COMMUTER BICYCLE ROUTE CHOICE: ANALYSIS OF MAJOR DETERMINANTS AND SAFETY IMPLICATIONS

By

LISA AULTMAN-HALL, B.ENG., M.SC.(ENG.)

A Thesis

Submitted to the School of Graduate Studies

in Partial Fulfilment of the Requirements

for the Degree

Doctor of Philosophy

McMaster University

BICYCLE ROUTE CHOICE: DETERMINANTS AND SAFETY IMPLICATIONS

DOCTOR OF PHILOSOPHY (1996)
(Civil Engineering)

McMASTER UNIVERSITY
Hamilton, Ontario

TITLE: Commuter Bicycle Route Choice: Analysis Of Major Determinants And Safety Implications

AUTHOR: Lisa M. Aultman-Hall, B. Eng. (McMaster University 1991), M. Sc. (Eng.) (Queen's University 1993)

SUPERVISORS: Drs. Fred L. Hall and Brian W. Baetz

NUMBER OF PAGES: xiii,224

Abstract

This research uses Geographic Information System (GIS) databases to manipulate the actual travel routes used by urban commuter cyclists to address issues related to bicycle route choice and bicycle safety.

Chapter 2 compares previously collected routes from Guelph to the shortest path routes. Most commuters divert little (0.4 km on average) and use major road routes. Although the cyclists tend to avoid grades, grade-separated railway crossings and high activity areas, they do not avoid high speed traffic or bridges. The cyclists use traffic signals especially for crossing major roadways and for turning. High-quality off-road paths are used infrequently, the lower quality ones even less.

Chapter 3 uses a logit model for route choice. The choice set determination is critical; logic that checks alternative routes for duplication of attribute combinations is used. A multinomial logit model that exhibited independence from irrelevant alternatives is estimated. The model identifies route attributes similar to those described above. In addition, personal variables (age, gender, winter cycling) were found to be significant.

Chapter 4 describes the survey methodology used to collect two larger commuter bicycle route datasets in Toronto and Ottawa. Questionnaires containing a map for route collection as well as questions relating to cycling patterns and accident history were placed on cross-bars of parked bicycles. The return rate was 47% of the 6043 questionnaires.

The overall rates per 100,000 commuter kilometres of collisions, falls, injuries and major injuries were found to be 3.26, 9.51, 7.60 and 1.10 respectively (Chapter 5). These are approximately 10 times comparable rates for automobiles. The GIS was used to determine the distance in the regular route that was undertaken on-road, off-road or on sidewalks in the Ottawa study area. Collision rates on different infrastructure were not statistically different. However, injury and fall rates were highest on sidewalks (4 times that of roads) followed by off-road paths (1.6 times that of roads).

Acknowledgements

I feel fortunate to have received generous financial support for my graduate studies. Scholarships were provided by The Natural Sciences and Engineering Research Council of Canada (NSERC), the Transportation Association of Canada (TAC), CP Rail, Emery Geotechnical Engineering Limited, the Canadian Transportation Research Forum (CTRF), the School of Graduate Studies at McMaster University, and the NSERC operating grants of my supervisors. I am particularly grateful to the Highway Safety Research Office of the Ontario Ministry of Transportation, which provided a research grant to support the initial phase of data collection for this thesis. Research assistance for this effort was also supported in part by student employment programs of the governments of Ontario and Canada. The remainder of the survey research effort was supported by NSERC, through Fred Hall's research grant .

The bicycle routes and GIS network information data used for Chapters 2 and 3 were donated by the City of Guelph, Ontario. I appreciated the assistance of Derek McCaughin, Pam Ross and others.

I wish to thank Eric J. Miller for use of his logit model estimation software. I thank Ezra Hauer for use of his accident count analysis software HYPTEST. I appreciated the use of Stan Pietruszczak's UNIX workstation throughout my research.

The bicycle route and safety study described in Chapter 4 is the product of contributions from many individuals. The Regional Municipality of Ottawa-Carleton, the City of Toronto, Metropolitan Toronto and the Regional Municipality of Hamilton-Wentworth provided digital map information that allowed for production of maps in the survey questionnaire. The following individuals provided valuable advice on the format and content of the questionnaire. My co-researchers and I assume full responsibility for the final format of the questionnaire.

Karen Baker, Hamilton-Wentworth Region Citizens' Cycling Advisory Committee
Avery Burdett, Citizens for Safe Cycling, Ottawa
Brett Delmage, Citizens for Safe Cycling, Ottawa
Susan Elliott, Department of Geography, McMaster University
Dan Egan, Toronto City Cycling Committee
Daphne Hope, City of Ottawa
John Kane, Citizens for Safe Cycling, Ottawa
David Keane, Faculty of Health Sciences, McMaster University
Charles Maurer, Hamilton Region Citizens' Cycling Advisory Committee
John van der Mark, Regional Municipality of Hamilton-Wentworth
Members of the Ontario Ministry of Transportation Highway Safety Office
Many graduate students and faculty at McMaster University

I am grateful to the employers and organizations in Ottawa, Toronto and Hamilton who allowed the questionnaires to be attached to parked bicycles on their property. The response of the commuter cyclists who completed the questionnaires was overwhelming, in terms of their total number, as well as with respect to the specific detail and completeness with which they provided information.

Management of the data generated by the bicycle survey was an onerous task. The GIS work, in particular, was tedious and riddled with set-backs. Dr. Steven Reader in the Department of Geography showed extreme patience as well as flexibility in terms of continual re-design of how our group's data were managed. Emily Andrews contributed not only to the collection and analysis of the route data, but also taught me my first lessons on supervising students. I commend her for staying with the project. I knew that with Georgina Kaltenecker the data that I viewed as precious was in the best hands possible. She has persevered with admirable dedication in the face of many "incidents".

I expected no colleagues in transportation research upon return to McMaster. I am glad I was wrong. My debates with Sean Doherty have resulted in valuable contributions to this research. My office-mate, Michael Cullip, has been proofreader, questionnaire distributor, map/diagram maker, program debugger, and friend.

In my opinion, I have been supervised by one of the best thesis committees ever assembled. Brian Baetz joined the committee as co-supervisor when the research was intended to be a cross between transportation and land use planning. I appreciate the flexibilty and support he has provided despite the research's change in focus. His ideas on sustainable urban land use patterns were the original motivation for the work. These ideas have changed forever my view of the interrelationship between urban form and transportation. Without the expertise of Eric Miller, the discrete choice modelling portion of this work would not have been possible. His dedication to the project and prompt assistance with modelling were beyond the call of duty. Bill Anderson has represented openness and flexibility on the committee. His advice was always unique due to the alternative perspective and experience he brought to the project. I have worked closest with Fred Hall. His tireless pursuit of perfection has made this research, as well as the expression of its results in writing, much better than would have been otherwise possible. I am grateful for his confidence in my research ability, constant availability for consultation, provision of research assistants, and willingness to "go to bat for me" on many occasions.

I am grateful to my children, Nicholas and Rachel, for allowing me to drag them away from their home in Kingston and "Back to Mac". I am most indebted to my husband, Douglas Hall, for the sacrifice in terms of his research and professional progress that this completed thesis represents.

Table of Contents

List of Tables

List of Figures

List of Exhibits

Preface

The chapters of this thesis are material that has been prepared with the intention of dual use as both chapters as well as publication elsewhere. Chapters 2, 3 and 5 are intended for submission to research journals. The first six sections of Chapter 4 are the contents of an interim research report to the Ontario Ministry of Transportation. The remaining sections of the chapter will be included with the interim report sections in the final report to the Ministry in the Fall of 1996.

This thesis format has several consequences. The literature review is embedded in appropriate locations for the papers and report. Each chapter contains a concluding discussion. Therefore only a summary of conclusions is provided in the concluding chapter (6) and that discussion focuses on the thesis' implications for further work. References are listd at the end of each chapter. Some minor duplication occurs between chapters. The literature review, data analysis and initial drafting of all work was conducted by the author of this dissertation. Complete references to the chapter in its alternative form are provided before each chapter along with a description of the role of each co-author.

Chapter 1: Introduction

This thesis research grew out of a larger project which began in the winter of 1994 to study environmentally sustainable urban land use patterns. Transportation planning is a key part of this issue because people need transportation to participate in activities throughout an urban area. Transportation is central to how land-use patterns, such as the mix and density of land uses, impact the environment. Not only do the by-products of most motorized forms of transportation contribute to local air quality problems and potential global warming, but equally important, the many automobiles require a large amount of space for parking and travelling, forcing the urban area outwards into agricultural or natural areas. This effectively increases the distance between activities and further increases the demand for, and impacts of, transportation. It seemed appropriate to focus efforts on the use of non-motorized urban travel modes, and therefore commuter bicycle transportation was chosen as the focus for the thesis.

In Ontario, the use of bicycles has increased dramatically over the past decade. In downtown Toronto for example, the number of bicycles crossing the central area cordon daily grew from 16,959 to 29,708 between 1987 and 1993 (Toronto City Cycling Committee, 1994). A study in the Regional Municipality of Ottawa-Carleton (Cumming Cockburn Ltd. 1992) estimated that the region contained approximately 47,000 commuter cyclists (defined as cyclists who travelled to work or school two or more times per week), representing about 9% of the population. In response to the growing use of bicycles and the increasing concern about traffic congestion, municipalities are planning bicycle networks, specifying bicycle transportation in their budgets, and hiring staff to be responsible for cycling issues. The revised Ontario Bicycle Policy (1992) mandates that the focus for policy and bicycle infrastructure provision is to be utilitarian or purposeful bicycle use. Utilitarian cycling includes trips that are not discretionary, such as commuting to work or school, as well as trips that are characterized by more flexibility in terms of timing and specific destination, such as shopping, visiting or errands. An additional important goal mandated in the provincial policy is to increase cycling safety.

One main focus for municipal bicycle planning is creating a transportation network that is more "bicycle friendly" to encourage use of the bicycle for more utilitarian trips such as commuting to work or school. Investigation of previous studies revealed that there were very little bicycle travel data that could be used for a study of the types of issues that affect people's use of the bicycle. The existing conventional travel behaviour datasets (which contain information such as traveller demographic and household characteristics, trip purposes, timing and mode) contain very few bicycle trips because samples are usually drawn randomly from the population and a relatively small proportion of people use the bicycle. The availability of a bicycle route dataset collected in the city of Guelph, Ontario, shifted the research aimed at understanding what affects bicycle travel into the area of route choice analysis. It was postulated that by studying the routes used by commuter cyclists, insight could be obtained into the type of infrastructure that would encourage bicycle commuting.

During the initial work with Guelph routes, an opportunity arose to collect more bicycle route data through a safety research grant program in the Ontario Ministry of Transportation. The Ministry had expressed an interest in collecting an improved database on bicycle collisions, and investigating patterns of bicycle travel. It became evident at that time that the analysis of bicycle routes could provide a measure of travel exposure that would benefit bicycle safety measurement efforts by improving the estimates of risk on different types of facilities (paths versus roadways, for example). This information is of interest to bicycle planners to ensure that the relative safety of different bicycle infrastructure proposals can be considered along with the route travel preferences of cyclists. For primarily a bicycle risk analysis, a research grant was awarded from the Ministry to conduct a mail-back survey of 6000 urban commuter cyclists to collect accident histories, commuter routes and personal characteristics. These data will also be useful for future route research.

This thesis makes practical quantitative contributions to the area of bicycle transportation planning in terms of understanding the factors that affect bicycle route choice, and the relative safety of travel on roads versus off-road paths and trails. The methodological contributions have implications for other transportation modes as well as the bicycle in terms of use of actual travel route data to calibrate discrete route choice models and for the use of Geographic Information Systems (GIS) for quantification of exposure in transportation safety analysis.

Chapter 2 of this thesis describes how a GIS was used to manage the Guelph route data and then to extract information describing the routes from the database that contained the characteristics of the transportation network. The chapter also presents the descriptive results of the route analysis and their implication for bicycle transportation planning. An indication of whether cyclists choose their routes because there are no reasonable alternatives, or whether they prefer certain route features to others, is gained by comparing the route chosen to the minimum path route generated by the GIS between each cyclist's origin and destination.

Chapter 3 is an extension of one concept illustrated in Chapter 2: the necessity to compare the cyclist's actual route to other routes that were not used in order to understand whether the route is used because of its specific characteristics or whether no reasonable alternative exists. A modelling approach that compared several alternative paths between each individual's start and end locations was necessary. However, very few actual travel route databases exist. Methods to model disaggregate individual route information are only recently starting to be explored. Planners and researchers usually rely on minimum cost or distance paths for the traffic assignment modelling stage of transportation planning. With the widespread use of GIS and the overall move to more dissaggregate analysis, it has become necessary to study what factors beyond travel time or distance affect the choice of route. As well as being easier to collect than automobile routes, due to bicycles travelling shorter distances, bicycle routes can be expected to be more affected by factors beyond time and distance, such as traffic signals or road type, that can be stored in a GIS network database. This made the bicycle route dataset ideal for initial exploration of appropriate modelling approaches and procedures for route choice. The conclusions can be of benefit for related future research with automobile routes where objectives might include understanding the effect of traveller information systems, or improving stochastic traffic assignment procedures. The resultant bicycle model provides more complete insight into the factors affecting bicycle commuter route choice than the single variable analysis of Chapter 2.

As described earlier a mail-back survey was conducted in Toronto and Ottawa. Chapter 4 describes the questionnaire design process, the survey execution, and some results related to the quality of the survey instrument. Placing questionnaires on the cross-bars of parked bicycles and using maps for route collection was very successful and the survey methodology itself will be of interest to those intending to survey cyclists for related information.

Chapter 5 reports on the bicycle safety results for Ottawa, in which the prime objective was to compare the relative incident and injury rates of on- and off-road bicycle travel. There has been a long-standing debate over where it is safer to cycle. These results are a step towards providing more complete quantitative information for informed decision making. This study's methodology is particularly useful for this debate because the route information provides a good estimate of travel exposure by route type and because accident histories collected from cyclists are more complete than those contained in police reports. The Ottawa data are ideal for comparison of on- and off-road bicycle travel because of the extensive off-road path systems throughout the region.

Chapter 6 summarizes the conclusions of the analyses but primarily focuses on directions for further work. Overall, the thesis has demonstrated that useful travel behaviour information can be extracted from actual routes. Efforts to collect route data should be undertaken to allow for further development of research methodologies that involve actual travel routes not just for bicycle transportation but for other modes as well.

References

Cumming Cockburn Limited. (1992). *The Ottawa Carleton Cyclist Profile Survey.* Ottawa: The Regional Municipality of Ottawa-Carleton and the Regional Cycling Advisory Group, May.

Ontario. (1992). *Revised Bicycle Policy.* Toronto: Ministry of Transportation Ontario, May.

Toronto City Cycling Committee. (1994). *City Cycling Facts,* Bicycle Transportation Research Bulletin #1, October.

Preface to Chapter 2:

This chapter is a slight adaptation of the research paper cited below[1]. Contributions from Drs. Hall and Baetz consisted of critiques, discussion and revisions to draft versions.

---

[1] Aultman-Hall, Lisa, Fred L. Hall and Brian B. Baetz. (1996). "Analysis of Bicycle Commuter Routes Using GIS - Implications for Bicycle Planning" submitted to the Transportation Research Board for peer-review for presentation at the 1997 Annual Meeting and publication in *Transportation Research Record*.

Chapter 2: Analysis of Bicycle Commuter Routes Using GIS - Implications for Bicycle Planning

2.1 Introduction

This paper reports on the information obtained by analyzing actual urban bicycle commuter routes from Guelph, Ontario in a Geographic Information System (GIS). The exact actual route, consisting of the series of links, used by a person to travel through a transportation network is rarely collected. Instead analyses involving routes usually assume the traveller uses some form of minimum cost or distance path from their origin to their destination. However, the analysis of actual routes in a GIS can provide information to allow transportation planners and engineers to evaluate where users choose to travel, and hopefully to eventually move beyond traffic assignment based on only distance or time towards calibration of route models against travel behaviour. This consideration of factors beyond travel time and distance is particularly important for bicycling, as cycling levels are considered to also be affected by many additional characteristics of the network such as road type and automobile volumes (Goldsmith 1992). This paper has three main objectives: first, to present quantitative information describing bicycle commuter route behaviour; second to discuss the implications of these results for bicycle planning; and finally, to explain how GIS was used for the route analysis.

There is relatively little recent quantitative data on bicycle travel behaviour that includes a measure of the proportion of travel undertaken on different route types. The lack of bicycle exposure information has been noted by Rodgers (1995), who used an innovative method to estimate riding exposure from a study which relied on people recalling and estimating the amount of time they spend riding on different types of infrastructure. His analysis uses data from The Consumer Product Safety Commission (1993) survey that contained a four point subjective scale,"always", "more than half of the time", "less than half of the time", "never", to measure the amount of travel on different route types.

A bicycle commuter route database was collected using survey maps in Calgary in 1993 but results are not yet available. Collecting routes on a map and then using the GIS to estimate the amount of travel on different types of links is simple and reduces potential recall and perception errors. This analysis method is used in this paper with the Guelph commuter routes. It is capable of providing not just travel infrastructure measures but detailed information such as turns and traffic signal use. It is hoped that these results will serve to increase the amount of quantitative information available for two particular bicycle planning tasks. First, in order to design bicycle networks to encourage commuter cycling it would be useful to know what type of infrastructure people choose to cycle on. Second, for safety analysis, route analysis can provide detailed exposure information.

This paper has four main sections. The first describes the data used in the analysis and how the network database was built. The second section outlines the analysis procedure used to extract information describing the routes from the GIS network database that contains the characteristics of the links and nodes. The overall distance people travelled and the type of routes they travelled on is presented in section 2.4. Section 2.5 compares the actual routes to the shortest path routes generated by the GIS. Section 2.6 discusses the implications for bicycle planning.

2.2 The Data

The bicycle route data used in this study were provided by the City of Guelph (population 93 000), which is located approximately 80 kilometres west of Toronto, Ontario, Canada. Guelph is a good setting to conduct bicycle research because it offers a range of urban cycling route options and conditions. While the majority of the city is relatively flat, there are significant hills rising from two rivers that join in the city's downtown core. The University of Guelph is a major destination for bicycle traffic. Although there were no bicycle lanes in the city at the time of the study, high quality unpaved recreation paths follow several banks of the main rivers in three different sections, two of 4.0 kilometres and one of 3.5 kilometres in length. A parkway with a similar path follows a creek a total of 8 kilometres. There is also a trail along 1.6 kilometres on an abandoned rail line within the main part of the city. The core of the city, with traditional grid-patterned streets, is surrounded by more recent subdivisions of winding streets and crescents. These newer areas have wide collector roads leading to main arterial roadways. There is a limited access highway, where cycling is prohibited, that runs north/south through the city and has wide signalized intersections rather than freeway interchanges/overpasses. The winter climate in Guelph includes significant snow (an average of 144 centimetres per year), occasional freezing rain and cold temperatures (the average daily high in January is -3.4° C) (Environment Canada 1996).

The data used in this analysis were collected for the City in the 1993 Guelph Community Bicycle Survey and the 1993 Guelph Bicycle User Survey. Both surveys were part of a larger Guelph and Area Transportation Review. The community survey was a random mail-out/mail-back survey, while the user survey was placed at bicycle shops and handed to cyclists on the street. A total of 2700 community surveys were mailed out, while the total number of user surveys distributed is unreported (Fenco MacLaren 1994b). The two surveys did not contain identical questions; however, the information extracted from the returned questionnaires for this study was common to both (Appendix A contains a copy of each questionnaire). Each survey contained several copies of a map of the approximately 68 square kilometre urban area of the City of Guelph. The map contained single lines representing the street network as well as railway lines, rivers and major street names. Participants were asked to trace the routes on which they travelled by bicycle to work or school, for non-commuting utilitarian bicycle trips and for recreation. The survey also contained questions on cycling season, frequency of cycling, preferences for cycling improvements, deterrents/incentives to cycling, and personal information. The results of the study have been reported by the consultant to the city (Fenco MacLaren 1994a and 1994b). The route information, analyzed by visual inspection, was used in their study to present desire lines between zones for bicycle travel and to provide qualitative information on the cycle routes were being used.

For the research described in this paper commuter cyclists were of interest, so only the responses that provided a route to work or school were used. Some routes were eliminated as implausible due to travel on railway lines, crossing rivers where no bridge existed or travelling through an area that based on a site inspection was deemed impassable due to buildings, grades or vegetation. Many of these problems were assumed to have occurred due to misinterpretation of the map. A total of 338 responses with 397 routes to work or school were available for analysis. Multiple routes resulted from an individual having more than one work or school location, having a different route for each direction, or simply providing alternative routes. Of the 397 routes, 259 were from the community survey and 138 from the user survey. The age, sex, and days cycled in each month of the year were entered into a spreadsheet database for use in this study.

A digital version of the street network for Guelph was generously provided by the City of Guelph's GIS Services Department. This information was then imported into the GIS software ArcInfo. The network file was augmented with the off-road paths and trails that might be used for cycling, based on information from a path/trail map from the City's Department of Parks and Recreation, site visits and paths drawn onto the maps by survey participants. The information from survey participants was always confirmed by site inspections. It was not possible to add all of the sidewalks and paths on the University of Guelph campus, but a representative set of paths was added.

In order for the network database to be used to determine the route characteristics, the network file was augmented with attribute information describing all the nodes and links in the network. Each node was assigned two attribute variables. The first indicated whether or not the intersection had a traffic signal. The second indicated if the intersection was a major traffic signal such as the intersection of two highways or other major roads. The location of signalized intersections was obtained from the City of Guelph's Traffic Department, while the second variable was based on judgement. The variables entered for each link in the network are shown in Table 2-1 along with the source of the information.

Table 2-1: Link /Arc Attributes contained in the Guelph Network Database

Attribute	Description	Source
Type	Indicates whether the particular link is one of the following: - 4/6 lane arterial roadway - 2 lane arterial roadway - collector roadway - minor / local roadway - poor quality off-road path/trail - average quality off-road path/trail - good quality off-road path/trail	Roads: Fenco MacLaren (1994a) Off-Road: based on site inspection
Speed Limit	Indicates the posted speed limit on roads in kilometres per hour	City of Guelph Traffic Department
Volume	Indicates which of the following ranges the on-road link' s AADT falls in: < 5000 vehicles 5000 - 10000 vehicles 10000- 15000 vehicles > 15000 vehicles	Based on the most recent two-way counts for individual roadway sections from the City of Guelph Traffic Department
Grade	Equal to 1 for an up grade and 2 for a down grade - recorded only for grades considered significant for cycling, greater than approximately 7%	Approximated using Ontario Base Map 10 17 5600 48150 (1:10000 scale) (1983)
One-way	Dummy variable indicating the direction of one-way streets	Street map
Bus Route	Indicates the number of buses per hour that travel along the link	Guelph Transportation Commission
Bridge	Indicates a bridge over a river is contained on that arc	Street map and site inspections
Railway crossings	Indicates if one of the following types of railway crossing is contained on the link -level crossing perpendicular to road traffic -level crossing angled to road traffic -grade-separated crossing	Fenco MacLaren (1994a)

The routes were digitized into ArcInfo by interactively selecting the arcs (links) of the route using a computer mouse. Each respondent's routes are contained in a numbered route system. It is worth noting that the network building and route entry portion of this GIS route analysis was extremely time consuming. When digitizing routes manually, our experience would suggest allowing 6 - 8 minutes per route.

2.3 Analysis Procedure

For the route analysis, the GIS was used to manage the route data and determine the characteristics of the routes. This section briefly outlines the procedures used to accomplish these tasks.

The node and link attributes for each network element are contained in the GIS attribute tables. It was possible to relate each route's sections (arcs) to the attributes for the corresponding links and nodes. This link-by-link and node-by-node information was then downloaded to ASCII files from the GIS for further analysis. In addition to the link and node attributes, the GIS can generate a turn table. The turn table contains the angle of every possible link-to-link movement in the network. In this analysis the turn table was related to the arc attribute table so that the link type of the "to" and "from" arcs for each turn movement was also contained within that table. The turn table was also downloaded to an ASCII file. A FORTRAN program was written to analyze the route and turn data files. Summary variables describing the link and node characteristics presented in section 2.2 as well as the following turn information were output for each route:

number of turns;
turns at signals;
turns at major signalized intersections;
turns between major and minor roads <u>with</u> and <u>without</u> a traffic signal; and
movements from a minor road or path to a minor road or path across a major road <u>with</u> and <u>without</u> a traffic signal.

There is one short-coming in the questionnaire relating to route direction that limits which summary variables can reasonably be produced. Although the home and destination locations of the individual were known from the survey responses, it was unclear due to question wording whether people were indicating their route to work or school or their route in both directions. The survey question did not specifically ask people to indicate direction and the trip home was not directly included. Only 5 of the respondents used arrows to indicate direction for multiple routes, clearly indicating that some participants interpreted that they should provide their route in both directions. Twenty-three others indicated more than one route but gave no indication if these routes were used as alternatives in both directions or if certain routes were used in only one direction. Most people indicated only one route, but it was impossible to say whether this was their route in both directions. Therefore, to avoid an assumption on how participants interpreted the question, variables affected by direction were combined into nondirectional variables when the summary variables were generated. The attributes affected by direction are whether a cyclist is travelling the right or wrong way on a one-way street, whether a turn was left or right and whether travel was up or down a hill.

It was necessary in order to use the minimum path algorithm to know the start and end node identification numbers of each route. However, ArcInfo only defines routes as comprised of arc/link sections. Due to this arc/link definition, start and end nodes cannot be directly obtained from the route tables. The FORTRAN program used to create the route summary variables was also used for determining node ids by relating the route arcs to the node ids in the arc attribute table. Once the route start and end node ids were known, it was possible to use the GIS to calculate the minimum path route for each individual and store it as an additional route in each route system. All characteristics were compared for the actual and shortest path routes, and of particular interest was the shortest path length and how it compared to the length of the route chosen.

2.4 Bicycle Route Results

2.4.1 Length of Travel

Figure 2-1 illustrates the distribution of trip lengths for the actual routes. The mean one-way distance was 3.7 kilometres. This value is similar to those obtained in studies in other urban areas in Ontario. An average one-way distance of 3.3 km for adult home-to-work or to-school bicycle trips for Metro Toronto was estimated based on data from the Transportation Tomorrow Survey (TTS) obtained from the Joint Program in Transportation at the University of Toronto. The Ottawa-Carleton Cyclist Profile Survey (Cumming Cockburn Limited 1992) found the average self-reported travel distance for commuter cyclists travelling to work to be 5.5 kilometres. The average distance for Ottawa commuters travelling to school was 3.3 kilometres (this includes children, as does the Guelph data reported on here). The Ottawa Cycling Advisory Group (1992), in its study of commuter cycling, recorded one-way trip length in minutes. Using a speed of 12 kilometres per hour they converted the times to distances which ranged from 3 to 12 kilometres. The speed of 12 km/h results in an average distance of 4.6 kilometres. GIS analysis of commuter routes from a 1995 Ottawa survey found an average one-way distance of 6.6 kilometres (Aultman-Hall et al. 1996). The average trip length for bicycle commuters may vary between different urban areas due to differences in the physical urban form and the bicycle networks. However, consideration of the various sources of trip length data also points to the advantage of calculating trip distances with actual route information. Speed estimates are not necessary; and the estimation and recall errors of the individuals do not affect the results.

The average one-way trip length for women and men in Guelph was 3.6 km and 3.8 km respectively. Based on a t-test, this difference is significant at the 0.02 level indicating that on average women do not commute by bicycle quite as far as men. A regression analysis revealed no significant relationship between age and one-way distance for the adults, although the few individuals under age 18 in the sample cycle a slightly shorter distance

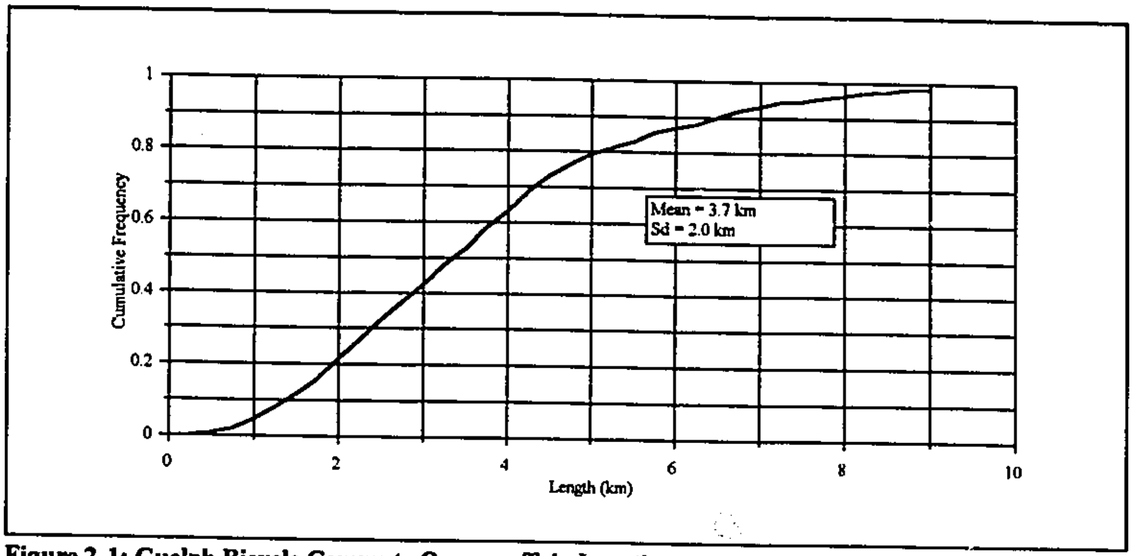


Figure 2-1: Guelph Bicycle Commute One-way Trip Length

for their commute. Individuals who cycle in January do not have a mean commuting length different than those who do not cycle in the winter (not significant at the 0.05 level).

Figure 2-2 illustrates the distribution of the difference between the minimum path distance and the actual distance travelled. A total of 58 (14.6%) of the routes follow the exact shortest path calculated by the minimum path algorithm. While 37.5 % of routes were within 0.1 kilometres of their minimum distance, some others divert long distances to either avoid some aspect of travelling on portions of the network or seek out sections they prefer. There was no significant relationship between the shortest path distance between the start and end point of a route and the percent extra distance the cyclist actually travelled.

2.4.2 Type of Route Used

Figure 2-3 illustrates the percent of the total travel that was undertaken on each type of network infrastructure: arterial roadways, collector roadways, local streets and off-road paths or trails. Nearly half of the commuter bicycle travel is undertaken on the main

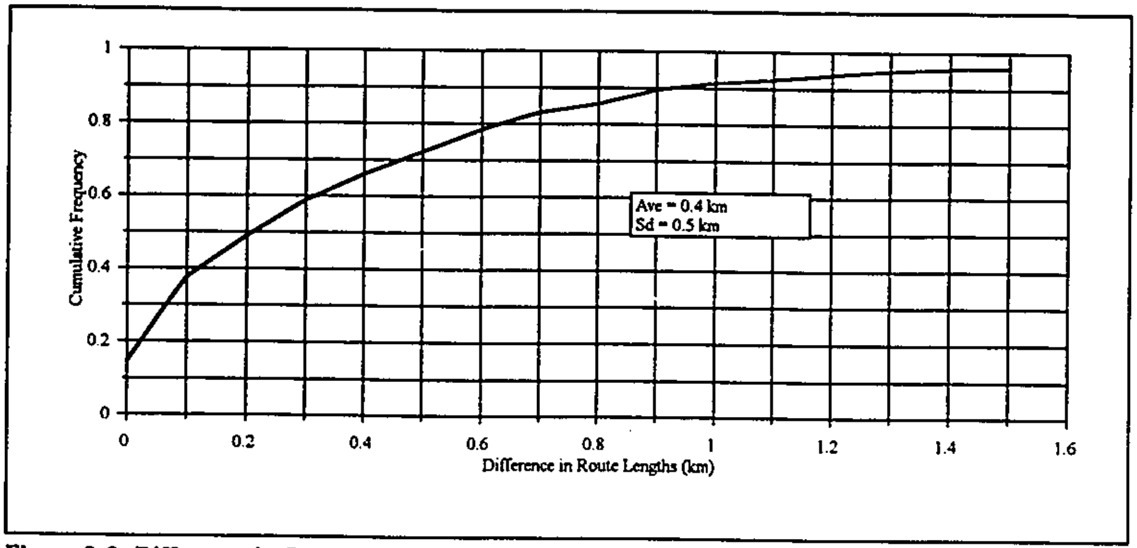


Figure 2-2: Difference in One-way Length Between Actual and Minimum Path Routes

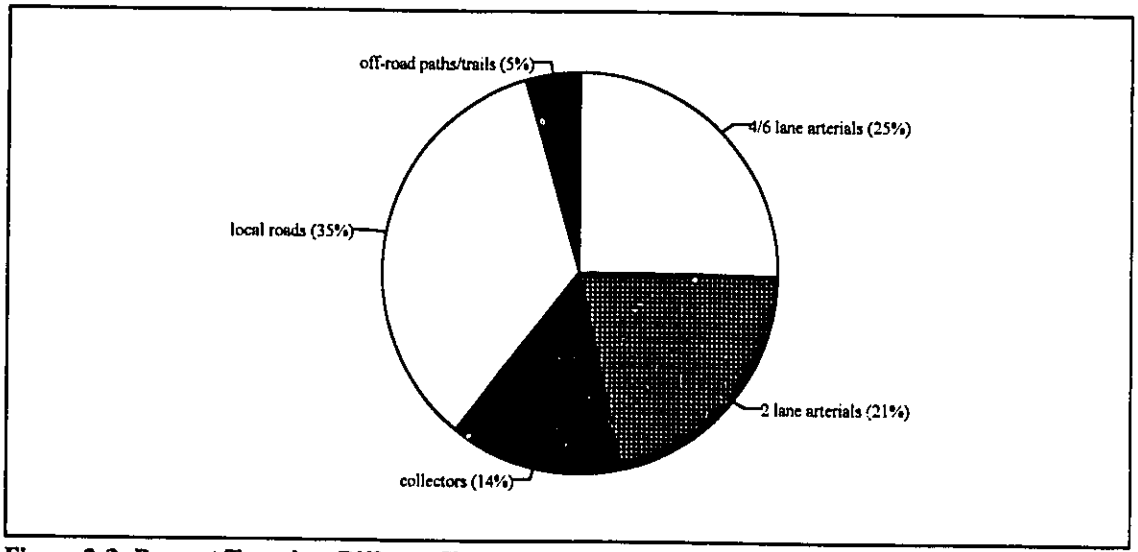


Figure 2-3: Percent Travel on Different Types of Network Components

arterial roadways in the City of Guelph. Although the proportion of travel on minor roads also seems high, it is affected by the fact that travel on local roads is often necessary to enter and exit the local neighbourhood where one's home or workplace is located. One might consider that the small proportion of travel undertaken on off-road paths or trails is due in part to the relatively few kilometres of off-road components found in the city. However, 7% of the available length of network in Guelph is off-road, suggesting that cyclists find the off-road routes unappealing or they are inappropriately located for the work/school origin and destination locations.

As described in the introduction, many of the paths and trails are extensive and many are reasonably direct in Guelph. Yet the existing commuter cyclists are choosing other routes especially when paths are not direct or not of excellent quality. There are five corridors where a higher-quality pathway exists directly parallel to roadways, such that comparison of the number of bicycle routes using each might provide meaningful results. These locations are shown in Figure 2-4 in capital letters. The arrows by the letter indicate the travel direction of the corridor. Table 2-2 summarizes the characteristics of each pathway and the alternative parallel roads in the corridor. Also reported in Table 2-2 is the number of bicycle routes of the total of 397 using each of the roads or paths in each corridor. Only routes that travel through the complete corridor were considered. Recall that a route will be chosen by a cyclist not just for the characteristics of individual sections or corridors but also by considering the options it leads from and to. The numbers are not integers due to routes using the road for part of the corridor and the pathway for the remainder as well as cyclists using the corridor in only one of multiple routes provided. Comparison of the totals indicates that in all corridors the road is more frequently used, but, where the pathway is direct and of the highest quality it is used relatively more often (along corridor "C" for example).

Inspection of the total amount of off-road travel undertaken on various quality off-road paths further supports the conclusion that commuter cyclists for the most part use only higher quality paths. Of the off-road travel, 7.2%, 35.4%, and 57.4 % was undertaken respectively on poor, average or good quality paths/trails. The quality of an off-road path or trail was subjectively determined by the researchers according to the following rules. If a path or trail was wide with a good quality surface and extended a relatively long distance with easy access points it was considered of good quality (12.6 km of the total of 31.0 km

Figure 2-4: Location of Off-road Path/Trail Comparison Corridors and Bridges in Guelph

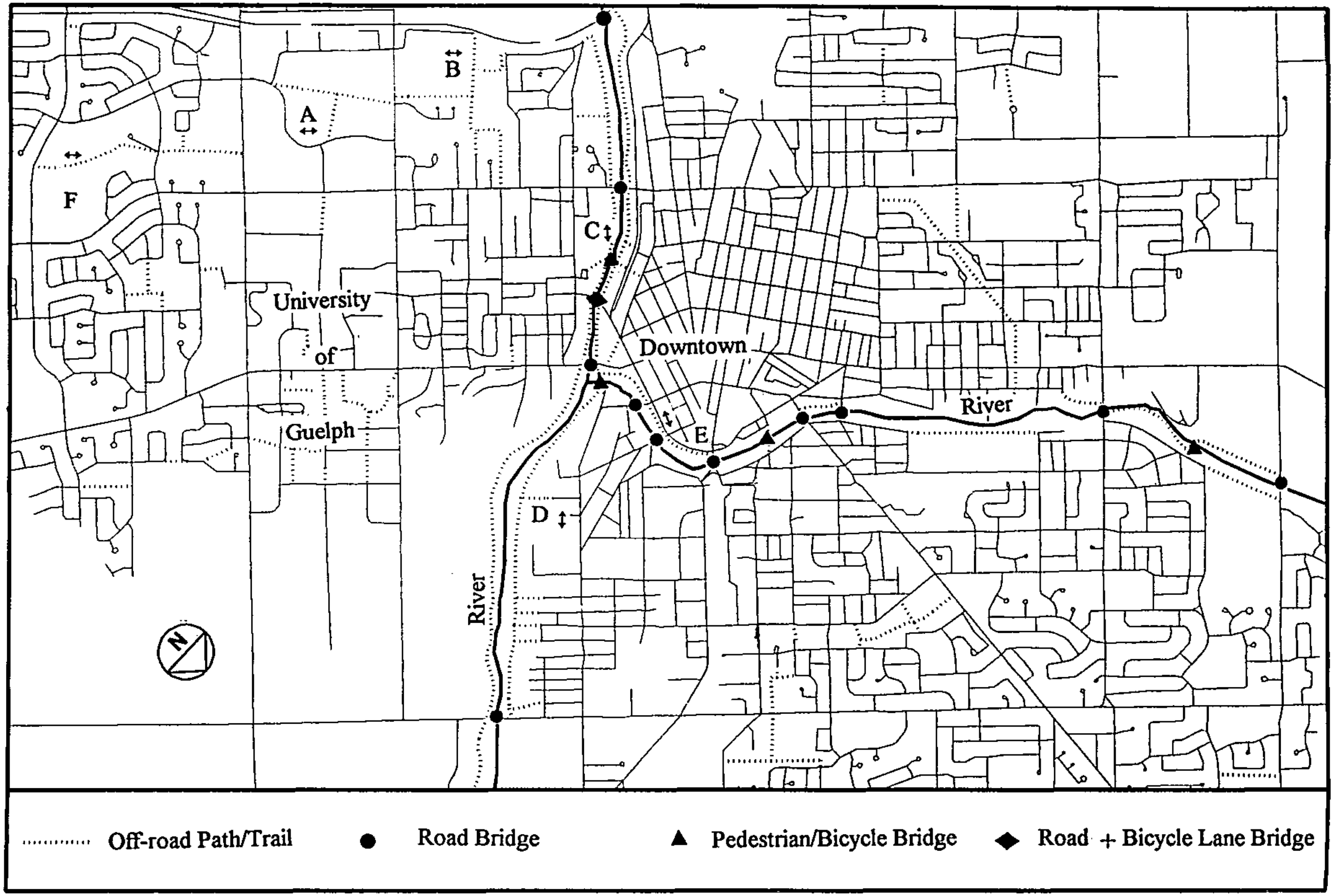


Table 2-2: Number of Routes Using Road Versus Off-road Path/trail in Selected Corridors

Corridor (see Fig. 2-4)	Road Alternative Characteristics	Number of Routes	Off-road Alternative Characteristics	Number of Routes
A	one winding wide 2 lane collector, one 2 lane collector, one four lane arterial	7.5	rolling path through park surfaced with limestone screenings	2.5
B	4 lane arterial	5.5	path through park and school land surfaced with limestone screenings	4.5
C	multi-lane divided arterial and 2 lane collector	8.5	unpaved paths on either side of river	7
D	wide 2 lane arterial	12.5	path along river surfaced with limestone screenings	7
E	hilly two lane arterial with closely spaced signals	15.5	Recreational path with secluded section following a river behind a commercial strip mall (limestone screenings)	7
F	2 lane arterial, 2 lane collector, combination of minor residential roads and a gravel service road/lane along freeway	13.5	unpaved path through treed area and a paved path through a neighbourhood park	2

of off-road paths/trails). The paths that extend several kilometres along the creek are an example of a good path. An off-road route such as those with stairs, comprised of a narrow pedestrian walkway, cutting across private property (ie: golf course), or comprised of a dirt trail across a field were labelled poor quality (a total of 5.9 km). All other paths, such as those cutting across neighbourhood parks, were considered average. The travel information extracted from the routes suggests that people use the good quality off-road routes significantly more than the others that probably represent more delay and inconvenience. The choice to use an off-road path or trail obviously depends on the distribution of origins and destinations throughout the city with respect to the location of the off-road routes. However, even with a reasonable length of extended river and creek recreation paths, only 27% of the commuter routes analyzed from this survey reported any travel along off-road segments. This is more interesting when one considers that 49% of the shortest path routes generated in the GIS contain some off-road segments.

In order to consider how uniform people's routes are, one can consider the percent of individual routes that are on different subsets of infrastructure types. For example, a total of 26.4 % of the routes have greater than 80% of their travel on minor / residential roads, off-road paths / trails and / or collector roads. A total of 46.3 % of the routes have greater than 70% of their route on arterial or collector roads. This 70% level can be considered the point where essentially as much of the route as possible has been made along major direct roads, and is lower than the 80 % level used above because most individuals would have to use minor roads to leave and enter their home neighbourhood. Collector roads are considered in both subsets because they offer a direct path both to cyclists trying to avoid major roads as well as those who are comfortable riding in higher traffic volumes. Together these two types of uniform route choice support the notion that there are two types of cyclists (Wilkinson 1994); those that are comfortable cycling with all vehicular traffic volumes and those who prefer to avoid vehicular traffic (this group can include both those comfortable riding in traffic and those who are not).

2.4.3 Bridges

The crossing of bridges is often considered a deterrent to cycling due to wind, cold, poor snow removal or narrow lanes. Although road bridges are often considered to exemplify negative qualities for cycling, the Guelph dataset indicates that cyclists choose road bridges even when reasonably direct pedestrian/bicycle bridges over the rivers are available. Figure 2-4 illustrates the location of the rivers within the urban area of Guelph and the approximate location of the bridges crossing the rivers (all bridges, but only major roads, are shown). One special case exists. An old stone bridge with a one-way traffic lane which joins a residential street to a parkway on the opposite side of the river has a two-way bicycle lane on it. This bridge does not exemplify many of the negative elements of roadway bridges for cycling. The pedestrian/bicycle bridges and road/bicycle bridge are well placed for use by cyclists considering the location of downtown and the university. They could reasonably be used by cyclists preferring to avoid road bridges without making a significant detour.

Obviously, many cyclists will not require any river crossings between their home and work or school location. Others may have the choice between one or two crossings. The only meaningful information on bridge preference and usage might come from considering the number of total crossings of each category of bridge. There are 208 road bridge crossings among the 397 routes, but only 33 pedestrian/bicycle bridge crossings and 23 crossings of the one-way traffic/ bicycle lane bridge. Although the road bridges in Guelph are not high or particularly long as might be the case in other locations, based on this data it seems that road bridges are not a deterrent to commuter cyclists.

2.4.4 High Speed Roadways

High speed traffic is another feature of the transportation network that planners may assume bicycle routes should avoid (City of Windsor 1990 for example). More than a quarter (27%) of the commuter bicycle routes from Guelph have some segment where the speed limit is greater than 50 km/h. These routes have an average of 1.1 kilometres of travel on these higher speed links. It is not possible to say whether these people are choosing these routes for their directness and other qualities, or if they have no reasonable alternative in terms of other bicycle routes or modes of transportation. These data might be a further indication of the different types of cyclists and an indication that cyclists who are willing to travel with vehicle traffic are not significantly affected by the speed of the traffic.

2.5 Comparison of the Actual and Shortest Path Route Characteristics

The mean of many of the route summary variables is provided in the second column of Table 2-3. The units used in Table 2-3 vary and are based on what is most meaningful given the quantity being measured, but also its effect on the comparisons made below. Although these estimates are specific to a moderate size sample of commuter cyclists in Guelph, given the dearth of actual quantitative bicycle data and the cost of data collection, this information may be useful in estimating exposure with more limited data such as trip lengths for other locations. However, beyond limited use in exposure estimation, the information in column 2 alone is of little value without information on the available alternative routes that were not used by the cyclists. It is only within the context of the unchosen routes that variables such as signals or turns can be meaningful and where results can provide input that will assist bicycle planners. Information on unchosen routes is needed to indicate whether the cyclists are choosing a route because they like its characteristics or whether they have no other reasonable route or mode choice.

The third column of Table 2-3 indicates the mean value of the summary variables for the minimum distance routes generated by the GIS. Comparison of these values with those for the actual route provides the initial insight into the attributes that may affect bicycle commuter route choice. When comparing these values note that on average 55% of an individual's actual route overlapped with their shortest path route. Also, while the variables in Table 2-3 may show a difference between the shortest and actual route, these are not necessarily the reasons why people chose the route they did. All variables cannot be properly considered here, as the shortest path is only one of a very large number of alternative routes available. Some variables simply do not measure any difference between these two routes even though in reality they may be important to cyclists. The absolute difference in the variable means is very small, especially because attributes have been aggregated over the whole route and because of the overlap of routes. Variable means that are statistically different for the two routes, based on a paired t-test at the 0.05 confidence level, have an asterisk in column 4.

Table 2-3: Variable Means for Actual and Shortest Path Routes

Variable	Actual Route	Shortest Path Route	Significant Difference at 0.05 level
Turns	6	5.7	
Turns per kilometre	1.8	1.9	*
Signals	3.9	3.4	*
Signals per kilometre	1	1	
Major Signals	1	0.9	*
Turns at Signals	1.2	0.7	*
Turns at Major Signals	0.3	0.2	*
Proportion of movements between a Major and Minor Road with a signal	0.09	0.06	*
Proportion of movement from a Minor/Path to a Minor/Path across an arterial with a signal	0.03	0.02	*
Proportion of Route on Arterial Roads	0.5	0.4	
Proportion of Route on Collector Roads	0.14	0.11	*
Proportion of Route on Local Roads	0.3	0.4	
Proportion of Route Off-road	0.02	0.04	*
Road Bridges	0.5	0.6	
Travel on Grade (km)	0.09	0.12	*
Level Railway Crossings	0.61	0.55	*

Several interesting comparisons are noteworthy from Table 2-3d. On average the actual routes contain more traffic signals than the shortest paths. A higher proportion of the traffic signals travelled through in the actual routes are used to make a turn. This suggests that cyclists chose to use traffic signals, even major traffic signals, especially for turning movements. However, as direction has been excluded from this database it is impossible to demonstrate a difference between left and right turns at signals. A preference for using traffic signals for travel between major and minor streets can be seen.

The shortest path routes contain more travel along segments with a grade, suggesting that cyclists alter their routes to avoid grades. The fewer level railway crossings in the shortest routes suggest these are preferred to the grade separated crossings. The seeming preference for direct arterial routes noted previously is supported by the absolute proportion of routes on arterial roadways in Table 2- 3 (0.5) but is not statistically significant compared to the shortest route. A preference for collector roadways is more clearly suggested by these data. Comparison of the off-road travel percentages suggests most commuter cyclists prefer not to use paths or trails. There are fewer turns per kilometre in the actual paths suggesting that cyclists might consider the delay of turns a disincentive to use a route. Finally, the actual routes contain significantly less travel on segments with more than 2 bus routes. For Guelph, the only links that have more than two buses per hour are in high activity areas such as the downtown core or adjacent to the major shopping mall. This variable might be considered a surrogate for these high activity areas that cyclists seem to be avoiding.

None of the route summary variables, including those presented in Table 2-3, show any correlation with the personal variables (gender, age etc) collected in the survey.

