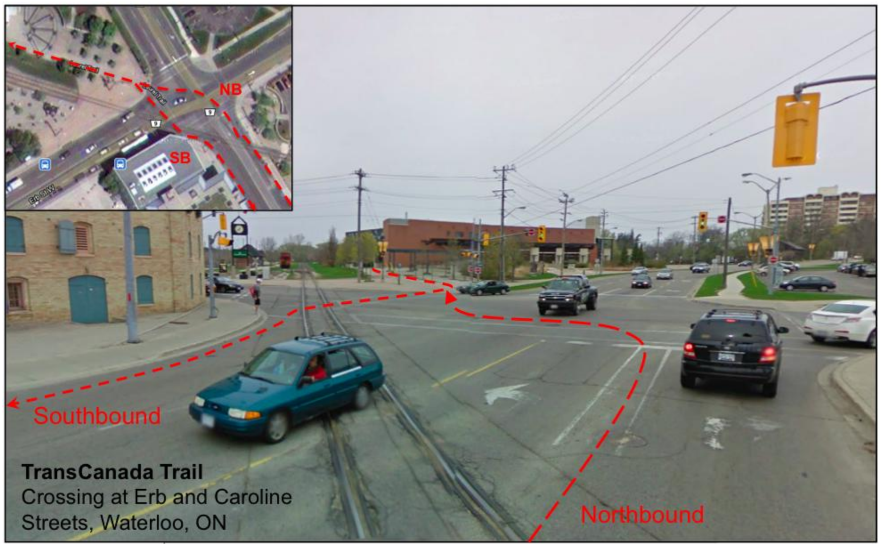


Figure 28 Density of Hazards on Shared Network

It should be noted, that some road segments (as illustrated in ArcGIS) are larger than others, and as a result have been able to capture a greater number of hazards. As well, in some instances multiple hazard flags have been recorded for an individual hazard, as this hazard could be particularly dangerous or frequently experienced.

From Figure 28 we can note two major concentrations of hazards. The first is the intersection of Caroline and Erb Streets in Waterloo. This intersection is located south of Waterloo Park (and the Universities of Waterloo and Laurier) and is part of the Trans-Canada National Trail. This intersection experiences high motorists and cycling volumes, and has been repeatedly flagged by cyclists as dangerous. A plan and streetview are presented in Figure 29. Note the complexity of the left turn movement for northbound cyclists. Also note the presence of the rail tracks, which extends the crossing distance for southbound cyclists.



Hazards:

1. One-way street
2. Irregular routes (SB and NB)
3. Railway Tracks
4. Large intersection
5. Connectivity
6. Presence of multiple parking lots
7. High volumes

Figure 29 Caroline and Erb Streets

Secondly, we note in the centre of the map (Figure 28) the Iron Horse Trail that connects the Cities of Waterloo and Kitchener (Figure 30). This trail, which is also a part of the Trans-Canada National Trail is highly used as a mixed-use path and allows regional residents to travel amongst neighbouring municipalities.

Hazards:

1. Abrupt street crossing – motorized traffic and pedestrians
2. High volume arterial traffic
3. Poor signage
4. Connectivity
5. Poor visibility

Figure 30 Iron Horse Trail

While the trail is designated to the controlled intersection to the northeast, the most direct path for cyclists along this trail is to cross Victoria and Strange streets mid-block. Anecdotal observations suggest that cyclists most often choose the most direct path. This situation reflects an opportunity where investment in traffic calming and cycling supportive infrastructure may increase cyclists' safety.

Investigation also took place to examine if cyclists would travel further to reach attractive (more bikeable) infrastructure. Specifically, how far, and how long would cyclists travel out of their way and why. Essentially, I aimed to answer how cyclists' travel behaviour and route choice is affected by infrastructure.

As discussed in the methods section, one impact of roadway network design is that with curvilinear, discontinuous networks, cyclists are required to travel longer than necessary distances to travel between origin and destination. Excess Travel (see equations 4 and 5) defines this distance relative to the x,y shortest path.

Excess travel was computed for all origin destination pairs in the data set. In Figure 31, the cumulative percentage of trips is plotted as a function of the excess travel.

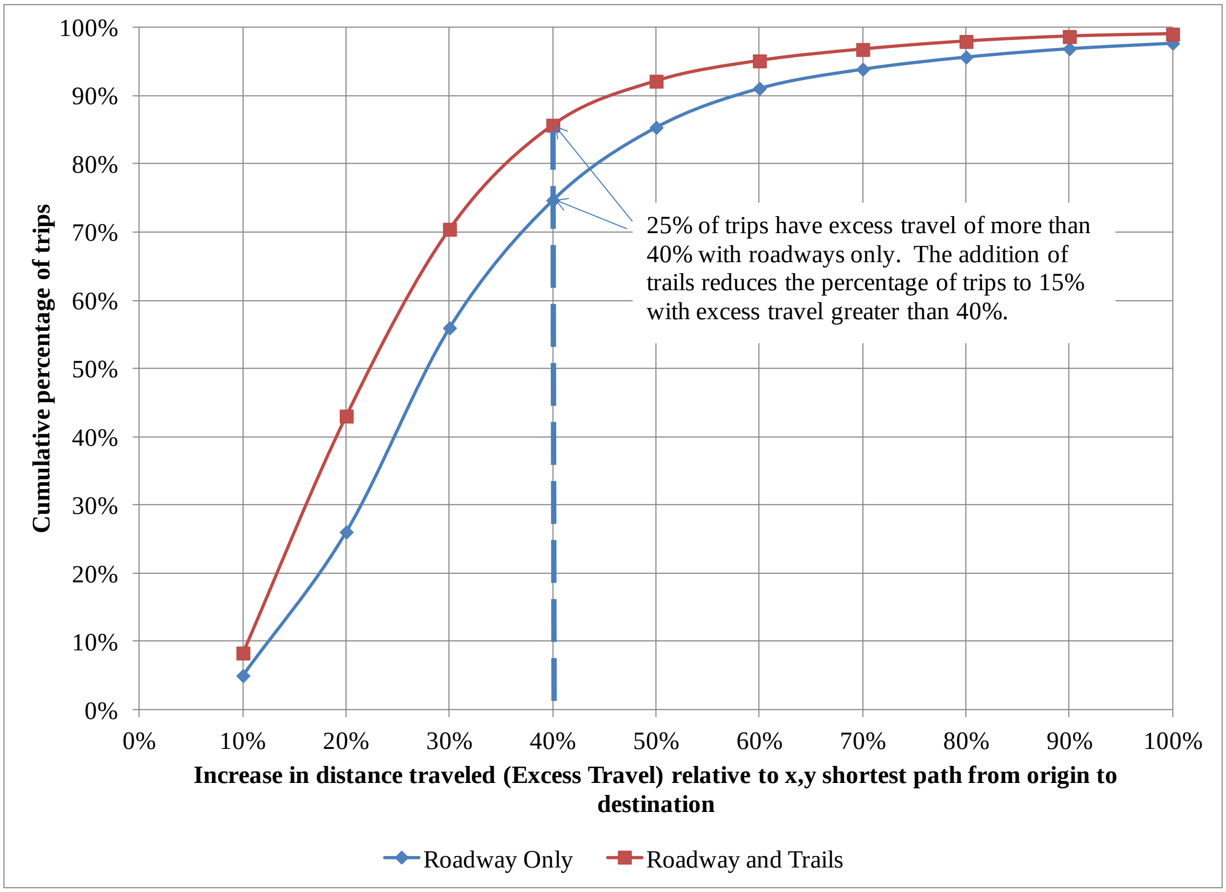


Figure 31 Change in Travel Distance

We can interpret these data in the following manner. Approximately 8% of origin destination pairs are connected by a path along roadways and trails which exceed the x,y (Euclidean distance) by less than 10%. Similarly, 43% of OD pairs have road and trails paths that exceed the minimum path by less than 20%. The data in Figure 31 show the impacts of trails on reducing excess travel distance. With the addition of trails – greater integration and connectivity allows for reduced cycling distances, where 85% of trips have excess travel (with trails) ≤ 40%, and 75% of trips have excess travel (roadway only) ≤ 40%.

Next the ratio of the actual path taken (with recreational trips removed) was compared to the shortest available path on the roadway with trails network. This was undertaken to observe how far cyclists deviate from the shortest available path. Essentially, this metric calculates observed amongst cyclists in the study.