2.6 Conclusions and Implications for Bicycle Transportation

In terms of procedural conclusions, GIS is a valuable tool for route analysis. The analysis of bicycle commuter routes from the City of Guelph has provided detailed information that is of use for estimating exposure for cyclists. In order to obtain information on route preferences that could be useful for bicycle transportation planning comparison of the route chosen with those not chosen was necessary. Preliminary insight into factors affecting cyclist route choice were obtained by comparing actual routes to the shortest path routes. Carrying the work further to use of a modelling approach that considers more than one alternative route would certainly provide further insight.

One of the motivations for this research was to study the travel of current commuter cyclists in order to determine what types of policies and infrastructure programs might encourage the use of the bicycle, a non-motorized mode of transportation, for utilitarian or purposeful trips to reduce automobile use. The results of this analysis suggest that two types of route behaviour exist among commuter cyclists: travelling along direct major routes; and travelling along routes that avoid vehicular traffic. A question that requires further research is which type of cyclist the latent demand represents, or what proportion of each of the two types it represents.

If the majority of potential cyclists have bicycle travel preferences similar to the majority of existing bicycle commuters, then efforts to attract new utilitarian cyclists are the same as the efforts this study suggests should be made to further accommodate current commuter cyclists. These efforts should be focused on improving the road network and not on providing pathways. Reasonable efforts might include providing wider curb lanes, actuated traffic signal detectors that recognize the presence of bicycles, or installation of signals along heavily used bicycle corridors at locations where turns or major street crossings are required. Projects to build off-road paths or trails should be either recognized as primarily for recreation or designed to be direct and convenient.

However, if the potential cyclists are more similar in bicycle travel preferences to the minority of commuter cyclists in this sample who prefer to avoid motor vehicle traffic, then efforts to attract new cyclists should be different. In this case, projects that make the network of local roads and pathways more connective and direct such as provision of pathways between neighbourhoods may encourage new commuter cyclists.

2.7 References

Aultman-Hall, Lisa, Sean T. Doherty, Fred L. Hall, and Emily Andrews. (1996). *Urban Commuter Routes and Risk Preliminary Report on Accident/Fall Statistics and Bicycle-riding Patterns.* Interim report submitted to the Ontario Ministry of Transportation, Highway Safety Research Branch, February.

Consumer Product Safety Commission of the United States. (1993). *Bicycle Use and Hazard Patterns in the U.S. and Options for Injury Reduction.* November.

Cumming Cockburn Limited. (1992). *The Ottawa Carleton Cyclist Profile Survey.* Ottawa: The Regional Municipality of Ottawa-Carleton and the Regional Cycling Advisory Group, May.

Environment Canada. (1996). Climatic Centre, Toronto, Ontario.

Fenco MacLaren. (1994a). *Guelph and Area Transportation Study Report.* Guelph: City of Guelph, County of Wellington and the Ontario Ministry of Transportation, June.

Fenco MacLaren. (1994b). *Guelph and Area Transportation Study Appendices.* Guelph: City of Guelph, County of Wellington and the Ontario Ministry of Transportation, June.

Goldsmith, Stewart A. (1992). *Reasons Why Bicycling and Walking are Not Being Used More Extensively as Travel Modes,* Case Study Number 1, National Bicycling and Walking Study, U.S. Department of Transportation, Federal Highway Administration, Washington, D.C.

Ottawa Cycling Advisory Group. (1992). *Commuter Cycling in Ottawa-Carleton A Survey.* June.

Rodgers, Gregory B. (1995). "Bicycle Deaths and Fatality Risk Patterns". *Accident Analysis and Prevention,* Volume 27, No. 2, pp. 215-223.

Wilkinson, W. C. (1994). *Selecting Roadway Design Treatments to Accommodate Bicycles.* McLean, Virginia: U.S. Federal Highway Administrative.

Windsor, City of. (1990). *Bicycle Use Development Study.* Windsor, Ontario.

Preface to Chapter 3:

This chapter is a slight adaptation of a draft paper[2] intended for submission to a research journal. Contributions from Drs. Hall and Anderson consisted of critiques, discussion and revisions of draft versions. Dr. Miller provided extensive input on designing the methodology, and provided computer programs as well as critiques and revisions to drafts of the paper.

---

[2] Aultman-Hall, Lisa, Eric J. Miller, Fred L. Hall and William P. Anderson (1996). "Use of a Logit Model for Bicycle Commuter Routes".

Chapter 3: Use of a Logit Model for Bicycle Commuter Route Choice

3.1 Introduction

The objective of this paper is twofold. First, commuter bicycle route data are used to develop a model of route choice that provides useful quantitative information on bicycle travel behaviour. However, an issue that remains open for debate is how route choice should be modelled when actual travel routes are known. The actual routes used to travel through transportation networks are rarely collected, but were in this case. Therefore, a considerable portion of this paper is devoted to its second objective: presentation of the procedure used to generate alternatives to a set of known routes and the subsequent calibration of a multinomial logit choice model.

In travel demand forecasting procedures, the step that involves routing is usually handled by some kind of route assignment method. Route assignment is usually based on a function of travel time or cost that is not calibrated with actual route data. Several developments in the past decade have driven the need for a better understanding of routing behaviour. First, the design and implementation of traveller information systems to manage traffic involves the provision of information to alter people's travel patterns. The necessity to understand the underlying route behaviour in order to alter it is obvious. Second, related research into stochastic traffic assignment requires an understanding of actual route behaviour to properly calibrate travel time uncertainty functions against driver's perceptions of travel time. Third, attempts to utilize transportation management systems to accomplish a system optimum routing scheme in terms of fuel consumption or pollutant emissions needs an existing conditions base with which to compare and measure progress. The actual routing patterns of people are required for this task. Finally, the wide-spread use of Geographic Information Systems (GIS) has made storage and analysis of routes possible. The development, by local government and transportation agencies, of GIS network databases that contain the transportation infrastructure and their attributes, makes it possible to meaningfully analyze the route data.

After a brief description (section 3.2) of the data source for this study, section 3.3 of this paper describes related previous work. Section 3.4 describes several characteristics of the discrete choice modelling approach that make it desirable for use in route applications. Unfortunately, complications arise in its application to actual routes. Section 3.5 describes the development, using a GIS network database, of a choice set of alternative routes that addresses these complications. The quality of the choice set and the seriousness of potential violation of the logit formulation assumption of independence from irrelevant alternatives (IIA) can only be assessed by evaluation of the resultant model (section 3.6). The final section of the paper describes the parameters of the route utility equation and their implications for bicycle planning.

3.2 Data

The data available for this modelling exercise are comprised of the complete routes from origin to destination used by commuter cyclists in Guelph, Ontario (Fenco MacLaren 1994a and 1994b). The average one-way route length was 3.7 kilometres. Although the survey collected routes for different types of trips, the focus for this analysis is commuter cycling, of which 397 work and school trips are available. The work/school trip routes had clear end points and the complete trip could be readily identified from the map in the questionnaires. A limited number of personal variables (age, gender and which months of the year the person cycles) were collected and can be used in the model.

The bicycle routes were digitized into a GIS network database that contains all the roads and off-road paths/trails in the 68 square kilometre area of the City of Guelph. The database contains variables that describe the characteristics of the 2983 links and the 2090 nodes of the network. The attributes of the routes, such as the total number of traffic signals or distance of travel along different types of links, are easily obtained through query of the link and node attribute tables within the GIS database. The same procedure is used to extract the route attribute variables for the alternative routes generated for the model development. The amount of distance the person travelled beyond the minimum path distance is easily calculated from the GIS route output and was added to the personal variables available for model estimation. The exact details of the Guelph bicycle route dataset and the attributes coded in the network database can be found in Chapter 2.

3.3 Previous Work

There have been previous studies of automobile, bicycle and transit routing. These studies can be categorized by the type of data used: route behaviour information with no specific route data; stated preference or simulation data that often involve individuals choosing between hypothetical routes or route scenarios; or actual link by link travel routes similar to those available for this work. This section of the paper describes how these previous studies relate to this research. In particular, it is necessary to illustrate why none of the previous research, even that which makes use of discrete choice models, has dealt with the critical issue in this paper: development of a choice set for modelling when actual routes are known.

Most of the recent automobile route research (both that with actual route data and that without) has been motivated largely by the need to understand the effect of traveller information systems. Some route studies involve consideration of routing behaviour, without consideration of exact routes (Polydoropoulou et al. 1994, Khattak et al. 1994 and Abdel-Aty et al. 1994 for example). It is possible with this type of data to use discrete choice methodology to predict for example the frequency of route switching or whether travel information is used. In these cases because the item being predicted is not the route used, the issues for development of a set of alternative routes are not faced.

Other studies depend on simulation or stated preference type data (Adler et al. 1993 and Vaughn et al. 1993 for example). In these cases individuals may be asked to choose between hypothetical routes or scenarios. It is possible with the simulated and stated preference data to develop a discrete choice model in which the choice of route is modelled. The significant advantages of stated preference (including simulation) techniques to collect route choice data are succinctly stated by Bradley and Bovy (1984, p40):

> -the presentation of choice situations, the composition of choice sets, and the characteristics of the alternatives are controlled, ensuring data suitable for [model] estimation,
> -choice factors may be included at levels which they are not found or are difficult to observe in reality, [such as traveller information] and
> -many observations may be obtained with relatively few subjects and low expenditure.

These advantages make the stated preference data ideal for use in discrete choice models.

Bradley and Bovy (1984) recognize a main problem with stated preference type data in that external data should be used to validate the judgement of subjects. This leads to one of the premises on which the work in this paper is based: some route research must involve analysis of the actual routes used in the real transportation network by travellers. Efforts to compare stated and reported route diversion have been made (Khattak et al. 1994) as well as to incorporate both actual route data and simulation data into one large study effort (Abdel -Aty et al. 1995a and Vaughn et al. 1996 are two of several papers resulting from an extensive route research project at the University of California at Davis that involved several surveys and simulation techniques). In one portion of that study (Abdel-Aty et al. 1995b) revealed and stated preferences techniques are cleverly combined. The actual route was collected in an initial survey and used to custom design individual second phase questionnaires. In the second phase, participants stated their preference between route scenarios that included their regular route and alternatives between their origin and destination. This approach resulted in a dataset that could be used with discrete choice methodology because the choice set was determined a priori during the questionnaire design.

Discrete choice methods are also found in studies with actual observed route data where the choice of routes is limited, such as in a transit network (Hunt 1990) or where limited alternative routes are considered in only a portion of a network with fixed origin and destination points (Hamerslag 1981). In both these cases, the number of available alternatives was small and could all be included in the model estimation. Other analysis of actual routes (Hatcher and Mahmassani 1992) has simply not involved the modelling of route choice. However, as more vehicle probe and route guidance systems come into operation, researchers will have more actual route data for study and more comprehensive modelling of the route choice will become possible.

All of the above approaches avoid the primary complication faced in this paper when the dataset of interest contains the actual observed travel routes of individuals in a large network: defining the choice set. In the earlier studies, either the choice set was defined during data collection through the options that were provided to the participant in the survey, or the network was small enough that all alternatives could be considered. It is easier to generate larger quantities of stated preference or simulated data than to work with actual revealed preference data. The circumstances in the actual route data case are uncontrolled; although the actual route is known with a high degree of certainty, the context of the route choice is uncertain. Bradley and Bovy (1984) point to four challenges that must be overcome for the use of actual revealed preference route data, such as the bicycle routes in this work. First, the relevant choice sets are not always known. Second, the alternative routes may be strongly interdependent. Third, the important characteristics of the routes may not be known. And finally, data on many routes are needed and the collection and processing may be costly and time consuming. For this paper, an approach to overcome the first two challenges is discussed in section 3.4.

In order to address the final two challenges regarding data collection, processing and obtaining characteristics of the network, the bicycle focus of the research can be exploited. There are two factors that make cyclist route choice ideal for initial exploration of the proposed logit choice modelling procedure. First, it is somewhat easier to collect the actual link by link routes used by cyclists because bicycles generally do not travel as far as automobiles. A technique of following a sample of cyclists who started at a given origin has been used in the Netherlands (Hopkinson, 1989), while Lott and Tardiff (1978) used a mapping interview. For the city of Guelph, Ontario, where the data for this study were collected, a map of the 68 square kilometre urban area fit on a single page within a survey questionnaire. For most of the commuter cyclists, travel outside the city was impractical. Cyclists simply traced their routes on the map. This method of fitting the available network on a questionnaire would not have been easy to accommodate for automobiles.

The second advantage of bicycle routes for testing the discrete choice logic is that bicycle routing is known to be affected by factors beyond travel time and distance that can be easily stored as attributes of the network components in a GIS network database. Previous studies indicate these factors include surface quality, safety and gradient (Hopkinson et al. 1989) based primarily on stated preference surveying), available types of infrastructure (Lott and Tardiff 1978) based on actual routes in a limited single corridor) and traffic levels (Ashley and Banister 1992) based on comparing relative cycling levels in various corridors exemplifying different characteristics). The exact factors that affect automobile route choice are not as well established. Although there are several studies that have established the factors affecting bicycle route choice (Axhausen and Smith 1986) and Bradley and Bovy 1984) in addition to those mentioned above), all but one of these have used European bicycle route data. The applicability to North American bicycle conditions is unknown. Therefore, an important result of this modelling work with data from Guelph, Ontario will be to provide quantitative input to North American bicycle planning.

In summary, previous discrete choice route models have not involved actual travel routes or have been undertaken in a limited network where all alternatives could be considered in a modelling framework. As a consequence, issues for development of a route choice set for discrete choice model calibration with actual routes have not been fully explored. In addition to this methodological issue the application in this paper to urban bicycle routes, is of practical interest to bicycle transportation planners due to limited North American data on bicycle route patterns.

3.4 Use of Discrete Choice Modelling

Before elaborating on the problematic issues surrounding use of the logit model formulation for this specific route choice application, it is useful to consider the reasons why the discrete choice approach is desirable. Strictly speaking, discrete choice analysis is the modelling of a choice from a set of mutually exclusive and collectively exhaustive alternatives (Ben-Akiva and Lerman 1985). Discrete choice models are well suited to, and routinely used in, modelling transportation decisions of mode or destination choice. However, the possible routes one can use for travel through an urban area are not strictly discrete and can be made up of overlapping combinations and variations of each other. In addition it is impossible to exhaustively consider all alternatives.

Regardless of the inconsistencies between route choice modelling and the strict definition of discrete choice analysis above, an attempt to use the methodology on the route choice problem is warranted for several reasons. First, as evident from the initial quantitative analysis of the actual routes used in this study (Chapter 2), one can only evaluate the attributes of a route and their effect on the route choice decision only by considering them in light of the attributes of the unchosen routes. Discrete choice modelling approaches that use utility maximizing assumptions allow for the consideration of both the chosen and unchosen alternatives. Second, individuals in an urban area each face a unique set of route choice alternatives between distinct origins and destinations. Discrete choice model methodology has the ability to accommodate the dissaggregate route possibilities and variable characteristics of the routes for each individual in the sample. Also possible within the modelling framework is the ability to use personal variables to account for different effects of route attributes for different segments of the population. Finally, the discrete choice methodology allows for the inherent probabilistic nature of the route choice process and the certain fact that all attributes of a route that affect the traveller's choice behaviour are not observed within the database.

Specification of a choice set is a critical stage in discrete choice modelling. This issue as it pertains to destination choice models is addressed by Thill (1992). His concern that mis-specification of a choice set may lead to gravely incorrect estimation of parameters and even incorrect policy conclusions based on model results is equally applicable to discrete choice route modelling. The complications originate from the violation of the two components of the definition provided in the first paragraph of this section. The alternative routes within a network are not mutually exclusive. They may have sections in common or overlap. However, even if it were possible to consider all of the large number of alternatives exhaustively, this is not what is necessary. The whole choice set is only the subset that is actually evaluated by the user of the near-infinite possible routes in the network. Practically speaking this choice sub-set is also extremely large and unknown. Therefore, the model calibration must occur with an even smaller subset of the evaluated alternatives.

There are two typical ways to create manageable choice sets when the actual choice set is extremely large: aggregation and random sampling (Ben-Akiva and Lerman 1985). Neither is appropriate in this route choice case. In order to aggregate alternatives we would require a common attribute, such as spatial location in destination choice, over which to aggregate the alternatives. However, in the route problem every individual faces a unique set of alternatives between their origin and destination and the combination of attributes within each set is unique. In order to use a random sample of the routes in the choice set it would be necessary to establish the set of actual routes to draw the sample from. As this set is extremely large it is impractical to undertake such an approach.

If one can meet the independence from irrelevant alternatives assumption (IIA) of the logit model it is possible to calibrate a route choice model using a logit formulation on any subset of the actual choice set evaluated by the traveller. However, despite this desirable quality of the logit formulation, interdependence and duplication among the alternative routes may make meeting the IIA assumption difficult in the route modelling case. Because a logit model is driven by the difference in the utility of the alternatives, where the utility is a function of the route attributes, not only physical overlap of routes is of concern with respect to violation of the IIA assumption but also the commonality of attributes.

The types of duplication and correlation among alternatives that create IIA problems are most certainly present in a route choice set. For example, a person who has a preference for one route comprised of only local residential streets will certainly have a similar preference for a route through another neighbourhood but perhaps an aversion for a route along only arterial roadways. One common way to deal with such correlation problems within the alternatives of the choice set is to adopt a nested model structure. However, because the choice sets for every cyclist in the sample will be a unique set of alternatives between their specific origin and destination, there will not be a pattern or common elements across people to establish a nesting structure.

An alternative approach to reducing correlation between routes in the choice set would be to include only one route exhibiting a certain combination of characteristics within each individual's route choice set. For example, a route through one residential neighbourhood can be considered representative of all similar local road options between the individual's start and end point. Therefore, only one such route could be included in each person's choice set. This assumption and limitation of the choice set is not problematic if one accepts that this modelling exercise is intended to achieve an understanding of travel behaviour and not for exact predictive or forecasting purposes. It might also seem that certain alternatives are being eliminated from the choice set, thus creating bias. However, this step of eliminating alternatives identical with respect to observed variables is necessary for removing bias from the Logit model parameter estimates. The random or unobserved portions of the utility for two routes with identical characteristics are likely to be correlated and this adjustment to the choice set is intended to remove the parameter bias that the correlation would create.

The considerations raised in the previous paragraphs result in the following set of criteria for use with the GIS to determine a subset of the alternative routes between a person's origin and destination for estimation of the route choice model:

1) the actual route must be in the choice set;
2) the subset must contain realistic routes which the cyclist would have actually evaluated and considered using; and
3) routes should be dissimilar such that at least one of the 25 variables describing route attributes differs by some threshold value from all other routes in the individual's choice set.

Criterion 2 addresses the issue of requiring that the routes included in the model were actually evaluated by the cyclist, while criterion 3 results from the need to ensure IIA.

The choice set used can only be evaluated through consideration of the resultant models. A successful route choice set generation procedure will produce a model that is consistent across different reasonable choice sets and passes a formal IIA test. Embedded in this idea is the assumption that there will exist "true" behaviour that will be constant across choice sets that exhibit a range of route options. In particular for this exercise, a valid model and choice set will exhibit IIA. However, given this restriction, there maybe certain attributes whose effect on the route choice cannot be measured in the exercise because their addition to the model causes it to violate the IIA assumption.

It is tempting at this point of choice set generation in the analysis to want to analyze the attributes of the routes in the choice set in hope of establishing how "good" the choice set is. Twenty-five variables describing each route are output from the GIS. The means and distributions of these variables for the actual routes for the whole sample are known.

Comparison of the alternative characteristics to the characteristics of the actual routes might provide insight as to whether the routes in the choice set are realistic. However, it is not just realistic routes that cyclists will use that are wanted in the alternative choice set; routes that cyclists would never use are also needed as long as the cyclist is aware of them. The requirement for a valid choice set is that the cyclist must have evaluated the option or in other words been aware that it existed. For example, a cyclist might be aware of a route that includes a high speed heavy volume arterial road with poor quality pavement and no shoulder but under no circumstances would the cyclist choose to use this route. This type of alternative is desirable in the choice set and any measurement scheme that compared actual routes to the choice set might eliminate this route when it contributes valid information to the model. The discrete choice model methodology requires information about the unchosen alternatives that this type of route represents. Although it is possible to describe the choice set characteristics it is impossible to measure their appropriateness or validity by comparing them to the actual routes used.

Alternatively, one might wish to measure how "good" the choice set is by considering the physical overlap between an actual route and its GIS generated alternatives. It might seem that a choice set that had very little actual overlap was a good set. However, it is possible to conceive of a situation where all routes in a choice set are the same except for one section where three very different options are available; perhaps a school yard, a hilly dirt trail and a very busy road section. Even though the overlapping portions might make up most of the physical length of the route the difference observed at the single section provides important information to the model and the choice set is valid. Likewise three non-overlapping routes that simply follow different paths through a residential neighbourhood might seem good by the overlap criterion might seem good even though they actually provide no information to the model. Clearly lots of variation within the choice set is good, but there exists no benchmark with which to compare the amount of variation. As indicated previously, the only test of the choice set is in the final model.

There is one further special characteristic of a discrete choice route model as it can be used for this type of analysis that requires mention. The utility function describing the alternatives is a linear in parameters function of the attributes of the routes and individuals. The label of each route is simply nominal, ie each individual's route alternative #5 has no particular quality or meaning when related to any other individual's route #5. Therefore the model is by necessity generic and no alternative-specific variables are used. This has implications for both personal variables and route lengths. Personal variables must be interacted with route variables for use in the model as they would otherwise be the same for each alternative in an individual's choice set and provide no information to the model. Direct measures of length cannot be used. This length limitation results from the generic model combined with the use of the minimum path algorithm to generate alternatives. In most cases the alternatives tend to be shorter than the actual paths and inclusion of a length variable results in an estimation that indicates individuals simply use the longest route available to them. It is unreasonable to assume commuter cyclists want to travel further just for the sake of travelling further. The issue of interest in this case is what characteristics of the routes affect the route choice such that people travel out of their way to avoid or find something.

3.5 Development of a Bicycle Route Choice Set

A minimum path algorithm (based on Dijstra's algorithm, see E S R I (1995) for more information) built into the GIS ArcInfo can easily determine the minimum path between each cyclist's start and end location. The impedance used in the algorithm is, by default, distance along the links. This impedance can be altered and impedance can be added to nodes within the turn or node attribute tables. There was no prior information that could be used to evaluate what or how impedance values should be altered to generate more than just the minimum distance path. Use of subjective rules was necessary. In this case, the objective was to create reasonable routes that were sufficiently different from each other to exhibit a range of all attributes. Each of nine rules were used to generate one of nine alternative routes. These rules are listed in Table 3-1. The rules only make use of the link type, turn type and signal variables. The goal was to obtain routes that exhibited differences not just with respect to these variables. Lengths were halved or doubled as opposed to more exaggerated changes to ensure routes remained reasonable. The signal and turn penalty of 75 metres was based on the amount of travel time that would be lost due to a slow down. The details of these subjective rules are not considered important as long as they develop enough routes that are sufficiently different for the modelling exercise. As indicated below these rules served their purpose satisfactorily and like the final choice set can only be evaluated by considering the final model results.

Table 3-1: Impedance Rules Used to Generate Alternative Routes in the GIS

1. All off-road links have impedance equal to half length;
   all other links have impedance equal to length

2. All turns are penalized by 75 metres.

3. Local/minor street links have impedance equal to half length;
   all other links have impedance equal to length.

4. Local/minor and collector street links have impedance equal to half length;
   all other links have impedance equal to length.

5. All links with a railway crossing, grade, one-way traffic, bridge or speed limit above 50 kph have impedance equal to twice the length;
   all other links have impedance equal to length.

6. Arterial street links have impedance equal to half length;
   all other links have impedance equal to length.

7. Nodes with traffic signals are penalized by 75 metres.

8. All good quality off-road paths/trails have impedance equal to half length;
   all other links have impedance equal to length.

9. Links with AADT > 15000 vehicles have impedance equal to half length;
   all other links have impedance equal to length.

Once the alternative routes had been generated by the GIS's minimum path algorithm the attributes of the links and nodes in each route were obtained in the same manner as for the actual routes by relating the route tables to the link, node and turn tables within the database. Once the attributes were obtained they were downloaded to ASCII files for input to the choice set determination algorithm. The algorithm logic used to evaluate which of the eleven possible routes (the nine rule generated routes, the actual route and the shortest distance path route) would be included in each individual's choice set is shown in Figure 3-1. Essentially the first check was intended to ensure the route was reasonable and would have been evaluated or considered by the cyclist. This involved ensuring the route was not more than 1.7 times the length of the minimum path route between the person's start and end location. This value was based on the 99th percentile of diversion from the minimum path among the 397 actual routes for the sample of commuters. Previous research in California (Abdel-Aty et al. 1995b) has found that people were familiar with alternative routes and the overall network between their origin and regular destination and therefore this check was considered sufficient to ensure the route had been evaluated. Very few routes failed this test which would be expected given that the minimum path algorithm was used and impedances were only altered slightly.

The second test, shown in Figure 3-1, involved checking if the route under consideration was different in at least one measure of the 28 measures from all routes already placed in the individual's choice set. The threshold levels used were subjectively determined and are listed in Table 3-2. Distances along different types of infrastructure are measured as percentages of the total route because percentages are felt to be a closer representation to reality. For example, if one 0.3 km route is all pathway and a second route is 0.4 km long but consists of 0.3 km pathway and 0.1 km on an arterial roadway, comparing the absolute amount of path would indicate the routes are the same with respect to path travel. However, one is 100% path and the other is only 75% path and the percentages convey more meaningful information. Nine of the 397 routes had no alternatives beyond the actual route that met the criteria listed in section 3.0 and Table 3-2. Investigation of these routes revealed that in some cases no other route existed, while in others the only alternatives were through different blocks of a residential neighbourhood which the algorithm would have labelled equivalent. The estimation program will reject these observations from the model estimation. For 15 routes all 10 additional alternatives were found to be different in some way and were included in the choice set. On average each route choice set contains 6.5 different options including the actual route.

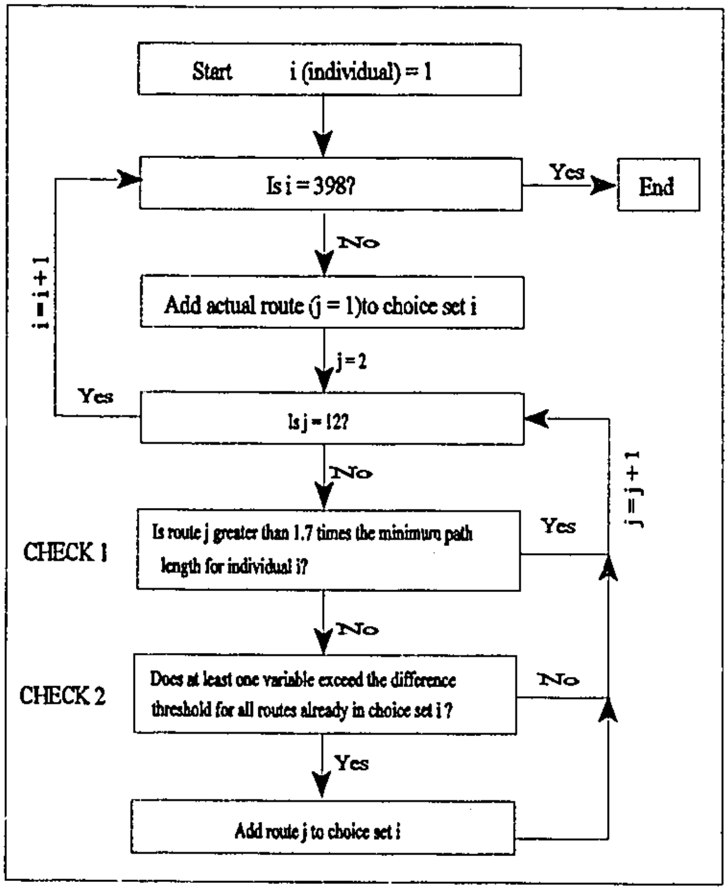


Figure 3-1: Choice Set Algorithm Logic

Table 3-2f: Threshold Values of Each Route Variable[3]

Route Variable[4]	Threshold Level
Travel along each of 6 different categories of infrastructure type as a percent of the total route length	5%
Absolute travel distance along links with greater than 50 km/h speed limits	0.1 km
Absolute travel distance along links with greater than a certain number of buses per hour (2 levels)	0.1 km
Total number of 11 categories of turns or intersection movements	1
Total number of traffic signals	1
Total number of major traffic signals	1
Total number of road bridges	1
Total number of railway crossings (3 categories)	1
Absolute travel distance along one-way streets	0.1 km
Absolute travel distance along links with a grade	0.1 km

3.6 Model Estimation

After determining the choice set for each individual, the route attribute variable information was used in a logit maximum likelihood estimation program. This program estimates the maximum likelihood parameter coefficients for a linear in parameter generic utility function of the variables describing the alternative routes. In this case the basic logit model shown in Equation 3-1 was used.

---

[3] When the difference between the measurements of the given variable for two routes is equal to or exceeds the threshold the routes are labelled different with respect to that variable.

[4] These are all of the variables used in the choice set generation algorithm but are not a complete list of those available for the route choice model estimation.

$$P(X_i = x) = \frac{e^{U_{ix}}}{\sum_{J_i} e^{U_{ij}}} \qquad \forall j \subset J_i \qquad [3\text{-}1]$$

where: $P(X_i = x)$ = the probability individual i chooses choice x in set J
J_i = the set of all alternatives for individual i
U_{ix} = the actual utility of choice x for individual i (this quantity is equal to an observed utility V_{ix} such as equation 3-2 or 3-3 plus an unobserved portion assumed to be independent and identically distributed according to the Gumbel distribution with zero mean)

Initially a binary choice model was estimated using only the actual route and the shortest path route. This choice set is reasonably defensible as a valid choice set. If one assumes cyclists wish to travel the minimum distance necessary then they would most certainly consider using the minimum path yet many choose not to. The final utility function for the shortest path model is shown in Equation 3-2. The model has a Rho^2 of 0.22. Parameters are significant based on t-tests at least at the 0.05 level except for collector road travel which is only significant at the 0.18 level. Note that except for the dummy variable indicating if an individual diverted more than average from their minimum path route no personal variables enter the model. With only two routes in the choice set the model has insufficient information to allow for statistically significant sample stratification.

People can reasonably be expected to have considered more than two routes. Many of the types of attributes within the network are not exhibited by either of the two routes in this binary choice set for an individual and cannot be tested. For many variables of interest there was no difference between the actual and shortest path and therefore the effect of these variables could not be measured either. In a larger dataset the effect of different factors might be measured because over all the individuals some people would have each of the variables of interest in their choice set. Rather than conclude more data collection was necessary given the cost and complexity of collection, the testing of a multinomial logit model was warranted.

$$V_{ix} = 1.3\, C_{ix} + 4.6\, T_{ix} - 2.2\, G_{ix} - 10.7\, P_{ix} - 1.05\, B_{ix} - 2.1\, D_i A_{ix} \qquad [3\text{-}2]$$

where:
V_{ix} = the observed utility of route x for individual i
C_{ix} = proportion of the total travel undertaken on collector roads
T_{ix} = proportion of turns with a traffic signal
G_{ix} = kilometres of route on a grade
P_{ix} = proportion of the total travel undertaken on a bad or average quality off-road path or trail
B_{ix} = kilometres of travel on links with more than 2 buses per hour
D_i = dummy variable equal to 1 if the difference in length between the individual's actual route and their shortest path was greater than the average difference of 0.4 km, equal to 0 otherwise
A_{ix} = proportion of the total travel on arterial roadways

Development of the multinomial logit model proceeded in a slightly unusual manner. First, estimation with only route variables (no personal variable interactions) was undertaken. For each model the resultant parameter values, their significance, sign (+/-) and correlations with other parameters were considered. If variable coefficients were insignificant, they were assumed not to affect route choice for this sample of commuters. If the parameter was correlated with another parameter in the model the correlation was noted. If the parameter had an unexplainable sign the variable was noted as troublesome. In most such cases it was concluded that it could not be determined with this dataset how these variables affect route choice.

If a parameter passed with respect to the above checks the model was re-estimated with a truncated choice set. The truncated choice set contained only the first three alternative routes (plus the actual route) that passed the choice set determination algorithm criteria. This re-estimation was undertaken in place of formal IIA tests for preliminary models.

Any variables that were found to have significant inconsistencies between the choice sets in either parameter value or significance were eliminated. Several parameters were found to greatly improve the fit of the model with one particular choice set but were not consistent with other choice sets and have not been included in the final model. The effect of these particular variables on route choice cannot be determined from this dataset.

Once the important route variables for inclusion in the model had been established, it was possible to consider how personal variables could be interacted with route variables. In order to incorporate personal variables, the model was re-estimated for sub-groups of the sample to determine which parameter estimates were consistent for population groups. Any variables found to change were targets for interaction trials. Some route variables not found significant for the whole sample were also tested for certain sub-groups. In the end bicycle commuter route choice was found to be different for different groups of cyclists. It was not possible to find these personal variable effects with only the binary choice set.

The final utility equation for the multinominal logit model, estimated using all routes deemed acceptable by the choice set algorithm described in section 3.4, is shown in Equation 3-3. The Rho^2 for this model is 0.14. This goodness of fit statistic is not overwhelming but must be considered in light of the large number of alternatives and the necessity that the exact route chosen be predicted in order to get credit for it being predicted right. The Rho^2 also reflects the major variation among cyclists with respect to their preference for cycle routes. Table 3-3 indicates the t-statistic associated with each parameter. While the overall model fit is moderate most parameters are very significant.

In addition to the ability to find significant personal interactions when the dataset for model estimation contained more routes and thus more information regarding alternatives, there are other differences between the binary model and the multinomial logit model. First, route characteristics (grade-separated railway crossings and major street crossings

$$V_{ix} = 2.0\,C_{ix} - 0.4T_{ix} - 0.4M_iB_{ix} - 1.8Y_iX_{ix} - 0.7O_iX_{ix} + W_i\,(-2.5G_{ix} - 0.5R_{ix}) - 0.8S_i\,R_{ix} - 3.0P_{ix} \qquad [3\text{-}3]$$

where V_{ix} = the observed utility of route x for individual i
C_{ix} = percent of route x that is on a collector roadway
T_{ix} = number of turns to/from a major road to/from a minor road without a traffic signal
M_i = 1.0 if cyclist is male, zero otherwise
B_{ix} = length of route with greater than 2 buses per hour (km)
Y_i = 1.0 if cyclist is younger than 19 years, zero otherwise
X_{ix} = number of crossings of a major road from a minor/collector/path to a minor/collector/path with no traffic signal
O_i = 1.0 if cyclist is older than 18 years, zero otherwise
W_i = 1.0 for a winter cyclist (cycles at least once in January or March)
G_{ix} = kilometres on an up or down grade of greater than approximately 7%
S_i = 1.0 for a summer only cyclist ($W_i = 0.0$)
R_{ix} = number of grade separated railway crossings in the route
P_{ix} = kilometres on an average quality off-road path or trail

Table 3-3: Multinomial Logit Model Parameter Coefficients and Corresponding t-statistics

Parameter	Coefficient Estimate with full choice set	t-statistic ($t_{0.05} = 1.6$) ($t_{0.1} = 1.3$)
C_{ix}	2	3.7
T_{ix}	-0.4	6.7
M_iB_{ix}	-0.4	1.8
Y_iX_{ix}	-1.8	1.7
O_iX_{ix}	-0.7	4.3
W_iG_{ix}	-2.5	2.7
W_iR_{ix}	-0.5	1.3
S_iR_{ix}	-0.8	2.2
P_{ix}	-3	5.4

without traffic signals) that were not significant in the binary model were significant in the multinomial model. This is assumed to be due to the nearly triple increase in information that the multinomial model had available for estimation. Second, the variable equal to the product of percent travel on arterial roads and a dummy variable for people who diverted more than average from the minimum path was not consistent across multinomial choice sets suggesting that its significant presence in the binary model should be questioned. Together these factors suggest that for this type of data a binary model is not sufficient for choice model development.

In order to test that the final model met the IIA assumption the Chi Square test proposed by Hausman and McFadden (1984) was used. Three restricted choice sets were developed. Recall that the routes in the choice set are completely generic; route #5 for one individual does not necessarily have any quality in common with route #5 for another individual. Therefore, the first restricted choice set was created by eliminating one random alternative from each cyclist's choice set. For the second, the route created by the ninth subjective rule in Table 3-1 was eliminated. This route was chosen because it was checked first for inclusion in the choice sets and therefore 91% of the sample had route 9. The third restricted set was created by eliminating route 7 from the choice sets. A total of 50% of cyclists had route 7 in their choice set and it was chosen because it was created with very different criteria from route 9. The IIA testing did result in changes to the model specification. The resulting Hausman and McFadden statistics for a comparison of these three restricted choice sets with the final model presented in equation 3-3 are 12.2, 15.2 and 6.1. These statistics follow the Chi-square distribution with 9 degrees of freedom. These values are not significantly different from zero (0.05 level critical value = 16.9). The conclusion is that the model does meet the IIA assumption.

Throughout the modelling procedure that led from parameter significance testing, through calibration with a truncated choice set, and investigation of parameter correlations to IIA testing, variables were labelled with respect to their effect on bicycle route choice. All variables tested fall into three categories: variables that are in the final model and whose effect on route choice for this sample can be approximated; variables that are inconsistent across choice sets or interact with other parameters and whose affect on the route choice cannot be determined for this sample with this modelling procedure; and finally variables that were not significant and can be concluded to not affect route choice for this sample. A listing of the variables that were tested and fall into each of these categories can be found in Appendix B along with additional personal variable interactions that were attempted.

A final note should be made regarding an attempt to estimate parameter elasticities for the model. It would be useful to estimate elasticities for the model coefficients in order to evaluate the relative importance of the variables that are found in the final model. However, several complications preclude this estimation. A problem arises from consideration of the meaning of elasticities in this generic route context. In a mode choice problem one might try to find the elasticity of the probability of choosing a particular mode. But in this instance all routes are unrelated across individuals. It might be meaningful to consider the average or distribution of the point elasticities for the actual route. This could be interpreted as finding how a change in the variable would result in increasing the probability that the actual route is chosen. However, many of the variables in the model are either dummy variables or integer variables that are often zero. When the value of a variable is zero for an individual for a given route, the direct logit elasticity is zero even though this lack of an attribute (such as a grade) may be an important factor for this choice being taken or not taken. Although it might be possible to estimate sample-averaged arc-elasticities the context of the elasticity with respect to the generic alternatives resulted in a decision not to pursue this issue.

3.7 Bicycle Route Model Interpretation

Previous work with this dataset (Chapter 2) considered only the mean values (and some distributions) of the route attributes output from the GIS and compared them to the same attributes for the minimum path route. This previous approach had some disadvantages in that comparison was only made to the shortest route and the simplistic single dimensional comparison did not account for interactions and did not reveal any effects that were related to personal variables. The multinomial logit estimation provides a stronger result in that variables found to factor significantly into the utility equation were stable over choice sets and with other model formulations. The estimation is multi-variate and considers interactions between the route variables. In interpreting the results it is important to note that all of the route variables shown in equation 3-3 had statistically significant parameters before the personal variables were interacted. These parameters had the same sign (+/-) as the final variable but had slightly to moderately different magnitudes.

Several of the Chapter 2 results are re-confirmed by this model. Guelph commuter cyclists like to travel on collector roadways. This effect is presumably due to the direct nature of this class of roadway combined with its relatively lower traffic volumes compared to arterial roadways. The cyclists have an aversion for making turns to or from a minor road from or to a major road without a traffic signal. Similarly, crossing from a minor road or path across a major road to another minor road or path without a traffic signal is also found to be a negative attribute in a route. The commuter cyclists have an aversion for grades. These particular results are not contrary to what municipal bicycle planners believe is true of bicycle travel behaviour: cyclists like direct routes and use traffic signals to cross or merge through or into heavier traffic. What is important is that these ideas of bicycle travel behaviour can be confirmed by quantitative analysis of actual bicycle travel.

The model indicates that bicycle travel along links with more than 2 buses per hour represents a negative factor in terms of utility. This variable has an interesting context for the City of Guelph. Guelph is only a medium size city with a population of 93 000. Transit service is limited. The only links within the urban area that have more than 2 buses per hour are those found within the downtown core of the city, along one side of the city's regional mall and along two main east/west corridors. In the downtown core these streets are busy (in terms of automobiles, pedestrians and other activities), wide and have parking along both sides with closely spaced traffic signals at intersections. The mall area is similarly a high activity area. One of the east/west corridors is along two lane roadways across most of the city cutting directly through downtown. These particular roads are in many spots and were probably not originally designed as major routes across the city but have become such. The second east/west corridor has greater than two buses for only approximately 2 kilometres that lead to the university. In this case the road is neither narrow or parallel to high activity areas such as commercial establishments. The bus variable in all but the last case can be considered a surrogate measure for these types of high activity streets. The model indicates cyclists prefer to avoid these sections. Downtown and other commercial areas are perplexing for bicycle planners attempting to lay out bicycle networks. While bicycle networks should perhaps lead through these areas as they represent destination locations, this model suggests it is more important to the bicycle commuters to developed networks that lead cyclists around the high activity areas.

The bus variable is an interesting one with which to consider the role of the personal variable interactions within this logit model. This term in the utility equation is multiplied by a dummy variable that is equal to one for men, but zero otherwise. The proportion of routes in the database travelled by men was 63%. The bus variable itself without the gender interaction was also significant. A bus variable multiplied by a dummy variable equal to 1 for women also resulted in a negative coefficient suggesting women also have a aversion for these links. However, the parameter for women was not significantly different from zero. This result could indicate that not enough women have routes on either side of these specific areas for the attribute to be present in their choice sets. It might also indicate that overall women prefer to go through some of these areas such as the downtown or mall area perhaps to carry out household errands or other tasks. However, it seems more reasonable to assume given that the sign of the parameter is the same as the parameter for men that this dataset is simply too small for this relationship to be statistically significant. This factor is presumed to be at play for most of the personal variable interactions. The lack of interactions for certain groups is not necessarily considered an indication of a lack of a relationship for that group of cyclists but rather a limitation of the small dataset used for this initial model development.

The difference between adults and children in the coefficient for the number of crossings of major streets from minor streets or paths to another minor street or path is considered meaningful. The difference between the parameter values suggests logically that children have a stronger aversion for this type of crossing than adults. A total of 72 of the 397 routes in the dataset were travelled by persons 18 years and under. The average age of this sub-group was 10.4 years. It is intuitive that children have more difficulty with such crossings compared to adults. Both results suggest that installation of traffic signals along major bicycle corridors where major street crossings are necessary will improve bicycle travel and that cyclists, especially children, will use the signals.

The negative effect of grade-separated railway crossings was not anticipated. It was postulated that perhaps level crossings that might catch bicycle tires and cause falls would have a negative influence on the route choice. However, this effect was not found. Instead it seems the grade and perhaps narrow underpasses (many of the grade-separated crosses are underpasses in Guelph) of the grade-separated crossings affect cyclist route choice. People who cycle in the winter show less aversion for the crossings which seems reasonable given that these cyclists tolerate winter cycling conditions (52% of the total 397) in Guelph and therefore might be more tolerant of other non-ideal route sections.

It is unexpected that only winter cyclists had a significant coefficient for gradients. If, as postulated above, people who cycle throughout the year are more tolerant of negative aspects of the available routes, one would expect the summer-only cyclists to also avoid grades and possibly with a larger negative coefficient in the utility equation. Whether or not a section was on a grade could only be indicated by a dummy variable due to the nature of the data available to build the network database. A grade of approximately 7% was the breakpoint where a section was considered to have a grade. This level is quite high. It may be that individuals with any grade (the 7% sections or the less steep alternatives that can be found along the river valleys in Guelph) between their origin and destination do not bicycle to work or school because of this grade. Therefore, only the dedicated cyclists who also cycle in the winter are found in the sample with grades between their origin and destination and the summer-only cyclists did not have non-zero grade variables in their choice set to result in a significant parameter.[5]

Regardless of the exact explanation for why the unusual personal variable interactions were found to be significant, a more important conclusion for bicycle planning relates to the fact that it was possible even with such a small dataset to find personal variable interactions. In Chapter 2 it was suggested that in order to use route information from current cyclists to plan policies and program that would increase levels of cycling, it would be necessary to determine what factors characterize the latent demand. It is unknown if the potential cyclists would behave at all like the existing cyclists or a particular sub-group of them. It is possible that the characteristics of the people who might be encouraged to cycle could be obtained. With this information the route choice model developed based on the behaviour of current cyclists could be applied to potential cyclists. Of course this approach would require a more detailed route model than was possible with the limited Guelph dataset.

The number of kilometres of travel on an average quality path is also found to be a negative quality for the bicycle commuter routes. Off-road paths and trails were categorized three ways by site inspection. If a path or trail was wide with a good quality

---

[5] This discussion is not intended to suggest that those who cycle in the winter are somehow "better" than those who do not. It is only intended as an exploration of the possible reasons for counter-intuitive result. The dummy variable used to indicate if a person was a winter cyclist was very liberal. If a survey participant indicated that they cycled at least once in either January or March the dummy variable was equal to one.

surface and extended a relatively long distance with easy access points it was considered of good quality. The paths that extend several kilometres along the creek are an example of a good path. An off-road route such as those with stairs, comprised of a narrow pedestrian walkway, cutting across private property (eg: golf course), or comprised of a narrow dirt trail across a field were labelled poor quality. All other paths, such as those cutting across neighbourhood parks, were considered average. There was a total of 12.6, 12.5 and 5.9 kilometres of good, average and poor quality path respectively. All combinations of paths variables were tested in the model. For example, one combination was the sum of travel along either good or average quality paths. Some of these transformations were found to be significant but only for some choice sets or they could not pass an IIA test. Based on the different combinations that resulted in significant parameters it seems that poor quality paths did not enter the final model because there simply were not enough of them in the choice sets to find a significant result. On the other hand, it seems the good quality paths did not enter the final model due to different behaviour within the sample. Some cyclists liked to use the good quality paths while others did not. This stratification was not found to fall along any division that could be made with the personal variables available. However, based on the very strong negative utility coefficient for the average paths this model suggests that commuter cyclists in general do not prefer use of paths. It may be that paths represent inconvenience or delay. The previous result in Chapter 2 that the shortest path routes contain more off-road travel than the actual routes suggests that this aversion is not due to the poor location of paths given the distribution of origins and destinations but rather a choice to use other infrastructure. These conclusions suggest that efforts to accommodate current commuter cyclists should not be focused on off-road paths or trails. These results cannot suggest however, what efforts with respect to off-road infrastructure might encourage or attract new bicycle commuters.

3.8 Conclusions

This modelling exercise has found that GIS-generated alternative routes and their disaggregate attributes can be successfully used to estimate consistent logit route choice models. Model parameters vary depending on the choice set used for estimation; extreme care must be used to determine which relationships are relatively independent of the choice set. Parameters that result in a model that does not exhibit IIA must be rejected even if significant in one estimation because no separate means to evaluate the quality of the choice set is available beyond the consistency of the final model. While it is impossible to determine the effect of these variables on route choice, many other variables in this bicycle commuter route dataset were found to affect or not affect the route choice of cyclists. In addition to determination of the effect of these route variables, the multinomial logit model formulation was useful in establishing interactive relationships between personal characteristics and certain aspects of route choice. Bicycle commuter route behaviour varies within the overall sample and although the predictive power of the model is weak, it is a valuable tool for understanding route behaviour. A binary choice set was found to be inappropriate to exhibit a sufficient range of attributes for modelling and comparison. The multinominal logit having on average 6.5 alternatives was adequate for testing most variables.

Finally, the multinomial logit model has implications for bicycle planning. The model supports the notion that most cyclists prefer use of collector roads and traffic signals. They avoid grades and many off-road paths. Perhaps more importantly however the model measured several personal variable interactions with route preferences which suggests that with a larger dataset it may be possible to pursue a more complete understanding of the different types of cyclists and their different cycling preferences. With this more stratified information it will be possible to more accurately design policy and infrastructure to improve the travel experience of current cyclists and possibly attract others to a healthy and environmentally friendly mode of travel.

3.9 References

Abdel-Aty, Mohamed A., Ryuichi Kitamura, Paul P. Jovanis, Prasuna Reddy and Kenneth M. Vaughn (1995a). "New Approach to Route Choice Data Collection: Multiphase, Computer-Aided Telephone Interview Panel Surveys Using Geographic Information Systems Data Base". *Transportation Research Record 1493.* Transportation Research Board, National Research Council, Washington, D.C. pp. 59-169.

Abdel-Aty, Mohamed A., Ryuichi Kitamura, and Paul P. Jovanis (1995b). "Exploring Route Choice Behaviour Using Geographic Information System-Based Alternative Routes and Hypothetical Travel Time Information Input". *Transportation Research Record 1493.* Transportation Research Board, National Research Council, Washington, D.C. pp. 74-80.