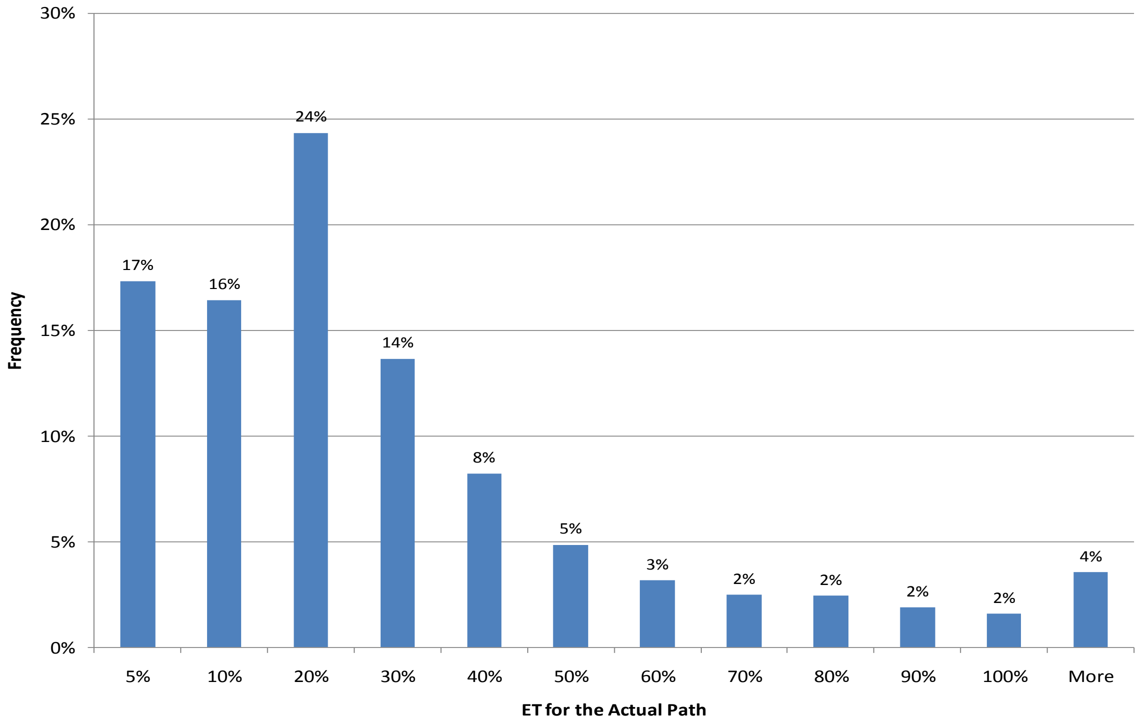


Figure 32 Excess Travel - Actual Path to Shortest path

These data reflect the dichotomy of cycling opportunities in the Region of Waterloo. For approximately 33% of observed trips, the actual path taken exceeds the shortest possible path by less than 10%. This indicates that about $\frac{1}{3}$ of the trips in the study are made with very little excess travel. Conversely, the data in Figure 32 indicate that 20% of trips taken required more than 40% excess travel. This suggests that nearly $\frac{1}{5}$ of trips taken were connecting origin destination pairs via a path requiring significant excess travel. Presumably, this excess travel reflects a cyclist's wish to travel on a path with greater safety or lower perceived "costs."

To further understand the impacts of roadway network design and built form on excess travel, the land use characteristics of TAZs containing low and high excess travel origin and destinations were analyzed. Trips with low excess travel typically began or finished in a zone with roadway patterns or land uses that are more supportive of bicycle travel (left-hand side of Figure 33). In contrast, trips with a high excess travel rate were found to have begun or finished in a zone considered unfriendly for bicycle travel (right-hand side of Figure 33).

Figure 33 TAZs with Low (left) and High (right) Excess Travel

Graphically, we are able to see that infrastructure characteristics of these two zones vary significantly. Zones with low excess travel support cycling with more traditional grid-pattern layouts, and increased bicycle facilities. Zones, such as that on the right of Figure 33, have been planned in a more contemporary layout, where cul-de-sac neighbourhoods are surrounded by high volume arterials.

Given this, it may be derived that bikeability is strongly correlated with cycling activity. This relationship shows a positive association, where more bicycle friendly infrastructure results in increased cycling activity. It can be interpreted that cyclists are willing to increase their travel times to reach more bicycle friendly infrastructure, and by increasing bikeability, we can shorten travel times, ultimately reducing a cyclists' cost of travel.

Maximizing the value of the data

In order to maximize the value of the data, a database is proposed and encompasses two distinct sections.

1. An Access database which stores demographic and cyclist level statistics;
2. A Geodatabase (with 3 feature classes) which stores cyclists’ and track level statistics.

Software requirements for this database include;

1. *Microsoft Access 2007/2010*
2. *ArcGIS 10*

Section 1: Access Database

Survey data and basic trip information collected from each participant was stored in a comprehensive database, built in Microsoft Access. This database was developed to enable an individual to search for cyclists’ track information based on a number of survey and GPS combinations (Figure 34), including:

- General characteristics;
- Driver characteristics;
- Trip information;
- Cyclist characteristics;
- Cycling initiative preferences;
- And purchases and maintenance.

Results that matched the specified criteria of the query were exported to a text file. The content of the text file was used to display the tracks of the particular cyclist(s) in ArcGIS.

The following steps outlined the procedure to complete a query:

1. Open "*GPS Cycling Study*” database in Microsoft Access 2007/2010.
2. Open the “*Query Search Form*”.
3. Select the desired search criteria and specify the value of each criterion.
4. Click “*Run*” Query to search database.
5. Click “*Save Results*” to save the query to a text file (insert desired query output name).

The text file was saved in the same folder as the Access database (and on the clipboard) under the desired query name.

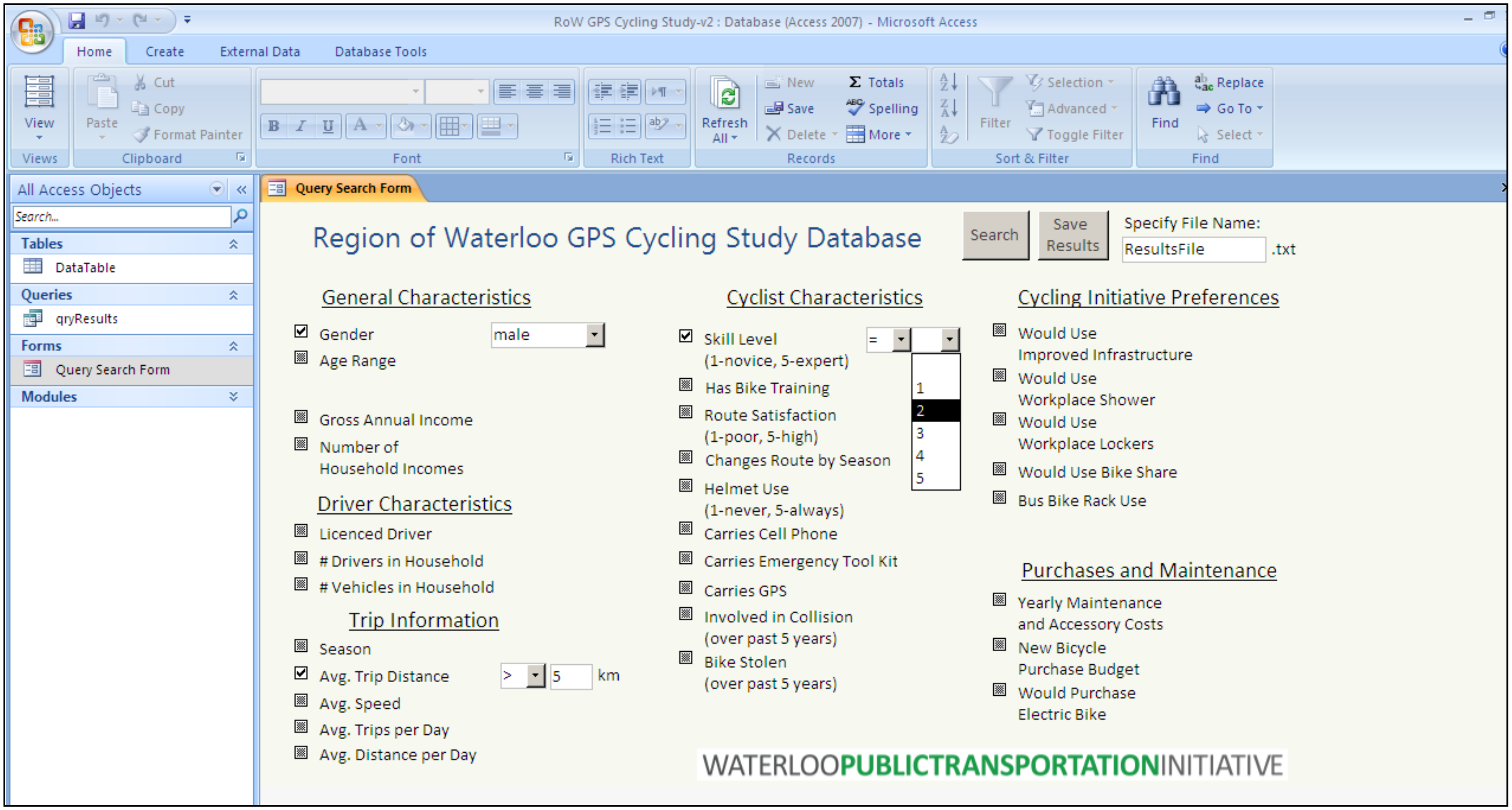


Figure 34 Microsoft Access Database

Section 2: ArcGIS GeoDatabase

Given the exported *text file* from the Access database, queried data can be illustrated and spatial analysis can be conducted in ArcGIS 10.