Abdel-Aty, Mohamed A., Kenneth M. Vaughn, Ryuichi Kitamura, Paul P. Jovanis, and Fred L. Mannering (1994). "Models of Commuters' Information Use and Route Choice: Initial Results Based on Southern California Commuter Route Choice Survey". *Transportation Research Record 1453.*

Adler J., W. Recker and M. McNally. (1993). "A Conflict Model and Interactive Simulator (FASTCARS) for Predicting Enroute Driver Behaviour in Response to Real-time Traffic Condition Information." *Transportation* 20:2.

Ashley C. and C. Banister. (1992). "Ward Level Modelling of Cycling to Work" in *Mathematics in Transport Planning and Control.* Proceedings of a Conference on Mathematics in Transport Planning and Control at University of Wales, College of Cardiff in September 1989. T.D. Griffiths ed.

Axhausen K. W. and R. L. Smith Jr. (1986). "Bicyclist Link Evaluation: A Stated-Preference Approach". *Transportation Research Record* 1085.

Ben-Akiva, Moshi and Steven R. Lerman. (1985). *Discrete Choice Analysis: Theory and Application to Travel Demand.* Cambridge, Massachusetts: MIT Press.

Bradley, Mark A. and Piet H. L. Bovy. (1984). "A Stated Preference Analysis of Bicyclist Route Choice". *Proceedings of Seminar H at the Planning and Transport Research and Computation (International)* Volume P257 July 10-13.

Environmental Systems Research Institute (E S R I) Inc. (1995). *ArcInfo User's Guide,* Chapter 8 of Release 7.0 Network Analysis.

Fenco MacLaren. (1994a). *Guelph and Area Transportation Study Report.* Guelph: City of Guelph, County of Wellington and the Ontario Ministry of Transportation, June.

Fenco MacLaren. (1994b). *Guelph and Area Transportation Study Appendices*. Guelph: City of Guelph, County of Wellington and the Ontario Ministry of Transportation, June.

Hamerslag R. (1981). "Investigation into Factors Affecting the Route Choice in "Rijnstreek-west" with the Aid of a Disaggregate Logit Model" *Transportation* 10 pp. 373-391.

Hatcher S. Gregory, and Hani Mahmassani. (1992). "Daily variability of route and Trip Scheduling decisions for the Evening Commute". *Transportation Research Record 1357.*

Hausman J. and D. McFadden. (1984). "Specification Tests for the Multinomial Logit Model." *Econometrica* 52:1219-1240.

Hopkinson P.G., O.M.J. Carsten and M.R. Tight. (1989). *Review of Literature on Pedestrian and Cyclist Route Choice Criteria.* University of Leeds Institute for Transport Studies Working Paper 290.

Hunt, John Douglas. (1990). "A Logit Model of Public Transport Route Choice". *ITE Journal* 60:2.

Khattak, Asad, Adib Kanafani and Emmanuel Le Colletter (1994). "Stated and Reported Route Diversion Behaviour: Implications of Benefits of Advanced Traveller Information System". *Transportation Research Record 1464.* Transportation Research Board, National Research Council, Washington, D.C. pp. 28-35.

Lott, Dale F. and Timothy Tardiff. (1978). "Evaluation by Experienced Riders of a New Bicycle Lane in an Established Bikeway System". *Transportation Research Record* 683.

Polydoropoulou, Amalia, Moshi Ben-Akiva and Isam Kaysi (1994). "Influence of Traffic Information on Driver's Route Choice Behaviour". *Transportation Research Record 1453.* Transportation Research Board, National Research Council, Washington, D.C. pp. 56-65.

Thill, Jean-Claude. (1992). "Choice Set Formation for Destination Choice Modelling". *Progress in Human Geography* 16,3. pp. 361-382.

Vaughn, Kenneth M., Ryuichi Kitamura and Paul P. Jovanis. (1996). "Modeling Route Choice Under ATIS in a Multinomial Choice Framework" presented at the 75th Annual Meeting of the Transportation Research Board January 7-11 Washington D.C.

Vaughn, Kenneth M., Mohamed A. Abdel-Aty, Ryuichi Kitamura, Paul P. Jovanis, Hai Yang, Neal E. A. Kroll, Robert B. Post and Brian Oppy (1993). Experimental Analysis and Modelling of Sequential Route Choice Under an Advanced Traveller Information System in a Simplistic Traffic Network. *Transportation Research Record 1408*. Transportation Research Board, National Research Council, Washington, D.C. pp. 75-82.

Preface to Chapter 4:

The first six sections of Chapter 4, which describe the design and execution of a bicycle route and safety survey conducted in Ottawa and Toronto, were written originally as the interim report cited below[6]. Although the report was primarily authored by me, there are three co-authors who in addition to providing comments on draft versions of the report contributed to the execution of the research. Dr. Fred Hall supervised the research. Mr. Sean Doherty assisted with the questionnaire design. Ms. Emily Andrews was an undergraduate summer researcher who assisted with survey distribution and data entry. Ms. Andrews wrote the first draft versions of sections 4.6.1 and 4.6.2. I assisted her with this initial preparation and subsequently added many changes myself. Ms. Andrews also prepared Appendices H and I.

The additional sections of the chapter describe response rates and results relating to measuring the quality of the questionnaire as a survey instrument. This information will be included with the interim report sections in the final research report to the Ministry in the Fall of 1996.

Data collection is one of the most expensive portions of many research projects. Recognizing this fact, the questionnaire and survey design described in chapter 4 were intended to collect data not just for this thesis research but also for further analyses that were deemed relevant to bicycle transportation planning. Therefore analyses referred to in this chapter that impacted portions of the survey design have not necessarily been conducted yet. Only analyses related to the primary research objective of comparing the relative safety of different types of bicycle routes are subsequently reported in the thesis.

---

[6] Lisa Aultman-Hall, Fred L. Hall, Emily Andrews and Sean T. Doherty, *Urban Commuter Bicycle Routes and Risk - Survey Research Design and Execution*, interim research report submitted to the Ontario Ministry of Transportation, September 1995.

Chapter 4: Urban Bicycle Commuter Routes and Incident Rates: Survey Research Design, Survey Execution and the Quality of the Survey Instrument

4.1 Introduction

This chapter contains four types of discussion regarding a bicycle route and safety study conducted under a research grant from the Highway Safety Research Office of the Ontario Ministry of Transportation. First, a brief review of previous work studying bicycle safety is presented (section 4.2). Second, the study methodology (section 4.3) and the questionnaire design process including the final design (section 4.4) are described. Third, the stages of survey execution in Ottawa (section 4.5) and Toronto (section 4.6) are discussed. Finally, results of the study which relate to the quality of the questionnaire as a survey instrument are presented. These include issues related to response rate (section 4.7) and recall bias (section 4.8).

The revised Ontario Bicycle Policy (1992) mandates that the focus for policy and bicycle infrastructure provision is to be utilitarian or purposeful bicycle use. An additional goal mandated in the provincial policy is to increase cycling safety. Safety should therefore be a consideration in cycling network design. In bringing safety considerations into the design, it would be valuable to have information about the relative safety of different types of cycling network components: regular city streets of various types; roadways with specially marked lanes; and bike paths. The primary objective of this research project is to evaluate the relative incident and injury rates for urban commuter cyclists for travel on different types of roadways and cycling infrastructure.

4.2 Previous Work on Bicycle Facility Safety

Quantitative information on bicycle safety that includes consideration of facility type is limited and conclusions vary. In order to illustrate that data collection was necessary, this section provides an overview of some previous study conclusions and one method used to collect a bicycle exposure dataset in the United States. The available Canadian bicycle data and their appropriateness for a bicycle facility incident rate analysis are described.

The following examples of European studies illustrate how the information that exists on bicycle safety can dictate contradictory courses of action with respect to the provision of special bicycle infrastructure. Morgan (1994) reports that 60% of fatal cycle accidents occur on principal roads even though only 20% of cycling takes place on these roads. The conclusion from this analysis of only fatality data might suggest that provision of cycle routes would increase safety. Shipley (1994) found that the construction of a dedicated cycleway resulted in no change to the total number of accidents involving bicycles along a single travel corridor. This result might suggest that provision of a cycleway has no effect on safety. Wegman and Dijkstra (1988) report that stretches of road with cycle paths are safer for cyclists than those without, and that it is safer to have no facilities than to have marked bicycle lanes. Junctions (ie: intersections) are reported safer for cyclists if the road has neither lanes nor paths. These analyses also lead to contradictory conclusions on whether cycling infrastructure should be provided.

Although a large amount of information on bicycle facilities is available from European sources the applicability to the Ontario situation is unknown. The urban form, attitude towards bicycles, levels of ridership, and availability of dedicated facilities are very different in Europe and this presumably affects the safety of bicycle facilities. Several previous Canadian bicycle surveys (Cumming Cockburn Limited 1992, Marshall, Macklin and Monaghan 1994, and Greater Vancouver Regional District 1993 for example) have obtained information on the respondents' accident histories, but most do not obtain information on the location of the incidents or the proportion of bicycle travel made on different types of infrastructure. A survey in Guelph (Marshall, Macklin and Monaghan, 1994) asked the location of the accident, and also obtained information on the routes travelled. Although respondents indicated the general location of the accidents, they were not asked if they were on a sidewalk, road or trail, making it difficult to categorize the accident by type of facility. Even if the type of facility on which the accident occurred were known, to calculate relative rates the travel exposure by facility type is also required.

The Ontario Accident Database (OAD) contains information on bicycle accidents throughout the province. A study of 1991 Toronto cyclists (Egan, 1995) has estimated that only about 5% of all bicycle incidents are reported to police and are therefore recorded in the OAD. However, any accident involving a motor vehicle and a bicycle that resulted in a serious injury or fatality would be found in this database. Although this database contains very detailed information about the accident location and circumstances, there is no Ontario data available on bicycle travel patterns or routing that could be used to estimate exposure to calculate incident rates for bicycle riders on different types of facilities using the OAD.

One large bicycle data set, collected in the City of Calgary in 1993, includes route data that could be used to quantify travel exposure by facility type. The dataset contains almost 2000 routes drawn by cyclists on maps provided with a questionnaire. Details of the survey questions are not known as the City of Calgary is still validating the data and has not made a decision as to the data's public availability. The City has analyzed the route information and the results should be made public within a few months. Information on accidents and their location was collected and an incident rate analysis will be conducted by the City at a future time.

The limited available information on bicycle exposure patterns has also been identified by Rodgers (1995). In his study, Rodgers uses the results of a 1991 U.S. bicycle exposure telephone survey (Rodgers et al. 1994) in combination with cyclist deaths and fatality data (from other sources) to consider the relative risk of fatality for different categories of people or those with various riding characteristics. Rodgers (1994) outlines how the riding pattern information was quantified by the 1991 telephone study and used to estimate travel exposure. One portion of the survey related to exposure by facility type.

Participants were asked to place the portion of time they spent cycling on sidewalks, neighbourhood streets, major thoroughfares, bikepaths, unpaved roads and trails into five categories. The categories were "always", "more than half of the time", "less than half of the time", "never" and "unknown". People were also asked to estimate in how many of the last 12 months they had bicycled and in how many of the last 30 days they had bicycled. Participants were asked how many hours of bicycle riding they did in an average month when bicycles were used, and on an average day when a bicycle was used. The percentage of time spent travelling on different types of facilities could be adjusted with the riding times to obtain an estimate of the overall exposure to risk on different types of facilities. There is a level of uncertainty to this type of exposure estimation, especially for the exposure by facility type, in that it relies on people's recall of their bicycle travel and is susceptible to their perceptions and recall errors.

Review of the background information that relates to the determination of the accident rates on different types of bicycle facilities reveals a need for a study that collects both accident history and travel exposure. Collection of accident history is necessary to have a database containing the minor accidents that often go unreported. The bicycle travel exposure is necessary because current information does not exist that will allow for an estimate of travel exposure by facility type for cyclists in Ontario. It is complicated to collect exposure information by telephone: the resulting exposure measures are crude and susceptible to recall errors. The mail-back questionnaire with a map for cyclists to trace their route on, such as was used in Calgary, is deemed an appropriate method to collect the travel exposure for a single regular trip such as a commuter bicycle trip to work or school. If the analysis conclusions are to be used to make decisions with respect to the safety of bicycle facilities in urban areas of Ontario, data should be collected in those areas. Without such a study, the applicability of data and studies from elsewhere is unknown. In the study described within this chapter, data are collected that will provide information on all types of bicycle accidents and the travel patterns of urban commuter bicycle trips in Ontario. This information will be used to compare the rates for different types of accidents on different facilities.

4.3 Study Methodology

This section describes three important aspects of this study's methodology. The first outlines how the incident rates will be quantified with the data that has been collected. The second section describes the sampling procedure and the properties of the sample. The final section discusses why Toronto and Ottawa were chosen for study.

4.3.1 Incident Rate and Exposure Methodology

The core of this study's methodology is the use of a GIS with cyclist route data to quantify the exposure to incidents on different network components. The exposure of cyclists to incidents is measured as the travel (bicycle-kilometres) that is undertaken on each type of cycling facility. In the case of intersection types, the exposure can be quantified in terms of the absolute number of intersections of different types the cyclists cross. The survey participants were asked to trace the route(s) they use on a map. This methodology avoids the problem of inaccurate recall of travel distances along different types of network routes. The routes are input into a GIS database that will contain the full network of the area and the characteristics of the available network links. The GIS will then be used to calculate actual travel distances along various network components.

The incident information and the travel exposure will be combined to estimate the average rate of various classes of incident on different types of routes. The rate will be calculated as shown in Equation 4-1. Once the rates have been calculated it will be necessary to determine if a statistical difference between the rates for different categories of routes or cyclists exists.

$$R_{in} = \frac{N_{in}}{d_n} \quad [4\text{-}1]$$

where : R_{in} = incident rate in incidents per cycle-kilometre

i = incident category

n = network category

d_n = total cycle-kilometres travelled on network type n

N_{in} = number of incidents of type i on network type n

4.3.2 Sampling Methodology

The method used to collect the incident and route data for urban commuter cyclists was a mail-back questionnaire that was attached to the cross-bars of parked bicycles in Ottawa and Toronto. Each questionnaire was placed in a clear plastic bag with a business reply envelope. The top of the clear plastic bag was folded over and held closed with a small removable sticker. The sealed bags were then placed over the cross bar of the bicycle and held in place with a sticker as shown in Figure 4-1.

Even with careful city and site selection (see sections 4.3.3,4.5.1 and 4.6.1), this survey method does not result in a random sample. It would be desirable to have a random sample of cyclists in Ontario or within particular urban areas so the results of this study could be generalized to the whole population of cyclists. However, finding a random sample of cyclists is problematic. It would be possible to obtain a random sample of cyclists by contacting a random sample of the general population by telephone or mail. However, as cyclists represent a very small portion of the total population, the number of people contacted would have to be very large in order to collect enough data for the incident rate analysis. It was too expensive to conduct a mail-out survey in this manner. It was also considered impractical to collect the route information by telephone. Attaching questionnaires to parked bicycles was relatively inexpensive and allowed cyclists to be easily identified from the population.

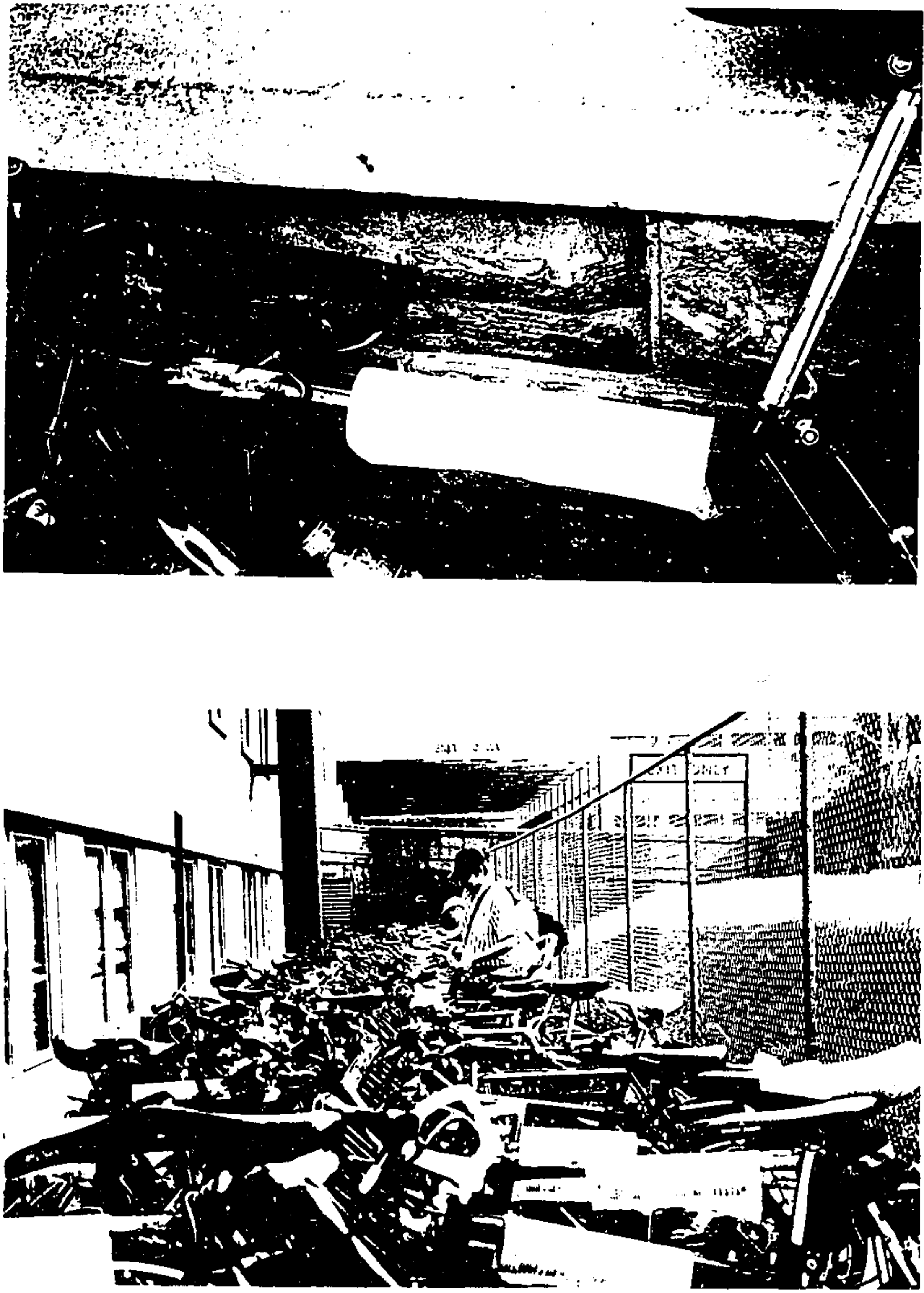


Figure 4-1: Questionnaire Distribution on Bicycles in Toronto

In order to obtain a representative sample of all cyclists by attaching questionnaires to parked bicycles, it would be necessary to know the number of cyclists in the province who have certain personal and cycling travel characteristics and where they park their bicycles. This is not known. The sample is therefore potentially biased by the locations and times of day when we attached questionnaires to bicycles. For example, it was practical to survey only a limited number of areas, because a map was included in the questionnaire. Also for practicality, distribution took place during the daytime when large numbers of parked bicycles could be found. Consequently, people who ride in areas with lower cycling levels, only at night, or in municipalities other than Ottawa-Carleton or Toronto have been systematically eliminated from our study.

The sample is also limited to only urban commuter cyclists. A commuter cyclist is a person who makes a trip from a single origin (usually home) to a single destination (work, school, place of volunteer work or transit stop) by bicycle on a regular basis. This trip is usually not discretionary and has a routine pattern with respect to timing, routing and frequency. This routine pattern is useful for quantifying travel exposure. Given the current focus by the Ontario Ministry of Transportation (Ontario, 1992) and others on utilitarian cycling a study of commuter cyclists is deemed an important first step in quantification of bicycle incident rates by network type. Questionnaire distribution areas and times were chosen to focus on commuter cyclists. People were asked to answer the questionnaire for their most frequent trip to one of the commuter destinations listed above. Limiting the route collection to one trip and destination simplifies both the requirements for the participant filling in the map and the researchers interpreting the map. In addition, if routes and incidents for all types of travel were collected, a means to estimate the cyclist's total travel on each route for each particular purpose would be necessary and complications would arise.

Three universities and three colleges were among the many employment and educational areas surveyed in Ottawa and Toronto. In the late spring and summer when distribution took place, the university undergraduate and college students were present on campuses in much lower numbers than would be the case during the fall and winter terms. This affects the make-up of the sample. However, it was more important to sample during the peak cycling season than to include a large number of students in the sample. During June and July most graduate students, some undergraduate students and some summer student employees are on campus which ensured students were included in the sample.

4.3.3 Selection of Cities for Study

The Downtown of the City of Toronto and portions of the Regional Municipality of Ottawa-Carleton were chosen as the areas for questionnaire distribution owing mainly to the large number of bicycle commuters in both locations. A large number of cyclists located in single areas was a practical necessity in the questionnaire distribution for several reasons. First, enough cyclists had to be found in a large area to justify the production, including expensive printing costs, of a map for the area. Second, the labour required for questionnaire distribution was lower for single locations with large numbers of bicycles. Third, each site required travel and communication with property owners. Toronto and Ottawa were found to house many individual sites appropriate for this study.

The Regional Municipality of Hamilton-Wentworth was also considered for questionnaire distribution. However, a major bicycle route along an abandoned rail-line leading to the university was closed for construction in the spring and summer of 1995 affecting the route choice of many cyclists at the only major bicycle destination in the Region. As the collection of the cyclists' regular route would have been complicated during construction, only the pre-test of the questionnaire (discussed in section 4.4) was conducted at McMaster University in Hamilton-Wentworth before the construction began.

Another consideration in the selection of Hamilton-Wentworth, Toronto and Ottawa-Carleton was cooperation from the various levels of local government. Assistance in the form of GIS network files was received from the Regional Municipality of Ottawa-

Carleton, the City of Toronto, Metropolitan Toronto and the Regional Municipality of Hamilton-Wentworth. GIS network files were necessary to create the maps within the questionnaire on which participants traced their routes. During the analysis the GIS files have been used to build databases to allow for exposure and incident rate calculations by route type. In addition, individuals responsible for bicycle planning or transportation in the City of Ottawa, the Regional Municipality of Hamilton-Wentworth and the City of Toronto were very helpful: they participated in questionnaire design, and assisted in finding large bicycle parking areas. Their participation contributed to the recognition of the study's legitimacy when contacting property owners. They also provided input on the location of cycling infrastructure so it could be added to the GIS network files.

It was expected that the urban form and availability of cycling infrastructure would affect people's route choice and thus exposure patterns. It was considered important to choose urban areas that could offer a variety of urban form and cycling network characteristics. The downtown core of Toronto offers limited cycling lanes (although they had only been in place just over a year), a variety of street and intersection types, and limited paths through parks. The area consists mainly of grid patterned streets and a traditional urban form. In Ottawa-Carleton, there are extensive cycling path networks and on-street bicycle lanes spread throughout the region. Cycling levels are high in both the urban and suburban portions of Ottawa-Carleton. Questionnaires were distributed in the high density grid patterned downtown, the older suburban areas, and the newer low density suburban areas with winding street patterns. Between Ottawa and Toronto, an acceptable variety of urban form and cycling routes could be found.

4.4 Questionnaire Design

The first draft questionnaire for this study was written in January 1995 for submission to the McMaster University President's Committee on the Ethics of Research on Human Subjects. The committee gave its approval for the study in March 1995. Following this approval and receipt of the research grant, transportation researchers at McMaster

University were consulted on the format and content of each question. Following the internal consultation, the questions were put together with a map of the area surrounding McMaster University and distributed to various individuals for comment. These individuals were provided with a summary of the objective of the study and the type of analysis that would be conducted. In addition to members of the research group, comments were received back from the following: three municipal civil servants responsible for bicycle transportation; one bicycle safety organization; a professor of transportation planning; a researcher in survey instrument design; a professional responsible for the conduct of survey research; several members of cycling committees or groups; and several commuter cyclists. Following revisions in light of these comments, a pre-test of cyclists was conducted at McMaster University. Based on pre-test results, a final draft version of the questionnaire was prepared and a small final pre-test of graduate student cyclists (who had not previously assisted with the questionnaire design) was conducted to verify that changes were effective.

This section of the report describes three aspects of the questionnaire design: the Hamilton pre-test execution, the question content, and the map design considerations.

4.4.1 The Execution of the Hamilton Pretest

A copy of the Hamilton pre-test version of the questionnaire can be found in Appendix C. The map that accompanied the pre-test questionnaire was created using the GIS street line network files donated to the project by the Regional Municipality of Hamilton-Wentworth. The pre-test was to be distributed at McMaster University, so the extent of the map was based upon the experience of the researchers on the project team.

The pre-test questionnaires were produced on a photocopier by the researchers, not on a printing press the way the actual study questionnaires were. Therefore the pre-test questionnaires were not in the same single-sheet fold-out format as the final questionnaires. This made the pre-test version less visually appealing and less convenient to answer. For example, it was not possible to see the map while reading the questions that directed the participants to it. The questionnaire package consisted of the questionnaire and a pre-addressed stamped envelope in a clear plastic bag.

On Tuesday May 9, 1995 a total of 110 of the pre-test questionnaire packages were attached to the cross-bars of parked bicycles at McMaster University. The bicycles were deliberately chosen in three clustered areas in order to provide an estimate of distribution time per bicycle. This assisted in the planning for an appropriate number of people to be hired for questionnaire distribution in the actual study areas. Most of the day was sunny with cloudy periods, but there was significant rainfall in the mid to late afternoon, continuing through the night. Inspection of questionnaire packages on the ground or still on bicycles the next morning revealed that the plastic bag provided excellent protection against the rain. None of the remaining questionnaires had been damaged.

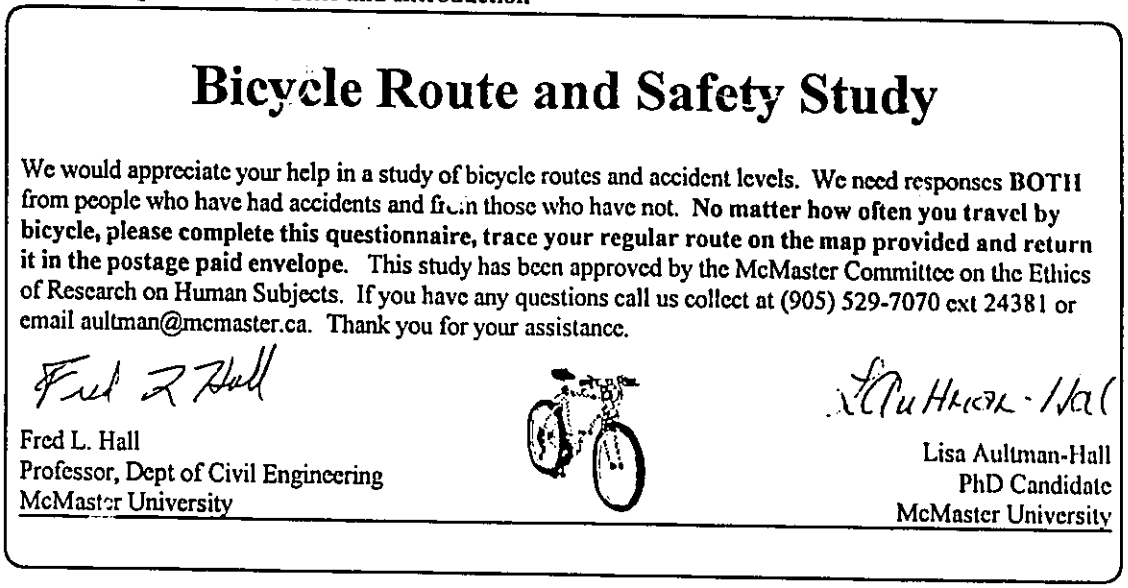
By July 31, 1995, 49 of 110 questionnaires had been returned either through regular or campus mail. One questionnaire had inadvertently been placed on the bicycle of a friend of the researchers. The response rate, excluding this individual, was 44% (48/109). The pre-test version was also distributed to faculty and graduate students in the Department of Civil Engineering who were known to be commuter cyclists. Three replies were received. The research team met on May 17, 1995 to discuss the pre-test questionnaire responses. At that time a total of 35 completed questionnaires had been received. The nature of these responses led to several changes in the questionnaire. The next section describes the questions as they appear in the final versions.

4.4.2 The Questionnaire Content

The questionnaire consists of a map of the area and questions regarding the person's history as a bicycle commuter, the characteristics of their current bicycle commute trip, and their incident history. The complete Toronto questionnaire is shown in Appendix D. The Ottawa questions differed only slightly. Appendix E contains the three questionnaires used in Ottawa. The three questionnaires were each a different colour, had a different map and were used at distribution sites in different areas of the city. The actual questionnaires used in Ottawa and Toronto were in a single-page fold-out format. Due to the binding requirements for the thesis, actual questionnaires could not be provided in the appendices. In addition, the map which was originally approximately 11 by 17 inches has been photo-reduced. This section of the report includes exhibits that contain photo-reduced portions of the questionnaire used in Toronto. Each exhibit is accompanied by a short discussion of the questions' purpose and the role of the responses in the analysis. The purpose of this discussion is not only to document the objective of each question but also to record the experience gained during the design stages of this study.

The introduction section, shown in Exhibit 1, was used on the questionnaire in place of a formal letter. This approach was chosen for four reasons. First, an additional piece of paper for the letter would have put our package over the weight limit for the lowest postage rate, thereby doubling mailing costs. In a bicycle study conducted in Guelph in 1993 many participants mailed back the letter of introduction that was stapled to the questionnaire. Second, participants in the questionnaire design phase had indicated a preference for a single fold-out questionnaire that did not involve stapled papers. They preferred a layout where the map and questions concerning the map were together. Third, this introduction paragraph format allowed the front face of the questionnaire with the large title and cycle logo to be placed up on the cross-bar of the bicycle. This immediately indicated to the cyclist that this package was a questionnaire about bicycles. It was hoped that as cycling was of interest to the individuals they would keep the package and complete it. Fourth, we wanted to be brief in communication to the cyclists in order to minimize the effort required of them.

Exhibit 1: Questionnaire Title and Introduction



Bicycle Route and Safety Study

We would appreciate your help in a study of bicycle routes and accident levels. We need responses BOTH from people who have had accidents and from those who have not. **No matter how often you travel by bicycle, please complete this questionnaire, trace your regular route on the map provided and return it in the postage paid envelope.** This study has been approved by the McMaster Committee on the Ethics of Research on Human Subjects. If you have any questions call us collect at (905) 529-7070 ext 24381 or email aultman@mcmaster.ca. Thank you for your assistance.

Fred L Hall

Fred L. Hall
Professor, Dept of Civil Engineering
McMaster University

L Aultman-Hall

Lisa Aultman-Hall
PhD Candidate
McMaster University

The intent of the introduction was to create a sense of legitimacy by: 1) communicating the names and identity of the main researchers and how they could be contacted; 2) identifying McMaster University as the institution conducting the research; and 3) informing the cyclist that the study had been approved by the ethics committee. It was also important in the introduction to emphasize that responses were required from people both with or without incidents in their experience. During the pre-test stages, discussion with cyclists revealed that they felt the map was a unique element to the questionnaire and that it made them more interested and willing to complete the questionnaire. For this reason the concept of tracing one's route on a map was mentioned in the introduction.

Several of the phone calls and email messages from participants concerning the questionnaire revealed that this section should also have provided more information on the purpose of the study and the type of analysis that would be conducted. People who called were intrigued by the purpose and nature of the study and indicated that they would be completing the questionnaire and returning it.

On the advice of a colleague at McMaster University the funding agency was not identified. Experience by members of the research team indicates that cycling as a mode of transportation can often be controversial. It was possible that non-cyclists might feel that public funding of such a study was inappropriate. In addition, several federal government locations in Ottawa indicated that if the Ontario Ministry of Transportation was identified on the questionnaire then it would have been necessary for the questionnaire to be bilingual for distribution on their property. Although it would have been ideal to have a bilingual questionnaire it was not feasible from the point of view of space on the questionnaire or mailing costs.

The first question, shown in Exhibit 2, establishes what types of trips the study is addressing. Originally the word "commute" had been used in this question to define the types of trips of interest. However, the pre-test respondents did not seem to share a clear common definition of the word. The word was in some ways jargon and meant different things to different people.

An "other" category was not included in order to fix the trip types in the sample. The "other" category in the pre-test resulted in people answering for shopping or visiting trips. The question in its final form excludes some cyclists but makes clear what trips we are interested in. The sentence that follows the question asks participants to answer the next portion of the questionnaire for the trip they identified in this question.

Exhibit 2: Question #1

1. Of the following possibilities, which ONE location do you travel to MOST OFTEN by bicycle? If you do not travel to one of these locations by bicycle please give this questionnaire to a friend who does.

Place of Employment ___
Place of Volunteer Work___
Transit Stop ___
Place of Education (where you are a student): University or College ___
Secondary School ___
Other schooling ___

Answer questions 2 through 9 for your trip to the location you indicated above.

Several people have contacted us from Toronto saying that they feel we are excluding people by this restriction on trip types. People have also suggested that other regular or routine trips, such as travel to a routine doctor's appointment, might be considered commuting. Although we regret that this situation may have led to resentment and exclusion, we felt it was necessary to clearly define the boundaries of our sample. Attempts to collect information on the particular trip being made while the questionnaire was attached to the bicycle, or attempts to question cyclists about more than one trip, resulted in confusing and cumbersome question wordings. The sample is made up of people who travel to the locations listed in question # 1.

Even with the final wording for this question, a few people checked more than one destination. The majority of these people seem to be checking university or college as well as place of employment. It is possible that these people work and go to school at the university or college and are therefore providing valid information.

The information obtained in the questions shown in Exhibit 3 will be used to estimate the total amount of commuter bicycle travel undertaken by each respondent. The travel distance and route determined from the map will be adjusted using the information collected in questions 2 through 4 for the frequency of travel, the times of the year the trip is made, and the length of time the trip has been made.

The accuracy of the responses to question #4 is not known. Pre-test results indicate that some people have a tendency to indicate that they bicycle everyday of the year. This reinforces the fact that all people's responses to this question are estimates of their actual bicycle commuter travel. Although question #3 could be used to consider the effect of weather on cycling volumes, it was included to allow for somewhat of a check on question #4. People will have a better recall of events in the previous week than in the previous year and their answers to question #3 should be consistent with their answer to #4. However, experience has shown that the questionnaires have arrived at McMaster as much as six weeks after they were distributed, so there will be some potential recall problems with the answers to #3.

Exhibit 3 : Commute Exposure Questions

2. How long have you been travelling by bicycle between your current home location and your current place of work or education?
   _________years_________months

3. During the week of July 3-9, 1995 (the week before this questionnaire was placed on your bicycle) which days did you make this trip by bicycle?

   Mon___ Tues___ Wed___ Thurs___ Fri___ Sat___ Sun___

4. Considering that vacation, holidays, weather, business travel and other changes to your routines may affect how often you can bicycle, please estimate the average number of times you made THIS round trip by bicycle in each month in the last year (July 1994 - June 1995).

   July ___ Oct ___ Jan ___ April ___
   Aug ___ Nov ___ Feb ___ May ___
   Sept ___ Dec ___ Mar ___ June ___

Exhibit 4 shows the supplemental commute questions that may be useful during the analysis. Depending on preliminary analysis it may be possible to stratify the cyclists by time of travel as recorded in questions #6 and #7. These questions together with the information in question #4 could be used to estimate what portion of the commuter bicycle travel was undertaken in the dark or dusk/dawn conditions. The responses to these questions will provide useful information on the travel patterns of commuter cyclists independent of the incident rate and exposure analysis. For example, the trip distance (from the map) and the travel time can be used to estimate an average speed. These two pieces of information are usually not collected together. Speed could prove to be an interesting variable with which to stratify the sample.

Exhibit 4 : Supplemental Commute Exposure Questions

5. On average, how much time does your trip take one way? ______________minutes
6. What time do you normally leave home for the location you indicated in question #1? ___ : ___ am pm
7. What time do you leave that location ? ___ : ___ am pm

The questions in Exhibit 5 have been included in the questionnaire not specifically for use in the incident rate analysis but because they provide valuable information with respect to cycling safety and transportation planning. It seemed timely to ask commuters if they were wearing helmets the summer before Ontario's bicycle helmet legislation was to take effect. Information on the modes of travel used by cyclists when they do not bike to work or school is important for assessing the extent to which the bicycle can offer a potential solution to urban transportation problems.

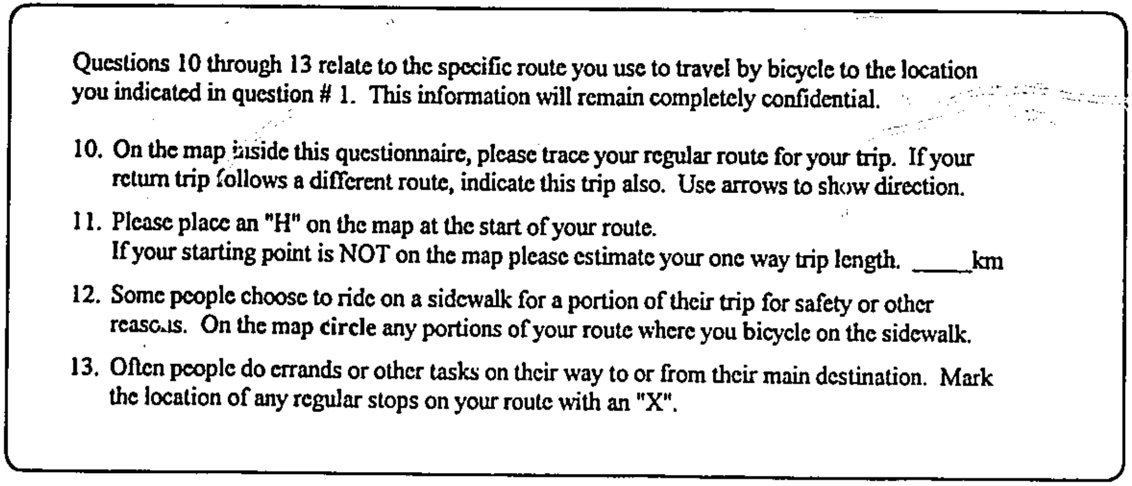
Exhibit 5 : General Information Questions

8. Do you wear a bicycle helmet for this trip? Yes___ No___
9. When you do NOT use your bicycle to travel to this location, how do you travel?

    Drive Alone ___ Dropped Off ___ Walk___
    Carpool ___ Public Transit ___ Other (specify)______________

The questions shown in Exhibit 6 were located inside the fold-out questionnaire beside the map so that completion would be as easy as possible. People were asked to trace their commuter route on the map, to indicate what end of the route was their home, where they used the sidewalk for riding and to locate any stops. This information was entered into the GIS and it was possible to determine the total distance travelled on each type of infrastructure. The participant is asked to estimate their one-way trip distance in question #11 only if their origin is outside the area shown on the map.

Exhibit 6 : Route Questions



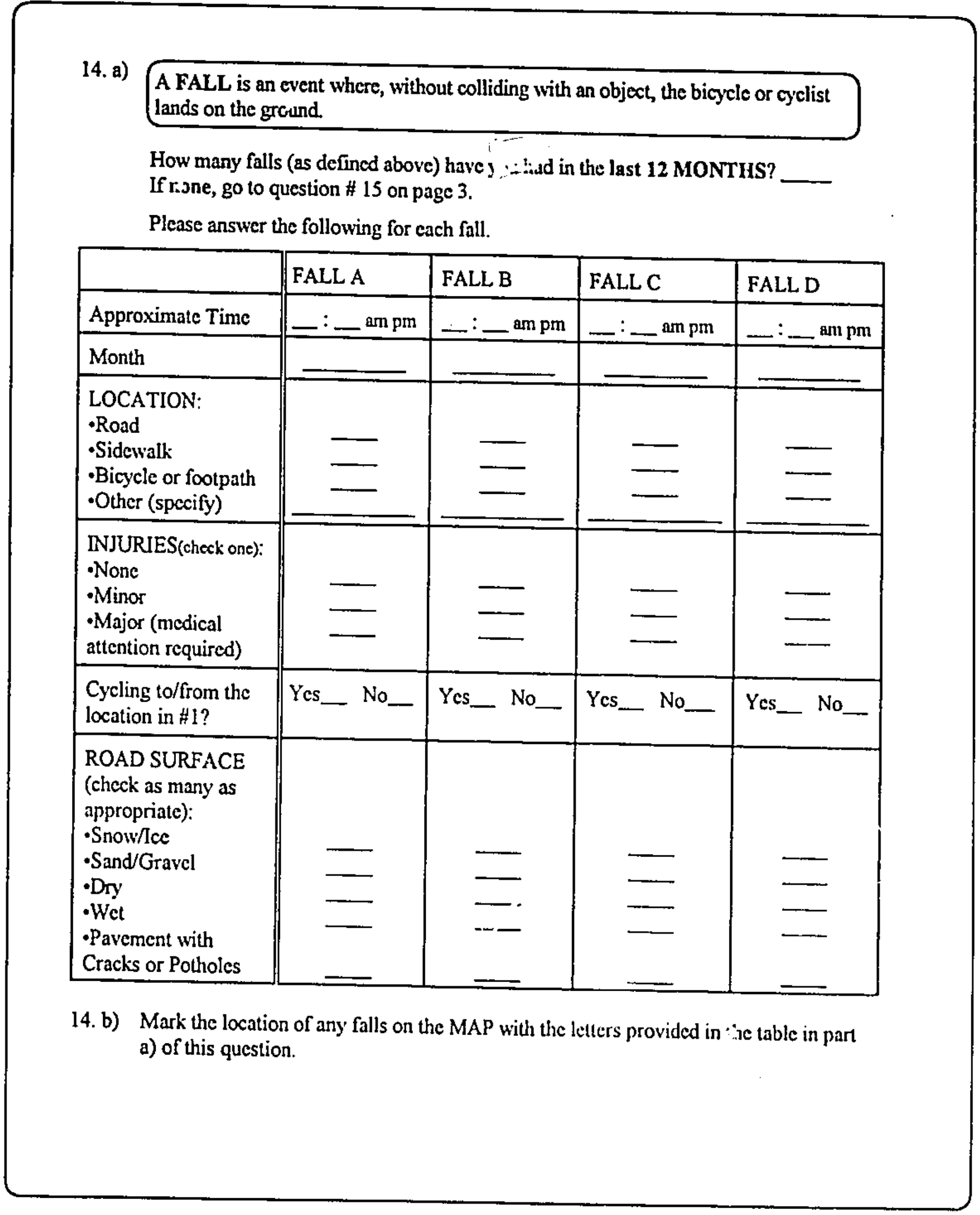
Questions 10 through 13 relate to the specific route you use to travel by bicycle to the location you indicated in question # 1. This information will remain completely confidential.

10. On the map inside this questionnaire, please trace your regular route for your trip. If your return trip follows a different route, indicate this trip also. Use arrows to show direction.
11. Please place an "H" on the map at the start of your route.
    If your starting point is NOT on the map please estimate your one way trip length. _____km
12. Some people choose to ride on a sidewalk for a portion of their trip for safety or other reasons. On the map circle any portions of your route where you bicycle on the sidewalk.
13. Often people do errands or other tasks on their way to or from their main destination. Mark the location of any regular stops on your route with an "X".

The route itself and the sidewalk question are the only information in this set of questions that will be used directly in the incident rate analysis. The other information collected in this section will be used in a related research project to build a route choice model. A bicycle route choice model would allow a similar type of rate analysis to be conducted for other locations with only a portion of the information being known. Given origin and destination information, such as that collected in a comprehensive city-wide travel behaviour survey such as the Transportation Tomorrow Survey, a route choice model would predict on which routes and infrastructure cyclists travel. With already existing accident data such as the Ontario Accident Database, a study of incident rates by infrastructure type could be conducted for other urban areas with the origin/destination data and the route choice model.

Exhibits 7 and 8 illustrate the tables used in the questionnaire to collect information on the "falls" and "collisions" a person had experienced. The definitions of these events were included in the questions. One year was deemed the appropriate amount of time over which a person might remember the details of a fall off a bicycle. More serious incidents were assumed to be remembered for a longer period of time and therefore collision history was collected over three years. Because the year of the collision was collected it will be

Exhibit 7: Fall Question



14. a) A **FALL** is an event where, without colliding with an object, the bicycle or cyclist lands on the ground.

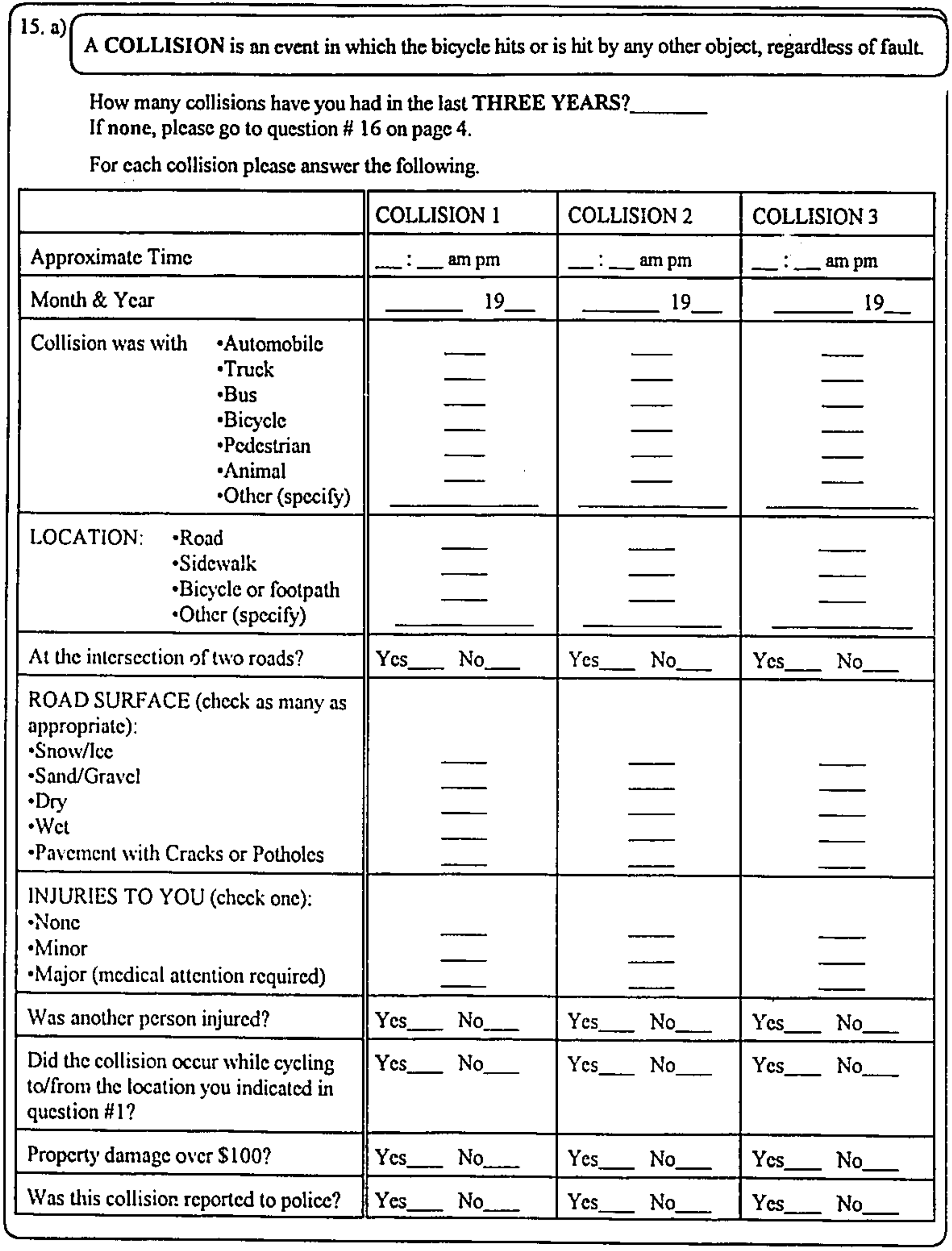
How many falls (as defined above) have you had in the last **12 MONTHS?** ____
If none, go to question # 15 on page 3.

Please answer the following for each fall.

	FALL A	FALL B	FALL C	FALL D
Approximate Time	__ : __ am pm	__ : __ am pm	__ : __ am pm	__ : __ am pm
Month	________	________	________	________
LOCATION: •Road •Sidewalk •Bicycle or footpath •Other (specify)	___ ___ ___ ________	___ ___ ___ ________	___ ___ ___ ________	___ ___ ___ ________
INJURIES(check one): •None •Minor •Major (medical attention required)	___ ___ ___	___ ___ ___	___ ___ ___	___ ___ ___
Cycling to/from the location in #1?	Yes__ No__	Yes__ No__	Yes__ No__	Yes__ No__
ROAD SURFACE (check as many as appropriate): •Snow/Ice •Sand/Gravel •Dry •Wet •Pavement with Cracks or Potholes	___ ___ ___ ___ ___	___ ___ ___ ___ ___	___ ___ ___ ___ ___	___ ___ ___ ___ ___

14. b) Mark the location of any falls on the MAP with the letters provided in the table in part a) of this question.