First, within ArcGIS, load the Geodatabase;

Feature classes:

1. *Polylines of Trips*;
2. *Origin and Destination Points*;
3. *Hazards*;

And any additional layers (Roads, TAZs, etc…)

In the selected Feature Class, right-click, and under *"Properties"*, "*Definition Query"* copy and paste the *Text File* output from Access (Figure 35).

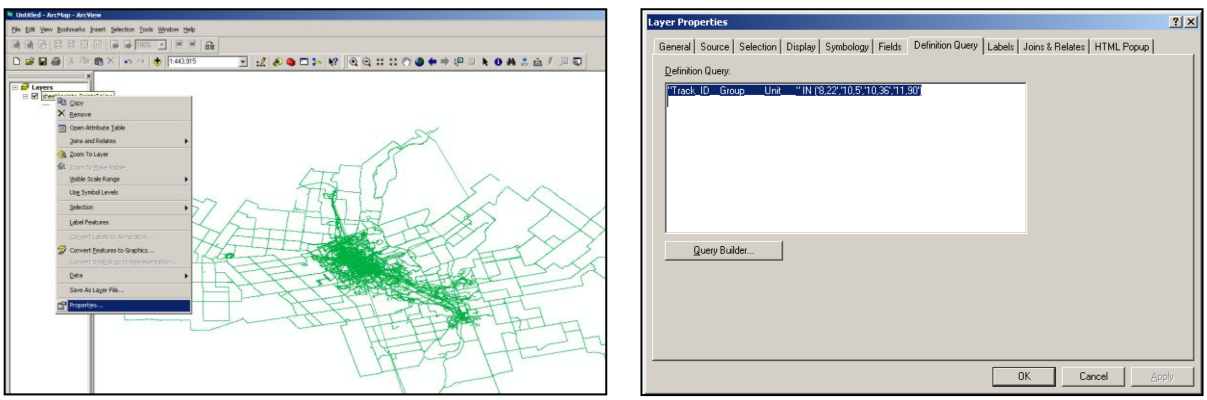


Figure 35 Properties & Definition Query

Sample Text File output for "Involved in Collision & Has Bike Training"

Query:

"Track_ID__Group____Unit___" IN ('5,46','5,94','7,57','7,60','7,80','7,96','8,7','8,23','8,32','8,35','8,46','8,47','9,93')

This will display only those units (trips, origins & destinations, and/or hazards – depending on which Feature Class was/were selected) that match the queried criteria (Figure 36).

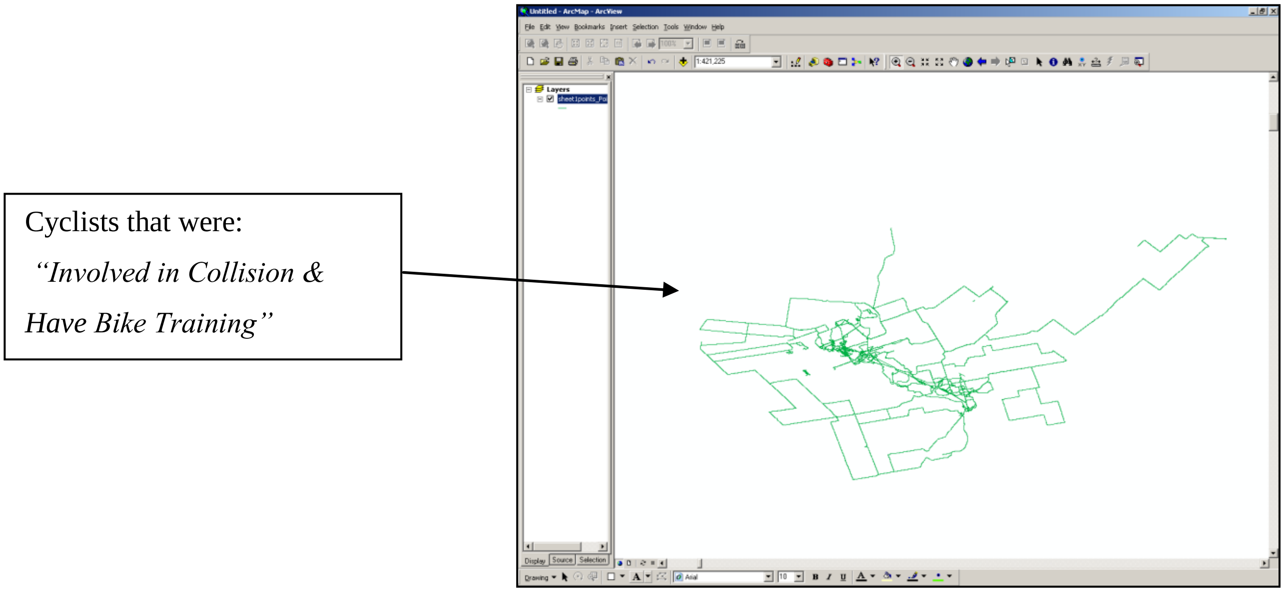


Figure 36 Queried Data

Given this selection, a report can be requested by ArcGIS to summarize unit level statistics (under Attribute Table). The selection can also be exported as a new layer, where further investigation can be conducted based on individual tracks within the selected units.

Developing a generalized cost function for cycling

Utility theory *"is an economic concept that attempts to measure the utility [satisfaction] derived from a good or service… [and] ranks alternatives in their order of preference to the consumer"*(Business Dictionary, 2012). In transportation planning, the concept of utility is translated into generalized costs – a combination of time, convenience and out of pocket expenses. Travelers select the destination, mode and path that minimize their generalized costs for a given trip.

Mode choice models assess the probability of choosing a mode for a given OD pair based on a comparison of generalized costs of competing modes.

For auto and transit, generalized cost models are well defined. Equation *(6)* presents a common example of a generalized cost model for transit.

$$GC_t = (\propto_0 AT + \propto_1 WT + \propto_2 IVT)VOT + fare \quad (6)$$

Where:

GC_t= generalized cost of a trip by transit,
$\propto_i$= relative importance of the component,
AT = access time to the line (min),
WT = waiting time, modeled as half the headway for short headways (min),
IVT = in-vehicle time (min),
VOT = value of time (dollars per minute), and
*f*are = transit fare (dollars).

(Casello, Nour, and Hellinga, 2009)

In the case of bicycling, there exists no widely adopted generalized cost model. However, our data (and previous research) suggest that a traveler's perceived cost for cycling depends upon several key variables, including: length of a trip; changes in elevation; speed of adjacent vehicular travel; volume of adjacent vehicular travel; presence (or absence) of bicycling facilities (on-road cycling lane or off-road path); the nature of the roadway (commercial or residential); the presence (or absence) of on street-parking; and others.

In order to generate a meaningful generalized cost formulation, it is necessary to understand the relative importance of each of these components – similar to the $\propto_i$ values shown in Equation 6. The method by which these weights are typically estimated is by presenting travelers alternative paths with different characteristics. The traveler then identifies the preferred path amongst the alternatives provided. With sufficient observations, the relative importance of each path component can be quantitatively determined using logistic regression.

Data collected in our research include actual paths for over 4,800 origin and destination pairs. Once recreational trips are excluded, it is possible to interpret the observed paths as the lowest generalized cost paths. Little is known, however, about alternatives not chosen by the cyclists. In order to develop and calibrate a generalized cost model for cycling, there is a need to automate the generation of alternative paths, and their characteristics, that were not chosen by cyclists such that the attributes of the lowest generalized cost paths (observed paths) can be compared to the alternatives.

In this research, two paths were previously identified for each OD pair: the shortest path along the roadway and the shortest path along the roadway and trails. Thus, for any trip where the observed path is not one of these shortest path, data exist on both the observed (selected) and two alternatives (not selected paths).

For each observed and alternative path, information on each segment of the path can be extracted. Through use of regionally developed GIS layers, specific data relating to length, elevation, travel properties (posted speed, vehicle volumes, number of lanes), and presence of cycling infrastructure (trail, bike lane, etc.) can be extracted for all link-segments (see Figure 37). Each path is comprised of common (shared) and unique segments that make up their route. A composite path parameter can be estimated by using a weighted average (by length of segment) over all segments on that path. The differences in characteristics of each of these paths can be converted through logistic regression to the weighting of attributes that make up cyclists' path choice. Table 10 shows a hypothetical weighted output for the segments and paths shown in Figure 37.

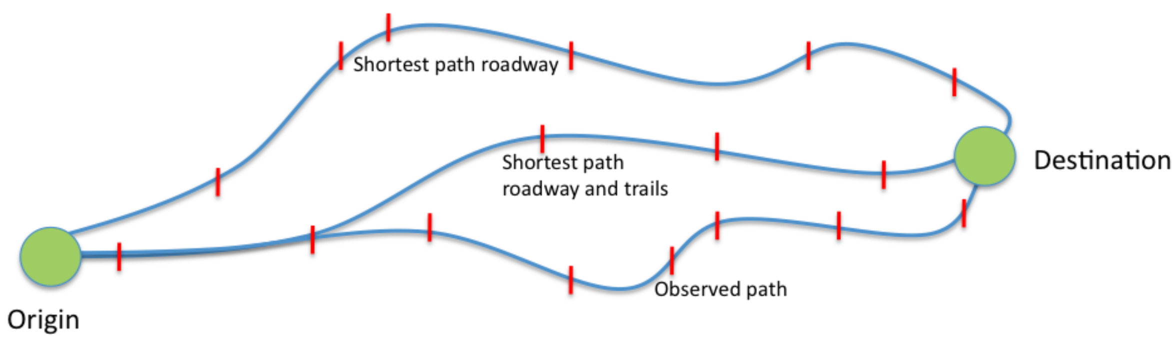


Figure 37 Cycling Mode Choice Alternatives

Table 10 Comparison of Segment Characteristics

Variables	Shortest path roadway	Shortest path roadway & trails	Observed path
Presence of a bike lane	20%	45%	95%
Posted speed limit	80km/hr	50km/hr	50km/hr
Length	7 km	6.8 km	9km
Traffic Volume	800 veh/hr	400 veh/hr	525 veh/hr
Number of lanes	1.8	1.6	1
Total # of Segments	7	6	9

Based on the final segments highlighted in Figure 37, regression analysis can be run to determine the coefficients of a cycling generalized cost model of the form:

$$GC_{OD} = \propto_1 length + \propto_2 speed + \propto_3 volume + \propto_4 bike\ lane + \propto_5 number\ of\ lanes \qquad (7)$$

Chapter 6
FUTURE CONSIDERATIONS

Results discussed in this thesis have provided direction on future policies influencing cycling legislation, transit, and future growth management within the Region of Waterloo. Specifically, findings have allowed transportation professional to better predict and plan for transportation demand management strategies.

In summarizing the analysis presented in this thesis, five key findings can be extracted. First, our data suggests that cyclists are above average earners, and choose to cycle for health benefits, not because they are limited to cycling by income. Secondly, by cycling, households are able to own fewer vehicles than licensed drivers, allowing for reduced household expenditures. Third, data suggest that many trips made by cyclists are commute based, and in removing these travelers from the motorized network during peak periods, the overall transportation system performance is improved. Fourth, with the introduction of trails to a network, greater connectivity and directness of route allow for decreased travel times for cyclists, and increased safety as interactions with motorized modes are decreased. Finally, in assessing route choice behaviour, we were able to identify that cyclists are willing to increase their Excess Travel (deviation from the shortest available path) to reach more bicycle friendly infrastructure.

Given these results, a better understanding of who cyclists are, where they travel to, and their relative motivations and obstacles to cycling will give way to improved planning and engineering initiatives catered to cyclists. Inclusive to this, the recent approval of Transit (LRT) and adapted Bus Rapid Transit (aBRT) system along the central transit corridor of the Region has generated increased investment and policy programming in the development of a multimodal network aimed at complementing modes, and increasing system performance.

The work presented in this thesis has been based on primary data collected in a yearlong cycling study in the Region of Waterloo. As may be gathered, there exists a large potential with the data that has been made available by this study. Future considerations on expanding on the developed structure for a cycling generalized cost model, and greater assessment of demographic profiles in relation to cycling activity are among possible areas that would thrive well with added attention.

With consideration on future population growth and increased vehicle ownership, the make-up of contemporary cities continues to change. Improved transportation options, land-use management, and accessibility are essential. Transportation Demand Management (TDM) and the promotion of Active Transportation provide innovative approaches in the development of efficient, balanced, multimodal transportation networks and need to be supported as we move forwards.

In the words of Albert Einstein, "*life is like riding a bicycle. To keep your balance you must keep moving*".