Exhibit 8 : Collision Question



15. a) **A COLLISION** is an event in which the bicycle hits or is hit by any other object, regardless of fault.

How many collisions have you had in the last **THREE YEARS?**______
If none, please go to question # 16 on page 4.

For each collision please answer the following.

	COLLISION 1	COLLISION 2	COLLISION 3
Approximate Time	__ : __ am pm	__ : __ am pm	__ : __ am pm
Month & Year	______ 19__	______ 19__	______ 19__
Collision was with •Automobile •Truck •Bus •Bicycle •Pedestrian •Animal •Other (specify)	___ ___ ___ ___ ___ ___ ________	___ ___ ___ ___ ___ ___ ________	___ ___ ___ ___ ___ ___ ________
LOCATION: •Road •Sidewalk •Bicycle or footpath •Other (specify)	___ ___ ___ ________	___ ___ ___ ________	___ ___ ___ ________
At the intersection of two roads?	Yes___ No___	Yes___ No___	Yes___ No___
ROAD SURFACE (check as many as appropriate): •Snow/Ice •Sand/Gravel •Dry •Wet •Pavement with Cracks or Potholes	 ___ ___ ___ ___ ___	 ___ ___ ___ ___ ___	 ___ ___ ___ ___ ___
INJURIES TO YOU (check one): •None •Minor •Major (medical attention required)	 ___ ___ ___	 ___ ___ ___	 ___ ___ ___
Was another person injured?	Yes___ No___	Yes___ No___	Yes___ No___
Did the collision occur while cycling to/from the location you indicated in question #1?	Yes___ No___	Yes___ No___	Yes___ No___
Property damage over $100?	Yes___ No___	Yes___ No___	Yes___ No___
Was this collision reported to police?	Yes___ No___	Yes___ No___	Yes___ No___

possible to consider the relative frequency of collisions. It is possible that the severity of the collision affected the ability of the participants to recall collisions. By including the year of the collision we will be able to adjust and use a subset of incidents if necessary.

Of particular interest in the pre-test was the number of falls and collisions that were reported by the cyclists. It had been intended that these incidents might be disaggregated by type or severity and by the type of infrastructure on which they occurred. Ten (or 28.5%) of the 35 pre-test respondents reported collisions with another object within the previous three years. One of those ten people reported two collisions. Eleven (or 31.4%) of the 35 respondents reported a total of 14 falls. The number of collisions and falls reported was considered sufficient to proceed with the plan to distribute a total of 6000 questionnaires. It was recognized that cycling conditions and cyclists differ from city to city and that this rate might vary significantly for Toronto and Ottawa.

The locations of 9 of the 11 collisions and 5 of the 14 falls were marked on the map in the pre-test. In the Ottawa version of the questionnaire, the question in part b) to mark the location of the fall or collision on the map was included within the portion of the question before the table. Using that arrangement only about 30% of people marked the location on the map, so the question was altered for Toronto. The incident rate analysis is still possible for Ottawa as the type of facility on which the fall or collision occurred is indicated in the tables.

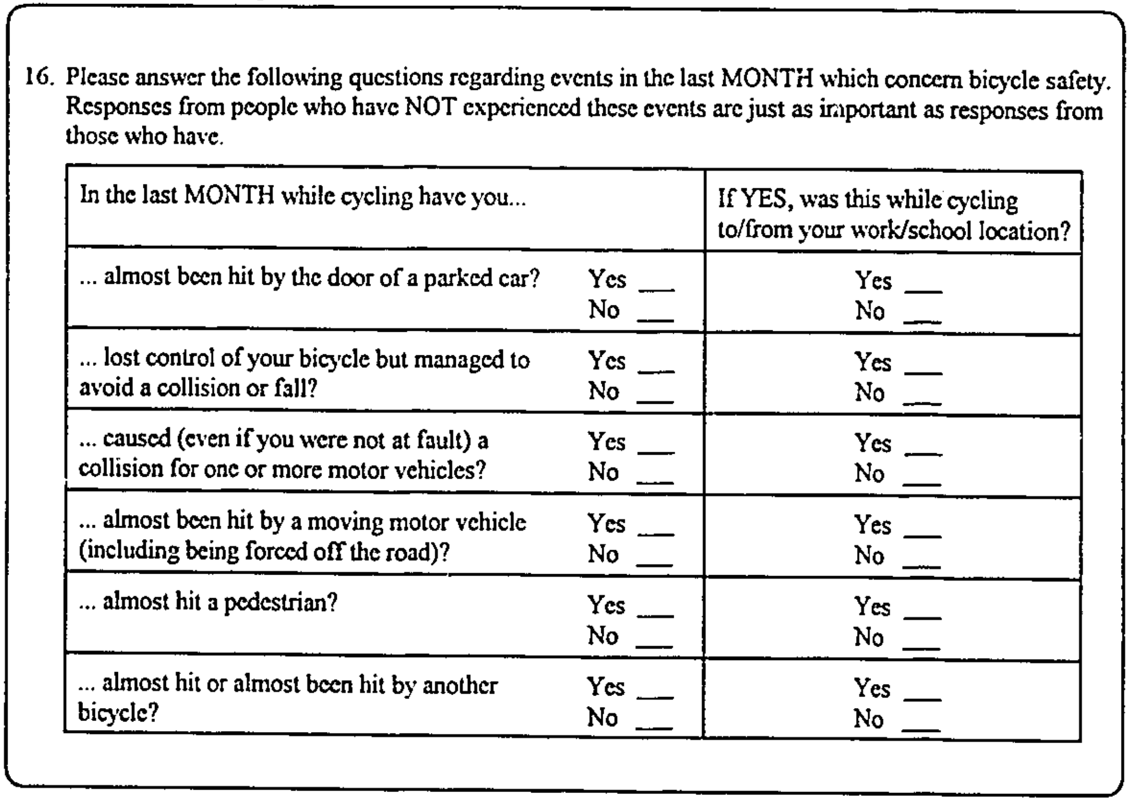
Two pre-test respondents indicated that their collisions did not occur in Hamilton and they could therefore not mark the location on the map. Some people reported falls that did not occur on their commuter route. This raised the issue of whether any of the respondents understood that only collisions and falls experienced while commuting by bicycle were of interest. It was possible that not all of the incidents indicated on the map had occurred while commuting. In addition, people in general seemed very willing to provide information on their experience as cyclists and in particular about incidents they had experienced. It was therefore decided based on the pre-test results that information on all collisions and falls experienced by the respondent would be sought. They would be asked to mark on the map the location of any of these events that occurred within the area shown. In addition people would be asked to indicate whether or not this incident had occurred while they were travelling to or from their commuter destination. It seemed worthwhile to collect information on all their incidents if the opportunity was available.

This anxiousness on the part of individuals to share their experience of falls or collisions on their bicycle makes it possible that people who have experienced falls or collisions were more willing to complete the questionnaire and return it. This inclination will be partially checked for among respondents. The date that the responses arrived has been recorded. Analysis will be conducted to determine if the rate of falls or collisions varied with the time elapsed between distribution and receipt of the completed questionnaire. If the rate decreases as time elapsed, it would indicate that people who had experienced falls or collisions were quicker to complete the questionnaire and return it. This might suggest that these individuals were overall more inclined to respond and an exercise to determine by how much the rates are overestimated will be necessary.

The reasons for including or excluding some of the questions in the fall and collisions table may not be obvious. Responses to the question of whether or not a collision was reported to police will provide insight into the completeness of police bicycle accident records. Respondents were asked to indicate if the collision occurred at the intersection of two roadways in case the exact location was not clear from the map. Whether or not collisions occur at an intersection is considered important information. Collisions were defined regardless of fault and the respondents were not asked to identify the party at fault. This issue was excluded from the question as it could have potentially made the cyclist feel uncomfortable or accused, and thus affected their tendency to reply to the questionnaire.

The near-miss questions shown in Exhibit 9 replaced a near-miss table used in the pre-test that was similar to the fall and collision tables shown above. Appropriately defining "near-miss" was problematic. The severity of the near-miss events was deemed to affect recall times for people, making it difficult to set a time interval over which to ask for near-misses to be reported. The near-miss table was originally included in case only a small number of actual incidents were reported. Near-misses and their location could have been considered an additional measure of the safety or relative incidents rates for different types of infrastructure. The pre-test results indicated that sufficient information on actual collisions and falls would be collected given the number of questionnaires intended for distribution. It was decided during analysis of the pre-test results to exclude the near-miss table. In place of the original table, the near-miss table shown in Exhibit 9 was used. Information collected in these questions will not be used directly in the relative rate analysis of different types of facilities, but the overall incident rates for these events will be calculated using the crude exposure measure collected in question #18 (described below).

Exhibit 9 : Near-miss Question



16. Please answer the following questions regarding events in the last MONTH which concern bicycle safety. Responses from people who have NOT experienced these events are just as important as responses from those who have.

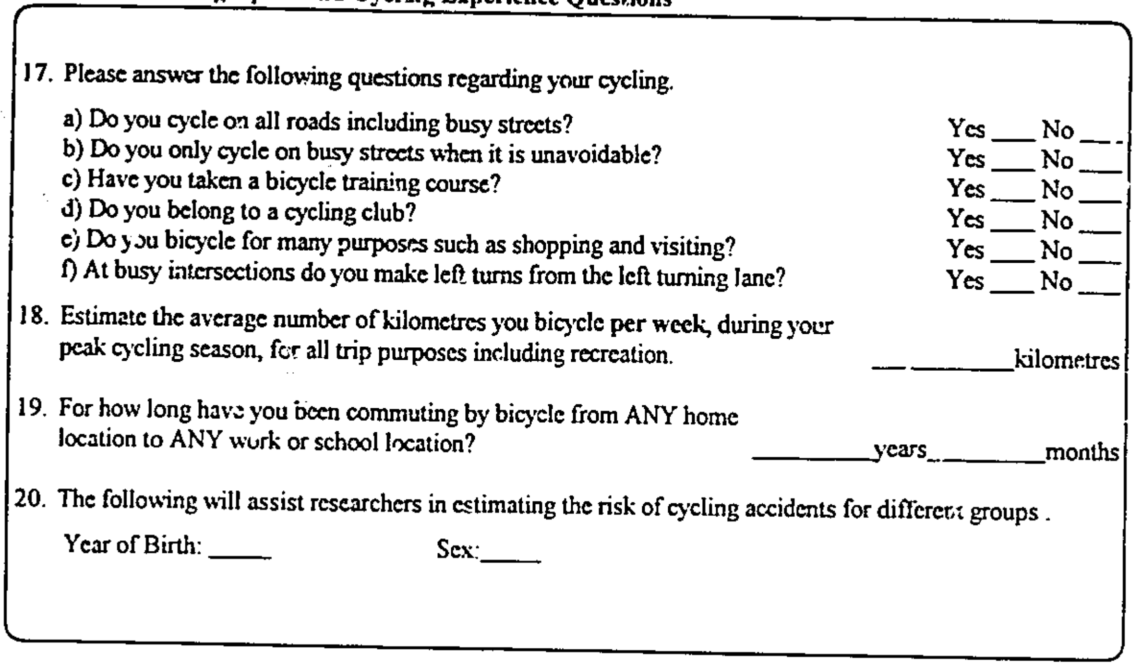
In the last MONTH while cycling have you...		If YES, was this while cycling to/from your work/school location?
... almost been hit by the door of a parked car?	Yes ___ No ___	Yes ___ No ___
... lost control of your bicycle but managed to avoid a collision or fall?	Yes ___ No ___	Yes ___ No ___
... caused (even if you were not at fault) a collision for one or more motor vehicles?	Yes ___ No ___	Yes ___ No ___
... almost been hit by a moving motor vehicle (including being forced off the road)?	Yes ___ No ___	Yes ___ No ___
... almost hit a pedestrian?	Yes ___ No ___	Yes ___ No ___
... almost hit or almost been hit by another bicycle?	Yes ___ No ___	Yes ___ No ___

The information collected in questions 17 through 20 (Exhibit 10) will be used when possible to stratify the sample. Reasons for including year of birth and sex are obvious and their use should be straightforward. The other questions are attempts to measure the type and experience of cyclists. This information can be used to determine the relative incident rates for certain groups of cyclists.

Each of the statements in question #17 is intended to be an indirect measure of experience. Parts a) and b) identify how comfortable and confident a cyclist is travelling on the streets with automobiles. Part c) is an attempt to determine if bicycle training courses are an effective way to improve cycling safety. It is possible that not enough people have received training courses for this question to have meaningful results. Part d) is intended to test the suggestion that members of cycling clubs have safer records than cyclists in general (Forester,1994). The question on shopping and visiting, part e), was included to ensure most cyclists could answer "yes" to at least one part of question 17 thereby feeling their input was valuable. The question regarding how people make left turns at busy intersections (part f) was intended to measure what the cyclist's behaviour in traffic was. There is no value judgement in any of these questions. It is unknown which type of cycling is actually safer.

Question 18 and 19 are also experience questions. It should be noted that information on how many kilometres a person cycles or how long they have been commuting by bicycle does not necessarily indicate a skill level and therefore this information should be used carefully. The average number of kilometres a person cycles in the peak cycling season will be adjusted and used as an overall measure of exposure for the total number of falls and collisions that are reported in the study (as opposed to those that occurred during the commute). This rate estimation cannot be connected to infrastructure type.

Exhibit 10 : Demographic and Cycling Experience Questions



17. Please answer the following questions regarding your cycling.

a) Do you cycle on all roads including busy streets? Yes ___ No ___

b) Do you only cycle on busy streets when it is unavoidable? Yes ___ No ___

c) Have you taken a bicycle training course? Yes ___ No ___

d) Do you belong to a cycling club? Yes ___ No ___

e) Do you bicycle for many purposes such as shopping and visiting? Yes ___ No ___

f) At busy intersections do you make left turns from the left turning lane? Yes ___ No ___

18. Estimate the average number of kilometres you bicycle per week, during your peak cycling season, for all trip purposes including recreation. ___________kilometres

19. For how long have you been commuting by bicycle from ANY home location to ANY work or school location? __________years__________months

20. The following will assist researchers in estimating the risk of cycling accidents for different groups .

Year of Birth: _____ Sex:_____

Participants were also asked to include in the space at the end of the questionnaire any comments they wished to make. Many people have made comments. A summary of the comments will be available to the Ministry of Transportation and the area municipalities.

4.4.3 Questionnaire Map Design

The design of the map was considered extremely important during the questionnaire design. If the map was difficult to read it would contribute not only to inaccurate routes but also to people becoming frustrated with the process and not responding. This section describes how the boundaries and scale of the map were identified for each city and how the maps were produced.

Previous studies and data from both Toronto and Ottawa were used to determine how extensive an area should be included on the maps. The objective was to include enough area that most people could trace all of their route on the map. Because the type of network components (paths versus roads for example) used for travel can only be determined in the GIS for those portions of people's routes that are traced on the map, the choice of area to include was very important. In order to determine the required area it was necessary to investigate bicycle commute length.

The bicycle commuter trip length distribution for Toronto was obtained from the Transportation Tomorrow Survey (TTS) through the Joint Program in Transportation at the University of Toronto. The TTS is a comprehensive travel behaviour survey conducted by telephone in the Greater Toronto Area, which contacts approximately 4% of households in the area. Information from the 1986 survey was used due to the separation of the bicycle trips from walk trips in this dataset. The trips made by adults from home to work or school in Metropolitan Toronto were separated from the other bicycle trips. As the survey is a random sample of the population the absolute number of adult home to work bicycle trips in the dataset is small (only 182 in this case). A histogram of one-way bicycle commuter trip lengths is shown in Figure 4-2. The average trip length was 3.3 kilometres. Eighty seven percent of trips were less than 6 kilometres one way.

The Ottawa-Carleton Cyclist Profile Survey (Cumming Cockburn Limited 1992) reports that the average travel distance for commuter cyclists travelling to work there is 5.5 kilometres. The average distance for commuters travelling to school is 3.3 kilometres (this includes children). Participants were asked to indicate their trip length in either time or distance. A speed of 10 km/h was used to convert. This speed may be considered low and could result in an overestimate of travel time based on speed and an underestimate of distance based on time. The Ottawa Cycling Advisory Group (1992) in its study of commuter cycling recorded one way trip length in minutes. Based on a speed of 12 kilometres per hour they report that three fifths of the commuters are travelling a range of 3 to 12 kilometres. A higher speed would result in an even larger range. The speed of 12 km/h results in an average distance of 4.6 kilometres.

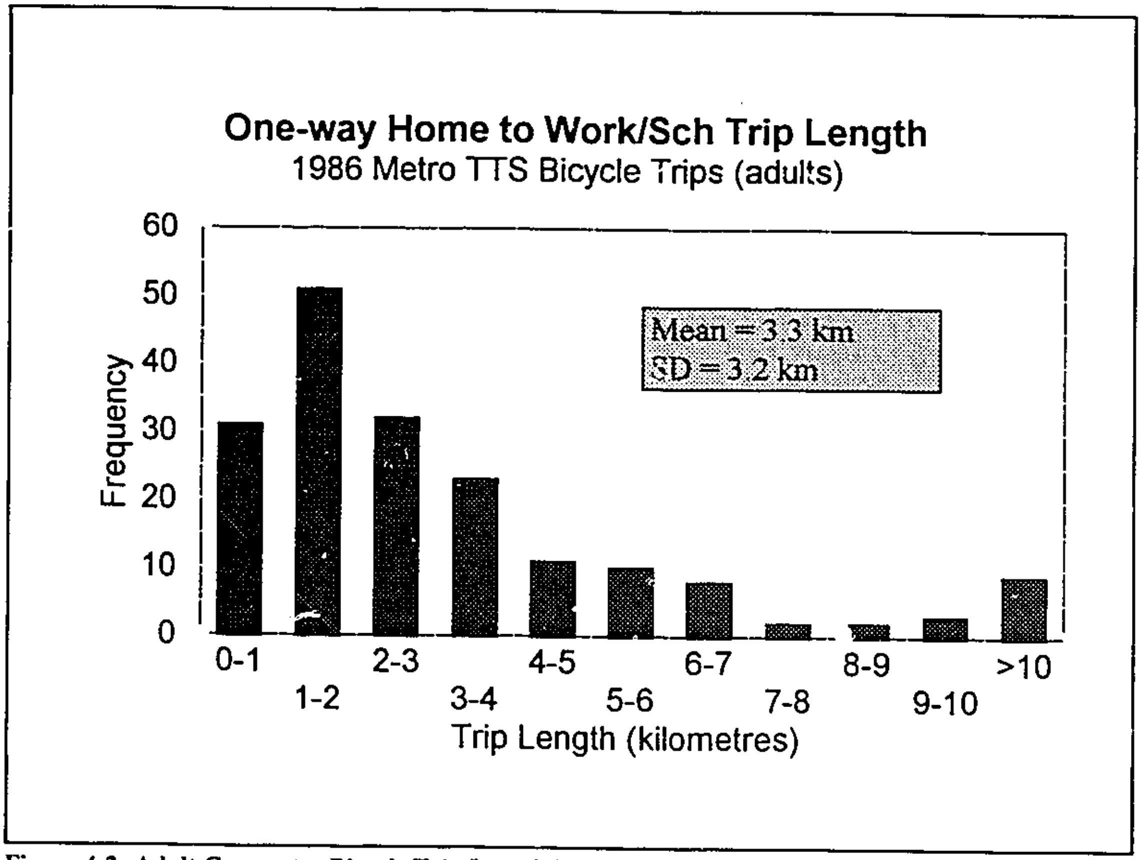


Figure 4-2: Adult Commuter Bicycle Trip Length Frequency Distribution for Toronto (TTS data)

Based on this distance information it was deemed acceptable to have at least six kilometres in all directions from distribution locations on the map provided with the questionnaire. The fold-out format of the questionnaire and the weight restrictions due to postage costs dictated that the map should be approximately 11 by 17 inches in size. Given this available space and using a reasonable scale, a distance of 6 kilometres from the centre area could easily be provided to only the east and west edges.

Fortunately the position of Lake Ontario south of the downtown core of Toronto, and the Ottawa River along urban and suburban portions of Ottawa, allowed for provision of a reasonable distance in the north/south dimension. By placing the bodies of water along the top or bottom edge of the map, the desired distance north or south would also be available on an 11 by 17 inch map. This arrangement had implications for the distribution site selection. Ideally the destinations where the questionnaires were distributed would be located in the centre of the map and then trips from all directions could be included. Distributions sites were in general located at the east/west centre area of the map, and close to the water. Three maps were used in Ottawa to allow for survey distribution at sites in both urban and suburban portions of the region. Questionnaires were printed on different colours of paper to easily ensure the appropriate questionnaire (map) was distributed at each site.

The maps were created using the ArcInfo GIS in the Department of Geography at McMaster University, from "dxf" files received from Metropolitan Toronto and the Regional Municipality of Ottawa-Carleton. Wherever possible, different line styles were used to denote different roads, paths and trails. Major street names were labelled. Only a selection of minor streets were labelled to provide orientation for the participants while avoiding a cluttered-looking map. Bodies of water and major landmarks were labelled. On the Ottawa maps many of the distribution areas were labelled as landmarks.

4.5 Conduct of the Ottawa-Carleton Survey

This section of the report describes the Ottawa-Carleton survey in two sections. First, the selection of sites for distribution, which occurred prior to the actual survey, is discussed. This is followed by a description of the procedures used to distribute the questionnaires, which took place over four days in June 1995.

4.5.1 Selecting Sites for Distribution in Ottawa-Carleton

Two trips were made to Ottawa to undertake site selection. On April 21st 1995, a trip was made to Ottawa to meet with an employee of the City of Ottawa and an employee of the Regional Municipality of Ottawa-Carleton. The purpose of this visit was to discuss the questionnaire format, to obtain GIS data and to be directed to employment and education sites where large numbers of cyclists could be found. Based on these recommendations, employers were contacted and permission sought to distribute the questionnaires on their property. The permission process varied from location to location. Some places required no information and told us permission was not needed. Others were satisfied to have the study described by phone and gave permission immediately. Still others requested that information be mailed or faxed describing the study.

On May 15, 1995, another trip was made to Ottawa to search for distribution sites and to count bicycles at the various locations. The weather was very cool for May and it rained through the previous night, stopping at approximately 7:00 AM. These conditions made the parked bicycle counts a low estimate of how many bicycles would be found in June. Nevertheless, the bicycle counts were used to determine how many sites should be used and how many questionnaires should be produced with each of the three maps. This visit was also used to find more distribution sites to be contacted for permission. Permission was not sought at downtown locations if bicycles were in a clearly public area. Also if the number of bicycles at a location was very small (less than 10) contact was usually not made. Contacting the appropriate authority was considered most important when the institution was on a separate piece of property with explicit or implicit boundaries. All institutions contacted gave their permission for the questionnaire distribution. A list of organizations that agreed to have questionnaires distributed on their property in Ottawa-Carleton can be found in Appendix F.

As discussed in section 4.3.3, it was considered extremely important to ensure as much variability as possible with respect to cyclist characteristics, urban form, network availability and parking type, all of which in turn were affected by the choice of sites. Table 4-1 shows the type of institutions where the questionnaires were distributed and also indicates the approximate total number of questionnaires that were eventually distributed at each. Many locations with few commuter cyclists and/or parked bicycles were chosen for questionnaire distribution, but most sites had at least 20 parked bicycles.

Table 4-1: Types of Organizations in Ottawa where Questionnaires were Distributed

Type of Institution	Approximate Number of Questionnaires Distributed
Post Secondary Educational	557
Hospitals	283
Private Sector Corporate (Urban)	203
Private Sector Corporate (Suburban)	414
Municipal Government Offices	57
Federal Government (Urban)	861
Federal Government (Suburban)	4
Downtown Core (Private and Public Sector)	650
Transit Station	24

The final and most strictly enforced constraint on the choice of questionnaire distribution sites was that the sites be located in the mid to upper centre of one of the maps being used. This ensured a sufficient distance for route tracing outward from the workplace. This was of course an iterative process. The sites found to be ideal for questionnaire distribution (lots of bicycles and permission granted) affected where the east/west boundaries of the three maps would be drawn. The businesses located in the City of Kanata are one exception to the upper centre map location rule. The western boundary of Kanata can be considered the western urban boundary of the Region. Therefore it was assumed that few cyclists would be travelling from west of Kanata and questionnaires were distributed to many locations in Kanata even though it was not located in the upper centre of a map.

Parking location was considered a potential source of bias in responses. People park in indoor bicycle rooms, outdoor parking, offices and parking garages. The effect of excluding any one parking group on the sample is unknown. It was considered impractical to find bicycles parked in offices. However, an effort was made to find indoor bicycle parking areas so that these cyclists would not be excluded from the sample. The City and Region's bicycle planners were asked for the location of any indoor parking areas. In addition, cyclists were stopped in the downtown core and asked if they knew of any indoor parking areas. Several business towers in downtown Ottawa and the city parking authority were contacted by telephone and asked if they provided any indoor bicycle parking. Indoor parking was found in two parking garages downtown. A total of 19 questionnaires were distributed at one of these garages. Bicycle parking was found in the parking garages of the External Affairs building and Ottawa City Hall. Both of these sites are located just outside downtown. A total of 174 questionnaires were distributed indoors at these two locations. One bicycle cage was found at Bell Northern Research on Baseline Road. A bicycle cage consists of a completely fenced locked area for secure bicycle parking. Arrangements had been made to distribute questionnaires in this cage, however, on distribution day the person who was to provide access was unable to meet the distribution team and the distribution did not take place.

4.5.2 Questionnaire Distribution in Ottawa-Carleton

A total of 3053 questionnaires were distributed in Ottawa-Carleton from Monday June 19 through Thursday June 22, 1995. The weather was extremely hot and humid on Monday, but for the remainder of the week the maximum daily temperature in degrees Celsius was in the high 20's. This weather likely affected the commuter cyclists who cycled to work during the week and were therefore parked at their workplace to receive a questionnaire. People at the workplaces visited on Monday indicated there were fewer bicycles than usual. Only approximately 300 questionnaires were distributed on Monday for this reason. On the other three days people indicated that the number of bicycles was similar to the usual number.

The distribution team consisted of three people, including Ms Aultman-Hall from McMaster. On Wednesday, Mr. Pascal Haddad of the Public Works Department for the

City of Ottawa assisted the distribution team. He had recently completed a study of bicycle parking in Ottawa and was very helpful with finding the parked bicycles in downtown. The other distributors were temporary high school student employees.

Due to the unknown effect of the weather and day of the week on cycling patterns, an effort was made to visit a variety of organization types and areas of the city each day. For example a hospital location was visited every day and not all of one area of the city was completed in a single day. Questionnaires were distributed generally between 9:00 AM and 4:00 PM. Distribution took place outside these hours only if arrangements had been made with an employer and the employees of the particular organization worked set hours beyond this range. The final number of questionnaires distributed in each area and the date of distribution is reported in Appendix G. This appendix also contains a map of Ottawa showing the general location of the distribution sites.

The questionnaire distributors returned to the distribution sites in the evening of distribution days and picked up any discarded questionnaire packages. This was undertaken based on results of the pre-test at McMaster University. Of the 110 questionnaire packages in the pre-test, ten packages were found on the ground in the bicycle parking areas the next morning. No questionnaires were found in the garbage cans nearby. In Toronto and Ottawa, only approximately 1% of the questionnaires were found discarded. It has been assumed therefore that the high number of discarded questionnaires at McMaster was due to the major rainfall on the day of distribution.

Several "rules of thumb" were used for questionnaire distribution. (These rules apply to Toronto as well as Ottawa.)

1. Courier bicycles if identified were not provided with questionnaires. Couriers might have been annoyed by repetitive placements of questionnaires on their bicycles.

2. All bicycles at targeted parking locations had questionnaires attached to them. It might have been reasonable at some locations with large numbers of bicycles to attach questionnaires to every second bicycle or according to some other random procedure. However, observation of people at McMaster University during the pre-test suggested that cyclists were very interested in the study. Passers by stopped to read the questionnaire. One person on campus emailed to say her bicycle was missed and could she please be mailed a questionnaire. Based on these responses from people it was concluded that a random sampling procedure at individual locations would result in people feeling left out.

3. Bicycles that were clearly disabled and not in operating condition were not surveyed.

4. At times questionnaire distributors were approached by a person who asked for a questionnaire. These people were asked if they travelled to work or school by bicycle and whether their bicycle was parked on the site that day. If they were a bicycle commuter and their bicycle was not parked on the site that day or was parked indoors a questionnaire was given to them. If their bicycle was parked in another area they were assured that a questionnaire would be placed on it. Although this procedure deviates from the standard distribution procedure, it happened in few enough cases that keeping a friendly and accommodating attitude was more important.

5. If a cyclist arrived or departed from the parking area while surveys were being distributed, the distributor briefly described the study and the person was asked if they would take a questionnaire.

6. In some areas, such as downtown, site selection was on-going as the questionnaires were distributed. In selecting public distribution sites, areas such as fitness clubs, tourist attractions, shopping centres, apartment buildings or parks were avoided in order to keep the focus on commuter cyclists.

4.6 Conduct of the Toronto Survey

Section 4.6.1 describes the selecting of individual sites for the Toronto distribution and section 4.6.2 describes the questionnaire distribution procedures. Particular emphasis is made on differences between Ottawa-Carleton and Toronto. General distribution practices such as the "rules of thumb" described above were the same for both cities and are not repeated.

4.6.1 Selecting Sites for Distribution in Toronto

Sites selected for questionnaire distribution in Toronto were all within the area bounded by Bathurst Street, Bloor Street, Parliament Street and Lake Ontario. There were two reasons for selecting this area. First, it has almost the same boundaries as the area used by the City of Toronto in their counts of bicycles entering the downtown core. In 1993, nearly 30,000 bicycles crossed into the downtown core on a weekday. Therefore it was reasonable to assume that sufficient bicycles would be found in this area for questionnaire distribution. The second reason for setting the outer boundaries for the sites was that using a reasonable scale and placing University Avenue at the east/west centre of the map, the distance of 6 kilometres from all distribution points to the edge of the survey map could be provided.

The individual site selection process began in early June 1995. Using information from the Toronto City Cycling Committee and knowing the locations of buildings, large employment areas and parking areas, four trips were made to Toronto to find and count parked bicycles. Bicycles were found at corporate business locations, industrial sites, hospitals and educational institutions. Permission to distribute the questionnaires was requested at locations with over 20 bicycles that were not on public property. One consideration when counting bicycles in June was that there would be fewer bikes during the distribution in July, because of the increased number of people on vacation. Bicycles were more hidden and often parked in smaller clusters in Toronto compared to Ottawa and this made finding enough bicycles and obtaining permission for those sites a cumbersome job. However, once the bicycles were located, in most cases a description of the study was provided by phone and permission was granted. Some properties required written information, often for security purposes.

For reasons described earlier, it was important to include a variety of bicycle parking locations in the sample. During the site visits to Toronto, the research assistant asked at individual buildings if any indoor bicycle parking was provided for employees. Phone calls were made to hotels and parking garages in the area to ask this information as well. Outdoor and indoor bicycle cages were found in many locations. Almost ten percent of the total number of questionnaires distributed were attached to indoor or caged bicycles. Appendix H contains a listing and map of the indoor and cage parking areas where questionnaires were distributed. It is felt that these locations are an under-representation of bicycles parked indoors in the downtown core, but a count is not available.

Not all of the corporations and institutions that were contacted granted permission for the survey distribution on their sites. Those that did are listed in Appendix I. Although the majority of people contacted had no problem with the execution of the study, it was obvious that security was a much bigger concern in Toronto than Ottawa. Litter was the primary concern of corporations that would not give permission for survey distribution on their property. Many bicycles were not located on specific sites and were often along the streets. The list in Appendix I represents only a portion of the institutions whose employees would have received questionnaires.

4.6.2 Questionnaire Distribution in Toronto

From July 10 to 14, 1995, 3000 questionnaires were distributed in the areas of Toronto shown in Figure 4-3. The number of questionnaires distributed in each area is listed in Table 4-2. Although the questionnaire distribution followed the same procedure and "rules of thumb" previously described for Ottawa-Carleton, the process was complicated by the dispersed pattern of parked bicycles and the weather during distribution week.

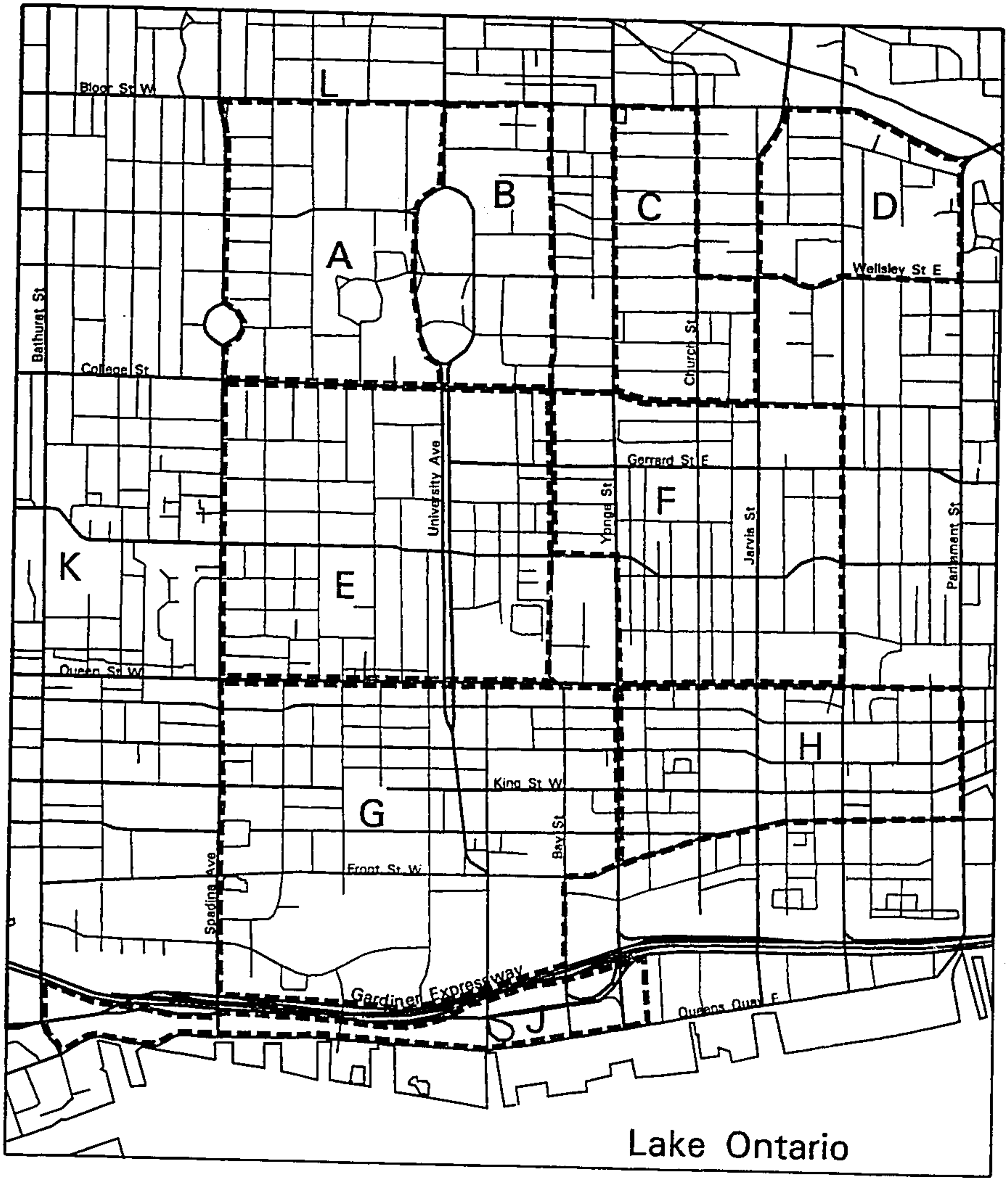


Figure 4-3: Map of Distribution Areas in Toronto

Table 4-2: Number of Questionnaires Distributed at the Locations in Toronto

Location (see Figure 4-2)	Description	Number Distributed
A	University of Toronto	680
B	Queen's Park	150
C	Bloor, Yonge, Carleton, Church Sts	225
D	Wellesley Hospital and area	125
E	Downtown Hospitals and area	605
F	Carleton, Bay Queen, Sherbourne Sts	185
G	Financial District	720
H	Queen,Yonge,Front,Parliament Sts	150
J	South of Gardiner	70
K	Toronto Western Hospital	80
L	Bloor Street (University to Spadina)	30

It was decided in advance that with a large enough group of distributors one or two days would be sufficient for distribution. It was intended that the area north of College Street would be surveyed one day and the area south of College the second. In Ottawa (outside of downtown) bicycles were usually clustered on large employment complexes with definable boundaries. They were often surrounded by open space. One site could be surveyed on one day and another site on a different day. However, in the downtown areas of both cities, bicycle parking areas were spread continuously throughout the area, separated by very little distance. Bicycles were everywhere. It was not possible to just stop at a certain time and return to pick up where one left off. It would have been impossible to know which bicycles had been surveyed and which had not. With this limitation in mind, downtown Toronto required a concentrated distribution effort.

The general approach for outdoor bicycle areas was for each distributor to be assigned an area bounded by certain streets or to be assigned a single street. They were responsible for attaching questionnaire packages to all bicycles parked outside appropriate institutions in their area. Once a section of street(s) had been surveyed it was not returned to at any time. If bicycles in a previously surveyed area were later noticed not to have questionnaires attached to them, it was impossible to know if the owner had removed the questionnaire.

The indoor or special security locations were surveyed by one individual. Distributors were provided with a list of locations in their area that required special instructions or had not given permission for questionnaire distribution.

Due to the nature of the distribution area and the method of distribution, workers travelled by foot, with the exception of the person going only to special sites. Walking made the most sense as there were not large clusters of bicycles and there was usually only a few metres between bicycles. Walking limited the number of questionnaire packages that people could reasonably carry so return trips to the cars (parked centrally) for more questionnaires were necessary.

Although Tuesday and Wednesday would have been the preferred days for distribution, the weather interfered with these plans. Monday was required to complete the preparation of the questionnaire packages. On Friday, the Molson Indy, a major city-street auto-racing event was scheduled, and was expected to change traffic patterns drastically. On Monday, showers were unfortunately forecast for Tuesday and possibly Wednesday. The questionnaire (question # 3) identified the previous week to the distribution week by date so it was necessary to distribute all questionnaires during the week of July 10-14. A quick decision was made to go to Toronto on Monday afternoon with the already prepared packages. A group of five distributed 1010 questionnaire packages between 1:00 and 3:30 pm in the area north of College Street. It was possible to distribute such a large number of questionnaires in such a short amount of time due to the large number of bicycles at the University of Toronto.

By Monday night, the rain was forecast for only Wednesday and extreme humidity was forecast for Thursday. A decision was made to go to Toronto on Tuesday. A total of 1707 questionnaire packages were quickly prepared through the night Monday. A group of seven distributed questionnaires between 9:00 AM and 4:00 PM with a one hour lunch break. All areas except J, K, and L on Figure 4-2 and some indoor locations were completed by the end of Tuesday.

On Thursday, when it was hot and humid, but unlikely to rain, two research assistants returned to distribute the remaining 283 questionnaires.

4.7 Survey Response Rates

The final response rates are 45.3% (1360 questionnaires) for Toronto and 52.5% (1603 questionnaires) for Ottawa. Although the bulk of the responses arrived at McMaster in the two weeks following each of the two distributions, completed questionnaires arrived through December 1995, six months after distribution. The overall rate is considered excellent given the nature of the survey: single contact, no follow-up. There are several possible reasons for the lower response in Toronto: multiple distributions on single bicycles; failure to identify couriers; a lower ability to target and identify commuters resulting in distribution to cyclists not of interest in the survey; and advanced advertisement of the survey at some Ottawa workplaces and in an Ottawa bicycle safety newsletter.

The remainder of this section describes two issues regarding response rate: the possibility of different response rates for men and women; and consideration of the relationship between time to respond and incident rates.

4.7.1 Response Rates of Men and Women

Of the returned questionnaires, 98% from Ottawa and 99% from Toronto indicated whether the respondent was male or female. Of these responses, 37% and 41% in Ottawa and Toronto respectively were from women . The issue of personal security related to the nature of the questions asked in this study and a possible gender response bias was raised by several people in our pre-test and design exercises. The questionnaire asks respondents to reveal their gender, the approximate location of their home, the route they use to travel by bicycle, and the time and frequency with which they travel the route. This information could, in the wrong hands, be a threat to any person's safety. In today's society, many people, but especially women, have become very sensitive and wisely cautious regarding revealing this type of information. It is possible that this concern could lead to a lower response rate from women. It is also possible that the group of women who would not respond might share unique route or accident experiences thus creating a systematic bias in the information of interest. An effort had to be made to include all groups. This section describes the efforts made during questionnaire design to address this problem and the exercise conducted in Toronto to measure the response rate difference between men and women.

The participants were assured on the questionnaire that their responses would remain completely confidential. A phone number and email address were provided so that participants with questions, including those regarding personal security, could contact the researchers. Questions that asked the participants for their name, exact address or postal code were excluded. The returned questionnaires have been kept locked and individual route information will not be shared with any other parties. The fact that none of the approximately 30 phone and email inquires received from Toronto and Ottawa were regarding the confidentiality or personal security issues is reassuring.

A comparison of the percentage of commuter cyclists known from other studies to be male and female to the percent female respondents does not provide a satisfactory answer to this issue of whether male and female response rates were different. A general percentage of bicycle commuters that are women is not necessarily an accurate predictor of the percentage of bicycles belonging to women at a our distribution locations. In order to address the issue, a plan was formulated to count female cyclists at the three Toronto locations shown in Figure 4-4 and to compare the male and female response rates for those destinations. One hospital, one university and one on-street parking area were observed until early evening by questionnaire distributors. The information collected is summarised in Table 4-3. The questionnaires were distributed at these locations at the beginning of the observation time interval indicated in the table. Of the cyclists observed leaving, approximately 46% of the recipients were female. It was not possible to stay until every bicycle with a questionnaire

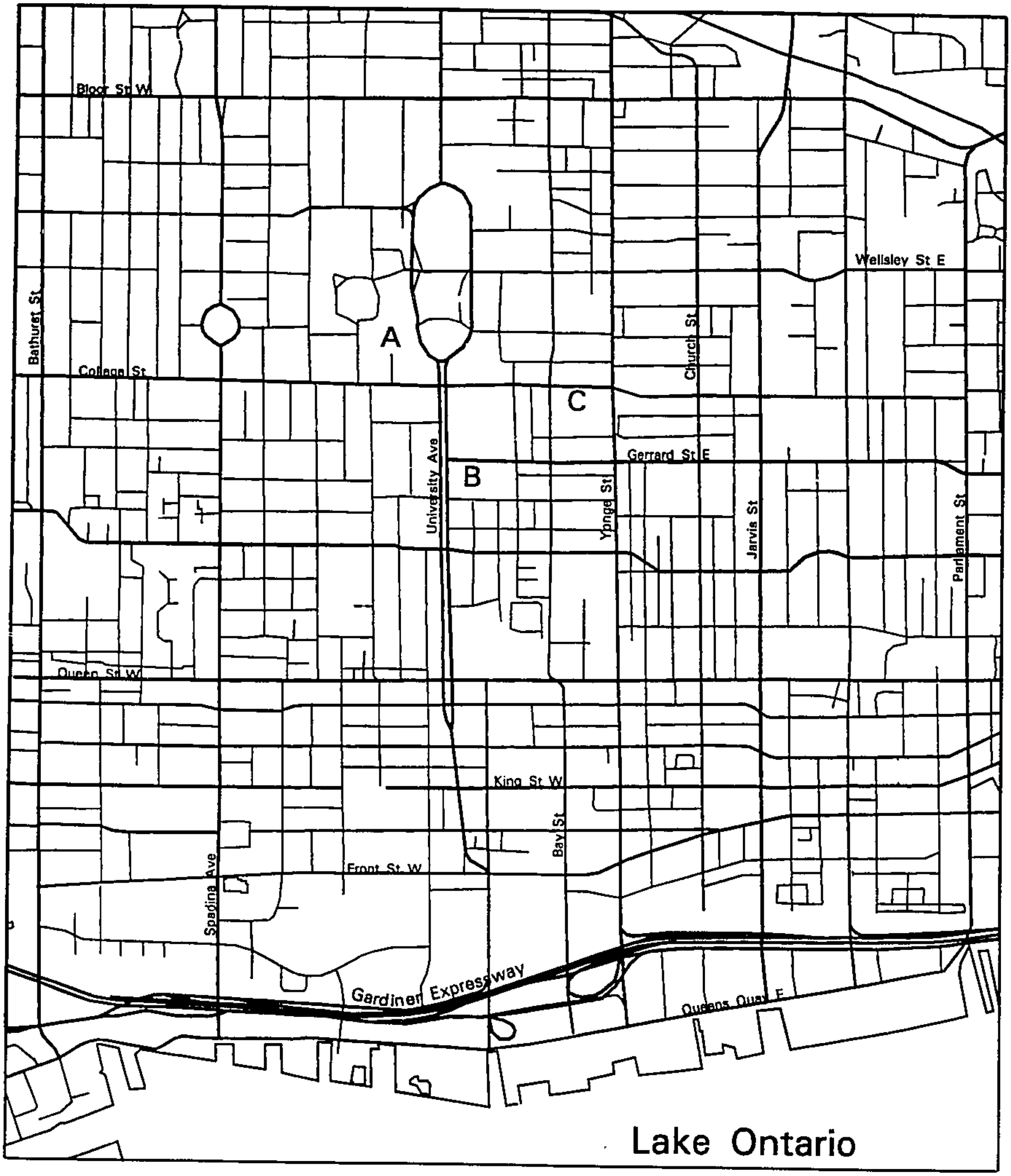


Figure 4-4: Locations of Recipient Gender Counts in Toronto
A: Medical Sciences Building, University of Toronto
B: Hospital for Sick Children
C: College Park (on-street parking on south side of College Street)

left. It may be that for personal security reasons more of the late stayers were men and this would result in an overestimate of women cyclists at these locations.

Table 4-3: Summary of Information Collected in the Gender Counts

Location (Fig 4-4)	Date 1995	Time Observed	Total Surveys Distributed	Total Cyclists Observed	Number o Females Observed	Female Recipients (%)	Total Responses	Number Female Responses	Female Responses (%)
A	July 10	3:45-7:15	40	29	13	45	17	4	24
B	July 11	3:30-8:10	97	73	34	47	41	20	49
C	July 11	4:00-6:45	33	23	10	43	15	10	67
Overal			170	125	57	46	73	34	47

The intent of this exercise was to determine, based on the destination for the routes shown on returned questionnaire maps, what percentage of the women who received questionnaires at these locations returned their questionnaire. This exercise in Toronto may demonstrate whether or not there is a difference between the overall response rate and the female response rate. It will not however, give any particular insight or information on why the response rates do or do not differ. The final column in Table 4-3 indicates the percentage of returned questionnaires with a route terminating at one of the studied locations that were from females.

Determination of whether a returned survey had been distributed at each location was based only on interpretation of the respondent's traced route as it was felt that identification markings on the surveys might deter response. There is some variability between location, however, overall the percent of respondents that are female is in good agreement with the percent of female recipients. Based on these results it can be concluded that there was not likely a serious gender response problem or bias.

4.7.2 Investigation of the Response Time and Incident Occurrence Relationship

It is possible that people who had experienced bicycle incidents were more likely than those without incidents to return the survey questionnaire due to an interest in bicycle safety or a desire to have their incident recorded. If this occurred, the incident rate estimates and incident rates will be biased by a high estimate of the number of incidents that had been experienced by the cyclists. It is difficult to evaluate this effect without information on the incident experiences of those who did not return their questionnaires. Normally, it would be possible to compare the event rate from a sample to existing estimates for the whole population. This is not possible in this case for three reasons. First, as this study's sample is not a random one, defining the population is not straightforward. Second, bicycle data are not commonly collected. Police databases, for example, do not contain complete incident records that include minor events and falls as were collected in this case. Finally, even where specific bicycle safety studies have been conducted, they typically define "accidents" or "events" differently making comparisons impossible.

As a surrogate measure for determining if a response bias occurred, the response time versus the number of reported incidents was investigated. For this analysis, it was assumed that the incident experience of the group returning the questionnaires earlier might be similar to people more likely to respond overall. In other words, if a cyclist who had experienced a fall or collision tended to return his/her questionnaire more quickly than someone who had not, it could be that more people with incidents were likely to return the surveys than those without.

The potential relationship was examined using two methods. The first was to compare the average return time for a response with no incidents, with the average return time for a response reporting at least one fall or collision. In this case the return time is considered to be the number of days between the last of day of distribution and the day the survey arrived in the Department of Civil Engineering at McMaster. This measure is crude. It is affected by the fact that not all surveys were distributed on that one day, but there was no way of determining which day the returned survey had been provided to the cyclist. The measure is also affected by the operations of the mail services department at the university. In addition to mail not being delivered on weekends, if mail services was busy on a particular day they would not process our business return envelopes until the next day.