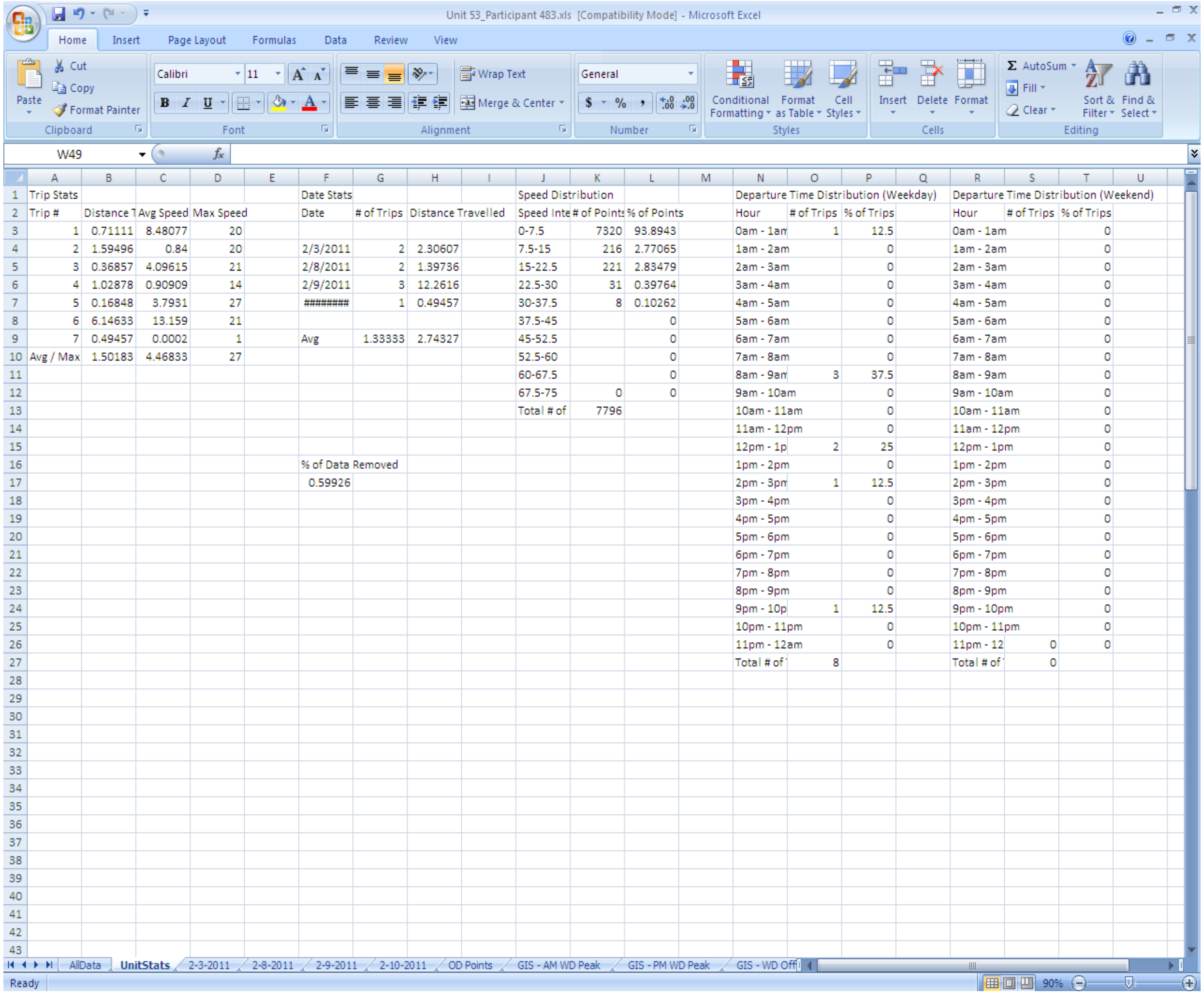
Appendix A

Data Sample

Group 11, Unit 53, Track 1

ID	Track #	Date	Time	Date	Start Time	Lat	N/S	Long	E/W	Alt m	Speed km	Distance
1	1	2/3/2011	13:05:01	2/3/2011	8:05:01	43.45925	N	-80.5268	E	339.5762	9	
2	1	2/3/2011	13:05:06	2/3/2011	8:05:06	43.45937	N	-80.5267	E	326.304	15	0.018623
3	1	2/3/2011	13:05:11	2/3/2011	8:05:11	43.45952	N	-80.5265	E	318.5003	15	0.023089
4	1	2/3/2011	13:05:16	2/3/2011	8:05:16	43.45964	N	-80.5263	E	305.8256	17	0.021762
5	1	2/3/2011	13:05:21	2/3/2011	8:05:21	43.45979	N	-80.526	E	298.233	17	0.025465
6	1	2/3/2011	13:05:26	2/3/2011	8:05:26	43.4599	N	-80.5258	E	284.7511	14	0.020657
7	1	2/3/2011	13:05:31	2/3/2011	8:05:31	43.46003	N	-80.5257	E	263.6248	11	0.01896
8	1	2/3/2011	13:05:36	2/3/2011	8:05:36	43.46016	N	-80.5254	E	269.5582	13	0.02267
9	1	2/3/2011	13:05:41	2/3/2011	8:05:41	43.46031	N	-80.5252	E	277.5272	16	0.025037
10	1	2/3/2011	13:05:46	2/3/2011	8:05:46	43.46045	N	-80.525	E	276.2942	14	0.023499
11	1	2/3/2011	13:05:51	2/3/2011	8:05:51	43.46055	N	-80.5249	E	257.1051	9	0.014915
12	1	2/3/2011	13:05:56	2/3/2011	8:05:56	43.46071	N	-80.5247	E	260.385	12	0.022901
13	1	2/3/2011	13:06:01	2/3/2011	8:06:01	43.46085	N	-80.5245	E	244.6082	15	0.02286
14	1	2/3/2011	13:06:06	2/3/2011	8:06:06	43.46098	N	-80.5243	E	230.0535	16	0.023842
15	1	2/3/2011	13:06:11	2/3/2011	8:06:11	43.46112	N	-80.5239	E	232.6759	18	0.030864
16	1	2/3/2011	13:06:16	2/3/2011	8:06:16	43.46128	N	-80.5236	E	255.4931	20	0.034911
17	1	2/3/2011	13:06:21	2/3/2011	8:06:21	43.46142	N	-80.5232	E	274.5126	16	0.030643
18	1	2/3/2011	13:06:26	2/3/2011	8:06:26	43.46147	N	-80.523	E	278.137	6	0.015732
19	1	2/3/2011	13:06:31	2/3/2011	8:06:31	43.46148	N	-80.5229	E	287.0109	0	0.009282
20	1	2/3/2011	13:06:36	2/3/2011	8:06:36	43.46145	N	-80.5229	E	286.8572	9	0.005351
21	1	2/3/2011	13:06:41	2/3/2011	8:06:41	43.46126	N	-80.5227	E	288.6855	19	0.026159
22	1	2/3/2011	13:06:46	2/3/2011	8:06:46	43.46105	N	-80.5225	E	289.2576	15	0.027987
23	1	2/3/2011	13:06:51	2/3/2011	8:06:51	43.461	N	-80.5224	E	285.2792	0	0.009105
24	1	2/3/2011	13:06:56	2/3/2011	8:06:56	43.46098	N	-80.5224	E	287.1891	0	0.004023
25	1	2/3/2011	13:07:01	2/3/2011	8:07:01	43.46099	N	-80.5224	E	290.6846	0	0.000946
26	1	2/3/2011	13:07:06	2/3/2011	8:07:06	43.46097	N	-80.5224	E	295.7595	0	0.002119
27	1	2/3/2011	13:07:11	2/3/2011	8:07:11	43.46097	N	-80.5224	E	299.1635	0	0.001519
28	1	2/3/2011	13:07:16	2/3/2011	8:07:16	43.46097	N	-80.5224	E	297.6402	0	0.000815
29	1	2/3/2011	13:07:21	2/3/2011	8:07:21	43.46097	N	-80.5224	E	296.2364	0	0.000196
30	1	2/3/2011	13:07:26	2/3/2011	8:07:26	43.46097	N	-80.5224	E	296.2364	0	0
31	1	2/3/2011	13:07:31	2/3/2011	8:07:31	43.46097	N	-80.5224	E	294.7131	0	0.000815
32	1	2/3/2011	13:07:36	2/3/2011	8:07:36	43.46097	N	-80.5224	E	294.7131	0	0
33	1	2/3/2011	13:07:41	2/3/2011	8:07:41	43.46097	N	-80.5224	E	294.7131	2	0
34	1	2/3/2011	13:07:46	2/3/2011	8:07:46	43.46096	N	-80.5224	E	294.1447	3	0.001315
35	1	2/3/2011	13:07:51	2/3/2011	8:07:51	43.46093	N	-80.5223	E	293.7533	9	0.008549
36	1	2/3/2011	13:07:56	2/3/2011	8:07:56	43.46105	N	-80.5221	E	291.7418	16	0.021367
37	1	2/3/2011	13:08:01	2/3/2011	8:08:01	43.46122	N	-80.5219	E	294.2784	16	0.024714
38	1	2/3/2011	13:08:06	2/3/2011	8:08:06	43.4614	N	-80.5217	E	297.8615	18	0.027
39	1	2/3/2011	13:08:11	2/3/2011	8:08:11	43.46155	N	-80.5215	E	302.2155	10	0.020146
40	1	2/3/2011	13:08:16	2/3/2011	8:08:16	43.46161	N	-80.5215	E	306.5256	0	0.007281
41	1	2/3/2011	13:08:21	2/3/2011	8:08:21	43.46159	N	-80.5215	E	305.1779	0	0.002896
42	1	2/3/2011	13:08:26	2/3/2011	8:08:26	43.46156	N	-80.5215	E	306.7574	0	0.002931
43	1	2/3/2011	13:08:31	2/3/2011	8:08:31	43.46156	N	-80.5215	E	303.9498	1	0.000323
44	1	2/3/2011	13:08:36	2/3/2011	8:08:36	43.46158	N	-80.5215	E	301.2056	9	0.003024
45	1	2/3/2011	13:08:41	2/3/2011	8:08:41	43.46174	N	-80.5213	E	294.3013	16	0.021852
46	1	2/3/2011	13:08:46	2/3/2011	8:08:46	43.4619	N	-80.5211	E	284.948	17	0.023588
47	1	2/3/2011	13:08:51	2/3/2011	8:08:51	43.46208	N	-80.5209	E	278.2269	15	0.025342
48	1	2/3/2011	13:08:56	2/3/2011	8:08:56	43.46227	N	-80.5209	E	276.6415	10	0.021296
49	1	2/3/2011	13:09:01	2/3/2011	8:09:01	43.46232	N	-80.5209	E	277.5745	0	0.006505
50	1	2/3/2011	13:09:06	2/3/2011	8:09:06	43.46238	N	-80.5209	E	281.1969	0	0.006652
51	1	2/3/2011	13:09:11	2/3/2011	8:09:11	43.46239	N	-80.5209	E	279.6455	2	0.001583
52	1	2/3/2011	13:09:16	2/3/2011	8:09:16	43.46239	N	-80.5209	E	279.6455	1	0
53	2	2/3/2011	17:07:37	2/3/2011	12:07:37	43.45962	N	-80.5284	E	279.0389	0	0.68214
54	2	2/3/2011	17:07:42	2/3/2011	12:07:42	43.45962	N	-80.5284	E	279.0389	0	0
55	2	2/3/2011	17:07:47	2/3/2011	12:07:47	43.45962	N	-80.5284	E	279.0389	0	0

Unit Statistic: Group 11, Unit 53, All Tracks



	A	B	C	D	E	F	G	H
1	Trip Stats					Date Stats		
2	Trip #	Distance T	Avg Speed	Max Speed		Date	# of Trips	Distance Travelled
3	1	0.71111	8.48077	20				
4	2	1.59496	0.84	20		2/3/2011	2	2.30607
5	3	0.36857	4.09615	21		2/8/2011	2	1.39736
6	4	1.02878	0.90909	14		2/9/2011	3	12.2616
7	5	0.16848	3.7931	27		########	1	0.49457
8	6	6.14633	13.159	21				
9	7	0.49457	0.0002	1		Avg	1.33333	2.74327
10	Avg / Max	1.50183	4.46833	27				
16						% of Data Removed		
17						0.59926		

	J	K	L
1	Speed Distribution		
2	Speed Inte	# of Points	% of Points
3	0-7.5	7320	93.8943
4	7.5-15	216	2.77065
5	15-22.5	221	2.83479
6	22.5-30	31	0.39764
7	30-37.5	8	0.10262
8	37.5-45		0
9	45-52.5		0
10	52.5-60		0
11	60-67.5		0
12	67.5-75	0	0
13	Total # of	7796	

	N	O	P	R	S	T
1	Departure Time Distribution (Weekday)			Departure Time Distribution (Weekend)		
2	Hour	# of Trips	% of Trips	Hour	# of Trips	% of Trips
3	0am - 1am	1	12.5	0am - 1am		0
4	1am - 2am		0	1am - 2am		0
5	2am - 3am		0	2am - 3am		0
6	3am - 4am		0	3am - 4am		0
7	4am - 5am		0	4am - 5am		0
8	5am - 6am		0	5am - 6am		0
9	6am - 7am		0	6am - 7am		0
10	7am - 8am		0	7am - 8am		0
11	8am - 9am	3	37.5	8am - 9am		0
12	9am - 10am		0	9am - 10am		0
13	10am - 11am		0	10am - 11am		0
14	11am - 12pm		0	11am - 12pm		0
15	12pm - 1p	2	25	12pm - 1pm		0
16	1pm - 2pm		0	1pm - 2pm		0
17	2pm - 3pm	1	12.5	2pm - 3pm		0
18	3pm - 4pm		0	3pm - 4pm		0
19	4pm - 5pm		0	4pm - 5pm		0
20	5pm - 6pm		0	5pm - 6pm		0
21	6pm - 7pm		0	6pm - 7pm		0
22	7pm - 8pm		0	7pm - 8pm		0
23	8pm - 9pm		0	8pm - 9pm		0
24	9pm - 10p	1	12.5	9pm - 10pm		0
25	10pm - 11pm		0	10pm - 11pm		0
26	11pm - 12am		0	11pm - 12	0	0
27	Total # of	8		Total # of	0	

Appendix B

Raw Survey

Survey Participant: _________ Return Date: __________ Unit # ____

NOTE: All information collected in this survey is confidential and the identity of the respondents will not be revealed.