The mean return time for different groups is shown in Table 4-4. The average return time for surveys indicating at least one incident (fall or collision) was not significantly different than those without any incident based on a Student's t-test at the 0.05 level for both Toronto and Ottawa. The mean return time for individuals experiencing one or more collisions (the more serious event compared to falls) was higher, but not significantly different, than that of the surveys with no incidents for both cities. Based on these estimates, it was concluded that experiencing a fall or collision has no bearing on when the survey was returned.

Table 4-4: Mean Return Time for Questionnaires

Number of Incidents	**Toronto Mean Return Time (days)**	**Ottawa Mean Return Time (days)**
none	12.2	11.6
one or more falls or collisions	11.9	12.9
one or more collisions	12.3	11.9

The second method of investigation involved regressing the number of incidents reported on the returned surveys versus the response time. This procedure allows the total number of falls and collisions to be considered not just whether or not any were reported, thus allowing for a test of the hypothesis that the more incidents one had experienced the more inclined one was to respond. None of the regressions of response time versus total number of falls, total number of collisions or total number of incidents had coefficients that were statistically different from zero, indicating no relationship between the number of incidents and the response time.

Using these two methods it can be concluded that there is no significant relationship between the response time and whether the cyclist had experienced an incident. We will extend this conclusion and infer that the overall incident rates are not biased by the issue of whether people who had experienced incidents were more likely to respond. However, the possibility of this bias cannot be completely discounted due to the lack of information from cyclists who chose not to respond to the questionnaire.

4.8 Incident Recall and Exposure Bias Characteristics

In the Toronto survey the 1360 respondents reported details of 465 falls during the 12 months prior to distribution and 662 collisions in the previous three years. The characteristics of these falls and collisions are discussed in Doherty et al. (1996). The 1604 Ottawa participants reported the details of 379 falls and 359 collisions. Initial summary statistics describing the Ottawa incidents can be found in Andrews (1996). This section of the thesis discusses possible incident and exposure bias in both datasets. Section 4.8.1 investigates the possibility of incident recall bias by considering the patterns in incident rates over the time periods used. Section 4.8.2 investigates the accuracy of the recall of travel exposure by comparing the different measures of exposure used in the questionnaire.

4.8.1 Incident Recall Bias

The are two concerns with respect to incident recall bias in the database. The first is whether individuals interpreted the definitions of a fall and collision as intended. The second is whether the time intervals provided for recording incident history were appropriate such that all incidents actually experienced by the cyclist within that time period were recalled and recorded.

In order to address the meaning of the terms fall and collision, and potential confusion for the participants, concise basic definitions were set out in the questionnaire. The definitions were placed in boxes to stress their importance within the questions. Without knowing the actual experiences of the cyclists it is difficult to correct the information collected for most types of possible inconsistencies or misinterpretations. However, there are two types of classification error concerning the falls and collisions that have been identified and corrected. Thirteen Ottawa respondents and fourteen Toronto respondents identified incidents in which they collided with a curb, pothole, edge of a sidewalk, stone or stream. These incidents were deemed to be falls and were moved into the fall database for the safety analysis if they had occurred during the previous 12 months (the more dated events were excluded from the analysis completely). Collisions reported to have occurred with rocks, posts, fences, snowbanks or walls remain in the collision database. The second error related to individuals reporting a single event as both a collision and a fall. In all instances the dual label was probably appropriate as collisions often cause falls. However, the double counting of events had to be eliminated by comparing the date and time of events for each individual. A total of 4 Ottawa falls and 7 Toronto falls were removed from the database because they had also been reported by the cyclists as collisions.

In order to consider a possible collision recall bias, the frequency of collisions by month throughout the three year period was considered. A total of 36 collisions (27 in Toronto and 9 from Ottawa) were reported to have occurred prior to the three year time interval. These collisions were removed from the databases. Seven collisions were reported to have occurred between August and December 1995, after the survey distribution. All of these questionnaires had arrived back at the university by August 2, 1995. It was assumed these collisions occurred in 1994 and the dates were adjusted. A total of 50 (Ottawa) and 64 (Toronto) collisions did not have the year, the month or the year and month specified. These observations are excluded only from analysis concerning the time of year.

Figures 4-5 and 4-6 illustrate the total number of collisions reported to have occurred in each of the previous 36 months for both cities. While these graphs clearly indicate a seasonal pattern for bicycle collisions, it is the trend downward over the time period that is concerning as it suggests collisions further back in the past may have gone unrecorded. However, these figures do not take into account any changes in the amount of recreational cycling, commuting or other cycling undertaken during the three years. Some of the cyclists may not

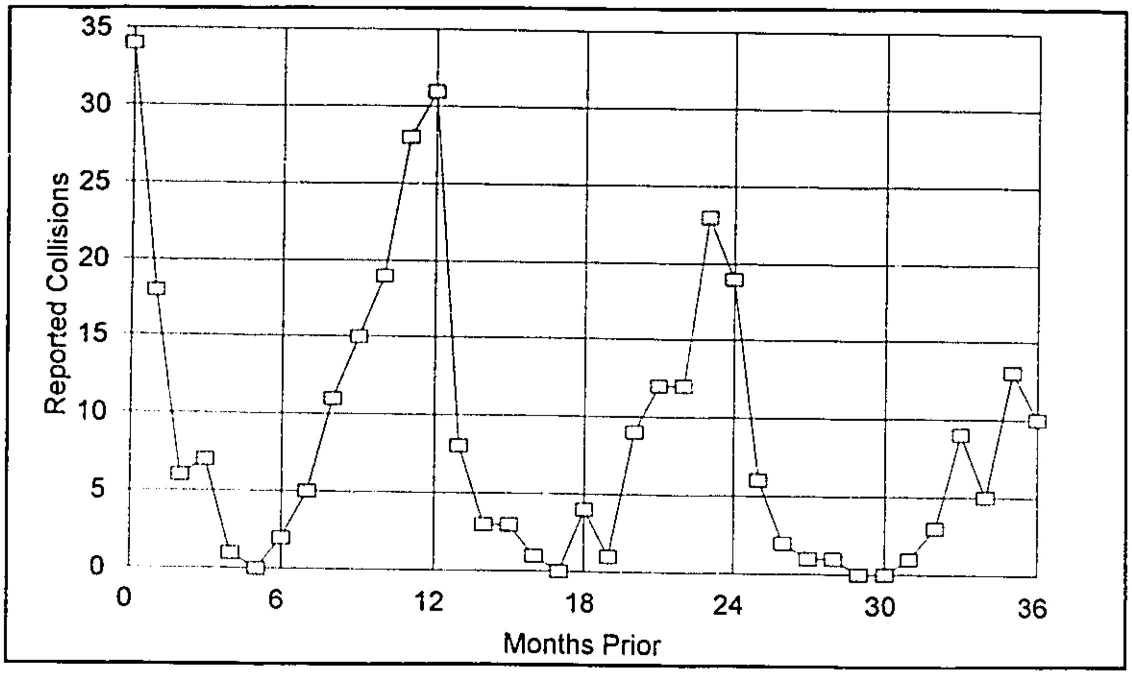


Figure 4-5: Ottawa Collisions by Month

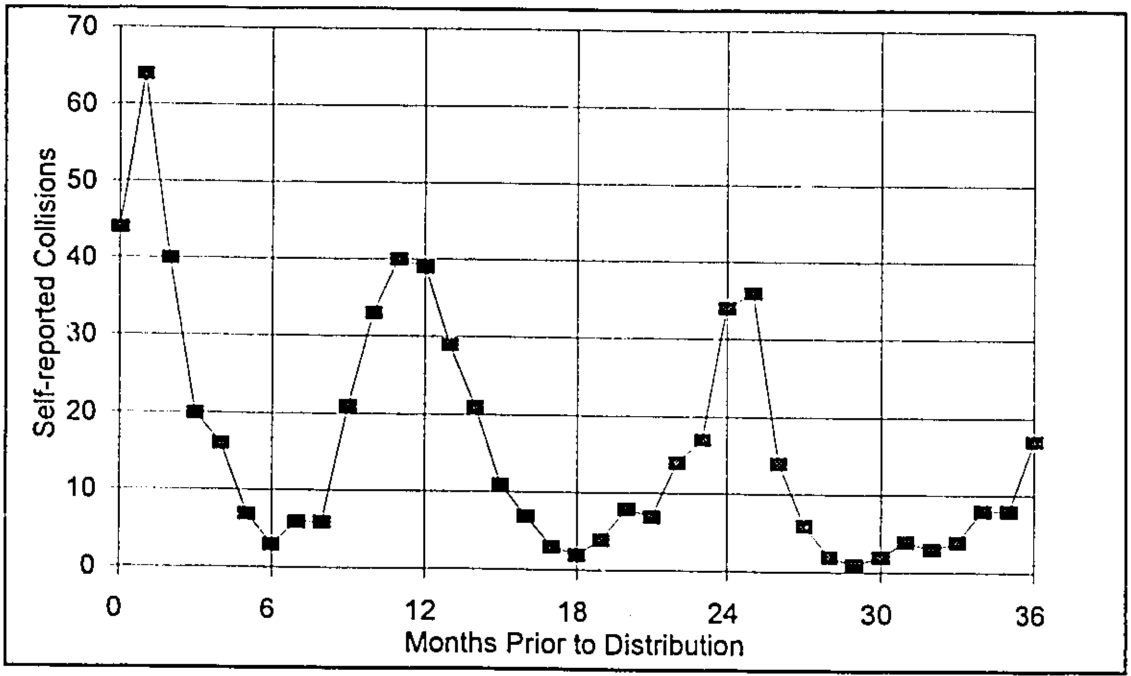


Figure 4-6: Toronto Collisions by Month

have been bicycling for the full three year period. An adjustment for this is possible for commuting exposure and collisions, so the analysis proceeded to only the commute collisions for further consideration of the trend over time.

Figures 4-7 and 4-8 illustrate the corrected number of collisions reported in the previous 36 months that occurred while the individuals were commuting to their current work or school location. These monthly totals are corrected for the time the individuals in the sample have been commuting by bicycle to their current commuter destination. This information is known from the responses to question #2. For example, if an individual just started commuting in the last six months, one would not expect the individual to report any commuting collisions before that time. However, for cyclists who have been cycling the full three years a reduction in the number of collisions reported into the past may be an indication that some collisions cannot be recalled for that long ago. Therefore, for a particular month, say June of 1993, the total number of commute destination collisions reported, 18, was divided by the proportion (0.49) of the sample of cyclists who had been cycling to their current work or school destination for at least 25 months. This results in an adjusted collision total of 36.6 for that month. This assumes that an individual's commuting exposure and travel patterns were the same each year that a person commuted to their current destination. Comparison of the summer peaks in the graph from year to year suggest that recall bias may be present for Ottawa but not for Toronto. In other words, for the Toronto sample the corrected number of collisions reported remained similar over the three year period but for Ottawa the number of reported collisions decreases with time into the past.

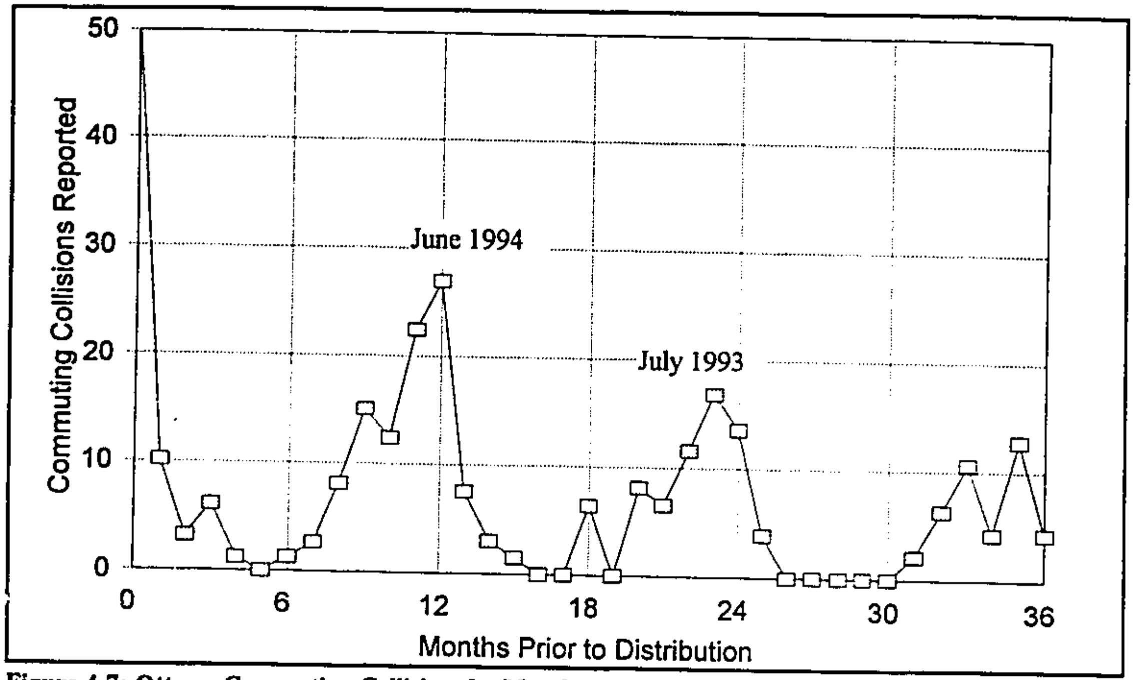


Figure 4-7: Ottawa Commuting Collisions by Month (Adjusted for Time to Current Destination)

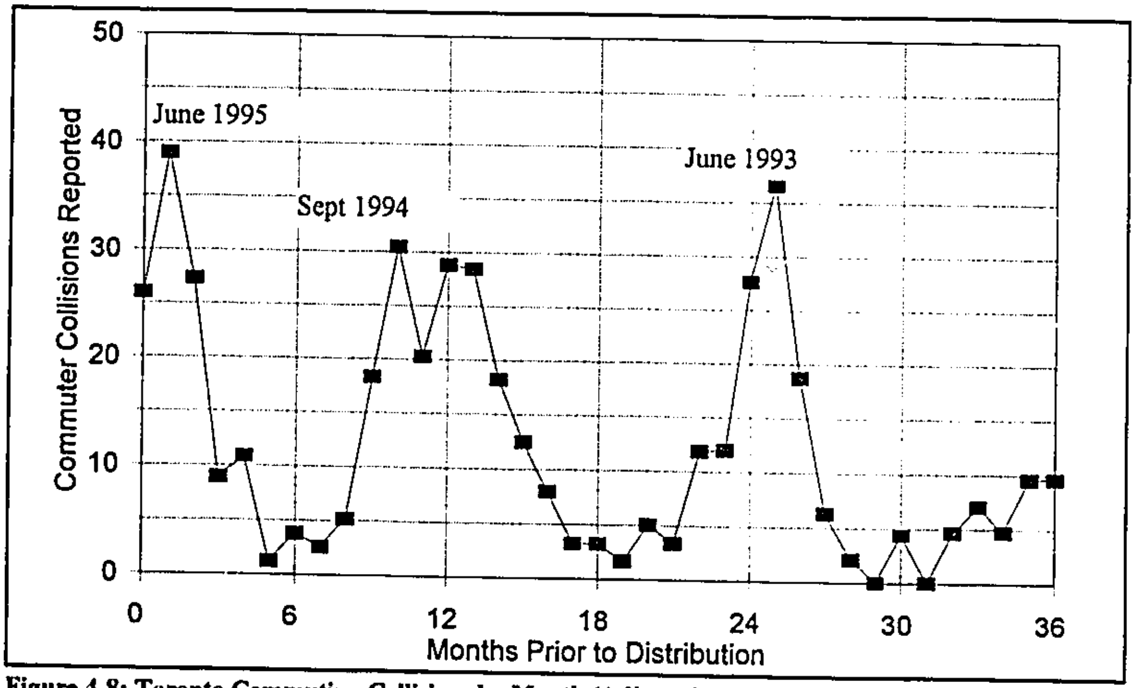


Figure 4-8: Toronto Commuting Collisions by Month (Adjusted for Time to Current Destination)

In order to investigate whether the variation in reported collisions over time was due to recall of minor collisions in the most recent past that are not recalled over longer periods, plots of reported collisions with motor vehicles were created (Figures 4-9 and 4-10). In this case a motorized vehicle was taken to be an automobile, van, taxi, truck or bus. The plots in Figures 4-9 and 4-10 indicate closer agreement between the three years suggesting that perhaps some minor collisions are under-reported further into the past. However, the Ottawa collisions still decrease backwards in time, and the number of collisions reported for June of 1995 (the month the survey was conducted) is particularly high. This recall bias is perplexing given the lack of bias in the Toronto collision tallies. It is unreasonable to assume that Ottawa cyclists have poorer memories than Toronto cyclists. There are three possible reasons for the discrepancy. First, cycling experience may be a factor in collision rates for Ottawa. In that case, the increased number of more recent collisions are being experienced by newer commuter cyclists who are more at risk. The lack of this effect in Toronto could be attributed to other factors, such as cycling conditions and traffic levels, being more influential on collisions rates. A second explanation for the recall bias may be that the cycling conditions in terms of vehicular traffic volumes, bicycle volumes or infrastructure conditions have deteriorated in recent years in Ottawa resulting in increased collision rates for cyclists. Support for these first two explanations will be sought in subsequent analysis. A final reason for the discrepancy might be found within the 50 collisions in Ottawa that did not specify the month or month and year and are therefore not available for inclusion in Figures 4-6 through 4-10. It seems reasonable to assume that dates may have been excluded because the cyclist could not remember the exact date and this seems more likely further into the past.

At this point it is considered unreasonable, especially given the relatively constant collisions tallies in Toronto, to adjust the number of reported Ottawa collisions based on the changing trend over time. No correction for this problem will be undertaken. It should be noted that collisions rates based on these three year histories may be an underestimate of the actual rates. However, based on the Toronto result, three years is not necessarily too long a time

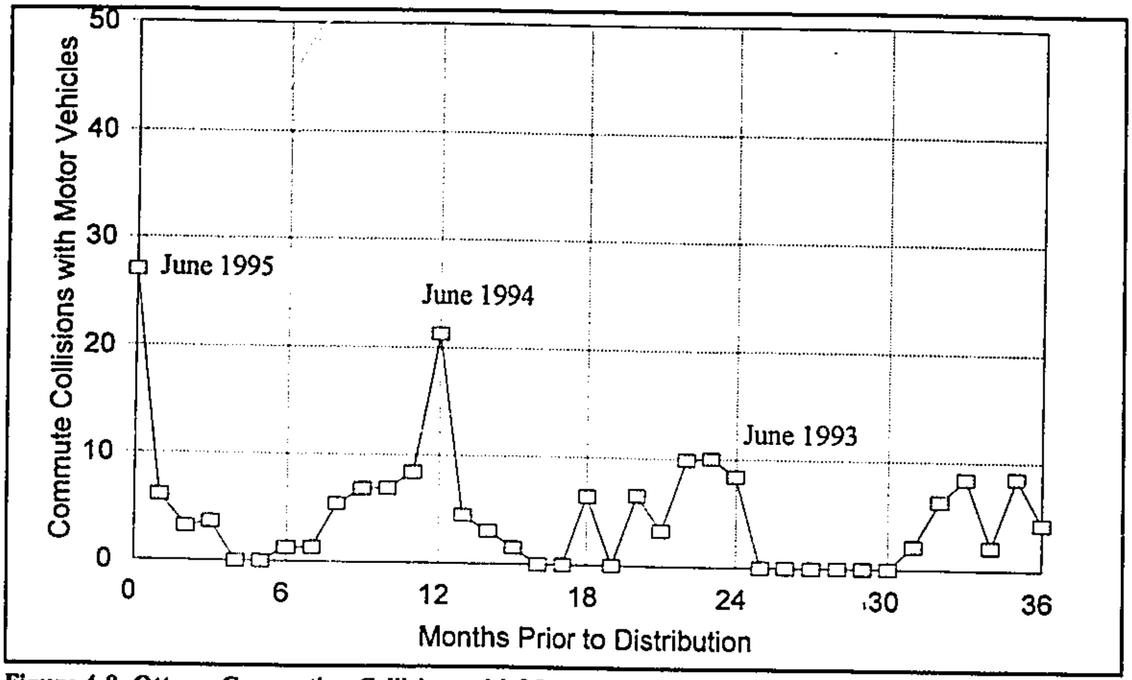


Figure 4-9: Ottawa Commuting Collisions with Motor Vehicles (Adjusted for Time to Current Destination)

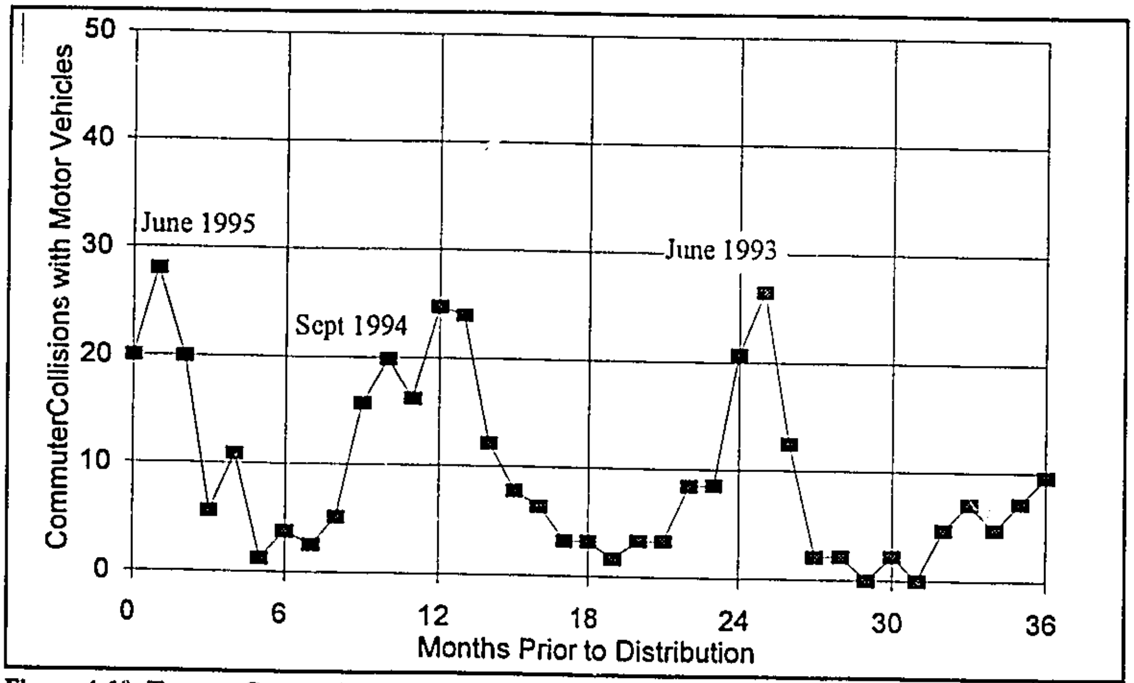


Figure 4-10: Toronto Commuting Collisions with Motor Vehicles (Adjusted for Time to Current Destination)

interval for bicycle collision history collection. A three year time interval was used in order to allow information on enough collisions for useful stratification to be undertaken. Collecting collisions over a shorter time history would require sampling more cyclists which requires more resources.

The pattern of falls reported over time is also of interest. A limited yet similar pattern over time for the number of falls reported can be noted in Figure 4-11 and Figure 4-12. The difference over time in reported events is small but in this case is present for both cities. As the questionnaire only asked people to record falls which had occurred in the previous 12 months, the year of the fall was not included. Therefore all reported falls are assumed to have occurred in the time period requested. Falls reported in the month during which the surveys were conducted are not shown as it was difficult to interpret whether the falls had occurred in 1994 or 1995. The falls reported in the month immediately preceding the survey execution are higher than the summer months of the previous year, especially for Toronto. As with collisions, changes throughout the year may be due to changes in ridership and cycling conditions. Again the higher number of falls reported in the more recent past suggests a possible bias and the resulting fall rates may be underestimated but no adjustments have been made to the dataset. An improvement in survey design that addresses this problem would be to conduct the survey in the autumn of the year when falls for the previous summer were still better remembered. Although travel surveys including bicycle surveys are typically conducted in the fall, the research schedule in this case would not allow for autumn distribution.

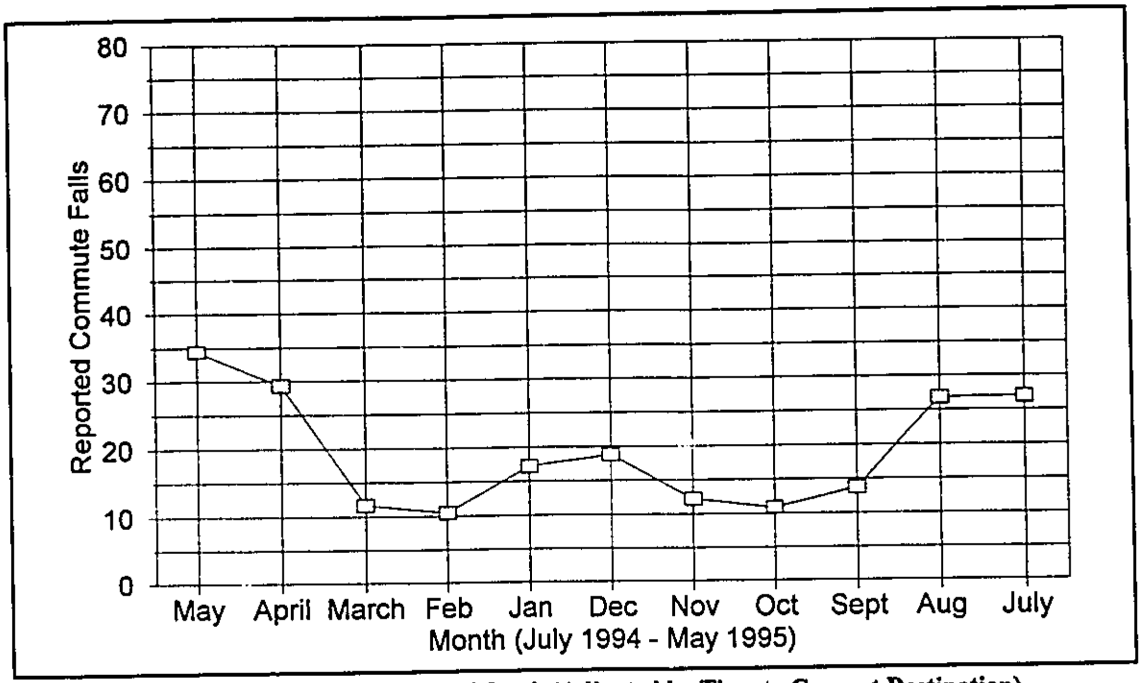


Figure 4-11: Ottawa Commuting Falls by Month (Adjusted by Time to Current Destination)

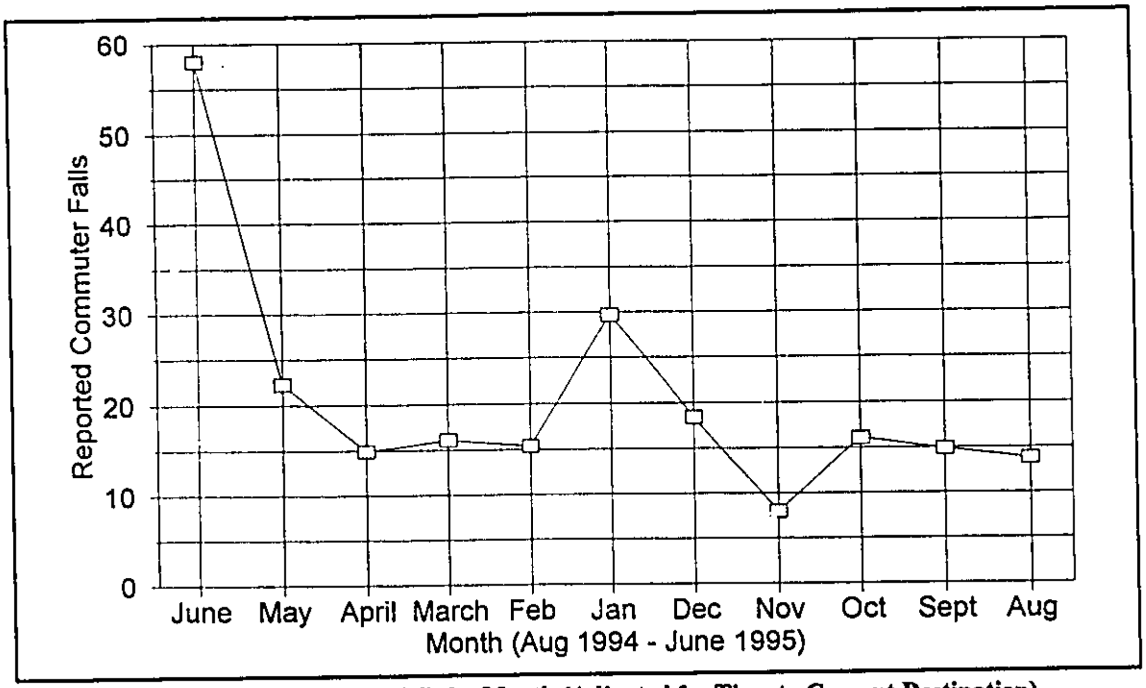


Figure 4-12: Toronto Commuting Falls by Month (Adjusted for Time to Current Destination)

4.8.2 The Accuracy of Exposure Measurement

Earlier in this chapter it was indicated that this survey method for incident rate analysis would provide a more accurate measure of exposure by facility type. While this is true because the traced route will presumably provide an accurate estimate of how much of the bicycle commute is spent on each type of road or path, this survey still relies on the recall and estimate of the participants to measure the frequency of the trip being made. As identified in section 4.4.2 several questions provide exposure estimate information that will be used in combination with the route to estimate exposure. Although it is impossible to completely measure the error in exposure estimates, comparison of the measures from different questions does provide some insight into the accuracy of the survey instrument in this regard.

In the Ottawa questionnaire, question #4 asked the participants to estimate the average number of times their round trip to their current commute destination was made in each week in each month in the past year. There was considerable concern over the wording and units used in this question. Many different versions of the question were pre-tested, but, different people still interpreted the question differently. This confusion contributed to some respondents not responding to the question (8% in Ottawa and 10% in Toronto). Figure 4-13 illustrates the frequency of replies to this question for the months May 1995 and June through September 1994 for Ottawa. The number of trips shown along the x-axis corresponds to the exact values provided by the cyclists who appear to have responded assuming different units and/or time periods. Based on this distribution it is postulated that individuals reported round trips per week (peaking at 5), round trips per month (peaking at 20), one-way trips per week (peaking at 10) and one-way trips per month (peaking at 30 and 40). The high frequency for zero trips is due perhaps to vacation or people only having been at their current destination a limited time. Multiple months are shown to illustrate that the pattern does not vary from month to month for the overall sample. Only these months are considered because it will be during these times that people might reasonably be expected to be cycling to work or school "full-time". Due to the confusion an alternative question wording was used to Toronto to collect round trips per month. Figure 4-14 shows that people still interpreted the question different ways.

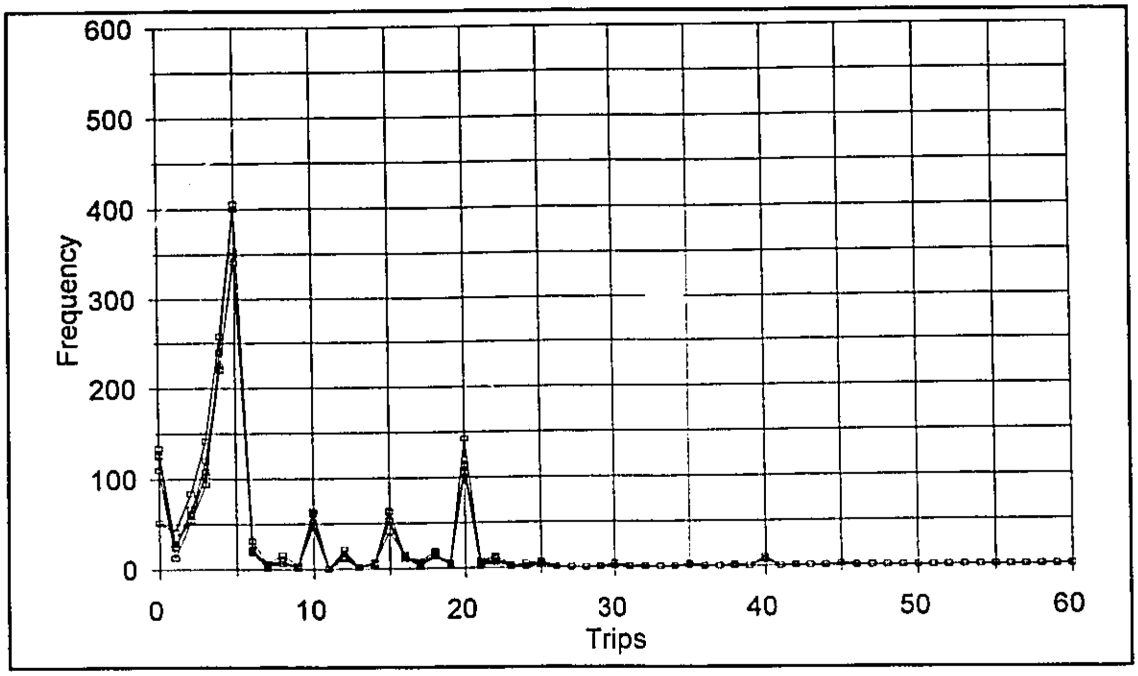


Figure 4-13: Ottawa Bicycle Commutes Reported per Month (May - September)

It was necessary to adjust the estimates provided in question #4 to common units, round trips per month. Due to the very large peak at 20 trips it is assumed that most people made their estimate based on 4 weeks in a month. If a person's response in any one month between May and September was greater than 27 trips, all 12 responses to question # 4 were assumed to be one-way trips per month. They were converted to round trips per month by dividing by two and multiplying by 4.3/4 to account for the actual number of weeks in a month being on average 4.3 not 4. If any one of the responses for May to September was greater than 13 trips but no responses exceeded 27, all responses for that individual were assumed to be round trips per month. They were adjusted by multiplying by 4.3/4. If any one of the responses for May to September was greater than 7 trips but no responses exceeded 13, all responses for that individual were assumed to be one-way trips per week. They were adjusted by multiplying by 2 and 4.3. All remaining individuals were assumed to have responded in weekly round trips and were adjusted by multiplying by 4.3. The survey instrument was weak with respect to this measurement but the correction is deemed sufficient.

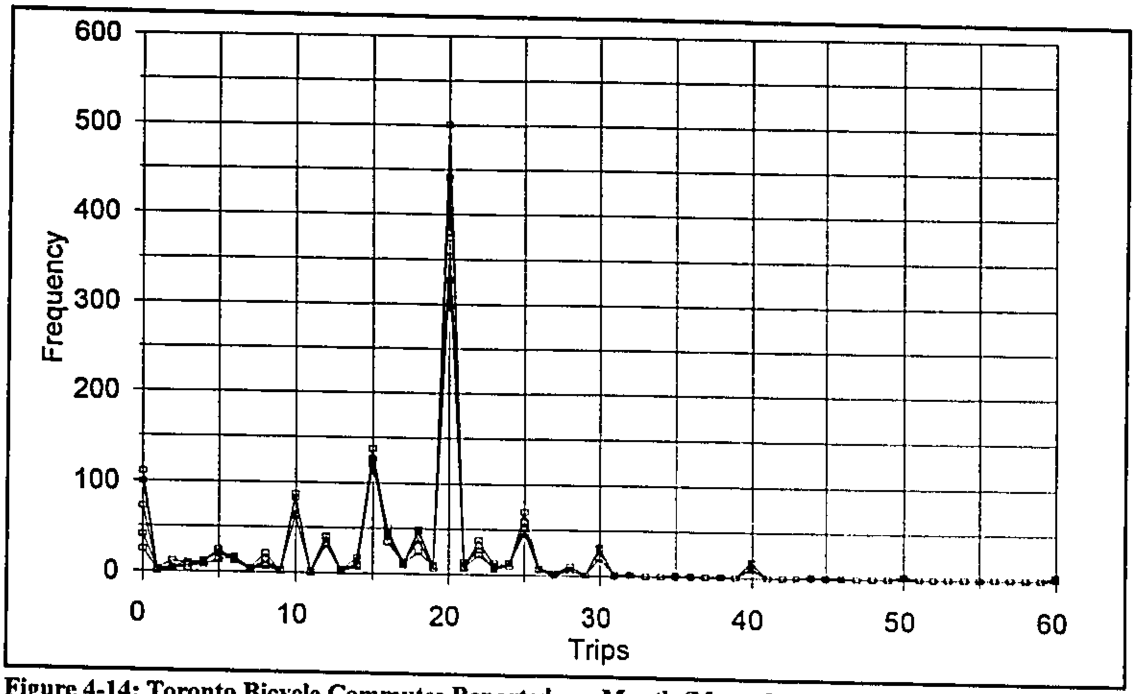


Figure 4-14: Toronto Bicycle Commutes Reported per Month (May - September)

The second accuracy issue that requires consideration is how well people can recall their estimate of trips per month for the previous year. The average round bicycle commutes per month calculated as described in the previous paragraph are shown in Figure 4-15 and 4-16 in the shaded bars. However, as with the incidents, an adjustment must be made for the fact that not all of the sample had been travelling to their current commute destination for the entire 12 month period. When the number of commutes are adjusted by dividing by the proportion of the sample that travelled to their current destination in each of the previous 12 months the estimate of round trips per month is as shown in the white bars of Figure 4-15 and 4-16. These estimates are significantly lower in the winter months as would be expected and the summer of 1994 trips are similar to the summer of 1995 trips. The distribution and

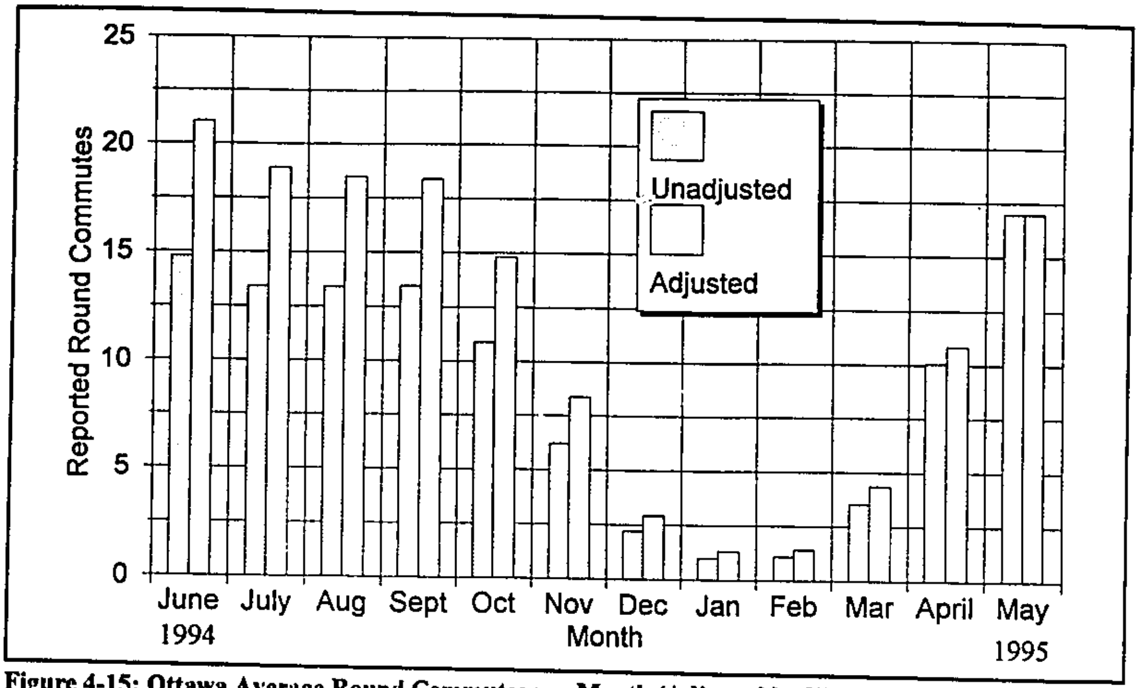


Figure 4-15: Ottawa Average Round Commutes per Month (Adjusted by Time to Current Destination)

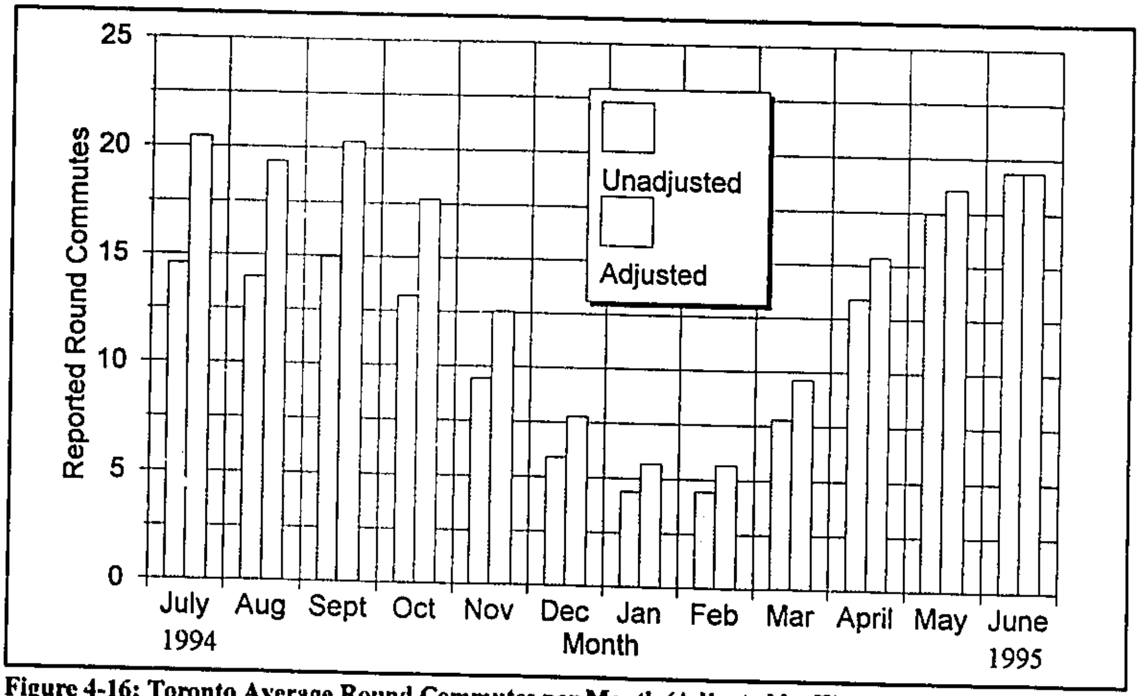


Figure 4-16: Toronto Average Round Commutes per Month (Adjusted by Time to Current Destination)

consistency of the estimate of round trips per month is considered satisfactory.

Question # 3 in the Toronto survey provides an interesting means to consider the accuracy with which people recall their recent commute cycle trips. People were asked to check which of the days of the week prior to questionnaire distribution they had made the bicycle trip to their commute destination. The Monday of the previous week was the Canada Day holiday and many people would not have worked. From the destination information in Table 4-2 it might be reasonable to assume that only some hospital workers, very few business / office type workers and no students commuted on the holiday Monday. Only approximately 27% of surveys were distributed at hospitals. However, as Figure 4-17 illustrates respondents indicate that nearly 80% of the trips made on the Tuesday to Friday were also made on the holiday Monday. Figure 4-17 also illustrates the total trips reported on surveys received within 6 days and within 8 days of the last day of distribution. One might expect individuals that completed the questionnaire immediately to have a better recall of their commutes in the previous week, but they do not show a different pattern. Therefore, based on these results, it is concluded that the instrument could not adequately measure the travel patterns of cyclists in the very near past or on particular days.

The accuracy of responses for cycling trips in the previous week requires some further consideration of the estimates of commutes per month. Responses to both questions show considerable variability as illustrated by Figures 4-13 and 4-14 across different individuals and Figure 4-15 and 4-16 for different times of the year. On average people reported 4.5 trips in Toronto and 4.4 trips in Ottawa in the week prior to survey distribution. The variance within the samples suggests that respondents were accounting for the effect of vacation, weather, business travel and other changes in their routines on their cycling travel patterns. Furthermore, the estimates from question #3 and #4 can be shown to be reasonably consistent. Based on replies to question #3 the average overall number of round commutes in Toronto for July is 19 and in Ottawa for June is 16. Based on question #4 the estimates are 18 and 19 round trips per month. The lower estimate based on the previous week from

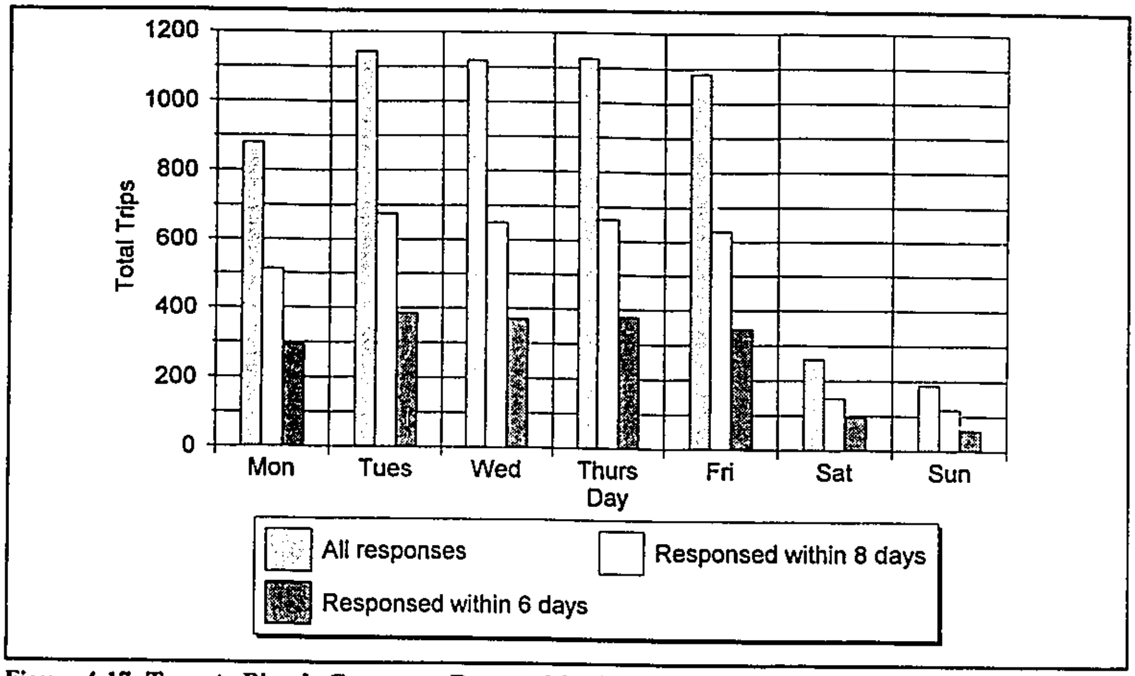


Figure 4-17: Toronto Bicycle Commutes Reported for July 3-9, 1995

Ottawa is consider to be caused by the extreme heat and humidity all five business days for July 12-18 1995 which might have been a disincentive to bicycle commuters. It is not possible to show that people are biasing their estimates either high or low. However on the consistency between responses to questions #3 and #4 and the similarity in corrected trips per month between the summer of 1994 and 1995 the average overall exposure estimates are considered sound.

4.9 Summary

The Ottawa and Toronto bicycle route and safety questionnaire was designed to collect an Ontario urban bicycle safety database that contained information on all bicycle falls and collisions as well as detailed information on exposure by facility. The survey execution targeted adult bicycle commuters by attaching the questionnaires on 6000 parked bicycles. The high response rates of 45.3% and 52.5% as well as reasonable consistency within the incident and exposure estimates provided by the participants support the questionnaire and survey methodology as successful in accomplishing collection of a valid database. Problems with commute exposure by month in both cities and the lack of incident location marking on the maps for Ottawa can be compensated for and will not impede the safety analysis. A discovery that falls and collisions may be slightly underestimated due to lack of recall will not be corrected for.

4.10 References

Andrews, Emily. (1996). *Risk Analysis of Urban Cyclists.* Honours Geography Thesis, McMaster University, March.

Cumming Cockburn Limited. (1992). *The Ottawa Carleton Cyclist Profile Survey.* Ottawa: The Regional Municipality of Ottawa-Carleton and the Regional Cycling Advisory Group, May.

Doherty, Sean T., Lisa Aultman-Hall and Fred L. Hall. (1996). "Commuter Cyclist Accident Patterns in Toronto." submitted for review to *Accident Analysis and Prevention.* June.

Egan, Daniel. (1995). Toronto Cycling Committee, communication regarding unpublished survey results, January 11.

Forester, John. (1994). *Bicycle Transportation - A Handbook for Cycling Transportation Engineers.* Cambridge, Massachusetts: MIT Press.

Greater Vancouver Regional District. (1993). *Greater Vancouver Regional Bicycle Survey Final Report.* Vancouver: Strategic Planning Department, February.

Marshall, Macklin and Monaghan. (1994) *The City of Guelph Transportation Study.* Guelph: City of Guelph Engineering Department.

Morgan, J.M. (1994). *Cycling in Safety.* Crowthorne: Transport and Road Research Laboratory, Traffic Safety Division.

Ontario. (1992). *Revised Bicycle Policy.* Toronto: Ministry of Transportation Ontario, May.

Ottawa Cycling Advisory Committee. (1992). *Commuter Cycling in Ottawa-Carleton: A Survey.* Ottawa: June.

Rodgers, Gregory B. (1995). "Bicycle Deaths and Fatality Risk Patterns". *Accident Analysis and Prevention,* Volume 27, No. 2, pp. 215-223.

Rodgers, Gregory B. (1994). "The Characteristics and Use Patterns of Bicycle Riders in the United States." *Journal of Safety Research,* Volume 25, No. 2, pp. 83-96.

Rodgers, Gregory B., Deborah Kale Tinsworth, Curtis Polen, Suzanne Cassidy, Celestine M. Trainer, Scott R. Heh, and Mary F. Donaldson. (1994). *Bicycle Use and Hazard Patterns in the United States.* Washington D.C.: U.S. Consumer Product Safety Commission, June.

Shipley, Fiona. (1994). *The Southhampton Western Approach Cycle Route Cyclist Flows and Accidents.* Crowthorne, Berkshire: Transport Research Laboratory, Project Report 93.

Wegman, Fred and Atze Dijkstra. (1988). "Safety Effects of Bicycle Facilities: The Dutch Experience", International Road and Traffic Conference, ROADS AND TRAFFIC 2000, Berlin, September 6-9.

Preface to Chapter 5:

This chapter is a slight adaptation of a draft paper[7] intended for submission to a research journal. Dr. Hall's contribution included collaboration in development of the analysis procedure as well as critiques, discussion and revisions of draft versions of the paper.

---

[7] Aultman-Hall, Lisa, and Fred L. Hall. (1996). "Ottawa-Carleton Commuter Cyclist On- and Off-road Incident Rates".

Chapter 5: Ottawa-Carleton Commuter Cyclist On- and Off-road Incident Rates

5.1 Introduction

A measure of the relative safety of on- and off-road bicycle travel is one of the pieces of information required to properly plan for the bicycle as an urban mode of transportation. The debate over the relative merits of provision of special bicycle infrastructure has raged for decades (see the discussion by John Forester and the subsequent author's closure accompanying Lott et al. 1978 as an example of the extremely strong convictions held by people on both sides of the debate). However despite the emotional debate and the common acceptance that bicycling is less safe than automobile travel (several studies estimate the accident rate is approximately ten times higher (Forester 1994)), there is very little actual data on which to base a decision regarding where it is safest to cycle. There are contradictory results among the few existing studies, some finding bicycle infrastructure safer than roads while others find the opposite. In addition to the contradictory results, one problematic factor that fuels the debate is that the only study with accident rates based on estimates of travel exposure on different types of infrastructure suggests that it is less safe to travel on bike paths than on roads (Kaplan 1976). This result is in direct contradiction with the subjective perception of many bicyclists and non-bicyclists who feel cycling away from traffic is safer (Goldsmith 1992 and Badgett et al. 1993). This perception of safety and the associated enjoyment level for some cyclists is an important factor in attracting new cyclists to use the bicycle in place of the automobile. More up-to-date and comprehensive bicycle safety data are needed to sort through such a charged and emotional debate over the relative safety of on- and off-road cycling.

There are two key limitations that hinder bicycle safety analysis: lack of complete incident databases; and lack of travel exposure information. For this study the known limitations of police and emergency room accident databases were overcome through use of a survey that asked cyclists to indicate their accident history. Only 15% of the self-reported collisions had been reported to the police. The need for route-specific exposure data to determine the amount of travel undertaken on different facilities and thus facility-specific incident rates is obvious. Accident counts must be corrected by the amount of travel that occurs in different locations. In this case the study was limited to the bicycle commute to work or school. By focusing on this trip, the exact regular route used could be collected on a map of the area. Analysis of the routes in a Geographic Information System (GIS) provided an estimate of the overall exposure on different types of infrastructure. With this more complete incident database and detailed estimates of exposure, 12 incident rates per kilometre were calculated: collisions, falls, injuries and major injuries; for travel on roads, off-road links and sidewalks. The large database allowed for statistical analysis that revealed statistically different relative event rates on different infrastructure. Several personal variables allowed for sample stratification to investigate the different rates for certain groups.

Before presenting the details of the method and findings, the next section of this paper reviews the existing literature on bicycle safety. The subsequent four sections each have two subsections, one dealing with methodology and procedures, and the second reporting the results. These sections describe the following elements of the study: the data collection and sample composition; the travel exposure; the relative event rates for travel on different infrastructure; and finally a comparison of the event rates for sub-groups of cyclists. The final section of the paper cautions about the limitations in generalizing these results, presents one interpretation for how these results could affect bicycle planning, and points to the further work that is needed.

5.2 Previous Work on Bicycle Safety

There are three categories of previous work that involve analysis of bicycle incidents: accident frequency or count analysis; accident rates per bicycle volume or population; and accident rates per travel distance. Examples of each of the three types are considered in this section. Most work in all three categories has been constrained by some combination of the following limitations: data on only a certain group of cyclists; data from only a specific geographic area; lack of complete incident records; and limited exposure data to allow for comparison between different categories of cyclists or travel. There are two additional aspects of some previous work that limits its appropriateness as input to present day Canadian and American urban areas: much of the work is dated (1970s); or from Europe, where the different urban form and attitude towards bicycling may affect incident rates. The analysis described in this paper moves forward with respect to most of these limitations. However, for practicality the study was limited to one urban area. In order to quantify exposure by infrastructure type, the analysis was limited to only commuter cyclists and incidents occurring during their commuting trip.

5.2.1 Bicycle Accident Frequency or Count Analysis

Among the three types of bicycle studies, the accident frequency analysis is the most common. It involves presenting summary statistics or counts of different categories of accidents. Most depend on use of police and hospital emergency room records. Many discuss the limitations of such data (Thom and Clayton 1993 for example) and some compare the two (Stutts et al. 1990) in hopes of furthering the case for better data collection and determining which types of incidents are being missed. For the most part, for various reasons, this type of data is the only bicycle incident data available. These types of analysis do provide a measure of some of the more serious events and in some cases even provide a valuable relative measure of the occurrences for different groups.

There are two problems with this type of analysis. First, the databases are not complete. Related work in Toronto, Canada (Doherty et al. 1996) has found that only 11% of collisions were reported to police. There are also bicycle falls which presumably were not reported to police at all. Only 7% of all the collisions and falls required medical attention and therefore might be found in an emergency room database. The data from Ottawa used in this study indicate only 15 % of collisions were reported to police and that only 9% of all collisions and falls required medical attention. Both of these statistics are considerably lower than previous estimates of the percent of actual incidents in police records, which range from

50% to 90% (Wessels 1996). Most of those estimates consider only incidents that would be eligible to be included in a police database; that usually requires that an automobile was involved. The need to consider more than just bicycle-automobile incidents in looking at bicycle safety should be obvious.

Even considering the incomplete databases used, accident frequency or count analysis cannot be used to answer whether cycling on- or off-road is safer. Although these studies can determine where more incidents occur, they have no measure of exposure with which to correct the accident tallies; therefore relative rate comparison is not possible. This argument is obvious and is not new. It has been presented by Thom and Clayton (1993) and Howarth (1982) as well. Even given this common knowledge, careful interpretation of accident count or frequency analysis is not always exercised. For example, the conclusion of Liu et al. (1995) that efforts should be made to separate bicycles from automobile traffic is based on the finding that nearly 80% of all bicycle accidents occurred on main roads. But a measure of how much of the total cycling had occurred on these roads is required before this conclusion can be supported.

5.2.2 Bicycle Accident Rates per Trip or Person

The second category of bicycle accident study moves towards correcting the reported incidents by travel exposure and uses bicycle volume counts or estimates of total bicycle trips to correct the accident count information. A selection is summarized here. Although they demonstrate an improvement over accident frequency analysis alone, there is still a need to move towards more comprehensive exposure estimates to provide a better measure of whether it is safer to cycle on- or off-road.

Perreault et al. (1977) used cyclist-reported estimates of the number of trips made per week in a limited survey to extrapolate to trips made across the entire state of Arizona to correspond to the state-wide accident records. This study is based on a limited incident database and unfortunately provides no measure of rates for different infrastructure types.

However the use of trips as exposure allows for a better comparison of event rates for different groups within the population than an analysis based only on accident counts.

Smith and Walsh (1988) undertake a similar procedure by using the city of Madison bicycle volume counts at routine locations to standardize the accidents observed along two roadways for four years before and after the installation of bicycle lanes. The absolute number of users is not known so only relative rates are estimated. They conclude that the bicycle lanes did not increase accident levels. However, the exclusion of two serious accidents that occurred in the first year following installation and the lack of accounting for a possible diversion to or away from the streets due to the installation make their results questionable.

Raub (1996) attempts to find high bicycle accident areas by dividing the number of police-reported bicycle incidents by the population of the census tracts within the Chicago area. His method rests on the premise that bicycle usage is proportional to population which he acknowledges is not true for certain areas such as the central business district. His interactive GIS-based visual presentation is useful but might be better with a different measure of exposure levels. This procedure allows no consideration of specific facilities or locations which may be more important for safety evaluation than rates over an entire census tract.

Wachtel and Lewiston (1994) use police-reported motor vehicle - bicycle intersection incidents along three arterial corridors in Palo Alto, California over a four year period. At the midpoint of the four year window, they took exposure counts that consisted of the relative number of different groups of cyclists travelling with the traffic on the road, with the traffic on the sidewalk, against the traffic on the road and against the traffic on the sidewalk. This method does not allow for a measure of absolute rates per travel distance or per trip but it does allow for defensible relative rate measures between different groups of cyclists riding on the road versus sidewalk. They found the incident rate for adults to be 1.8 times greater than that of children. The relative rates for men versus women did not show a statistically significant difference from 1.0. Those riding against traffic were found to have 3.6 times the risk of those riding with traffic. Finally the risk of riding on the sidewalk was found to be 1.8 times that of riding on the road. Although not completely accepted, there is a consensus that cycling on the sidewalk is more dangerous than cycling on roads. This is supported by guidelines such as those of AASHTO (1981). There is less consensus as to the relative safety of off-road paths or lanes.

Shipley (1994) also corrects before and after bicycle accidents on a single corridor by the bicycle volumes counted during the respective periods. In this British location where a separate bicycle pathway had been constructed, no overall change in the accident rate per cyclist was found. This method of concentrating on a single or limited number of corridors is frequently the factor that allows researchers to make the adjustments to the accident counts necessary to adjust for exposure that might not be possible in large study areas.

Lott and Lott (1976) use an extension of this approach to obtain an accident frequency measure by comparing the relative frequency of different accident types between two cities. One city had extensive bicycle lanes along arterial roadways and one did not. Even though the method does not allow for absolute measures of accident rates per kilometre, it did allow the authors to infer that differences in the proportion of accidents of certain types can be attributed to the existence of the bicycle lanes. They found that for 6 incident classes the bicycle lanes decrease accident rates while for 1 class the rate increased.

5.2.3 Accident Rates per Distance Travelled

In order to measure the relative incident rates on different types of infrastructure outside a limited corridor, as is the intent of this work, it is really necessary to have a measure of the amount of total travel or the proportion of travel that is undertaken on different types of facilities. Five previous studies have used a measure of the travel exposure (ie. distance) in their work. All of these studies are summarized and discussed by Forester (1994).

Chlapecka et al. (1975) surveyed elementary school children and found on average 720 incidents that involved an injury or property damage occurred for every million miles cycled. Schupack and Driessen (1976) found that college associated adults averaged 500 of the same class of incidents every million miles cycled. Watkins (1984) surveyed members of the British Cyclist's Touring Club. These presumably experienced and possibly trained cyclists reported 66 accidents that required medical attention or caused damage to the bicycle for every million miles travelled. The distance estimate of this third study is considered more reliable than that of the previous two because many of the club cyclists had odometers. These three studies did not attempt to compare the risk of cycling on different types of infrastructure. The other two did and are considered below in slightly more detail.

Kaplan (1976) surveyed members of the League of American Wheelmen (LAW) and found an average of 113 collisions or serious falls per million miles travelled. He measured exposure by asking the participants to indicate the total number of miles travelled per year. He further asked that they estimate the percentage of that travel that was on different types of infrastructure (major streets, minor streets, low-traffic streets and off-street paths). The locations of incidents were similarly classified. The results as reported by Forester (1994) are shown in Table 5-1 and indicate that cycling on off-road paths is by far the most dangerous. It might seem that the exposure measure was rather crude, however, many of the participants had odometers and made use of a LAW diary for keeping trip records. Kaplan's study has been the main evidence used since for those that argue for on-road bicycling. There are several reasons to move forward with more study on this issue. First, Kaplan's results are twenty years old. The transportation network, its operation and cyclists have changed over time. Second, the LAW are not representative of the average cyclist in North America. They are highly skilled and presumably shared a preference for certain types of travel patterns and therefore exposure that might not be similar to the general cycling public. Finally, it is desirable to have information on all incidents even minor falls, as they represent a disincentive to cycling and should be of interest to those who seek to encourage more cycling.

Table 5-1 Collision/Major Fall Rates reported by Kaplan (1976)

Infrastructure Type	Collisions or serious falls per million miles
Major Streets	111
Minor Streets	104
Bike-route Low Volume Streets	58
Off-street Paths	292

The Consumer Product Safety Commission (1993) recently studied bicycle safety and exposure patterns and made some progress towards updating the information available for comparing the relative risk of cycling on different types of infrastructure. Their sample is more diverse, using results of a random telephone survey, a random sample of emergency room reports and a survey from *Bicycling* magazine. Although the extensive work provides useful information on many aspects of bicycling in the United States including descriptive information on exposure pattern, its results for relative accident rates on different types of infrastructure are not solidly based. The report presents relative risks of an accident for children and adults on one type of facility compared to another. For example, the relative risk for adults of cycling on a residential road compared to a bike path is 6.83. The estimate of riding exposure relied on people recalling and estimating the amount of time they spend riding on different types of infrastructure and indicating this through use of a four point subjective scale:"always", "more than half of the time", "less than half of the time", or "never". Forester (1994) further points to the problems of using time instead of distance for the particular task of comparing rates on different facilities. It is necessary to move towards a more precise measure to estimate the proportion of travel that occurred on different types of infrastructure.

5.2.4 Summary of How this Study Relates to Previous Work

The analysis reported in this paper seeks to further the existing information on the incident rates for bicycle travel on different facilities in the following ways:

- use of recent data;
- use of travel throughout a large urban study area as opposed to a single corridor;
- use of more complete incident history as reported by the sample of cyclists
- correction of the accident frequency counts with an estimate of the amount of travel on different types of infrastructure; and
- more precise travel exposure estimates by focusing on regular routes used for commuting.

5.3 The Ottawa-Carleton Bicycle Route and Safety Study

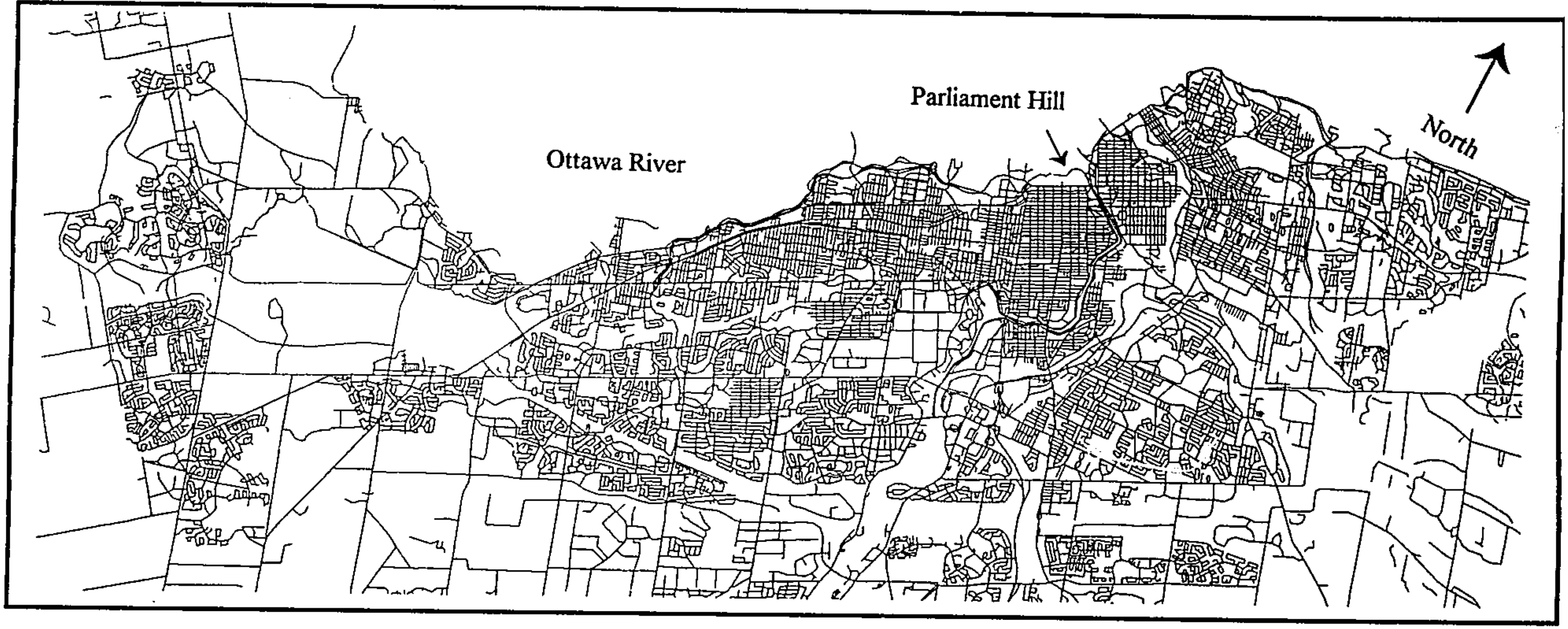
5.3.1 Survey Procedure and Methodology

Between Monday June 19th and Thursday June 22nd 1995, 3053 copies of the Ottawa-Carleton Bicycle Route and Safety Study questionnaire were distributed onto the cross-bars of parked bicycles at employment locations and post-secondary institutions. The questionnaire package consisted of a postage-paid return envelope and a 4-page fold-out questionnaire including a map of the surrounding area. Questions regarding the participants' bicycle travel patterns, their collision and fall history, and some personal characteristics were included. In addition, cyclists were asked to trace their regular route to and from work or school on the map provided. An effort was made to survey both indoor (174) and outdoor parked bicycles. A variety of distribution locations were chosen: hospitals (283), government complexes (922), the central business district (650), universities and colleges (557), public and private corporations (617) and others. Areas such as commercial businesses, tourist attractions, high schools or recreation areas were avoided in order to focus on adult commuter cyclists.

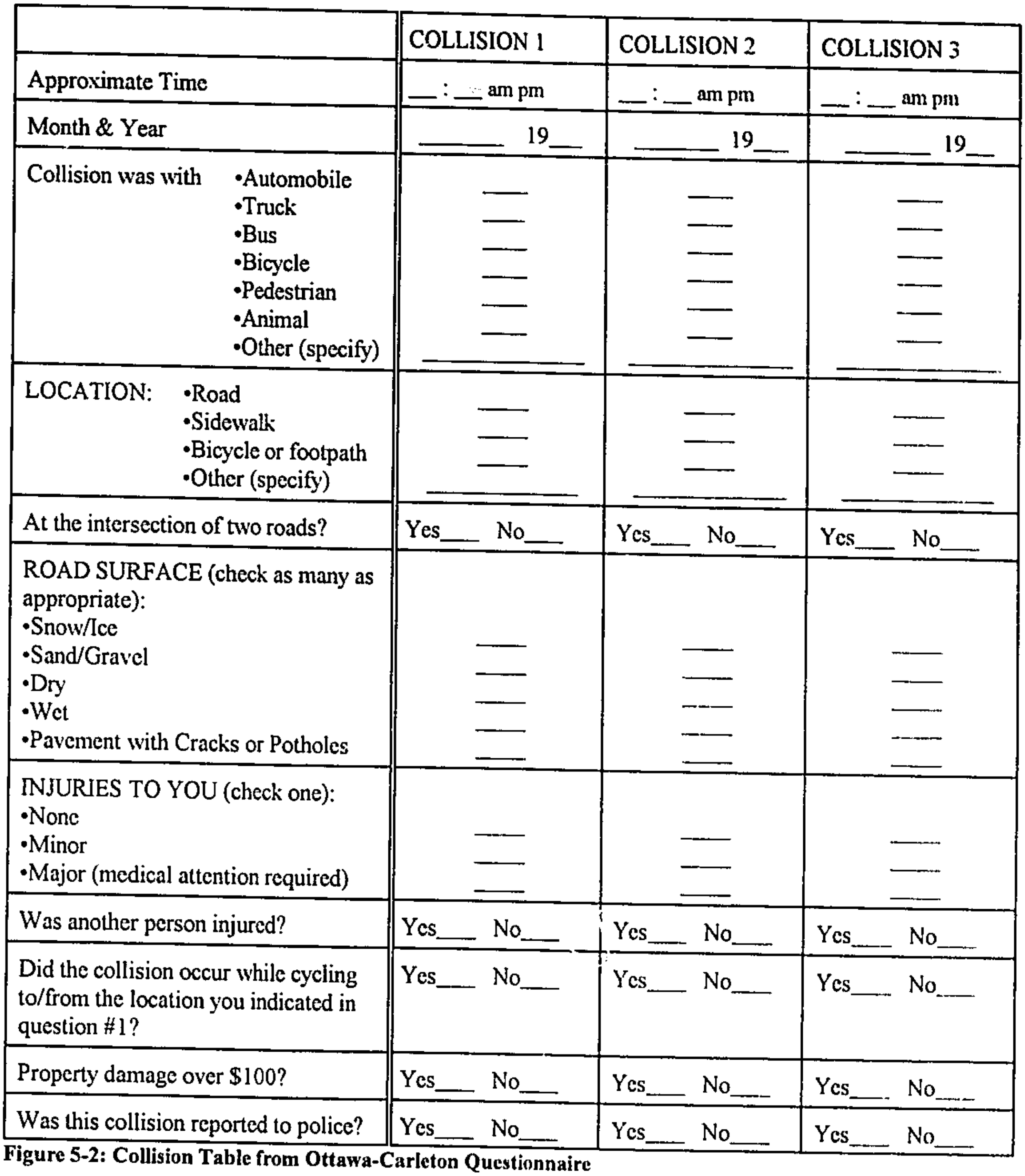
Three different maps were used depending on the distribution site location. Together they covered approximately 350 square kilometres of the Region. The complete study area is shown in Figure 5-1. It consists of most of Ottawa-Carleton's (population approximately 500 000) urban area as well as several greenbelts. Several municipalities as well as the National Capital Commission maintain extensive bicycle/pedestrian path systems through these greenbelts as well as along two rivers and one canal . The study area includes both the older downtown portions of the city with grid-patterned (often narrower) streets and the newer suburban areas with wider and often winding street patterns. In total the study area contains 2007 km of roads and 373 km of off-road paths and trails. One section of arterial road along the edge of the study area away from most distribution sites has bicycle lanes along both sides for approximately 9 km of its length. Approximately 4.5 km of one-way arterial roadway in downtown Ottawa have bike lanes on one side. These sections of road are not separately considered in this study because there is insufficent total length to calculate meaningful rates. The study area is deemed appropriate for evaluating the relative event rates for on- and off-road bicycle travel but not for evaluating the relative safety of bicycle lanes. It should be made explicit that off-road path or trail cycling, as referred to in this paper, is not "trail" or "mountain" biking but rather commuter cycling along urban off-road infrastructure.

Information on collisions experienced by the cyclists over the previous three years was collected using the table shown in Figure 5-2. A collision was defined as "an event in which the bicycle hits or is hit by any other object regardless of fault." The approximate time and date of collisions was used to remove collisions that had occurred prior to the three year window of interest. Collisions with objects such as curbs or potholes were deemed to be falls and were transferred to the fall database described below. All of the"other" locations indicated could be classified as either on-road, sidewalk, or off-road. A parking lot (the location of 4 collisions in total) was classified as on-road. Information on injuries for collisions in the past 12 months was combined with injuries from falls to obtain the total number of injuries and major injuries in the previous 12 months for use in the rate analysis. Note in the table that a major injury was defined as requiring medical attention. Towards the bottom of the table the cyclists were asked if the collision had occurred while cycling to the

Figure 5-1: Ottawa-Carleton Road / Bicycle Network



Approximate Scale: 1 cm = 1.33 km



	COLLISION 1	COLLISION 2	COLLISION 3
Approximate Time	__ : __ am pm	__ : __ am pm	__ : __ am pm
Month & Year	______ 19__	______ 19__	______ 19__
Collision was with •Automobile •Truck •Bus •Bicycle •Pedestrian •Animal •Other (specify)	___ ___ ___ ___ ___ ___ __________	___ ___ ___ ___ ___ ___ __________	___ ___ ___ ___ ___ ___ __________
LOCATION: •Road •Sidewalk •Bicycle or footpath •Other (specify)	___ ___ ___ __________	___ ___ ___ __________	___ ___ ___ __________
At the intersection of two roads?	Yes___ No___	Yes___ No___	Yes___ No___
ROAD SURFACE (check as many as appropriate): •Snow/Ice •Sand/Gravel •Dry •Wet •Pavement with Cracks or Potholes	___ ___ ___ ___ ___	___ ___ ___ ___ ___	___ ___ ___ ___ ___
INJURIES TO YOU (check one): •None •Minor •Major (medical attention required)	___ ___ ___	___ ___ ___	___ ___ ___
Was another person injured?	Yes___ No___	Yes___ No___	Yes___ No___
Did the collision occur while cycling to/from the location you indicated in question #1?	Yes___ No___	Yes___ No___	Yes___ No___
Property damage over $100?	Yes___ No___	Yes___ No___	Yes___ No___
Was this collision reported to police?	Yes___ No___	Yes___ No___	Yes___ No___

Figure 5-2: Collision Table from Ottawa-Carleton Questionnaire

location indicated in question # 1 of the questionnaire. Question # 1 asked the cyclist to identify their commute destination as work, school, transit stop, etc. This question is key in the collision table as it was used to separate the incidents into commuter and non-commuter collisions. Only the commuter collisions are of interest for use with the detailed exposure information obtained through analysis of the regular commuter routes in the GIS.

Information was also collected for falls in the Ottawa-Carleton study. A fall was defined as "an event where without colliding with an object the bicycle or the cyclist lands on the ground." A table similar to that used for collisions was used for falls but information was collected only on the time, month, location, injuries, road surface and whether the fall occurred during the commute. Only falls during the previous 12 months were of interest as it was felt that falls were not as serious as collisions and would not be recalled for as long into the past. It was not possible to reclassify the fall location indicated as a building entrance, but all other "other" locations were classified into the above categories including 10 parking lot falls as on-road.

One limitation of the study methodology was its exclusion of fatalities and injuries that were so serious that the person could not or would not cycle again. These individuals would not have had their bicycles parked at any location in June 1995 for survey distribution. Although cycling fatalities occur all too frequently, in a statistical sense they are rare events. During the year preceding the survey distribution in Ottawa-Carleton there were two cyclist deaths. Both were on-road and both cyclists were struck by cars. Neither was commuting at the time of the event. There is no means to assess the degree to which incidents that preclude or discourage future cycling impacted our results. However, this factor may lead to lower rates than might overwise have been found.

In addition to the fall and collision tables, two other types of questions in the questionnaire were used for this analysis: exposure estimation questions; and personal characteristic questions. The exposure questions are shown in Figure 5-3. These questions are used with the route information to estimate the total amount of exposure or travel on different types of infrastructure in the previous 12 months (and three years) to correspond to the time periods over which fall (and collision) information was collected.

How long have you been travelling by bicycle between your current home location and your current place of work or education?

Considering that vacation, holidays, weather and other changes to your routines may affect how often you can bicycle, please estimate the average number of times you made THIS trip by bicycle per week in each month in the last year (June 1994 - May 1995).

Figure 5-3: Exposure Questions

The personal and cycling characteristics questions are shown in Figure 5-4. The information from these questions is used in the rate analysis to stratify the sample for two purposes. First, it is possible that different groups of cyclists do not use on- and off-road routes in the same proportion. If so, a difference in the overall event rates for these groups might confound differences for different facilities. Second, it is desirable, to whatever extent possible, to sub-divide the sample and compare the event rates on different infrastructure for different groups of cyclists. This allows further understanding as to which groups of cyclists countermeasures should be targeted at.

The first two questions shown in Figure 5-4 are intended to be an indication of how cyclists interact with automobile traffic. Unfortunately, the question regarding busy street travel was poorly worded. It would have been more appropriate for the question to read "Do you cycle on busy streets only ...". Cyclists who answered "yes" to this question were found to have different proportions of travel on different infrastructure than those who answered "no". For this reason, even despite the potential that this variable was not measuring the intended cyclist characteristic due to wording, it was included in the analysis due to the possibility of confounding the infrastructure results.

Do you cycle only on busy streets when it is unavoidable?

At busy signalized intersections do you make left turns from the left most lane?

Do you belong to a cycling club?

Have you taken a bicycle training course?

Estimate the average number of kilometres you bicycle **per week**, during your peak cycling season, for all purposes including recreation.

For how long have you been commuting by bicycle from any home location to any work or school location?

Year of Birth

Sex

Figure 5-4: Personal and Cycling Characteristics Questions

It has been suggested previously (Forester 1994) that club cyclists have lower incident rates than the general cycling population. This assertion was the motivation for inclusion of the third question in Figure 5-4. An indication of whether a person has taken a training course is included because organizers of such courses presumably expect that the skills gained will improve safety. The club and training course questions are lumped together for the final analysis because too few participants answered "yes" to the individual questions. This grouping seemed reasonable because both variables indicate that the cyclist participates in organized cycling activities. The fifth and sixth questions in Figure 5-4 are intended as measures (albeit imperfect measures) of experience. Year of birth and sex were collected as previous studies of bicycle safety have found different incident rates for groups subdivided by these categories.

5.3.2 Survey Results

A total of 1604 questionnaires (52.5%) were received back from the Ottawa-Carleton survey. Of these, only 1452 cyclists could be included in the rate analysis. They provided both their commuter route on the map provided and answered the two exposure questions. These cyclists indicated a total of 359 collisions of which 194 occurred during their commute. A total of 375 falls were reported of which 234 occurred during the commute. These totals for events were arrived at after re-labelling limited collisions as falls (as indicated above), eliminating events outside the three year time period and deleting the fall events for incidents recorded by the cyclist as both a fall and a collision (4 cases). A total of 187 injuries to the cyclists were reported to have occurred during incidents while commuting. A total of 60 (32%) of these injuries were due to collisions. A total of 27 injuries (14%) were major injuries. Only 14 (54%) of the major injuries were incurred due to collisions. The sample size does not allow for the rate analysis to be stratified by the object the collision was with. However, for interest when interpreting the event rate results, the numbers of commuter collisions that were with different objects is provided in Table 5-2.

Table 5-2: Objects Collided With

Object Type	Number of Commuter Collisions Reported
Automobile (including vans, minivans and taxis)	115
Truck	4
Bus	3
Bicycle	31
Pedestrian	20
Animal	11
Other (includes posts, fences, poles etc)	15

The age distribution for the men and women who replied is shown in Table 5-3. The four individuals under 18 were eliminated from the sample due to a focus on adult commuter cyclists. Only 7 individuals in the commuter analysis did not provide their age and sex. The correlation calculated between age and sex was the only personal variable correlation greater than 0.5 (0.54) and reflects the pattern evident from Table 5-3 that the sample contains more older men than women. The fewer women in the sample is thought to be attributable to fewer women commuter cyclists due to the attire worn at work but also the choice of some workplace locations such as computer/electronic research and development companies where typically more men are employed. The possibility of a gender response bias has been discounted based on a sub-sample study from the same survey conducted in Toronto (Chapter 4).

Table 5-3: Sample Age and Sex Distribution

Age Group	Number of Women	Percent of Women	Number of Men	Percent of Men
< 18	3	0.8	1	0.1
18 - 24	66	17.6	104	9.7
25 - 29	64	17.1	140	13.1
30 - 39	125	33.3	397	37.1
40 - 49	74	19.7	281	26.3
50 -59	38	10.1	126	11.8
60 -69	5	1.3	17	1.6
> 70	0	0	4	0.4
Total	375	100	1070	100

The correlations between each pair of the additional personal/cycling variables (those derived from the questions in Figure 5-4) as well as each with sex and age were all less than 0.5 and most less than 0.1. This was interpreted as indicating that the personal variables each measure a unique characteristic of the sample.

It is also noteworthy that the proportion of cyclists answering each of these questions was high, resulting in loss of very little information when the sample was stratified to obtained different rates. Of the 1399 cyclists who answered the question regarding left turns, 1009 indicated they make the left turn from the left most lane. Of the 1429 individuals who answered the question regarding cycling on busy streets, 1017 answered yes (see figure 5-4). Only 86 individuals are members of a cycling club (3 non-responses); 112 cyclists had taken a bicycle training course (4 non-responses). Only 33 cyclists answered yes to both the club and course questions. A good range of both total kilometres travelled per week and years of commuting by bicycle was observed as shown in Tables 5-4 and 5-5.

Table 5-4: Total Travel per Week in Peak Cycling Season

Total Kilometres per Week in Peak Season	Number Observed	Percent
< 40	312	21.5
40 - 79	396	27.3
80 - 119	296	20.4
> 120	383	23.4
No response	65	4.5

Table 5-5: Years Commuting to Work or School

Years Commuting to Work or School	Number Observed	Percent
< 3	412	28.4
3 - 6	297	20.5
6 - 9	343	23.6
> 9	385	26.5
No response	15	

5.4 Commuter Exposure On-Road, Off-road and On Sidewalks

5.4.1 Travel Exposure Estimation Procedure

The network of roads and off-road paths and trails for the study area was represented as a system of links and nodes in a ArcInfo GIS coverage. The routes traced on the maps by the cyclists were digitized into ArcInfo. By relating each individual's route to the coverage's attribute tables the exact length of travel on each type of infrastructure link in the regular commute was obtained. The cyclists were asked to circle any portions of his/her route where they travelled on the sidewalk. These sections were identified in the GIS route systems and do not count as travel along the road but rather as travel on a sidewalk. Many cyclists indicated a different route to and from work or school. These cases presented no problem because the amount of travel was determined for the round trip. Many cyclists indicated more than one regular route to and/or from work/school. In this case, the distance travelled along each type of infrastructure was weighted equally for the trips to and from the destination and a mean distance was found for that individual. Some cyclists (26 % of those providing routes and answering the exposure questions) had home locations outside the area provided on their map. Given this lack of information, the assumption was made that the individual's route off the map is in the same proportion on-road, off-road and on sidewalks as that on the map. For these individuals, their travel on the different types of infrastructure was multiplied by the ratio of their estimate of their total oneway trip length to their total oneway distance on the map (average ratio of 2.8 for those requiring adjustment).

An estimate of the total travel or exposure to events was required for two time periods: the previous 12 months (for fall, injury and major injury events) referred to subsequently as the "fall exposure"; and the previous three years (for collision events) referred to subsequently as the "collision exposure". Regardless of the time periods used in the question regarding commutes per month (in several pre-test versions and a second survey execution in Toronto) participants responded to the question in round trips per week (peaking at 5), round trips per month (peaking at 20), one-way trips per week (peaking at 10) and one-way trips per month (peaking at 30 and 40). An adjustment (described in Chapter 4) was necessary to convert all replies to round trips per month.

For cyclists who had been travelling between their current home and work/school location for greater than or equal to 12 months, the fall exposure on each type of infrastructure was equal to the average distance travelled on each infrastructure type in the round trip multiplied by the number of trips made over the year. If the individual had been travelling between their current home and work location for less than one year (31%) the fall exposure was equal to the average distance times only the number of trips made in the appropriate months during the last year. The collision exposure was calculated in a similar fashion assuming that travel in each month of the year for the previous 2 years followed the same pattern on average as the average trips indicated for the previous 12 months. Adjustment was made if the individual had been making their commute for less than 3 years (59%). Note that individuals who had been making this trip for less than 12 months (or three years) were not necessarily new to bicycle commuting but may have changed work or home locations.

The total amount of exposure in the sample for different groups such as men and women is different. It is not possible, given the lack of knowledge of the population of all Ottawa commuter cyclists, to determine if the sample exposure is representative of all the bicycle commuter travel undertaken in the region in the last 12 months or 3 years. However, for the purposes of the relative rate analysis it is important to determine if different groups of cyclists undertook different proportions of their travel on the three types of infrastructure. This is required in order to evaluate if efforts are necessary to control for the possible confounding effects of certain personal characteristics with the relative rates on different infrastructure. For dummy variables (sex, left turns from left most lane, cycling club / course, the busy streets variable) t-tests for differences in the mean proportion on each type of facility were used to test for differences. For categorical variables with more than 2 levels (age, years commuting, peak km per week) one-way ANOVA tests were used to test for differences between means.

5.4.2 Travel Exposure Results

The average length of the one-way commute by bicycle in the Ottawa-Carleton sample was 8.4 km. The commutes were undertaken on average 72% on-road, 23% off-road and 4% on sidewalks. A total of 32% of the sample reported some (averaging 1.1 km) commuter travel on a sidewalk. In aggregate over the previous 12 months the sample reported a total of 2,461,187 km of commuter exposure: 1,770,254 km on-road; 590,227 km on off-road paths or trails; and 100,760 km on sidewalks. Over the previous three years the sample travelled a total of 5,953,652 km: 4,304,976 km on-road; 1,418,230 km on off-road paths or trails; and

230,551 km on sidewalks. Slight differences between the sum of the travel on the three types of infrastructure and the total travel are due to rounding error; one-way trip distances were output from the GIS in kilometres to two decimal places.

Results of the investigation of possible confounding patterns affecting the proportion of exposure on different infrastructure are reported here for the exposure during the previous 12 months. The analysis of exposure over the previous 3 years resulted in the same statistically significant differences. Tables 5-6 through 5-9 show the t-test results for the binary variables. The total travel exposures for the two categories of all four variables are statistically different. However, this difference is not necessarily critical for comparing the relative event rates on different infrastructure. It is simply a characteristic of the sample; some groups travel more than others. However, any differences in the proportion of travel on different infrastructure for certain groups are critical. If these groups have different event rates (ie. they have overall more or less events per kilometre relative to other groups), this will result in incorrect estimates of the relative risk of travel on the different types of infrastructure. To deal with this possibility, the exposure and event counts for the different infrastructure will be weighted so that the same proportion of these groups is contained in the sample for each. For the groups in Tables 5-6 through 5-9, all but those differentiated based on sex have significantly different proportions of travel on different infrastructure.

Table 5-6: Travel Exposure for Men and Women

Exposure Type	Men (N = 1070)	Women (N = 375)	p (from t-test)
Total Exposure previous 12 months (km)	1857	1226	0.0000
Proportion of Exposure on-road	0.734	0.724	0.53
Proportion of Exposure off-road	0.220	0.219	0.92
Proportion of Exposure on Sidewalk	0.046	0.058	0.13

Table 5-7: Travel Exposure for Those who Do and Don't use the Left Lane to Make Left Turns

Exposure Type	Do Use Left Lane (N = 1009)	Do Not Use Left Lane (N = 390)	p (from t-test)
Total Exposure previous 12 months (km)	1785	1413	0.0000
Proportion of Exposure on-road	0.753	0.680	0.0000
Proportion of Exposure off-road	0.208	0.245	0.013
Proportion of Exposure on Sidewalk	0.039	0.075	0.0000

Table 5-8: Travel Exposure for the Busy Streets Question

Exposure Type	Do you cycle only on busy streets when it is unavoidable?		p (from t-test)
	Yes (N = 1017)	No (N = 412)	
Total Exposure previous 12 months (km)	1606	1864	0.003
Proportion of Exposure on-road	0.700	0.808	0.0000
Proportion of Exposure off-road	0.247	0.151	0.0000
Proportion of Exposure on Sidewalk	0.041	0.053	0.13

Table 5-9: Travel Exposure for Those who Do and Do Not Belong to a Cycling Club or Have Taken a Training Course

Exposure Type	Cycling Club or Training Course (N = 164)	Do Not Belong to Club and have Not taken a Course (N = 1284)	p (from t-test)
Total Exposure previous 12 months (km)	2135	1632	0.0012
Proportion of Exposure on-road	0.764	0.727	0.097
Proportion of Exposure off-road	0.205	0.221	0.4
Proportion of Exposure on Sidewalk	0.031	0.051	0.011

Tables 5-10 through 5-12 illustrate the ANOVA results for the multi-category variables of age, years commuting and peak-season weekly total travel. Categories were chosen based on the distribution of the variables within the sample. Approximately equal sub-sample size was desired while providing meaningful divisions between groups. No statistical difference was found for different age group categories in the overall proportion of travel on different

Table 5-10 Travel Exposure for Different Age Groups

Exposure Type	Age Category			ANOVA p statistic
	18 - 29 (N = 376)	30 - 39 (N = 523)	> 40 (N = 546)	
Total Exposure previous 12 months (km)	1126	1851	1922	0.000
Proportion of Exposure on-road	0.7257	0.7408	0.7280	0.643
Proportion of Exposure off-road	0.2219	0.2079	0.2288	0.387
Proportion of Exposure on Sidewalk	0.0527	0.0513	0.0431	0.416

Table 5-11 Travel Exposure for Different Categories of Kilometres Cycled per Week in the Peak Season for all Purposes

Exposure Type	Weekly Kilometre Category				ANOVA p statistic
	0 - 40 (N = 312)	40 - 80 (N = 396)	80 - 120 (N = 296)	> 120 (N = 383)	
Total Exposure previous 12 months (km)	697	1269	1758	2976	0.0000
Proportion of Exposure on-road	0.77	0.72	0.70	0.73	0.025
Proportion of Exposure off-road	0.17	0.21	0.26	0.23	0.000
Proportion of Exposure on Sidewalk	0.06	0.06	0.04	0.04	0.004

Table 5-12 Travel Exposure for Different Categories of Years Commuting by Bicycle

Exposure Type	Years Commuting by Bicycle				ANOVA p statistic
	0 - 3 (N = 412)	3 - 6 (N = 297)	6 - 12 (N = 343)	> 12 (N = 386)	
Total Exposure previous 12 months (km)	1210	2137	1766	1793	0.0000
Proportion of Exposure on-road	0.70	0.74	0.75	0.74	0.07
Proportion of Exposure off-road	0.23	0.21	0.20	0.23	0.668
Proportion of Exposure on Sidewalk	0.07	0.05	0.04	0.04	0.001

infrastructure. The weekly distance variable resulted in statistically different proportions on different types of infrastructure. The years commuting variable resulted in a significant difference only for the proportion of travel on the sidewalk.

Both weekly kilometres and years commuting have 4 sub-categories which make them difficult to include in the weighting procedure. Exclusion of these variables in the weighting procedure would simplify the analysis. For this reason, the event rates stratified by these two variables were further investigated for possible differences in event rates on different infrastructure to determine if weighting was necessary. In this case the categories were aggregated into two groups (example: < 6 years and > 6 years) to maintain simplicity in this preliminary investigation of event rates on different infrastructure. No significant differences were found for any of the collision, fall, injury and major injury rates on the three different types of infrastructure for the different number of years commuting (the hypothesis testing procedure is described in section 5.6). Therefore, the final relative rates for different infrastructure are weighted for weekly kilometres travelled but not years commuting.

5.5 On-road, Off-road and Sidewalk Event Rates

5.5.1 Event Rate Analysis Procedure

The event rate analysis procedure consisted of four stages: event rate calculation; calculation of rates adjusted for confounding personal variables; statistical tests for differences in event rates; and development of confidence intervals for relative rates.

There are four types of events of interest in this study: collisions, falls, injuries and major injuries (this final category is a subset of the previous one). Due to the rare nature of all events, only consideration of aggregate event rates is meaningful. Rates for individuals are not useful. This has implications not just for how event rates are calculated but also for the statistical tests described below. The exposure to an event is considered the total distance of travel undertaken in the given sample or sub-sample during the time period that the event counts were collected (3 years for collisions and 12 months for the other events). The event rate in events per kilometre can be calculated using equation 5-1. The mean return time or average kilometres per event is the reciprocal of the event rate.

$$R_{in} = \frac{N_{in}}{d_n} \qquad [5\text{-}1]$$

where : R_{in} = incident rate in incidents per cycle-kilometre
i = incident category (collision, fall, injury or major injury)
n = network category (road, path/trail, or sidewalk)
d_n = total cycle-kilometres travelled on network type n
N_{in} = number of incidents of type i on network type n

In order to investigate differences in observed event rates that are inherent to travel on particular infrastructure, it is necessary to weight the exposure and events observed. This adjustment ensures that each set of exposure and event counts contains the same proportion of different categories of cyclists that were determined to have confounding exposure patterns in the previous section. Four confounding variables were found: left turn lane at busy intersections (2 levels), belonging to a club or having taken a course (2 levels), busy streets (2 levels); and total bicycle kilometres for all trip purposes per week (4 levels). Combined, these variable categories form 32 sub-groups of cyclists. In some survey research it is common for the sub-groups to be weighted for the final analysis relative to their known proportion in the population of interest. However, in this case the distribution of these 32 categories in the full population of cyclists is unknown. It is not reasonable to weight the groups equally. Therefore the group proportions for the infrastructure-specific event rate calculations are set equal to each group's proportion of the total exposure in either the 12 month or three year period. The cyclists (121 in total) who had missing values for one or more of the classification variables were lumped together as a 33rd category. It was felt that this lumping of individuals with some unknown characteristics was preferable to excluding them from the analysis.

An example can be used to illustrate how the weighting proceeded. Consider the group of people who do not belong to a club or have not taken a course, cycle less than 40 km per week in their peak cycling season, answered "yes" to the busy streets question and do not make left turns from the left-most lane. In the previous 12 months, they travelled 3231 total commute kilometres on sidewalks, 3.4% of the total sidewalk travel. Total travel for this group was 45 663 km which is 2.0% of the total 2 241 187 km of travel in the previous 12 months. Therefore, the sidewalk exposure for this sub-group is relatively over-represented and their event rate on sidewalks could distort the overall event rate if not corrected. The 12-month sidewalk exposure and event count (eg. 2 falls) for this group is corrected by dividing by the ratio of the group's share of sidewalk travel to their share of the total travel. In this case, 3.4% divided by 2.0% yields 1.7. The weighted exposure and event counts are 1 909 km and 1.18 falls. The corrected values are summed over all sub-groups to obtain input for the weighted aggregate event rate calculation. Results in the next section are presented for both the weighted and non-weighted case.

Two statistical tests are used to evaluate the difference between event rates for different groups or travel. The first is that described by Hauer (1996). The paper's companion software, HYPTEST, available on the internet from the University of Toronto, was used to conduct the tests. The software tests the null hypothesis that the means of Poisson distributed event counts are equal, against the alternative hypothesis that one is less than the other. The test is based upon determining the conditional probability that one count (say X the total events on the road) is equal to a certain value given that the two counts (say X and Y, where Y is total events off-road) sum to the particular value observed. Given that the two counts are assumed to be independent Poisson random variables, the conditional probabilities are binomial and can be calculated. The software systematically considers different values of the first count, given the sum of the two counts, to determine at what value of the first count the probability of the null hypothesis being true is less than the specified nominal level of significance. If the actual count of X is less than or equal to this value the null hypothesis is rejected. In this case, the alternative hypothesis is taken as: $X < kY$. The constant k is the ratio of the exposure for the group with count X to the exposure of the group with count Y. The value of k would be equal to the exposure on-road divided by the exposure off-road.