You may decline to answer any question. <u>Please circle your answer(s) to the following.</u>

A. Respondent information:

1. What is your gender:
   a. Female b. Male c. Other

2. What is your age:
   a. Under 12
   b. 12 – 18
   c. 19 – 30
   d. 31 – 40
   e. 41 – 50
   f. 51 – 60
   g. Over 60

3. Please indicate all the sources where you heard about the project:
   __ Word of Mouth
   __ Email
   __ Newspaper
   __ Other: _________________________

4. Please estimate your gross annual income:
   a. Less than $24,999
   b. $25,000 - $49,999
   c. $50,000 - $74,999
   d. $75,000 - $99,999
   e. $100,000 - $124,999
   f. $125,000 - $149,999
   g. Over $150,000
   h. Decline to answer

5. Please indicate the number of people earning a stable annual income in your household:
   a. 1
   b. 2
   c. 3
   d. 4
   e. 5

6. For your regular in-season travel, what percent of one-way trips use these modes:
   __ Bike to commute
   __ Bike to run errands, see friends, etc.
   __ Drive a vehicle
   __ Passenger in a vehicle
   __ Public transport
   __ Walk

7. For your regular off-season travel (winter), what percent of the one-way trips use these modes:
   __ Bike to commute
   __ Bike to run errands, see friends, etc.
   __ Drive a vehicle
   __ Passenger in a vehicle
   __ Public transport
   __ Walk

8. If you were not able to ride your bike for an extended period of time, what mode of transportation would you use?
   a. Public transport
   b. New personal vehicle
   c. Used personal vehicle
   d. CarShare/Car rental
   e. Walk
   f. Taxi
   g. Other: ________________________

9. Do you have a valid drivers licence?
   a. Yes
   b. No

10. How many licensed drivers are in your household?
   a. 0
   b. 1
   c. 2
   d. 3+

11. How many vehicles are owned or leased in your household?
   a. 0
   b. 1
   c. 2
   d. 3+

B. Please rate the following questions based on your regular cycling route:

12. Do you use bike racks on buses?	Times per week				
	Never	1-2	3-4	5-6	7+
13. How satisfied are you with your regular cycling route (route you take most often)?	Not Satisfied				Very Satisfied
	1	2	3	4	5
14. How do you rate your cycling skill level?	Novice				Expert
	1	2	3	4	5
15. How often do you wear a helmet when riding your bicycle?	Never				Always
	1	2	3	4	5

C. Please evaluate the following based on your regular cycling routine:

16. Reasons for cycling:	N/A	Least Important			Most Important	
a. Health / fitness	0	1	2	3	4	5
b. Recreation	0	1	2	3	4	5
c. Low Cost	0	1	2	3	4	5
d. Help Environment	0	1	2	3	4	5
e. More Convenient	0	1	2	3	4	5

17. How you choose your regular cycling route:	N/A	Least Important			Most Important	
a. Shortest by distance	0	1	2	3	4	5
b. Shortest by time	0	1	2	3	4	5
c. Low amount of traffic	0	1	2	3	4	5

d. Feels safe	0	1	2	3	4	5
e. Route is scenic	0	1	2	3	4	5
f. Best road conditions	0	1	2	3	4	5
g. Fewest stops	0	1	2	3	4	5

18. Discouragements from cycling:	N/A	Least Important			Most Important	
a. Distance travelled is long	0	1	2	3	4	5
b. Time travelled is long	0	1	2	3	4	5
c. High amount of traffic	0	1	2	3	4	5
d. Feels unsafe	0	1	2	3	4	5
e. Route is not scenic	0	1	2	3	4	5
f. Poor road conditions	0	1	2	3	4	5
g. Many stops	0	1	2	3	4	5
h. Lack of bike parking	0	1	2	3	4	5
i. Poor motorist behaviour	0	1	2	3	4	5
j. Poor weather	0	1	2	3	4	5

D. Evaluate your top five of the following safety hazards:

	N/A	Not a Hazard			Serious Hazard	
19. Not being seen by cars at night	0	1	2	3	4	5
20. Not being seen by cars at dawn / dusk	0	1	2	3	4	5
21. Opening of parked car doors	0	1	2	3	4	5
22. Cars passing too close	0	1	2	3	4	5
23. Cars passing at high speeds	0	1	2	3	4	5
24. Cars with distracted drivers	0	1	2	3	4	5
25. Cars making right turns in front of you	0	1	2	3	4	5
26. Oncoming cars making left turns	0	1	2	3	4	5
27. Poorly maintained roads	0	1	2	3	4	5
28. Other cyclists not obeying traffic laws	0	1	2	3	4	5
29. Poor weather conditions	0	1	2	3	4	5

E. Please answer the following based on your regular cycling routine:

30. Do you frequently carry a cell phone or other communication device when cycling?	Yes	No
31. Do you frequently carry an emergency bicycle tool kit when cycling?	Yes	No

32. Do you frequently carry a device capable of recording your position via GPS?	Yes	No
33. Do you have a valid driver's license?	Yes	No
34. If a shower were available at or near your workplace, would you use it?	Yes	No
35. If a locker were available at or near your workplace, would you use it?	Yes	No
36. If a better network of cycling infrastructure was put in place, would you cycle more?	Yes	No
37. Would you consider purchasing an electric bicycle?	Yes	No
38. In the past 5 years, have you had a bicycle stolen?	Yes	No
39. In the past 5 years, have you had a collision while riding your bicycle?	Yes	No
40. Have you had any formal bicycle riding training?	Yes	No
41. Does your regular cycling route change based on the seasons?	Yes	No

G. Cycling investments

42. How much money did you spend in the past year on maintenance, accessories, clothing, etc. for your bike (not including a new bike)
    a. $0
    b. $0.01 - $74
    c. $75 - $149
    d. $150 - $224
    e. $225 - $299
    f. $300 - $374
    g. $375 +

43. If purchasing a new bicycle, how much would you spend, including upgrades?
    a. $0 - $200
    b. $201 - $400
    c. $401 - $600
    d. $601 - $800
    e. $801 - $1000
    f. $1001 - $1200
    g. $1201 +

H. Estimating the monetary value of cycling:

44. Bicycle sharing programs are emerging worldwide. Montreal's 2009 Bixi program rates were $5 / day, $28 / month, $78 / year, and typically operates between 3000 and 5000 bikes. If such a program were deployed, would use it? a. Yes b. No

45. If you answered "Yes" to the previous question, for what purpose would you use the program?
____
____
____

I. Identifying Bikeway Infrastructure Priorities

Using the cycling improvements list below, please precisely identify locations in Waterloo Region where you think each improvement or infrastructure type is needed.

Improvements	**Locations**
On-Road Bike Lanes	
Multi-Use Paths/Trails	
Dedicated Bike Paths	
Bicycle Boulevards	
Increased Lighting	
Increased Signage	
Surface Maintenance	

Increased Summer Debris Removal	
Increased Winter Snow Clearing	
Bike Racks	
Secure Bike Compound	
Showers/Lockers	