It is often convenient in analysis of relative rates to develop confidence intervals. Use of Cox's F-test (Lee 1992) would also be an appropriate, although less powerful, test of statistically significant differences between the mean return times (distances) for different sub-groups in this analysis. Based on this test, the $100(1-\alpha)$ confidence interval of the ratio of two exponential event rates can be given as Equation 5-2. This formulation is used to develop the 95% confidence intervals for the relative rates for travel on the different types of infrastructure.

$$\frac{t_2}{t_1} F_{2r_1,2r_2,1-\frac{\alpha}{2}} < \frac{\lambda_1}{\lambda_2} < \frac{t_2}{t_1} F_{2r_1,2r_2,\frac{\alpha}{2}} \qquad [5\text{-}2]$$

where:

t_x = the mean return time (distance) for events in group x

λ_x = the event rate for group x

r_x = number of events in group x

F = ordinate of the F distribution

5.5.2 Event Rate Results

Tables 5-13 and 5-14 provide the unweighted and weighted total exposure, event counts, event rates and distance per event for each of the 16 event type / infrastructure type combinations. Both unweighted and weighted results are presented in order to assess the effect of the weighting procedure. Only the mean event rate for falls on sidewalks changes considerably but the correction procedure is still deemed necessary to improve the accuracy of the relative rate results presented below. Note that an event rate for major injuries on sidewalks cannot be estimated as no such events were observed. The exposure on different

Table 5-13: Unweighted Event Rates

Event Type	Total Exposure (x 10^5 km)	Total Events Observed	Mean Event Rate (event / 10^5 km)	Distance per Even (km)
Collision - All	59.5	194	3.26	30690
Collision - Road	43.0	139	3.23	30970
Collision - Off-road	14.2	43	3.03	32980
Collision - Sidewalk	2.3	7	3.04	32940
Fall - All	24.6	234	9.51	10520
Fall - Road	17.7	129	7.29	13720
Fall - Off-road	5.9	80	13.6	7380
Fall - Sidewalk	1.0	21	20.8	4800
Injury - All	24.6	187	7.60	13160
Injury - Road	17.7	110	6.21	16090
Injury - Off-road	5.9	56	9.49	10540
Injury - Sidewalk	1.0	18	17.9	5600
Major Injury - All	24.6	27	1.10	91160
Major Injury - Road	17.7	19	1.07	93170
Major Injury - Off-road	5.9	8	1.36	73780
Major Injury - Sidewalk	1.0	0	NA	NA

Table 5-14: Weighted Event Rates

Event Type	Total Exposure (x 10^5 km)	Total Events Observed	Mean Event Rate (event / 10^5 km)	Distance per Even (km)
Collision - All	59.5	194	3.26	30690
Collision - Road	43.0	138.5	3.22	31080
Collision - Off-road	14.1	44.2	3.12	32090
Collision - Sidewalk	2.3	6.6	2.86	34930
Fall - All	24.6	234	9.51	10520
Fall - Road	17.7	127.9	7.22	13840
Fall - Off-road	5.9	89.1	15.1	6620
Fall - Sidewalk	1.0	29.1	28.9	3460
Injury - All	24.6	187	7.60	13160
Injury - Road	17.7	110.2	6.23	16050
Injury - Off-road	5.9	58.8	9.96	10040
Injury - Sidewalk	1.0	25.0	24.8	4030
Major Injury - All	24.6	27	1.10	91160
Major Injury - Road	17.7	18.9	1.07	93660
Major Injury - Off-road	5.9	10.3	1.75	57300
Major Injury - Sidewalk	1.0	0	NA	NA

infrastructure does not add exactly to the total in each category due to rounding error (one-way trip distances for each facility type, as well as for the total, were known in kilometres to two decimal places).

The first row of each subsection of Table 5-12 indicates the total number of each type of event observed for all travel on all types of infrastructure. These numbers are quite high: 194 collisions (average 0.13 per cyclist) in the previous 3 years and 234 falls (0.16 per cyclist) in the previous 12 months. From inspection of the total number of each event, falls are the most common event experienced. They also have the highest event rate (9.51 falls per 100 000 kilometres). The importance of considering events per distance rather than event counts is evident from these tables. If one considers the various event counts on different types of infrastructure, it might seem that roads are the problem for falls, injuries and collisions. However, inspection of the rate data indicates that falls and injuries on sidewalks and off-road paths/trails are the more frequent events per kilometre travelled. Thus diverting cyclists from the road to sidewalks and paths/trails as might be suggested based on count analysis could be expected to increase overall event rates based on this analysis that accounted for travel exposure.

The magnitudes of the overall event rates in Tables 5-13 should be considered with respect to similar event rates for automobile travel. The Ontario Ministry of Transportation (MTO) (1992) reports 3.1 accidents per 1 000 000 km travelled. These accidents include single and multiple vehicle accidents and therefore could arguably be compared to the sum of bicycle collisions and falls which for the sample of commuters has a total event rate of 127.7 events per million kilometres (a rate 41 times that for automobiles). Even if compared only to bicycle collisions, the collision rate of 32.6 per million kilometres is still 10.5 times that reported for automobiles. The difference in injury rates is similar. This study found the injury rate per million kilometres to be 76.0 for commuter cyclists. MTO reports the rate of accidents causing personal injury (to any person, not necessarily the driver or other persons in the vehicle) to be 8.1 per million kilometres, only 10.6% the cyclist injury rate.

Exact comparisons of the rate estimates from this study to those previously made by others is not possible due to differences in incident definitions and the samples used. However, the magnitude of the rate estimates from this Ottawa commuter study are similar to those found by Kaplan (1976) and Watkins (1984). Both of those studies involved club cyclists. The estimates from Chlapecka et al. (1975) and Schupack and Driessen (1976) were much higher perhaps due to their focus on children and college students.

Table 5-15 indicates the weighted relative event rates for bicycle travel on different types of infrastructure as well as both the result of the Hauer statistical tests and the confidence intervals developed based on Cox's F-test. In all cases both tests agreed. The three subsections are ordered in Table 5-15 such that the fact that all significant relative rates are greater than or equal to 1.0 suggests overall that travel on roads has the lowest rates, followed by off-road paths/trails and then sidewalks. The rate of injury might be considered most important from a safety perspective while the collision and fall rates are more important from the perspective of promoting bicycling. The rate for major injury could only be considered for off-road paths versus roads as no major injuries were observed on sidewalks.

The relative rate of injury on the sidewalk versus the road is very high (4.0). Similarly, the relative injury rate on sidewalk versus off-road paths/trails is quite high (2.5). While the relative rate of injury between paths/trails versus roads is lower (1.6) it is still significant and only seems small because of its magnitude compared to the other relative fall rates. The relative rate of falls for the three pairings follows a similar pattern to that of injuries with the rate between the sidewalk and road being largest. The relative collision rates are not statistically different from 1.0. Finding such significant results for injuries but not collisions suggests that studies based only on the analysis of collisions could be improved by including other events.

Table 5-15: Weighted Relative Event Rates on Different Infrastructure

Relative Event Rate for ...	Event	Relative Rate	Statistical Significance (level)	Lower 95% Confidence Interval	Upper 95% Confidence Interval
Travel on Off-road Path/Trail to Travel on-road	Collision	1.0	No Sign. Diff (0.75)	0.7	1.4
	Fall	2.1	≠1 (0.001)	1.6	2.8
	Injury	1.6	≠1 (0.005)	1.2	2.2
	Major Injury	1.6	No Sign. Diff (0.25)	0.8	3.7
Travel on Sidewalk to Travel on-road	Collision	0.9	No Sign. Diff (0.75)	0.5	2.3
	Fall	4.0	≠1 (0.01)	2.7	6.2
	Injury	4.0	≠1 (0.001)	2.6	6.4
Travel on Sidewalk to Off-road Path/Trail	Collision	0.9	No Sign. Diff (0.5)	0.4	2.4
	Fall	1.9	≠1 (0.005)	1.3	3.0
	Injury	2.5	≠1 (0.001)	1.5	4.1

5.6 Event Rates for Sub-groups of Cyclists

5.6.1 Procedure for Rate Comparison for Sub-groups

The degree to which a sample can be subdivided is determined by the size of the sample and the number of events reported. Given the overall sample size (at best only 234 events) only one-way analysis is considered in this section. In some cases, the two tests used for hypothesis testing (described in section 5.5.1) differed. In general, Cox's test is not very powerful (Lee, 1992); therefore in most differing cases, Cox's test indicated the null hypothesis should not be rejected when the more powerful Hauer test indicated it should be. However, in some cases where the total sum of event counts for the two groups was small, the Hauer test (which is based on the assumption of Poisson counts) did not reject but Cox's test did. This conservativeness with respect to low incident counts is considered appropriate. The discussion here is based on the Hauer test results. The Cox F-test was conducted mainly to obtain an estimate of the confidence intervals.

Two slightly different procedures were used to consider the non-confounding and confounding variables. For the individuals in sub-categories of the personal variable that travelled approximately the same proportion on each type of infrastructure, only the overall fall, collision, injury and major injury rates were examined to determine differences between groups (1 test for sex, 3 paired tests for 3 age groups and 6 paired tests for 4 categories of years commuting). The categories used were those described in Section 5.3. However, for sub-groups that were found to have different proportions of travel on different infrastructure it was necessary to examine the relative rates for sub-groups on each type of infrastructure separately. The overall rates as well as the major injury rate on sidewalks were not considered, so there were 11 tests done for each pair of sub-groups. Three variables were simply yes - no: left turn type, busy streets and club/course. The four categories of weekly travel led to 6 pair-wise sets of tests for each of the 11.

5.6.2 Sub-group Event Rate Results

Results of the sub-group event rate analysis tests are tabulated in Appendix J. Exact relative rates are not reported in this section but rather the patterns noted are summarized.

No statistically different relative rates for falls, injuries or major injuries were found between men and women. However, men had only 0.7 times the collisions rate of women. Several differences were evident among the age groups. Cyclists under 30 have significantly higher fall and injury rates compared to those of the age groups over 30. Cyclists over 40 have significantly lower collision rates than those under 40. The age of the cyclists was not highly correlated (0.1) with the number of years the cyclist had been commuting. Therefore, these two variables sub-divide the sample into different groups. Of the relative rates for different number of years commuting by bicycle only two are statistically significant, both pertaining to the relative collision rates. The relative rate is greater for cyclists with less than three years experience compared both with 3 to 6 years and with greater than 9 years. This suggests that newer commuter cyclists are more likely to be involved in a collision. Note that these differences were not present in the hypothesis tests to investigate exposure patterns for two categories of years commuting described in section 5.5.

Of 66 tests performed on different levels of peak weekly cycling, only 6 gave rise to significant differences among the rates. Specifically, those who travel more per week have lower fall rates on the road in each of the four comparisons. The relative rates in two cases suggest that cyclists with longer total weekly distance also have lower collision and fall rates on paths.

None of the relative rates on different infrastructure between individuals who do and do not make left turns at busy signalized intersections from the left-most lane are statistically different from 1.0. No significant difference for any rate is found between those who belong to a club or have taken a course compared to those who have not. All of these results may be due to one category in each pair having significantly fewer cyclists and thus low event counts. The differences in event rates for those who answered yes to the busy street question are also not significant.

5.7 Concluding Discussion

This study has found statistically significant differences between the fall and injury rates for bicycle commuting on-road, off-road and on sidewalks. The differences for collision rates were not significant. These relative rates suggest it is safest to travel on-road followed by off-road paths and trails, and finally least safe on sidewalks. The result that 68% of injuries occurred in falls, not in collisions, suggests that bicycle safety analysis should be based on incident data that includes more than just collisions. The methodology used in this study also allowed for defensible measures of the absolute rates. The event rates per bicycle kilometre were found to be between 10 and 40 times higher than similar rates for automobile travel. Some preliminary differences in event rates were found for different sub-groups of cyclists.

Before interpreting these results for potential bicycle planning directions, it is necessary to consider limitations to any generalization. Despite the dearth of bicycle safety information, caution should be exercised in extrapolating these results. In order to use the routes traced on maps for a precise estimate of travel exposure, it was necessary to limit the sample to commuter cyclists in one urban area. It would be ideal to be able to conclude that these results apply more generally to the whole population of urban cyclists, at least in Ontario. However, these results apply strictly to only the specific sample of Ottawa-Carleton commuter cyclists. Further, commuters are familiar with their route and presumably therefore with the hazards it contains. Most commuters in the sample travel during the morning and evening peak traffic hours. These times represent high vehicle volume on the roadways but low recreational cyclist and pedestrian volumes on the paths/trails. These two and perhaps other factors could result in the relative incident rates for roads versus off-road facilities found here being different than for other groups or at other times. In addition, Ottawa-Carleton has been identified as a bicycle-friendly urban area by many sources. For example, one survey participant noted that "Ottawa is a far safer place to cycle [than Montreal]. There is a greater sense of responsibility here on the part of both cyclists and drivers." These factors could result in the on-road incident rates being lower than might be found elsewhere.

Even given these limitations, some conclusions in terms of policy directions for bicycle planning can be drawn. The finding that the relative risk of sidewalk travel is the most hazardous from the point of view of falls and injuries confirms earlier work. It should be an additional incentive to amend policies for those municipalities that still encourage or tolerate some form of sidewalk cycling.

The results with respect to off-road paths/trails versus roads suggest that moving cyclists away from automobile traffic onto paths is not the solution to the bicycle safety problem. At a quick glance one might read the result that paths and trails are more "dangerous" for bicycling and conclude that cyclists should be encouraged to use the roads. Certainly based on these results cyclists who wish to travel on the road should not be discouraged from doing so. However, diverting off-road cyclists onto roads is contrary to the repeated finding that many cyclists and some current non-cyclists prefer to bicycle on off-road paths and trails. This feeling relates not only to their perception of safety but also their enjoyment of the activity. Perceptions are important, because people often refuse to cycle where they are not comfortable. Even if these cyclists did use the roads it is reasonable to expect that their lack of comfort might translate into lack of confidence and/or skill, and a possible safety hazard.

As an alternative to changing where bicycles are travelling, policy could focus on improving the safety of the paths and trails. Forester (1994) suggests that roads are safer for travel because they have an established set of operating procedures that when followed provide for efficient and safe operation of the entire road system (including all types of vehicles). The data in this analysis cannot determine whether any specific factor or factors were the cause of the higher injury (1.6X) or fall (2.1X) rates on paths versus roads. However, the relative rates certainly suggest that in improving off-road facilities, bicycle planners might seek to make them operate more like roads. The operating rules of off-road paths and trails as well as their geometric and maintenance standards vary from location to location. Off-road facilities, particularly those for the shared use of pedestrians, bicycles, rollerbladers and skateboarders (as is the case in Ottawa-Carleton), have very limited operating rules. Even when publicized they are not uniformly followed. Issues such as which side of the trail pedestrians walk on and how to pass a pedestrian or bicycle remain contentious (Hope 1995).

It is possible that many paths are not necessarily built for the volume of non-motorized traffic they carry, or that their geometric standards are not sufficient for the speeds bicycles travel. Concerns over the operating conditions of pathways were expressed in the questionnaire comment section by some survey participants. One cyclist expressed confusion over whether rollerbladers were vehicles or pedestrians. Another comment suggested the use of warning bells might relate to the level of pedestrian-bicycle collisions. One cyclist indicated he simply travelled too fast for the pathways. Given cyclists' concerns for the operating conditions of pathways, and the possible link to safety issues, efforts aimed at improving path operations should be considered.

5.8 References

American Association of State Highway and Transportation Officials (AASHTO). (1981). *Guide for the Development of New Bicycle Facilities.* Washington D. C.

Badgett, Shauna I., Debbie A. Niemeier, G. Scott Rutherford. (1993). "Bicycle Commuting Deterrents and Incentives: A Survey of Selected Companies in the Greater Seattle Area". Presented at the 73rd Annual Meeting of the Transportation Research Board, Washington D. C. January 9-13.

Chlapecka, T. W., S. A. Schupack, T. W. Planek, H. Klecka and J. G. Driessen. (1975). *Bicycle Accidents and Usage Among Elementary School Children in the United States.* Chicago: National Safety Council.

Consumer Product Safety Commission of the United States. (1993). *Bicycle Use and Hazard Patterns in the U.S. and Options for Injury Reduction.* November.

Doherty, Sean L., Lisa M. Aultman-Hall and Fred L. Hall. (1996). "Commuter Cyclist Accident Patterns in Toronto." Research Paper, McMaster University, Hamilton, Ontario Canada.

Forester, John. (1994). *Bicycle Transportation - A Handbook for Cycling Transportation Engineers.* Cambridge, Massachusetts: MIT Press.

Goldsmith, Stewart A. (1992). *Reasons Why Bicycling and Walking Are and Are Not Being Used More Extensively as Travel Modes.* Washington: Federal Highway Administration, Case Study #1, FHWA National Bicycling and Walking Study.

Hauer, Ezra. (1996). "Statistical Test of the Difference Between Expected Accident Frequencies." Presented at the 75th Annual Meeting of the Transportation Research Board, Washington D. C. January 7-13.

Hope, Daphne. (1995). Personal communication. City of Ottawa, Engineering Department, May.

Howarth, C. I. (1982). "The Need for Regular Monitoring of the Exposure of Pedestrians and Cyclists to Traffic." *Accident Analysis and Prevention* Volume 14, Number 5.

Kaplan, Jerrold. (1976). *Characteristics of the Regular Adult Bicycle User.* Washington: Federal Highway Administration.

Lee, Elisa T. (1992). *Statistical Methods for Survival Analysis.* New York: Wiley.

Liu, Xiaoming, L. David Shen, and Jian Huang. (1995). "Analysis of Bicycle Accidents and Recommended Countermeasures in Beijing, China." *Transportation Research Record* 1487.

Lott, Dale F., Timothy Tardiff and Donna Y. Lott. (1978). "Evaluation by Experienced Riders of a New Bicycle Lane in an Established Bikeway System." *Transportation Research Record* 683.

Lott, Dale F. and Donna Y. Lott. (1976). "Effect of Bike Lanes on Ten Classes of Bicycle-Automobile Accidents in Davis, California." *Journal of Safety Research.* Volume 8 Number 4.

Ontario Ministry of Transportation. (1992). *Ontario Road Safety Annual Report.* Toronto.

Perreault, Richard G., Judson S. Matthias, and Mary R. Anderson. (1977). "Development of a Bicycle Accident Rate in Arizona". *Transportation Research Record* 629.

Raub. Richard A. (1996). "Identifying High-Hazard Locations for Pedestrian and Bicycle Crashes." Presented at the 75th Annual Meeting of the Transportation Research Board, Washington D. C. January 7-13.

Schupack, S. A. and G. J. Driessen. (1976). *Bicycle Accident and Usage Among Young Adults: Preliminary Study.* Chicago: National Safety Council.

Shipley, Fiona. (1994) *The Southhampton Western Approach Cycle Route Cyclist Flows and Accidents.* Crowthorne, England: Transport Research Laboratory, Project Report 93.

Smith Robert L. and Thomas Walsh. (1988). "Safety impacts of Bicycle Lanes." Presented at the Annual Meeting of the Transportation Research Board, Washington D. C. January.

Stutts, Jane C., Joseph E. Williamson and Theodore Whitley. (1990). "Bicycle Accidents and Injuries: A Pilot Study Comparing Hospital- and Police-Reported Data." *Accident Analysis and Prevention* Volume 22, Number 1.

Thom, Robert G. and Alan M. Clayton. (1993). "Accident Data Requirements for Improving Cycling Safety". *Transportation Research Record* 1405.

Watkins, S. M. (1984). Study of Cyclists of the British Cycling Touring Club.

Wachtel, Alan and Diana Lewiston. (1994). "Risk Factors for Bicycle-Motor Vehicle Collisions at Intersections". *ITE Journal,* Sept.

Wessels, Ralph L. (1996). "Bicycle Collisions in Washington State: A Six-Year Perspective, 1988 to 1993." Presented at the 75th Annual Meeting of the Transportation Research Board, Washington D. C. January 7-11.

Chapter 6: Conclusion

The components of this thesis, as well as being chapters, were designed to be used for publication elsewhere. As such, concluding discussions are contained within each chapter. As well as summarizing the main conclusions of the thesis, this chapter focuses primarily on the directions for further work. Section 6.1 considers the route choice aspects of the work; section 6.2 discusses the relative safety analysis. The final section considers the role of actual travel route analysis in the larger transportation research context.

6.1 Bicycle Route Choice

The route choice of commuter cyclists in Guelph, reported in Chapters 2 and 3, provides both substantive input for bicycle transportation planning and methodological contributions related to transportation planning models. In terms of substantive input, the analysis of route choice was intended primarily to further the understanding of the types of network infrastructure commuter cyclists prefer. Based on this knowledge, improvements to the current cycling network could be made for existing cyclists and/or improvements that might encourage more cycling could be undertaken. Commuter cyclists were found to use primarily main roads; to use traffic signals to their advantage; and to avoid grades, high activity areas and off-road paths/trails (especially those of average or lower quality).

It was not possible with the Guelph dataset to determine what proportion of cyclists travel in the traffic lanes as opposed to on the sidewalk. A more complete understanding of whether cyclists are using main roads because they prefer to or because no reasonable alternative exists requires consideration of where cyclists use the sidewalk. Future work should attempt to consider this factor. Both chapters provide support for the notion of different types of cyclists. In Chapter 2 most cyclists use direct main road routes while others divert significant distances and avoid main roads. Similar differences are suggested in Chapter 3 by the statistically significant interaction of several personal variables in the logit route choice model. In order to more adequately plan for the transportation needs of different types of cyclists, more work is needed to clearly sort out the personal variables that might correlate with or define different groups of cyclists. Furthermore, in order to encourage more cycling it would be ideal to determine the type of cyclist that comprises the latent demand. The Guelph route dataset was relatively small (397 observations). It is reasonable to suggest that further work with larger datasets will improve the understanding of cyclist characteristics as they relate to route behaviour.

The route analysis portion of this work utilized two alternative methodologies. The first (Chapter 2) involved reporting the route characteristics and subsequently comparing them to the characteristics of the shortest path routes between each individual's start and end location. The second approach, an improvement on the first, involved use of a logit choice model to consider the chosen route together with, on average 5.5, other alternative routes. By increasing the choice set more information was available to the model and additional determinants of route choice were found. This application of the multinomial logit model to route choice in a comprehensive urban network is preliminary. The procedure used is considered successful including the handling of violation of the independence from irrelevant alternatives (IIA) assumption that occurs in the route choice context.

Given the success of this preliminary application, several further avenues for analysis are recommended in order to further the understanding of the appropriateness of discrete choice methodology for modelling route behaviour. Efforts to further understand the effects of IIA in the logit model formulation might include comparing the parameters output for models estimated with carefully controlled choice sets that do and do not exhibit correlation with respect to route attributes. Such an effort might make use of hypothetical route scenarios as well as considering the effect of the number of alternatives available. The effects of several variables in this modelling effort were unknown. It is expected that model estimation with a larger route dataset (such as the Toronto or Ottawa dataset collected for this thesis) would increase the number of variables whose effect can be measured as well as the understanding of the IIA violation problem referred to above.

Application of a probit discrete choice model formulation would seem to offer a promising means to avoid the IIA complication. However, with this formulation the relative correlations between alternatives must be provided. A method to establish the correlations between routes in the choice set will not be straightforward. Application of a probit formulation should be attempted to consider this issue as well as to compare the logit and probit results for consistency.

The successful estimation of the bicycle route choice model suggests that a similar approach could be attempted to model automobile routes in order to further the understanding of that routing behaviour. Attempts to analyze actual automobile routes will likely prove less interesting than bicycle routing with respect to the physical characteristics of the network but the inclusion of variables such as travel time, delay, and traffic control will be important.

6.2 Bicycle Safety Analysis

The routes travelled by commuter cyclists in Ottawa-Carleton were used in Chapter 5 as a measure of the total commuter exposure to incidents on-road, off-road and on sidewalks. The exposure estimation allowed a measure of the relative rate of collisions, falls and injuries on different infrastructure that is more accurate than those previously available. Information regarding the relative safety of travel on different types of infrastructure is important for planners who design bicycle networks, especially those involved in location selection.

For commuters in Ottawa-Carleton it was found that although collision rates were not statistically different in the different locations, the rates for falls and injuries were. These rates were greatest on sidewalks, followed by off-road paths/trails and then roads. This result suggests that future bicycle safety work should consider all events not just collisions and particularly not just collisions with automobiles. The facility types with the larger event rates per kilometre were not necessarily those with the greatest total event counts. This result points to the necessity to correct event counts with a measure of exposure in order to allow for meaningful comparisons between facilities or different groups of cyclists.

Injury and event rates for commuter bicycling in Ottawa-Carleton were found to be at least 10 times that of similar rates for automobiles in Ontario. In light of the lower safety for cycling compared to driving, further work to understand factors affecting bicycle safety is warranted. Three of the possible directions for future work can be undertaken with the Ottawa-Carleton database used in Chapter 5. First, related to the route choice analysis above, further understanding is necessary of the characteristics defining different groups of cyclists and the different event rates for various types of cyclists. Although the analysis within this thesis focused on the infrastructure differences, further work could focus more closely on personal characteristics. Second, further stratification of the off-road routes according to geometry, surface type and operating conditions would be ideal. This analysis if conducted with the Ottawa data would require use of the map locations of the falls and collisions. Locations were provided for only approximately 30% of the reported events. Finally, incident rates other than those which occurred during the commuting trip should be investigated. This is only possible to a limited extent with the Ottawa-Carleton database. However, without the route information a detailed estimate of the exposure by infrastructure type will not be possible.

Several other directions for further bicycle safety research require the use and/or collection of other bicycle data. First, as indicated above, a more comprehensive analysis of safety for all cyclists not just commuters is required. The problem of how to collect a reasonable estimate of exposure by infrastructure type remains unsolved. Second, it is necessary to consider the event rates in several different cities that exhibit different levels of and attitudes toward cycling. One particular aspect of cycling that could not be considered in Ottawa was the event rates for travel on bicycle lanes. It is reasonable to assume that unique types of incidents occur in these lanes due to the interaction with automobiles in an adjacent lane. Analysis of the Toronto data, (the collection of which was described in Chapter 4), will allow some progress towards accomplishing an understanding of event rates in different urban areas and on routes with dedicated bicycle lanes. Neither of the databases collected in the thesis contain information describing the cause or fault of the incidents. Such information might be useful for designing counter-measures.

6.3 Route Analysis

The analysis of the actual routes used by travellers in a comprehensive urban transportation network is rare. The widespread use of Geographic Information Systems (GIS) and the corresponding development by municipalities and other agencies of transportation network databases enable the analysis of such route data. Given this ability to analyze routes, the only remaining barrier to more widespread comprehensive route behaviour research is lack of data. The quantitative results in this thesis, specific to bicycle commuter incident rates and factors affecting bicycle route choice, are examples of the information that can be obtained through route analysis. This should motivate further collection efforts, despite the fact that collection of route data is not straightforward.

The questionnaire used in this thesis was successful for the collection of bicycle routes. Given the dearth of bicycle travel data, the information that can be extracted from querying the GIS network database is very useful. The current state of urban transportation systems points to a need to promote non-motorized transportation to reduce congestion and pollution. The survey design and analysis methods in this thesis worked well for the bicycle. They demonstrate that methods to more adequately consider non-motorized transportation can be developed in the field of transportation planning. Therefore, future efforts to exploit the wealth of information inherent in bicycle routes for bicycle transportation planning should be undertaken.

Route analysis offers potential benefits for automobile travel as well. Examples include improvements to traffic assignment techniques such as confirming the user-equilibrium assumption or allowing for calibration of stochastic assignment techniques against real data. It is possible that automobile route data from route guidance and navigation systems will soon be more common. However, it is unlikely that such systems will provide widespread information on all types of automobile users in the near future. In this context, given the amount of useful information contained within route data, adaptation of both the bicycle route collection methods and modelling techniques within this thesis may be needed.

Appendices

Appendix A: Guelph Bicycle User Survey and Guelph Community Bicycle Survey

(The original Guelph community questionnaire contained 2 sets of maps for each of four persons in a household. Only one set is reproduced here. The only available copies of the community survey had been filled in but identifying information has been whited out for use in this thesis.)

CITY OF GUELPH

CITY OF GUELPH

CITY HALL, 59 Carden Street
Guelph, Ontario, Canada
N1H 3A1

CITY ENGINEER'S DEPARTMENT
File No: 11.425.042

April 19, 1993

Dear Sir\Madam:

Reference: **<u>Guelph & Area Transportation Study - Bicycle Survey</u>**

The City of Guelph and County of Wellington, with financial support from the Ministry of Transportation, have initiated the <u>Guelph & Area Transportation Study</u> to identify our transportation requirements over the next 20 years. The study includes a bicycle component which attempts to identify and address the needs of cyclists over this period of time.

In order to obtain a representative picture of current cycling trends, it is necessary to seek out public input. For this reason, the City of Guelph is distributing over 2,700 surveys to a random selection of households. Your assistance in planning for the future of bicycle facilities in Guelph is requested and we would appreciate if you would take the time to respond to the questionnaire and return it in the self-addressed envelope provided by no later than April 30th, 1993.

If you have any questions with regards to this survey, please do not hesitate to call either Derek McCaugha[illegible] Manager of Traffic Services, at extension 277 or Andrew Goldie, Park Planner, at extension 435.

Thank you for your anticipated response.

Yours truly,

R.D. Funnell

R. D. Funnell, P. Eng.,
City Engineer.

DJM*rm

☐ Administration/Operations
☐ Development/Design & Construction
☐ Waste Management/Recycling
TEL: (519) 837-5604
FAX: (519) 837-5635

☐ Traffic Services
TEL: (519) 837-5612
FAX: (519) 837-5635

☐ Public Works
TEL: (519) 837-5628
FAX: (519) 822-8714

☐ Water & Waste Water Services
TEL: (519) 837-5627
FAX: (519) 822-8837

April 1st, 1993

CITY OF GUELPH
COMMUNITY BICYCLE SURVEY

PLEASE ENSURE EACH PERSON IN YOUR HOUSEHOLD IS ACCOUNTED FOR IN YOUR RESPONSE TO QUESTIONS #1 TO #4. THE PERSON IN YOUR HOUSEHOLD WHO HAD THE MOST RECENT BIRTHDAY, AND IS 16 YEARS OF AGE OR OLDER, SHOULD ANSWER QUESTIONS #5 TO #8.

Please identify:

Person #1 - under column P1 ____________ FIRST NAME ______ AGE ______ GENDER

Person #2 - under column P2 ____________ FIRST NAME ______ AGE ______ GENDER

Person #3 - under column P3 ____________ FIRST NAME ______ AGE ______ GENDER

Person #4 - under column P4 ____________ FIRST NAME ______ AGE ______ GENDER

1.A) How many bicycles are in your household ?

4
NUMBER

B) Which persons use a bicycle ?

P1	P2	P3	P4
☑	☑	☑	☑

2.A) On average, please approximate on how many days does each person use their bicycle during each month ?

P1	P2	P3	P4	
0	0	0	0	January (available 31 days)
0	0	0	0	February (available 28 days)
0	0	0	0	March (available 31 days)
15	10	10	15	April (available 30 days)
20	10	10	25	May (available 31 days)
25	10	16	30	June (available 30 days)
25	10	10	31	July (available 31 days)
25	10	10	31	August (available 31 days)
20	10	10	20	September (available 30 days)
10	10	10	10	October (available 31 days)
0	0	0	0	November (available 30 days)
0	0	0	0	December (available 31 days)

B) **For the month in #2.A) with the highest number of cycling days, please approximate how often you used a bicycle for each of the following reasons ?**

P1	P2	P3	P4	
0	0	0	0	To work
0	0	0	0	To school/university (as students)
20	5	5	20	For shopping
31	10	10	31	For recreation
0	10	10	0	To social functions eg. visiting friends
0	0	0	0	others, please specify ____________

3.A) **For each person, please mark the streets and or trails that you use most often to cycle for commuting to and from work or school on Map #1 provided (please identify one route only) ?**

B) **For each person, please mark the streets, trails, and parks that you use to cycle for recreation on Map #2 provided (ie. for exercise, adventure or fun) ?**

C) **For each person, please list destinations for task oriented trips (ie. shopping, errands, and visiting)?**

P1	P2	P3	P4
WILLOW WEST	WILLOW WEST	WILLOW WEST	WILLOW WEST
M.GREEN PARK	M. GREEN PARK	M.GREEN PARK	M. GREEN PARK
WESTWOOD	WESTWOOD	WESTWOOD	WESTWOOD

4. If safe and convenient facilities for cycling are available, do you believe you would bike to and from work or school?

P1	P2	P3	P4	
☐	☑	☑	☐	Yes
☑	☐	☐	☑	No

THE PERSON WITH THE MOST RECENT BIRTHDAY AND OVER THE AGE OF 16 SHOULD ANSWER QUESTIONS #5 TO #8. PLEASE INDICATE WHO IS ANSWERING THE REMAINING QUESTIONS.

RESPONDENT FOR REMAINDER OF SURVEY (please circle one): [✓ P1] P2 P3 P4

B) For the month in #2.A) with the highest number of cycling days, please approximate how often you used a bicycle for each of the following reasons ?

P1	P2	P3	P4	
0	0	0	0	To work
0	0	0	0	To school/university (as students)
20	5	5	20	For shopping
31	10	10	31	For recreation
0	10	10	0	To social functions eg. visiting friends
0	0	0	0	others, please specify ____________

3.A) For each person, please mark the streets and or trails that you use most often to cycle for commuting to and from work or school on Map #1 provided (please identify one route only) ?

B) For each person, please mark the streets, trails, and parks that you use to cycle for recreation on Map #2 provided (ie. for exercise, adventure or fun) ?

C) For each person, please list destinations for task oriented trips (ie. shopping, errands, and visiting)?

P1	P2	P3	P4
WILLOW WEST	WILLOW WEST	WILLOW WEST	WILLOW WEST
M. GREEN PARK	M- GREEN PARK	M. GREEN PARK	M. GREEN PARK
WESTWOOD	WESTWOOD	WESTWOOD	WESTWOOD

4. If safe and convenient facilities for cycling are available, do you believe you would bike to and from work or school ?

P1	P2	P3	P4	
☐	☑	☑	☐	Yes
☑	☐	☐	☑	No

THE PERSON WITH THE MOST RECENT BIRTHDAY AND OVER THE AGE OF 16 SHOULD ANSWER QUESTIONS #5 TO #8. PLEASE INDICATE WHO IS ANSWERING THE REMAINING QUESTIONS.

RESPONDENT FOR REMAINDER OF SURVEY (please circle one): [✓ P1] P2 P3 P4

For questions #5 and #6 please place an "X" on the line to give your relative opinion on the statement made. If you have no opinion, or you believe the statement is not applicable, please check the box and do not mark the line.

5. "I do not ride my/a bicycle at all or I don't ride my/a bicycle as much as I would like to because....

my destination points are too distant."					X						☐
	Totally disagree									Totally agree	No opinion
the automobile is more convenient."										X	☐
	Totally disagree									Totally agree	No opinion
transit is more convenient."					X						☐
	Totally disagree									Totally agree	No opinion
walking is more convenient."	X										☐
	Totally disagree									Totally agree	No opinion
it is unsafe during the winter months."										X	☐
	Totally disagree									Totally agree	No opinion
of adverse weather conditions."										X	☐
	Totally disagree									Totally agree	No opinion
riding in automobile traffic is unsafe."										X	☐
	Totally disagree									Totally agree	No opinion
of traffic congestion."										X	☐
	Totally disagree									Totally agree	No opinion
I require my automobile for work."	X										☐
	Totally disagree									Totally agree	No opinion
there are no changerooms/showers at my destination."											☐
	Totally disagree									Totally agree	No opinion
there is no secure parking for my bicycle."										X	☐
	Totally disagree									Totally agree	No opinion
others, please specify ________________											☐
	Totally disagree									Totally agree	No opinion

6. "The following may encourage me to ride my bicycle more often."

Widen existing curb lanes to permit easier sharing by motorists and cyclists.	X										☐
	Totally disagree									Totally agree	No opinion
Painted lanes for bikes on the roadway.	X										☐
	Totally disagree									Totally agree	No opinion
Bike paths separate from the roadway.										X	☐
	Totally disagree									Totally agree	No opinion

Improved road maintenance	☐☐☐☐☐☐☐☐☐☒ Totally disagree Totally agree	☐ No opinion
Facilities for bicycle parking.	☐☐☐☐☐☐☐☐☐☒ Totally disagree Totally agree	☐ No opinion
More diligent enforcement of traffic laws as applicable to motorists and cyclists.	☐☐☐☐☐☐☐☐☐☒ Totally disagree Totally agree	☐ No opinion
Safer sewer grates.	☐☐☐☐☐☐☐☐☐☒ Totally disagree Totally agree	☐ No opinion
Changeroom/shower facilities at destination points.	☐☐☐☐☐☐☐☐☐☐ Totally disagree Totally agree	☐ No opinion
Improve the existing trail system.	☐☐☐☐☐☐☐☐☐☒ Totally disagree Totally agree	☐ No opinion
Expanded trail system.	☐☐☐☐☐☐☐☐☐☒ Totally disagree Totally agree	☐ No opinion
Others, please specify ________________	☐☐☐☐☐☐☐☐☐☐ Totally disagree Totally agree	☐ No opinion

7. Please indicate and rank your top 3 priorities for the implementation of cycling facilities ?

___ Increased curb lane widths for shared use by motorist and cyclists.
___ Painted lines for bikes on the roadway.
✓ Construction of separate bike paths.
✓ Construction of multi-use recreational trails.
___ Installation of safer sewer grates.
✓ Provision of safe bicycle parking facilities.
___ Public education regarding cycling.
___ Provision of changeroom/shower facilities at designation points.
___ Enforcement of traffic laws as applicable to motorists and cyclists.
___ Others, please specify ____________________________

8. Other comments.

THANK YOU FOR YOU CO-OPERATION !

PLEASE RETURN BY APRIL 30TH, 1993.

Improved road maintenance	Totally disagree ☐☐☐☐☐☐☐☐☐☒ Totally agree	☐ No opinion
Facilities for bicycle parking.	Totally disagree ☐☐☐☐☐☐☐☐☐☒ Totally agree	☐ No opinion
More diligent enforcement of traffic laws as applicable to motorists and cyclists.	Totally disagree ☐☐☐☐☐☐☐☐☐☒ Totally agree	☐ No opinion
Safer sewer grates.	Totally disagree ☐☐☐☐☐☐☐☐☐☒ Totally agree	☐ No opinion
Changeroom/shower facilities at destination points.	Totally disagree ☐☐☐☐☐☐☐☐☐☐ Totally agree	☐ No opinion
Improve the existing trail system.	Totally disagree ☐☐☐☐☐☐☐☐☐☒ Totally agree	☐ No opinion
Expanded trail system.	Totally disagree ☐☐☐☐☐☐☐☐☐☒ Totally agree	☐ No opinion
Others, please specify ______________	Totally disagree ☐☐☐☐☐☐☐☐☐☐ Totally agree	☐ No opinion

7. Please indicate and rank your top 3 priorities for the implementation of cycling facilities ?

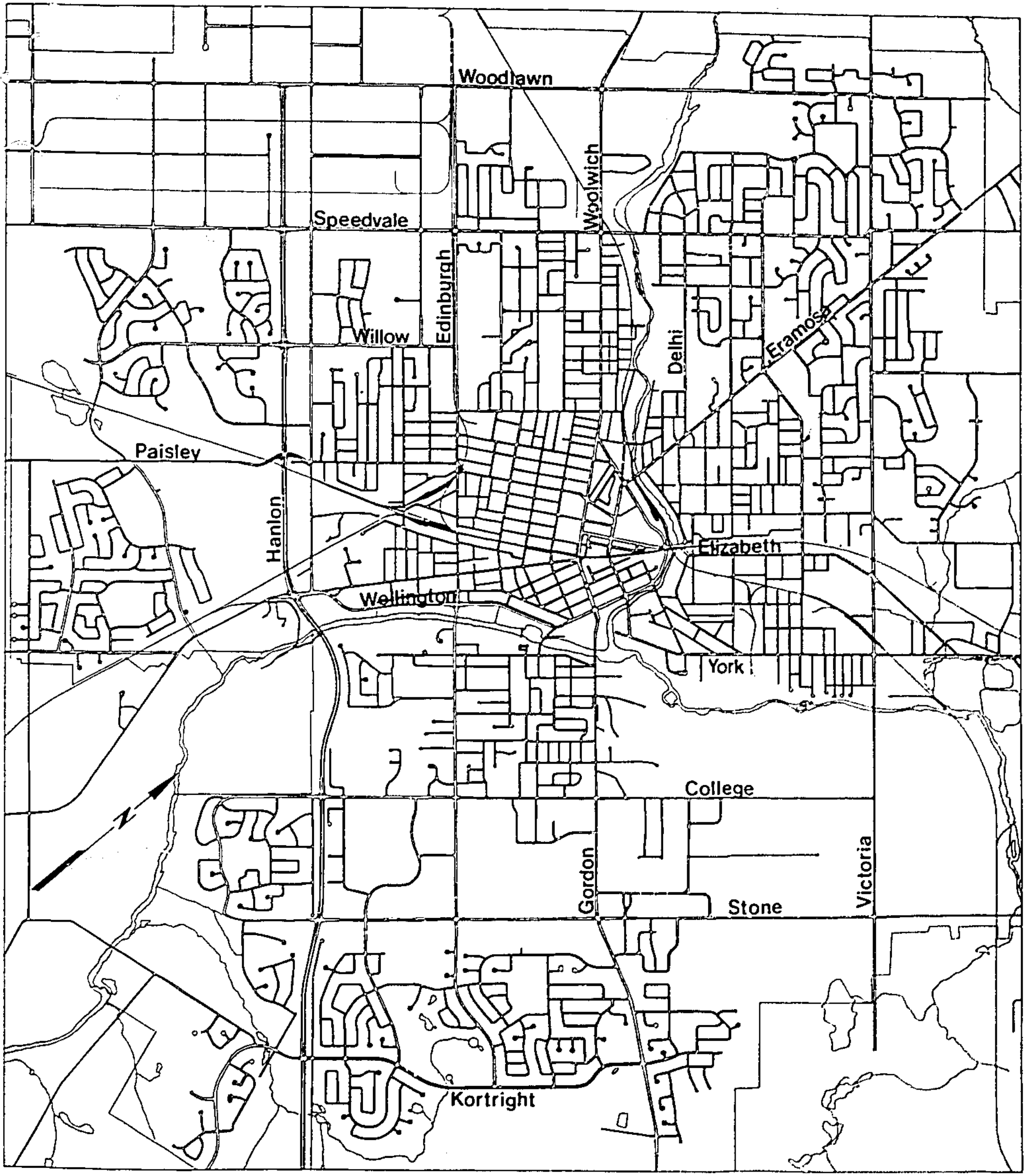
___ Increased curb lane widths for shared use by motorist and cyclists.
___ Painted lines for bikes on the roadway.
✓ Construction of separate bike paths.
✓ Construction of multi-use recreational trails.
___ Installation of safer sewer grates.
✓ Provision of safe bicycle parking facilities.
___ Public education regarding cycling.
___ Provision of changeroom/shower facilities at designation points.
___ Enforcement of traffic laws as applicable to motorists and cyclists.
___ Others, please specify ______________________

8. Other comments.

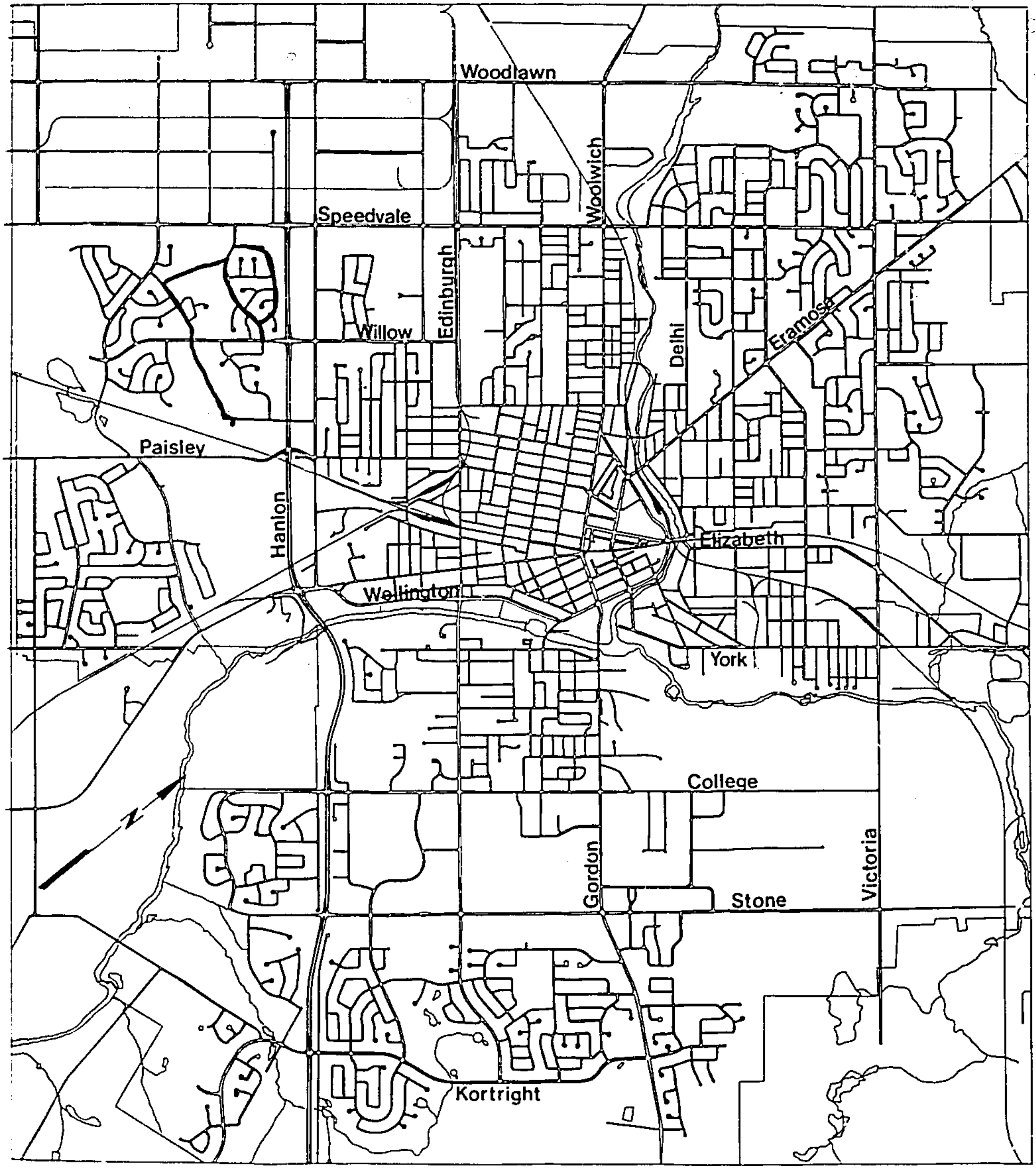
THANK YOU FOR YOU CO-OPERATION !

PLEASE RETURN BY APRIL 30TH, 1993.

3.A) ***For Person #1, please mark the streets or trails that you use most often to cycle for commuting to and from work or school (please identify one route only) ?***



3.B) For Person #1, please mark the streets, trails, and parks that you use most often to cycle for recreation (ie. for exercise, adventure or fun) ?



GUELPH AND AREA TRANSPORTATION STUDY
BICYCLE USER SURVEY - SPRING 1993

The purpose of this survey is to learn about the preferences and habits of existing cyclists within the City of Guelph. Your response will be used as part of the field data collected for use in the on-going Guelph and Area Transportation Study.

1. YOUR CYCLING SEASON.

Estimate the number of days per month you cycled in each in the past twelve months. Maximum number of days shown in brackets. Write in your estimates.

_____	April	(30)	_____	October	(31)
_____	May	(31)	_____	November	(30)
_____	June	(30)	_____	December	(31)
_____	July	(31)	_____	January	(31)
_____	August	(31)	_____	February	(28)
_____	September	(30)	_____	March	(31)

2. TYPE OF CYCLIST

For the month in which you cycled the most number of days (as identified in question 1 above), indicate the reason(s) for using your bicycle and the weekly frequency.