K. General comments including: cycling in Waterloo Region, specific problem roads

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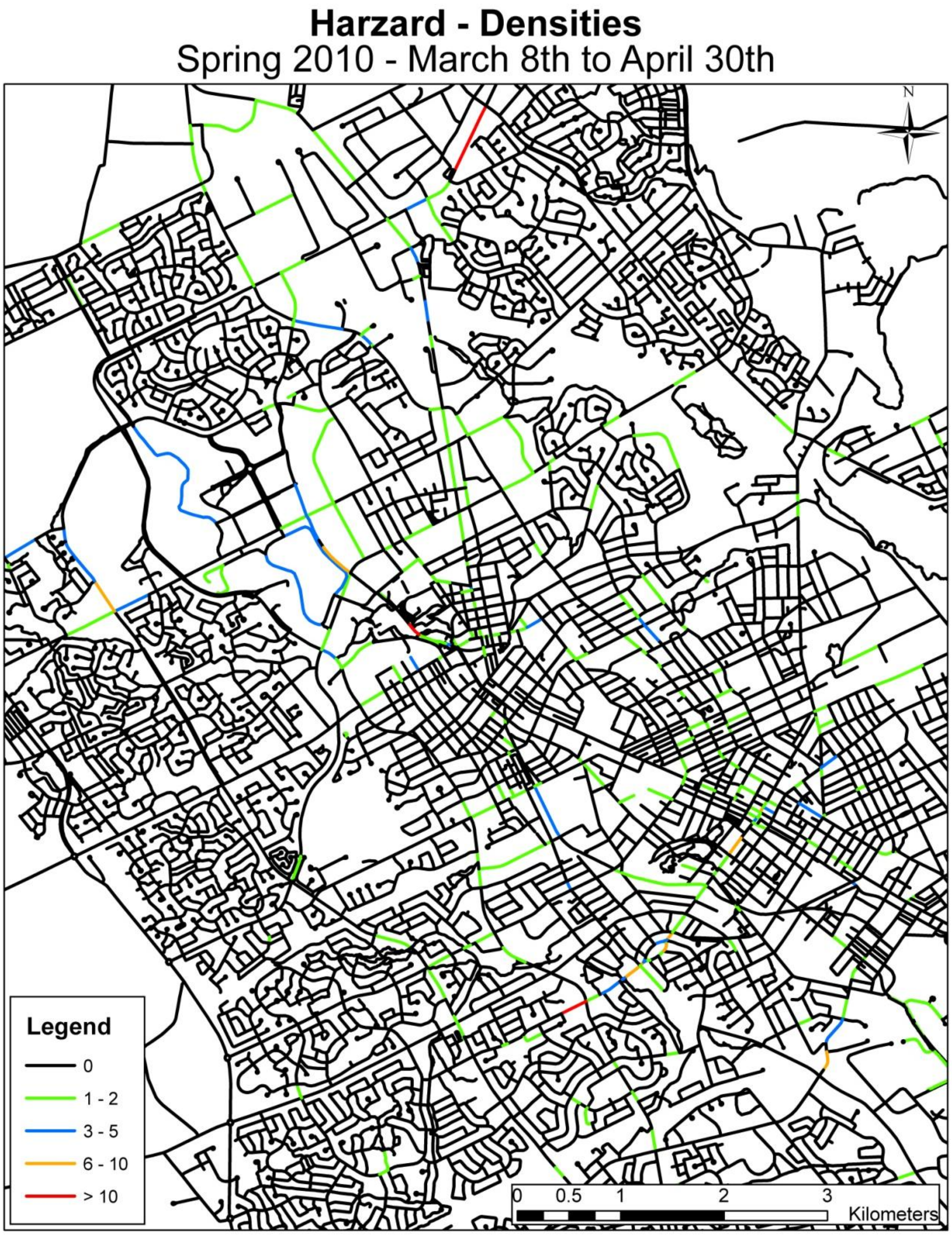
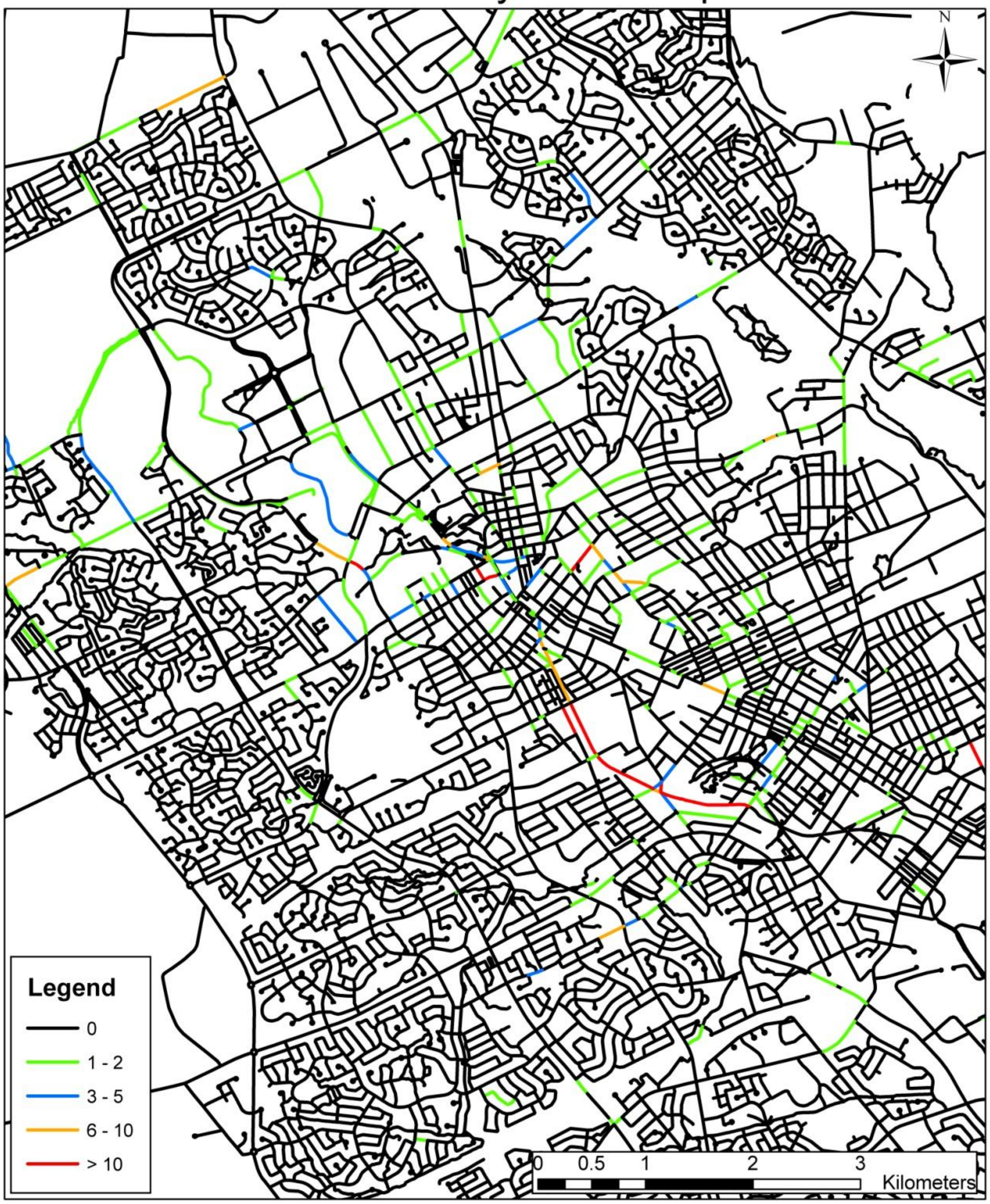
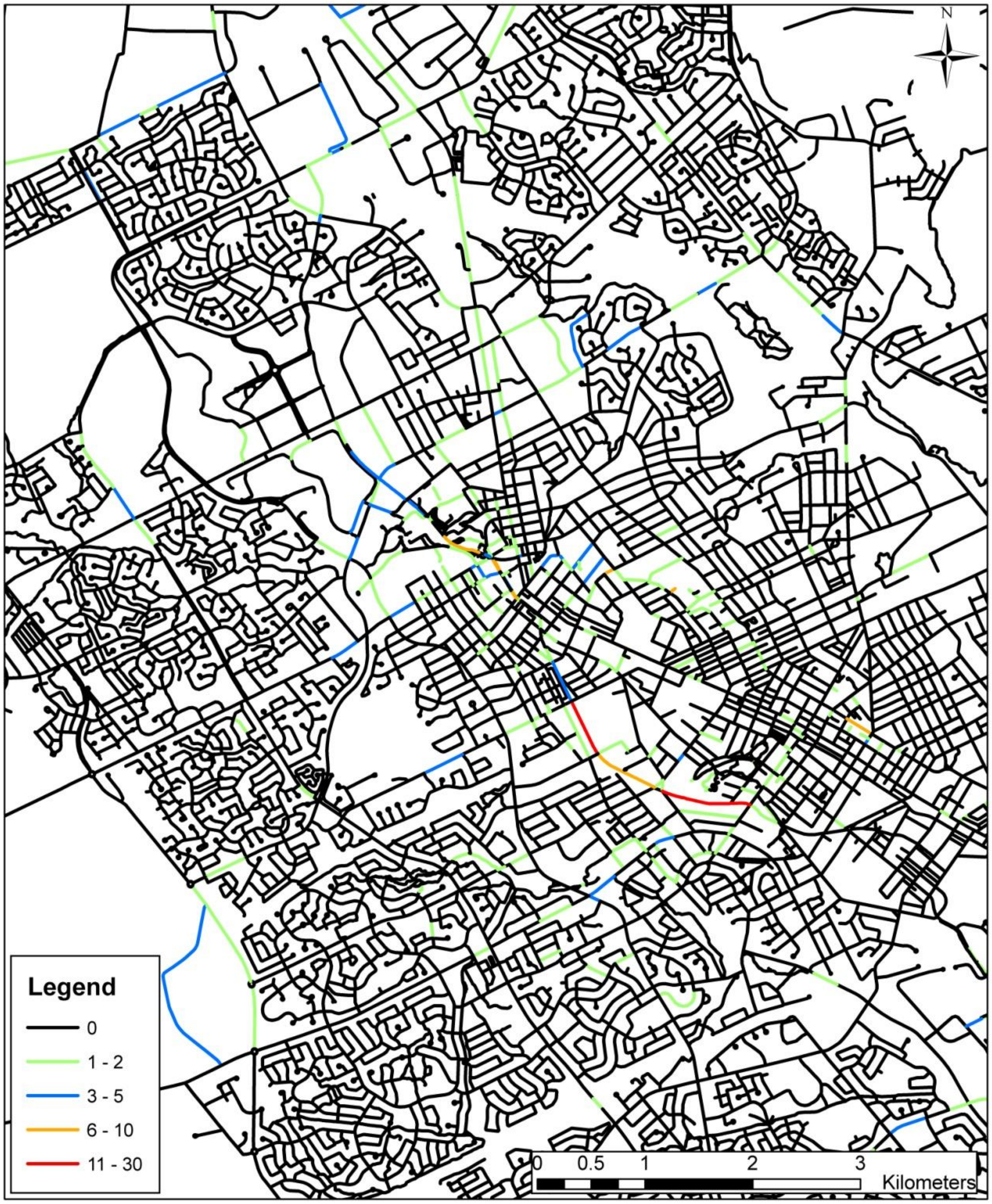
Appendix C
Seasonal Hazards

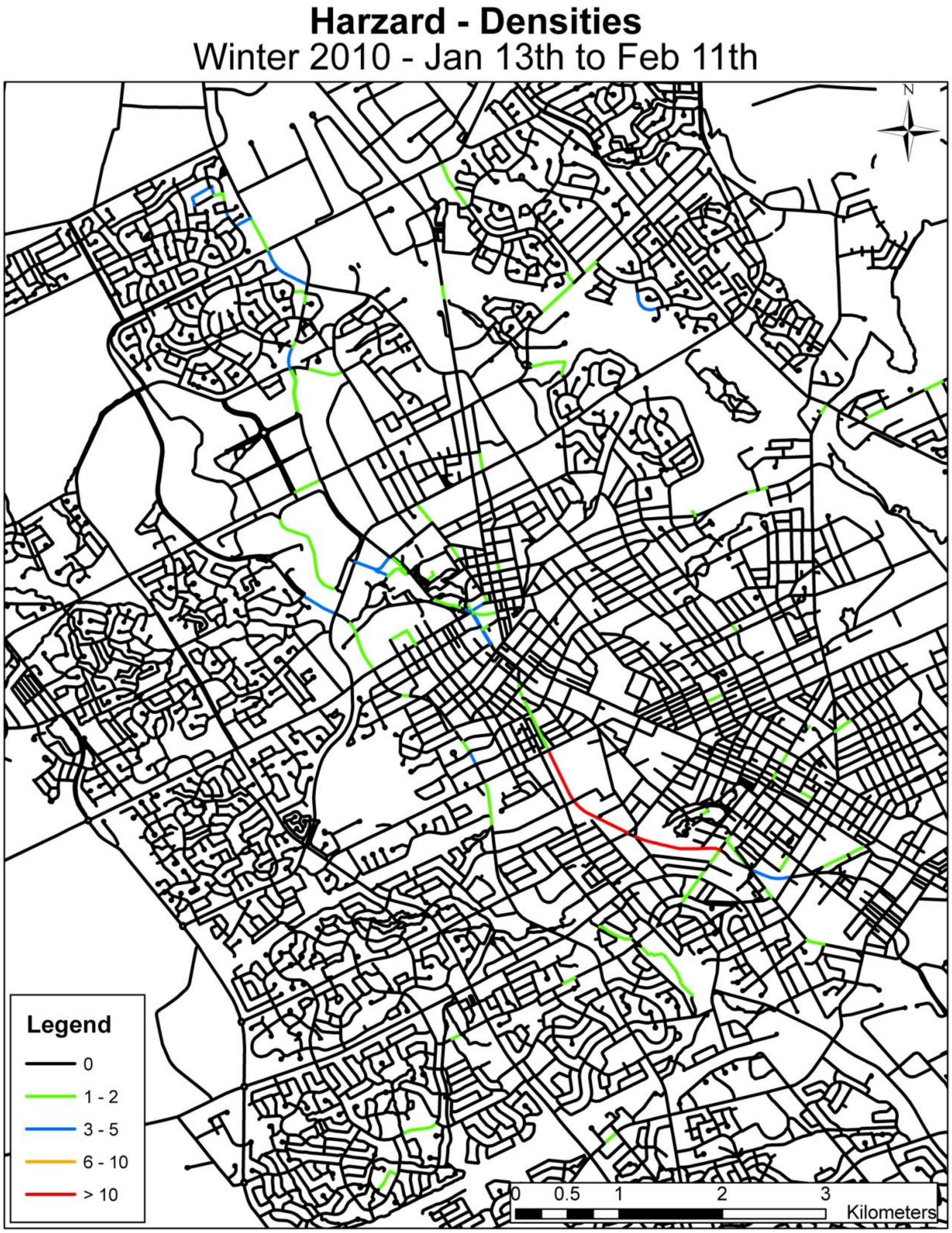


Harzard - Densities
Summer 2010 - July 15th to Sept 10th

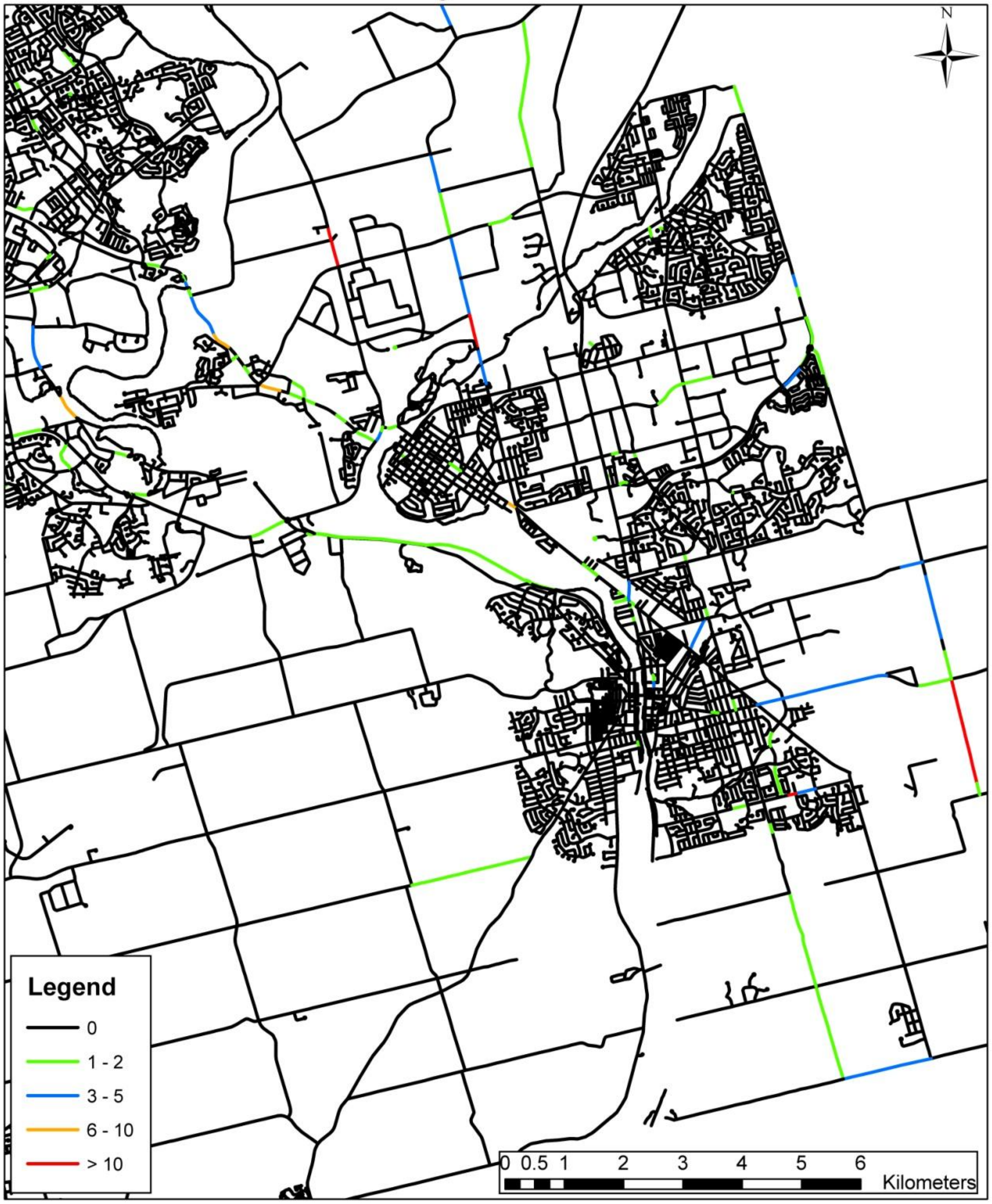


Harzard - Densities
Fall 2010 - Sept 20th to Nov 18th




Harzard - Densities
Winter 2010 - Jan 13th to Feb 11th
N
Legend
0
1 - 2
3 - 5
6 - 10
> 10
0 0.5 1 2 3
Kilometers

Harzard - Densities
Cambridge - All Hazards



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