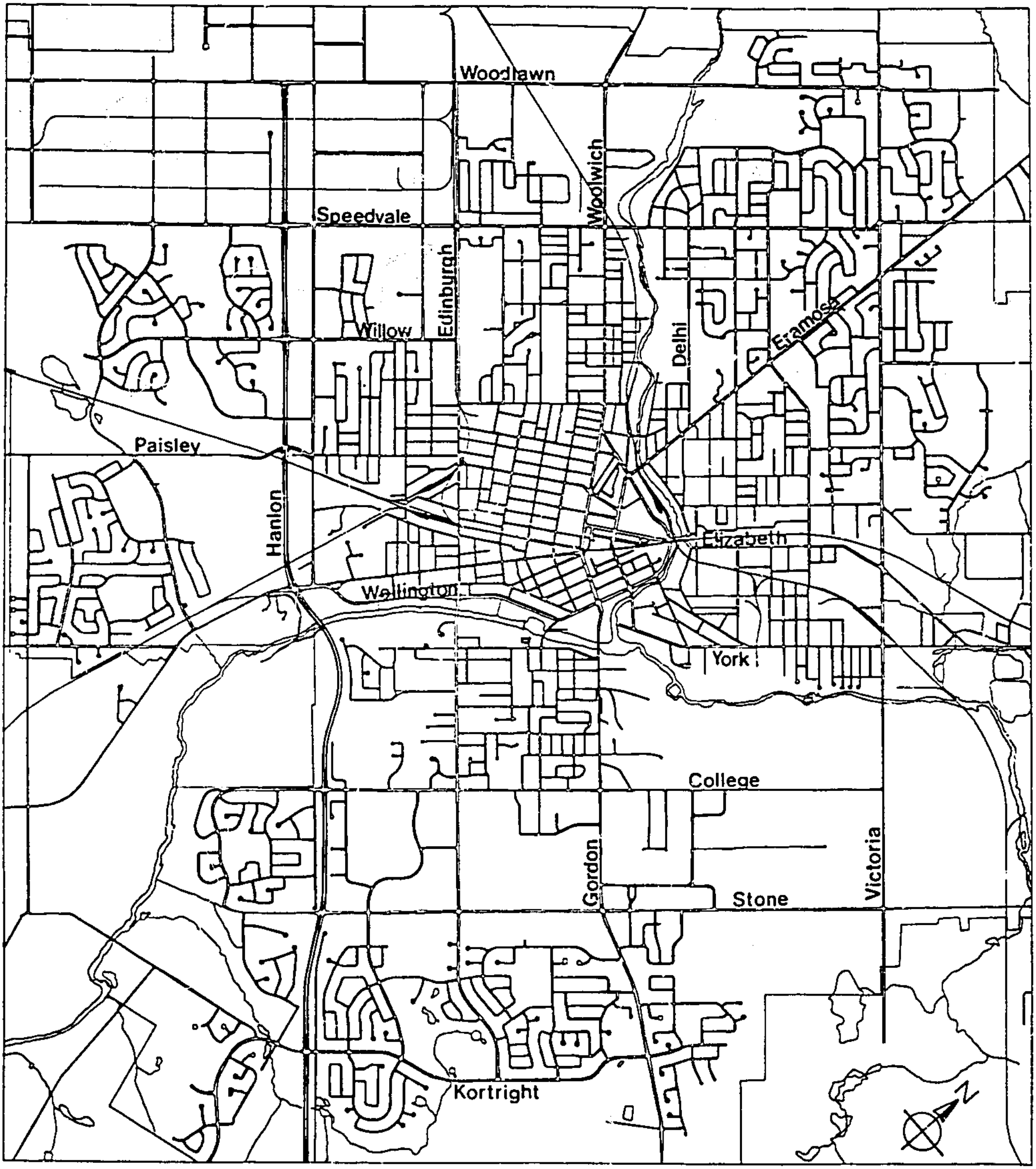
☐ I am an **OCCASIONAL CYCLIST**. I only cycled a few times that month for various reasons. (If you checked this category, proceed to question 3).

☐ I made a round trip commute ______ times per week between my home and my place of employment or education

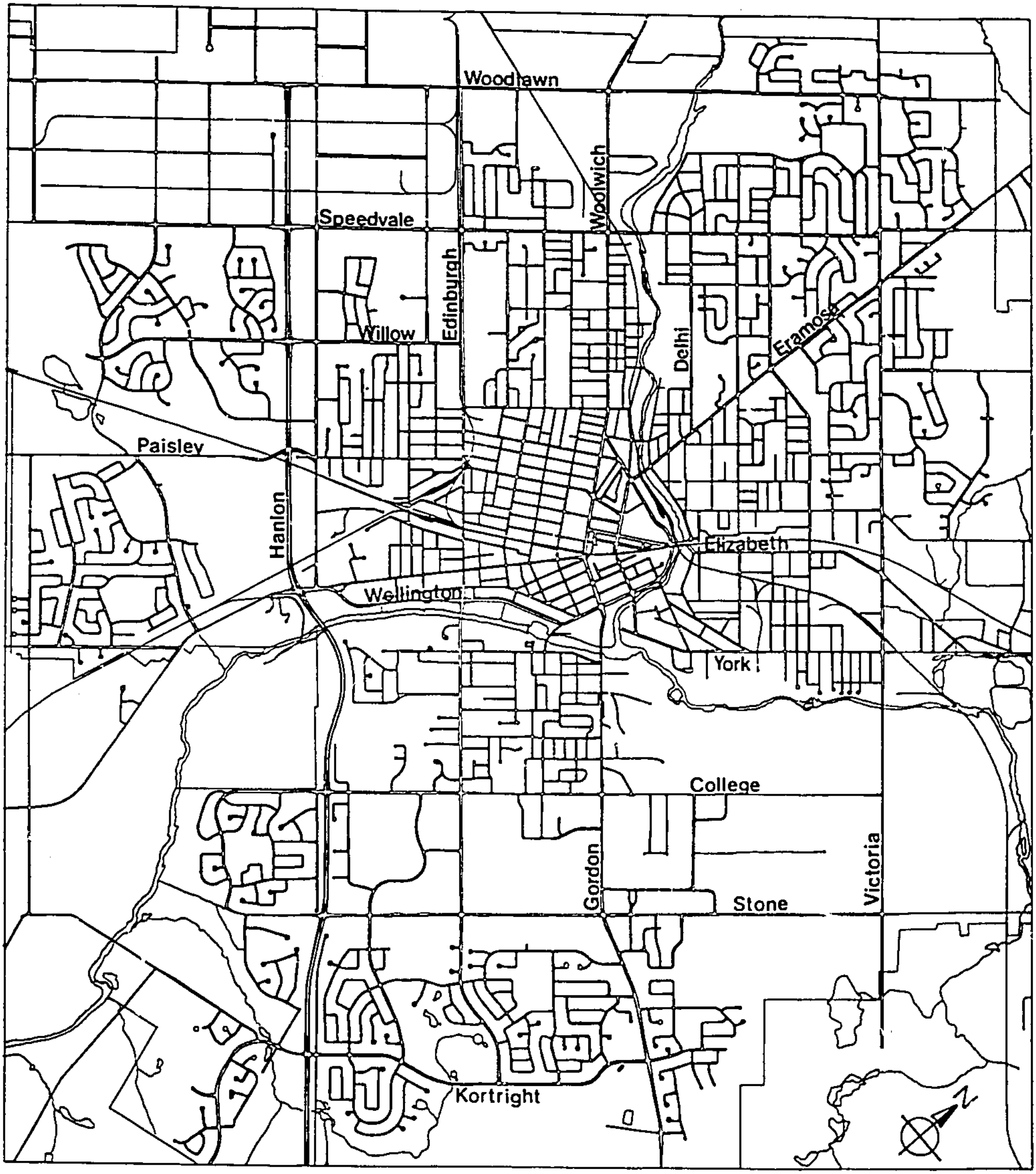
☐ I cycled ______ times per week as a means of transportation for shopping, doing errands, visiting or generally getting somewhere.

☐ I cycled _____ times per week for leisure, exercise, touring or for on or off-road training.

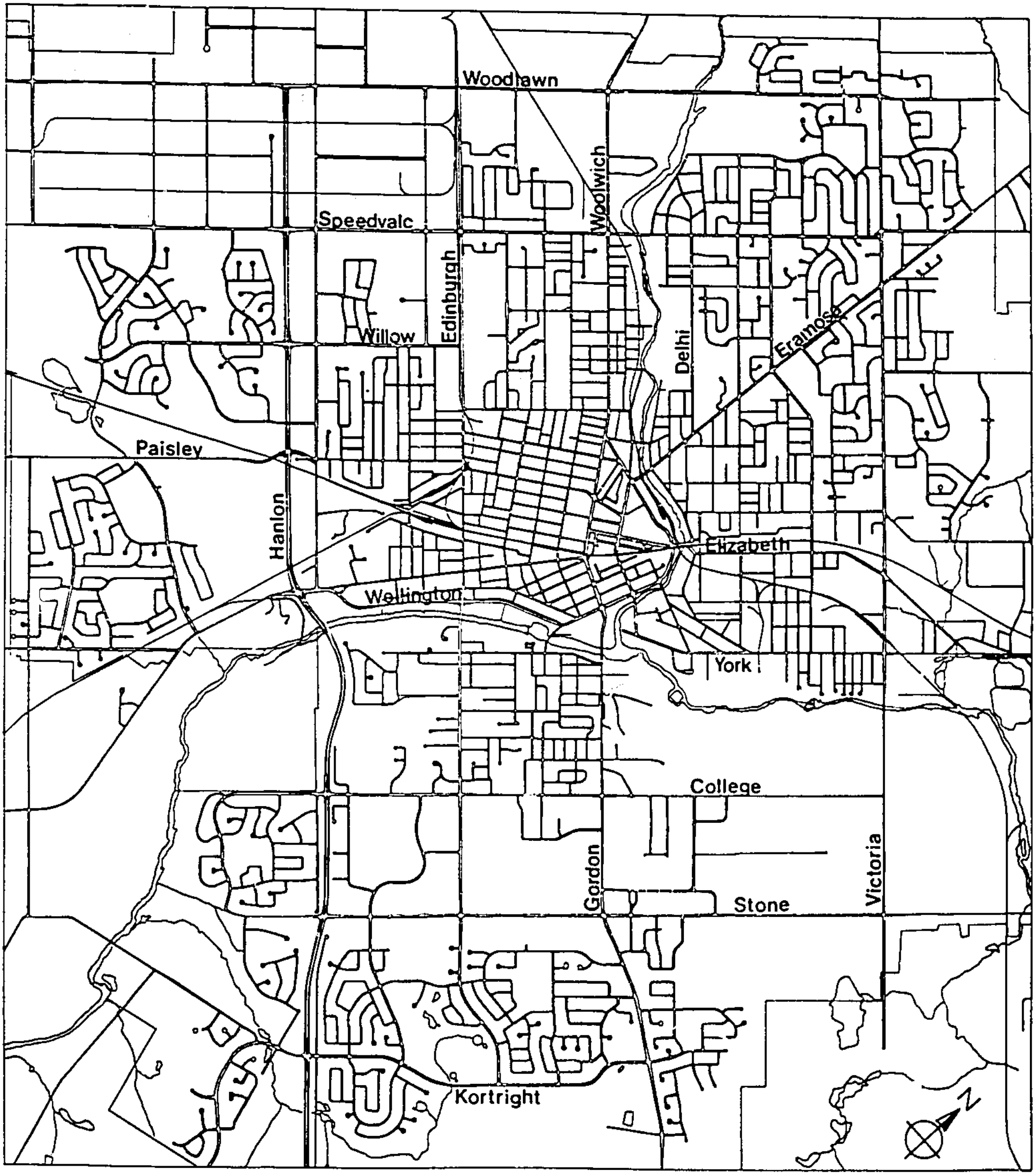
3. **YOUR PREFERRED COMMUTING AND UTILITARIAN CYCLING ROUTES.** On the blank map provided mark the **roads and trails** that you use for commuting and non-recreational cycling trips.



3. YOUR PREFERRED COMMUTING AND UTILITARIAN CYCLING ROUTES.
On the blank map provided mark the **roads and trails** that you use for commuting and non-recreational cycling trips.



4. **YOUR PREFERRED RECREATIONAL CYCLING ROUTES.**
On the blank map provided mark the **roads and trails** that you use for recreational cycling trips.



5. YOUR CYCLING DESTINATIONS.

Indicate destinations you travel to **by bicycle.**

	Name	or Closest Intersection
☐ Place(s) of Employment.		
☐ Place(s) of Education		
☐ Downtown		
☐ Shopping Malls		
☐ Other services or stores		
☐ Parks or athletic fields		
☐ Royal Recreation Trails		
☐ Restaurants or clubs		
☐ Bus, train or GO Transit		
☐ Others		

6. WAYS TO ENCOURAGE MORE CYCLING.

Place an X on the line to give your relative opinion on how effective each option would be to encourage cycling.

Curb lanes that are wide enough to be shared by both motorists and and cyclists.	Totally Disagree	☐	☐	☐	☐	☐ Totally Agree	☐ No Opinion
Special roadway lanes for the exclusive use of cyclists.	Totally Disagree	☐	☐	☐	☐	☐ Totally Agree	☐ No Opinion
Multi-use bike paths that are physically separated from the roadway.	Totally Disagree	☐	☐	☐	☐	☐ Totally Agree	☐ No Opinion

5. **YOUR CYCLING DESTINATIONS.**

Indicate destinations you travel to **by bicycle.**

Name ______ or Closest Intersection ______

☐ Place(s) of Employment. ______ ______

☐ Place(s) of Education ______ ______

☐ Downtown ______ ______

☐ Shopping Malls ______ ______
______ ______

☐ Other services or stores ______ ______
______ ______
______ ______

☐ Parks or athletic fields ______ ______
______ ______
______ ______

☐ Royal Recreation Trails ______ ______
______ ______

☐ Restaurants or clubs ______ ______
______ ______
______ ______

☐ Bus, train or GO Transit ______ ______

☐ Others ______ ______
______ ______
______ ______

6. **WAYS TO ENCOURAGE MORE CYCLING.**
Place an X on the line to give your relative opinion on how effective each option would be to encourage cycling.

Curb lanes that are wide enough to be shared by both motorists and and cyclists.
☐☐☐☐☐ Totally Disagree — Totally Agree ☐ No Opinion

Special roadway lanes for the exclusive use of cyclists.
☐☐☐☐☐ Totally Disagree — Totally Agree ☐ No Opinion

Multi-use bike paths that are physically separated from the roadway.
☐☐☐☐☐ Totally Disagree — Totally Agree ☐ No Opinion

WAYS TO ENCOURAGE MORE CYCLING - continued

Ensure roads are smoothly paved, and that utility covers and railway tracks are safe to cross.	☐☐☐☐☐ Totally Disagree … Totally Agree	☐ No Opinion
Provide secure bicycle parking facilities at all significant city destinations.	☐☐☐☐☐ Totally Disagree … Totally Agree	☐ No Opinion
Provide educational programs that would teach cyclists how to travel confidently and efficiently in traffic.	☐☐☐☐☐ Totally Disagree … Totally Agree	☐ No Opinion
Initiate a public relations campaign publicizing cyclists' rights to the road, and their responsibilities.	☐☐☐☐☐ Totally Disagree … Totally Agree	☐ No Opinion
More diligent enforcement of traffic laws for motorists and cyclists.	☐☐☐☐☐ Totally Disagree … Totally Agree	☐ No Opinion
Develop more opportunities for recreational cycling on public and private property.	☐☐☐☐☐ Totally Disagree … Totally Agree	☐ No Opinion
Develop a network of preferred or improved roads that are signed for cycling.	☐☐☐☐☐ Totally Disagree … Totally Agree	☐ No Opinion
Distribute a city map showing preferred and/or improved roads and trails for cycling.	☐☐☐☐☐ Totally Disagree … Totally Agree	☐ No Opinion
Develop a bicycle buddy program where experienced cyclists accompany new cyclists on commuting trips.	☐☐☐☐☐ Totally Disagree … Totally Agree	☐ No Opinion
Bike to Work Week activities.	☐☐☐☐☐ Totally Disagree … Totally Agree	☐ No Opinion

7. PERSONAL PROFILE

Age ____ Number of years as a cyclist ____

Female ☐ Male ☐

Postal Code _______, or address ______________________________

Student ☐ Employed full-time ☐ Retired ☐

Other ____

Do you own or have daily use of an automobile? Yes ☐ No ☐

When not using your bicycle what is your primary mode of transportation?
motor vehicle ☐ local City bus ☐ taxi ☐
interCity bus/train ☐ walking ☐ other ☐

Did you have an accident with your bicycle in the past year?

No ☐ Yes, a fall ☐ Location ______________________________.

Yes, a collision with a:
motor vehicle ☐ pedestrian ☐
another cyclist ☐ animal ☐ other ☐

8. YOUR OTHER COMMENTS.

Your completed questionnaire can be mailed via the return addressed envelope or dropped off at one of the following locations:

1) where it was acquired
2) at any City of Guelph facility
3) at any University of Guelph campus mailbox

Thank you for participating in the City's Bicycle User Survey.
If you have any questions do not hesitate to call **Derek McCaughan** at 837-5612 or **Andrew Goldie** at 837-5618.

7. PERSONAL PROFILE

Age ____ Number of years as a cyclist ____

Female ☐ Male ☐

Postal Code _______, or address ______________________________

Student ☐ Employed full-time ☐ Retired ☐

Other ____

Do you own or have daily use of an automobile? Yes ☐ No ☐

When not using your bicycle what is your primary mode of transportation?

motor vehicle ☐	local City bus ☐	taxi ☐
interCity bus/train ☐	walking ☐	other ☐

Did you have an accident with your bicycle in the past year?

No ☐ Yes, a fall ☐ Location ____________________________.

Yes, a collision with a:

motor vehicle ☐	pedestrian ☐	
another cyclist ☐	animal ☐	other ☐

8. YOUR OTHER COMMENTS.

____

____

____

____

____

____

____

Your completed questionnaire can be mailed via the return addressed envelope or dropped off at one of the following locations:

1) where it was acquired
2) at any City of Guelph facility
3) at any University of Guelph campus mailbox

Thank you for participating in the City's Bicycle User Survey. If you have any questions do not hesitate to call **Derek McCaughan** at 837-5612 or **Andrew Goldie** at 837-5618.

Appendix B: List of Variables Tested in the Multinomial Logit Route Choice Model

Route Variables Tested in the Multinomial Logit Model Estimation

1) The following utility equation variables were found to have a statistically significant coefficient independent of choice set and other equation parameters. The sign and value of these parameters is shown in Equation 2-1. Variables not in equation 2-1 had the same sign but not necessarily magnitude as the coefficient of the same variable interacted with a personal variable shown in equation 2-1.

- proportion of route on a collector roadway
- turns to/from a major road from/to a minor road without a traffic signal
- length of the route with greater than one bus per hour
- length of the route with greater than one bus per hour for male cyclists
- number of crossings of a major road from a minor/collector/path to a minor/collector/path with no traffic signal
- number of crossings of a major road from a minor/collector/path to a minor/collector/path with no traffic signal for cyclists under 19 years old
- number of crossings of a major road from a minor/collector/path to a minor/collector/path with no traffic signal for cyclists older than 18 years old
- kilometres on an up or down grade
- kilometres on an up or down grade for people who cycle in the winter
- number of grade separated railway crossings
- number of grade separated railway crossings for people who do not cycle in winter
- number of grade separated railway crossings for people who do cycle in winter
- kilometres on an average quality path

2) The following variables were sometimes found to have significant coefficients in the route choice utility equation but the coefficient magnitude, statistical significance or correlations with other parameters varied depending on the other variables included or the choice set used. It is therefore concluded that with this dataset the effect of these variables on commuter cyclist route choice cannot be determined.

- number of traffic signals in the route
- signals per kilometre
- proportion of the route on a good or average quality path
- proportion of the route on a bad or average quality path
- proportion of the route on all off-road paths
- proportion of travel on off-road paths for people who divert greater than average from their minimum path
- proportion of the route on an arterial roadway
- proportion of the route on an arterial roadways with 4 or 6 traffic lanes
- proportion of the route on an arterial roadway for cyclists who divert more than average from their minimum path route
- percent of travel on minor or collector roadways

- percent of travel on minor roadways or pathways
- total number of turns
- turns per kilometre
- percent of turns at signals
- percent of signals with turns
- kilometres on roadways with a speed limit above 50 kph
- number of major signalized intersections
- number of turns at major signalized intersections
- total distance
- length of the route with greater than one bus per hour for women
- length of travel on an up or down grade for people who cycle only in the summer
- kilometres on a poor or average quality path for people who do not cycle in winter
- kilometres on a poor or average quality path for people who do cycle in winter
- kilometres on a poor or average quality path

3) The following variables did not have statistically significant parameter coefficients with any choice set or model attempted. It therefore possible that these variables do not affect route choice for this sample of Guelph commuter cyclists.

- number of level railway crossings
- right angle level railway crossings
- angled level railway crossings
- number of bridges in the route
- number of bridges in the route for women
- number of bridges in the route for men
- number of bridges in the route for people who divert greater than average from their minimum path
- number of bridges in the route for non-adults
- travel on bad quality off-road pathways
- proportion of the route on an arterial roadway for women
- proportion of the route on an arterial roadway for men
- proportion of the route on an arterial roadway for adults
- travel on bad quality off-road pathways
- travel on bad quality off-road pathways for adults
- travel on bad quality off-road pathways for people who divert more than average from their minimum path
- proportion of travel on minor roadways
- proportion of travel on minor roadways for people who divert greater than average from their minimum path
- percent of travel on arterials and collector roadways
- number of major signalized intersections
- travel on oneway streets

4. In addition to the personal variable interactions listed above the following personal variable interactions were attempted but not found significant with any route variables.

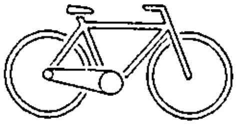
- a dummy variable indicating the route was almost all on paths or minor roadways
- a dummy variable indicating the route was almost all on arterial roadways
- a dummy variable indicating the route was almost all on arterials or collectors
- a dummy variable indicating there was less than the average diversion from the minimum path
- a dummy variable indicating the route was greater than the average one-way route length in the sample
- a dummy variable indicating the cyclist was older than 24 years
- a dummy variable indicating the cyclist was younger than 24 years
- the distance diverted from the minimum path

Appendix C: Bicycle Route and Safety Study Pre-test Questionnaire for Hamilton

(The map has been photo-reduced by 64% to fit within the thesis.)

Bicycle Route and Safety Study

If you <u>commute by bicycle to work or school</u> we would appreciate your help for a study of bicycle routes and accident levels. No matter how often you commute by bicycle, or whether you have ever had an accident, please complete this questionnaire and return it in the postage paid envelope. This study has been approved by the McMaster Committee on the Ethics of Research on Human Subjects. If you have any questions call us at 529-7070 ext 24381 or email aultman@mcmaster.ca. Thank you for your assistance.



Dr. Fred L. Hall
Professor, Dept of Civil Engineering
McMaster University

Lisa Aultman-Hall
PhD Candidate
McMaster University

If you commute to more than one location please answer this questionnaire for your most frequent trip.

1. Where do you COMMUTE by bicycle?
   - Work ___
   - University or College ___
   - Secondary School ___
   - Transit Stop ___
   - Other (please specify) ______________

2. For how long have you been commuting between your current starting point and current destination?

   ________years________months

3. For how long have you been commuting by bicycle from any home location to any work or school location?

   ________years________months

4. Last week (May 1 - 7, 1995) which days did you COMMUTE by bicycle?

   Mon___ Tues___ Wed___ Thurs___ Fri___ Sat___ Sun___

5. Considering that vacation, holidays, weather, and other changes to your routines may affect how often you can bicycle, please estimate how many times you commuted by bicycle per week in each month in the last year (June 1994 - May 1995).

   June ___
   July ___
   Aug ___
   Sept ___
   Oct ___
   Nov ___
   Dec ___
   Jan ___
   Feb ___
   March ___
   April ___
   May ___

6. Approximately how much time does your commute take (one way)? __________minutes

7. What time do you normally **leave home for** work or school ? __ __ : __ __ am pm

8. What time do you **leave** work or school ? __ __ : __ __ am pm

9. Do you wear a bicycle helmet to commute? Yes___ No___

10. When you do NOT use your bicycle to travel to work or school, how do you travel?

    Drive alone ___
    Carpool ___
    Dropped Off ___
    Transit ___
    Walk___
    Other (specify)__________

(CONTINUED ON REVERSE)

Questions 10 through 13 relate to the specific route you use to travel by bicycle to the location you indicated in question # 1. This information will remain completely confidential.

10. On the map inside this questionnaire, please trace your regular route for your trip. If your return trip follows a different route, indicate this trip also. Use arrows to show direction.
11. Please place an "H" on the map at the start of your route.
    If your starting point is NOT on the map please estimate your one way trip length. _____km
12. Some people choose to ride on a sidewalk for a portion of their trip for safety or other reasons. On the map **circle** any portions of your route where you bicycle on the sidewalk.
13. Often people do errands or other tasks on their way to or from their main destination. Mark the location of any regular stops on your route with an "X".

14. a) A **FALL** is an event where, without colliding with an object, the bicycle or cyclist lands on the ground.

How many falls (as defined above) have you had in the **last 12 MONTHS**? _____
If **none**, go to question # 15 on page 3.

Please answer the following for each fall.

	FALL A	FALL B	FALL C	FALL D
Approximate Time	__ : __ am pm	__ : __ am pm	__ : __ am pm	__ : __ am pm
Month	______	______	______	______
LOCATION: •Road •Sidewalk •Bicycle or footpath •Other (specify)	 ___ ___ ___ ______	 ___ ___ ___ ______	 ___ ___ ___ ______	 ___ ___ ___ ______
INJURIES(check one): •None •Minor •Major (medical attention required)	 ___ ___ ___	 ___ ___ ___	 ___ ___ ___	 ___ ___ ___
Cycling to/from the location in #1?	Yes__ No__	Yes__ No__	Yes__ No__	Yes__ No__
ROAD SURFACE (check as many as appropriate): •Snow/Ice •Sand/Gravel •Dry •Wet •Pavement with Cracks or Potholes	 ___ ___ ___ ___ ___	 ___ ___ ___ ___ ___	 ___ ___ ___ ___ ___	 ___ ___ ___ ___ ___

14. b) Mark the location of any falls on the MAP with the letters provided in the table in part a) of this question.

(CONTINUED ON PAGE 3)

17. A COLLISION is an event in which the bicycle collides with a stationary object or is hit by a moving object, regardless of fault or cause.

How many collisions have you had while COMMUTING in the last **THREE YEARS?**______
If **none**, please go to question # 19 on the back of this page.

Please answer the following for each of your collisions. (If you need more space - please use the last page of the questionnaire.)

	COLLISION 1	COLLISION 2	COLLISION 3
Month & Year			
Approximate Time	_ _ : _ _ am pm	_ _ : _ _ am pm	_ _ : _ _ am pm
Collision was with •Automobile •Truck •Bus •Bicycle •Pedestrian •Animal •Other (specify)	___ ___ ___ ___ ___ ___ __________	___ ___ ___ ___ ___ ___ __________	___ ___ ___ ___ ___ ___ __________
LOCATION: •Road •Sidewalk •Bicycle or footpath •Other (specify)	___ ___ ___ __________	___ ___ ___ __________	___ ___ ___ __________
At an intersection?	Yes___ No___	Yes___ No___	Yes___ No___
ROAD SURFACE (check as many as appropriate): •Snow/Ice •Sand/Gravel •Dry •Wet •Pavement with Cracks or Potholes	___ ___ ___ ___ ___	___ ___ ___ ___ ___	___ ___ ___ ___ ___
INJURIES TO YOU (check one): •None •Minor •Major (medical attention required)	___ ___ ___	___ ___ ___	___ ___ ___
Was another person injured?	Yes___ No___	Yes___ No___	Yes___ No___
Was your bicycle damaged?	Yes___ No___	Yes___ No___	Yes___ No___
Was other property damaged? If yes please specify what was damaged.	Yes___ No___ __________	Yes___ No___ __________	Yes___ No___ __________

18. Please indicate on the map the location of your collisions using the numbers (1,2 or 3) from question 17.

(CONTINUED ON REVERSE)

19. A "NEAR MISS" is an event in which a bicycle almost collides with a vehicle, cyclist, pedestrian or another object regardless of cause or fault. This includes being forced off the road.

How many "near misses" have you had while COMMUTING in the last **12 MONTHS**? ______
If **none**, please go to question 21 below.

Please answer the following for each NEAR MISS (If you need more space - please use the space below).

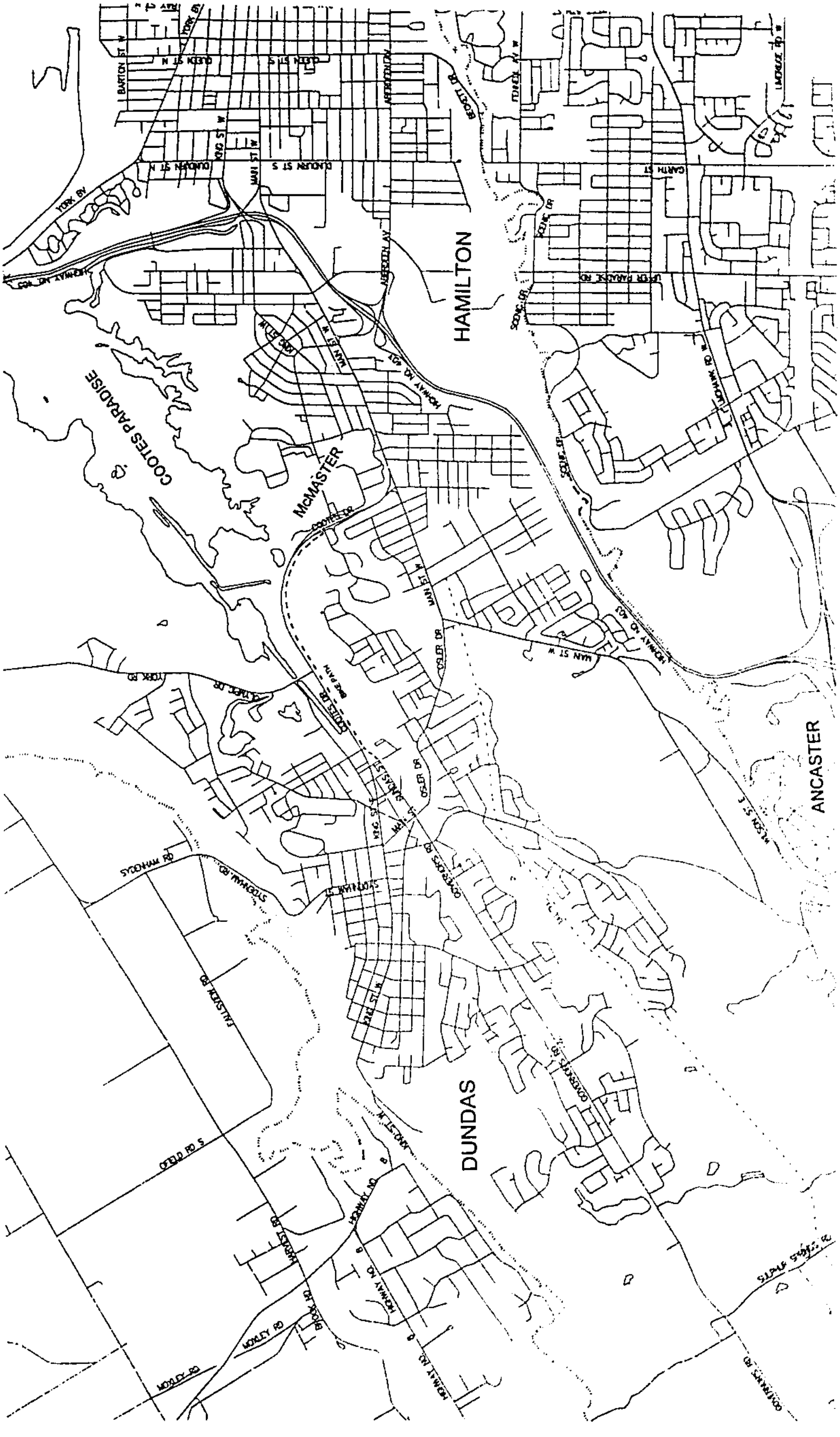
	NEAR MISS P	NEAR MISS Q	NEAR MISS R
Month			
Approximate Time	__ : __ am pm	__ : __ am pm	__ : __ am pm
NEAR MISS WITH •Automobile •Truck •Bus •Bicycle •Pedestrian •Animal •Other (specify)	___ ___ ___ ___ ___ ___ __________	___ ___ ___ ___ ___ ___ __________	___ ___ ___ ___ ___ ___ __________
LOCATION: •Road •Sidewalk •Bicycle or footpath •Other (specify)	___ ___ ___ __________	___ ___ ___ __________	___ ___ ___ __________
At an intersection?	Yes___ No___	Yes___ No___	Yes___ No___

20. Please indicate on the map the location of any NEAR MISSES using the letters from question 19 (ie P, Q or R).

21. The following information will assist researchers in estimating the risk of cycling accidents for different groups in the population.

Year of Birth: _____ Sex:_____

22. Thank you for your assistance. Please indicate in the space below any other comments you wish to make. This questionnaire will be used this year in other locations. If you would be willing to discuss your experience completing it with one of researchers involved in this study please indicate your name, phone number and a convenient time to contact you.


HAMILTON
McMASTER
COOTES PARADISE
ANCASTER
DUNDAS
YORK BV
BARTON ST W
QUEEN ST N
QUEEN ST S
ABERDEEN AV
DUNDURN ST N
DUNDURN ST S
KING ST W
MAIN ST W
MAIN ST S
HIGHWAY NO 403
GARTH ST
UPPER PARADISE RD
SCENIC DR
COOTES DR
YORK RD
OLYMPIC DR
BIKE PATH
OSLER DR
SYDENHAM RD
GOVERNORS RD
WILSON ST E
FALLSVIEW RD
OFIELD RD S
HARVEST RD
HIGHWAY NO 8
BROCK RD
MOXLEY RD

Appendix D: Bicycle Route and Safety Study Questionnaire for Toronto

(The original version of the survey questionnaire was in a single-page fold-out format. The maps have been photo-reduced by 62% to fit within the thesis.)

Bicycle Route and Safety Study

We would appreciate your help in a study of bicycle routes and accident levels. We need responses **BOTH** from people who have had accidents and from those who have not. **No matter how often you travel by bicycle, please complete this questionnaire, trace your regular route on the map provided and return it in the postage paid envelope.** This study has been approved by the McMaster Committee on the Ethics of Research on Human Subjects. If you have any questions call us collect at (905) 529-7070 ext 24381 or email aultman@mcmaster.ca. Thank you for your assistance.

Fred L. Hall
Professor, Dept of Civil Engineering
McMaster University

Lisa Aultman-Hall
PhD Candidate
McMaster University

1. Of the following possibilities, which ONE location do you travel to MOST OFTEN by bicycle? If you do not travel to one of these locations by bicycle please give this questionnaire to a friend who does.

   Place of Employment ___
   Place of Volunteer Work___
   Transit Stop ___
   Place of Education (where you are a student):
      University or College ___
      Secondary School ___
      Other schooling ___

Answer questions 2 through 9 for your trip to the location you indicated above.

2. How long have you been travelling by bicycle between your current home location and your current place of work or education? _________years_________months

3. During the week of July 3-9, 1995 (the week before this questionnaire was placed on your bicycle) which days did you make this trip by bicycle?

   Mon___ Tues___ Wed___ Thurs___ Fri___ Sat___ Sun___

4. Considering that vacation, holidays, weather, business travel and other changes to your routines may affect how often you can bicycle, please estimate the average number of times you made THIS round trip by bicycle in each month in the last year (July 1994 - June 1995).

   July ___
   Aug ___
   Sept ___
   Oct ___
   Nov ___
   Dec ___
   Jan ___
   Feb ___
   Mar ___
   April ___
   May ___
   June ___

5. On average, how much time does your trip take one way? _____________minutes

6. What time do you normally **leave home for** the location you indicated in question #1? ___ : ___ am pm

7. What time do you **leave that location** ? ___ : ___ am pm

8. Do you wear a bicycle helmet for this trip? Yes___ No___

9. When you do NOT use your bicycle to travel to this location, how do you travel?

   Drive Alone ___
   Carpool ___
   Dropped Off ___
   Public Transit ___
   Walk___
   Other (specify)_____________

(CONTINUED INSIDE)

Questions 10 through 13 relate to the specific route you use to travel by bicycle to the location you indicated in question # 1. This information will remain completely confidential.

10. On the map inside this questionnaire, please trace your regular route for your trip. If your return trip follows a different route, indicate this trip also. Use arrows to show direction.
11. Please place an "H" on the map at the start of your route.
    If your starting point is NOT on the map please estimate your one way trip length. _____km
12. Some people choose to ride on a sidewalk for a portion of their trip for safety or other reasons. On the map **circle** any portions of your route where you bicycle on the sidewalk.
13. Often people do errands or other tasks on their way to or from their main destination. Mark the location of any regular stops on your route with an "X".

14. a) A **FALL** is an event where, without colliding with an object, the bicycle or cyclist lands on the ground.

How many falls (as defined above) have you had in the **last 12 MONTHS**? _____
If **none**, go to question # 15 on page 3.

Please answer the following for each fall.

	FALL A	FALL B	FALL C	FALL D
Approximate Time	___ : ___ am pm	___ : ___ am pm	___ : ___ am pm	___ : ___ am pm
Month	________	________	________	________
LOCATION: •Road •Sidewalk •Bicycle or footpath •Other (specify)	 ____ ____ ____ ________	 ____ ____ ____ ________	 ____ ____ ____ ________	 ____ ____ ____ ________
INJURIES(check one): •None •Minor •Major (medical attention required)	 ____ ____ ____	 ____ ____ ____	 ____ ____ ____	 ____ ____ ____
Cycling to/from the location in #1?	Yes___ No___	Yes___ No___	Yes___ No___	Yes___ No___
ROAD SURFACE (check as many as appropriate): •Snow/Ice •Sand/Gravel •Dry •Wet •Pavement with Cracks or Potholes	 ____ ____ ____ ____ ____	 ____ ____ ____ ____ ____	 ____ ____ ____ ____ ____	 ____ ____ ____ ____ ____

14. b) Mark the location of any falls on the MAP with the letters provided in the table in part a) of this question.

(CONTINUED ON PAGE 3)

15. a) A **COLLISION** is an event in which the bicycle hits or is hit by any other object, regardless

How many collisions have you had in the last **THREE YEARS?**______
If **none**, please go to question # 16 on page 4.

For each collision please answer the following.

	COLLISION 1	COLLISION 2	COLLISION 3
Approximate Time	__ : __ am pm	__ : __ am pm	__ : __ am pm
Month & Year	______ 19__	______ 19__	______ 19__
Collision was with •Automobile •Truck •Bus •Bicycle •Pedestrian •Animal •Other (specify)	___ ___ ___ ___ ___ ___ __________	___ ___ ___ ___ ___ ___ __________	___ ___ ___ ___ ___ ___ __________
LOCATION: •Road •Sidewalk •Bicycle or footpath •Other (specify)	___ ___ ___ __________	___ ___ ___ __________	___ ___ ___ __________
At the intersection of two roads?	Yes___ No___	Yes___ No___	Yes___ No___
ROAD SURFACE (check as many as appropriate): •Snow/Ice •Sand/Gravel •Dry •Wet •Pavement with Cracks or Potholes	___ ___ ___ ___ ___	___ ___ ___ ___ ___	___ ___ ___ ___ ___
INJURIES TO YOU (check one): •None •Minor •Major (medical attention required)	___ ___ ___	___ ___ ___	___ ___ ___
Was another person injured?	Yes___ No___	Yes___ No___	Yes___ No___
Did the collision occur while cycling to/from the location you indicated in question #1?	Yes___ No___	Yes___ No___	Yes___ No___
Property damage over $100?	Yes___ No___	Yes___ No___	Yes___ No___
Was this collision reported to police?	Yes___ No___	Yes___ No___	Yes___ No___

15. b) Mark the location of the above collisions on the MAP with the numbers provided in the table in part a) of this question.

(CONTINUED ON PAGE 4)

16. Please answer the following questions regarding events in the last MONTH which concern bicycle safety. Responses from people who have NOT experienced these events are just as important as responses from those who have.

In the last MONTH while cycling have you...		If YES, was this while cycling to/from your work/school location?
... almost been hit by the door of a parked car?	Yes ___ No ___	Yes ___ No ___
... lost control of your bicycle but managed to avoid a collision or fall?	Yes ___ No ___	Yes ___ No ___
... caused (even if you were not at fault) a collision for one or more motor vehicles?	Yes ___ No ___	Yes ___ No ___
... almost been hit by a moving motor vehicle (including being forced off the road)?	Yes ___ No ___	Yes ___ No ___
... almost hit a pedestrian?	Yes ___ No ___	Yes ___ No ___
... almost hit or almost been hit by another bicycle?	Yes ___ No ___	Yes ___ No ___

17. Please answer the following questions regarding your cycling.

a) Do you cycle on all roads including busy streets? Yes ___ No ___
b) Do you only cycle on busy streets when it is unavoidable? Yes ___ No ___
c) Have you taken a bicycle training course? Yes ___ No ___
d) Do you belong to a cycling club? Yes ___ No ___
e) Do you bicycle for many purposes such as shopping and visiting? Yes ___ No ___
f) At busy intersections do you make left turns from the left turning lane? Yes ___ No ___

18. Estimate the average number of kilometres you bicycle per week, during your peak cycling season, for all trip purposes including recreation. ___________kilometres

19. For how long have you been commuting by bicycle from ANY home location to ANY work or school location? __________years__________months

20. The following will assist researchers in estimating the risk of cycling accidents for different groups .

Year of Birth: _____ Sex:_____

THANK YOU for your assistance.

Please indicate in the space below any other comments you wish to make.


Lake Ontario
Lake Ontario
Lake Ontario
Tommy Thompson Park
Ashbridge's Bay Park
Ontario Science Centre
York University (Glendon Campus)
Sunnybrook Park
Riverdale Park
University of Toronto
Queen's Park
Upper Canada College
CN Tower
Skydome
Union Station
High Park
Exhibition Park
Ontario Place
Yonge St
Bay St
Bloor St W
Queen St W
Dundas St W
King St W
Front St W
Spadina Ave
Bathurst St
Ossington Ave
Dufferin St
Lansdowne Ave
Keele St
Jane St
Eglinton Ave W
St Clair Ave W
Davenport Rd
Dupont St
Avenue Rd
Mount Pleasant Rd
Bayview Ave
Don Mills Rd
Don Valley Pkwy
Danforth Ave
Gerrard St E
Coxwell Ave
Pape Ave
Broadview Ave
Parliament St
Lake Shore Blvd
Gardiner Expy
Weston Rd
Black Creek Dr
Old Weston Rd
Rogers Rd
Vaughan Rd
Caledonia Rd
Oakwood Ave
College St
Harbord St
Windermere Ave
Runnymede Rd
LEGEND
Parks/Trees
Park
H
Hospital

Appendix E: Bicycle Route and Safety Study Questionnaires for Ottawa-Carleton

(The original version of the survey questionnaire was in a single-page fold-out format. The maps have been photo-reduced by 62% to fit within the thesis. The questionnaires with each of the three different maps were colour-coded. The colours have been labelled on these black and white map versions. Only one copy of the questions is included.)

Bicycle Route and Safety Study

We would appreciate your help in a study of bicycle routes and accident levels. We need responses **BOTH** from people who have had accidents and from those who have not. **No matter how often you travel by bicycle, please complete this questionnaire, trace your regular route on the map provided and return it in the postage paid envelope.** This study has been approved by the McMaster Committee on the Ethics of Research on Human Subjects. If you have any questions call us collect at (905) 529-7070 ext 24381 or email aultman@mcmaster.ca. Thank you for your assistance.

Fred L. Hall
Professor, Dept of Civil Engineering
McMaster University

Lisa Aultman-Hall
PhD Candidate
McMaster University

1. Of the following possibilities, where do you travel MOST OFTEN by bicycle? If you do not travel to one of these locations by bicycle please give this questionnaire to a friend who does.

   Place of Employment ___
   Place of Volunteer Work___
   Transit Stop ___
   Place of Education (where you are a student): University or College ___
   Secondary School ___
   Other schooling ___

Answer questions 2 through 9 for your bicycle trip to the location you indicated above.

2. How long have you been travelling by bicycle between your current home location and your current place of work or education? _________years_________months

3. During the week of June 12-18, 1995 (the week before this questionnaire was placed on your bicycle) which days did you make this trip by bicycle?

   Mon____ Tues____ Wed___ Thurs___ Fri___ Sat___ Sun___

4. Considering that vacation, holidays, weather, and other changes to your routines may affect how often you can bicycle, please estimate the average number of times you made THIS trip by bicycle <u>per week</u> in each month in the last year (June 1994 - May 1995).

   June___
   July ___
   Aug ___
   Sept ___
   Oct ___
   Nov ___
   Dec ___
   Jan ___
   Feb ___
   March ___
   April ___
   May ___

5. On average how much time does your trip take one way? _____________minutes

6. What time do you normally leave home for the location you indicated in question #1? ___ : ___ am pm

7. What time do you leave that location ? ___ : ___ am pm

8. Do you wear a bicycle helmet for this trip? Yes___ No___

9. When you do NOT use your bicycle to travel to this location, how do you travel?

   Drive alone ___
   Carpool ___
   Dropped Off ___
   Public Transit ___
   Walk___
   Other (specify)_______________

(CONTINUED INSIDE)

Questions 10 through 13 relate to the specific route you use to travel by bicycle to the location you indicated in question # 1. This information will remain completely confidential.

10. On the map inside this questionnaire, please trace your regular route for your trip. If your return trip follows a different route, indicate this trip also. Use arrows to show direction.

11. Please place an "H" on the map at the start of your route.
    If your starting point is NOT on the map please estimate your one way trip length. _____km

12. Some people choose to ride on a sidewalk for a portion of their trip for safety or other reasons. On the map **circle** any portions of your route where you bicycle on the sidewalk.

13. Often people do errands or other tasks on their way to or from their main destination. Mark the location of any regular stops on your route with an "X".

14. A **FALL** is an event where without colliding with an object the bicycle or cyclist lands on the ground.

How many falls (as defined above) have you had in the last 12 **MONTHS**? _____
If **none**, go to question # 15 on page 3.

Please answer the following for each fall. If the fall occurred within the map area, mark the location of the fall on the map with the letters given.

	FALL A	FALL B	FALL C	FALL D
Approximate Time	___ : ___ am pm	___ : ___ am pm	___ : ___ am pm	___ : ___ am pm
Month	__________	__________	__________	__________
LOCATION: •Road •Sidewalk •Bicycle or footpath •Other (specify)	____ ____ ____ ____________	____ ____ ____ ____________	____ ____ ____ ____________	____ ____ ____ ____________
INJURIES(check one): •None •Minor •Major (medical attention required)	____ ____ ____	____ ____ ____	____ ____ ____	____ ____ ____
Cycling to/from the location in #1?	Yes___ No___	Yes___ No___	Yes___ No___	Yes___ No___
ROAD SURFACE (check as many as appropriate): •Snow/Ice •Sand/Gravel •Dry •Wet •Pavement with Cracks or Potholes	____ ____ ____ ____ ____	____ ____ ____ ____ ____	____ ____ ____ ____ ____	____ ____ ____ ____ ____

(CONTINUED ON PAGE 3)

15. **A COLLISION** is an event in which the bicycle hits or is hit by any other object, regardless of

How many collisions have you had in the last **THREE YEARS?**_______
If **none**, please go to question # 16 on page 4.

Please answer the following for each of your collisions. If the collision occurred in the area shown on the map please mark the location with the numbers given. (If you need more room, please use the space on page 4.)

	COLLISION 1	COLLISION 2	COLLISION 3
Approximate Time	__ : __ am pm	__ : __ am pm	__ : __ am pm
Month & Year	_______ 19__	_______ 19__	_______ 19__
Collision was with •Automobile •Truck •Bus •Bicycle •Pedestrian •Animal •Other (specify)	___ ___ ___ ___ ___ ___ ______________	___ ___ ___ ___ ___ ___ ______________	___ ___ ___ ___ ___ ___ ______________
LOCATION: •Road •Sidewalk •Bicycle or footpath •Other (specify)	___ ___ ___ ______________	___ ___ ___ ______________	___ ___ ___ ______________
At the intersection of two roads?	Yes___ No___	Yes___ No___	Yes___ No___
ROAD SURFACE (check as many as appropriate): •Snow/Ice •Sand/Gravel •Dry •Wet •Pavement with Cracks or Potholes	___ ___ ___ ___ ___	___ ___ ___ ___ ___	___ ___ ___ ___ ___
INJURIES TO YOU (check one): •None •Minor •Major (medical attention required)	___ ___ ___	___ ___ ___	___ ___ ___
Was another person injured?	Yes___ No___	Yes___ No___	Yes___ No___
Did the collision occur while cycling to/from the location you indicated in question #1?	Yes___ No___	Yes___ No___	Yes___ No___
Property damage over $100?	Yes___ No___	Yes___ No___	Yes___ No___
Was this collision reported to police?	Yes___ No___	Yes___ No___	Yes___ No___

(CONTINUED ON PAGE 4)

PAGE 4 of 4

16. Please answer the following questions regarding events which concern bicycle safety. Responses from people who have not experienced these events are just as important as responses from those who have.

In the last MONTH while cycling have you...		If YES, was this while cycling to/from your work/school location?
... almost been hit by the door of a parked car?	Yes ___ No ___	Yes ___ No ___
... lost control of your bicycle but managed to avoid a collision or fall?	Yes ___ No ___	Yes ___ No ___
... caused (even if you were not at fault) a collision for one or more motor vehicles?	Yes ___ No ___	Yes ___ No ___
... almost been hit by a moving motor vehicle (including being forced off the road)?	Yes ___ No ___	Yes ___ No ___
... almost hit a pedestrian?	Yes ___ No ___	Yes ___ No ___
... almost hit or almost been hit by another bicycle?	Yes ___ No ___	Yes ___ No ___

17. Please answer the following questions regarding your cycling.

a) Do you cycle on all roads including busy streets? Yes ___ No ___
b) Do you cycle only on busy streets when it is unavoidable? Yes ___ No ___
c) Have you taken a bicycle training course? Yes ___ No ___
d) Do you belong to a cycling club? Yes ___ No ___
e) Do you bicycle for many purposes such as shopping and visiting? Yes ___ No ___
f) At busy signalized intersections do you make left turns from the left most lane?Yes ___ No ___

18. Estimate the average number of kilometres you bicycle per week, during your peak cycling season, for all trip purposes including recreation. __________kilometres

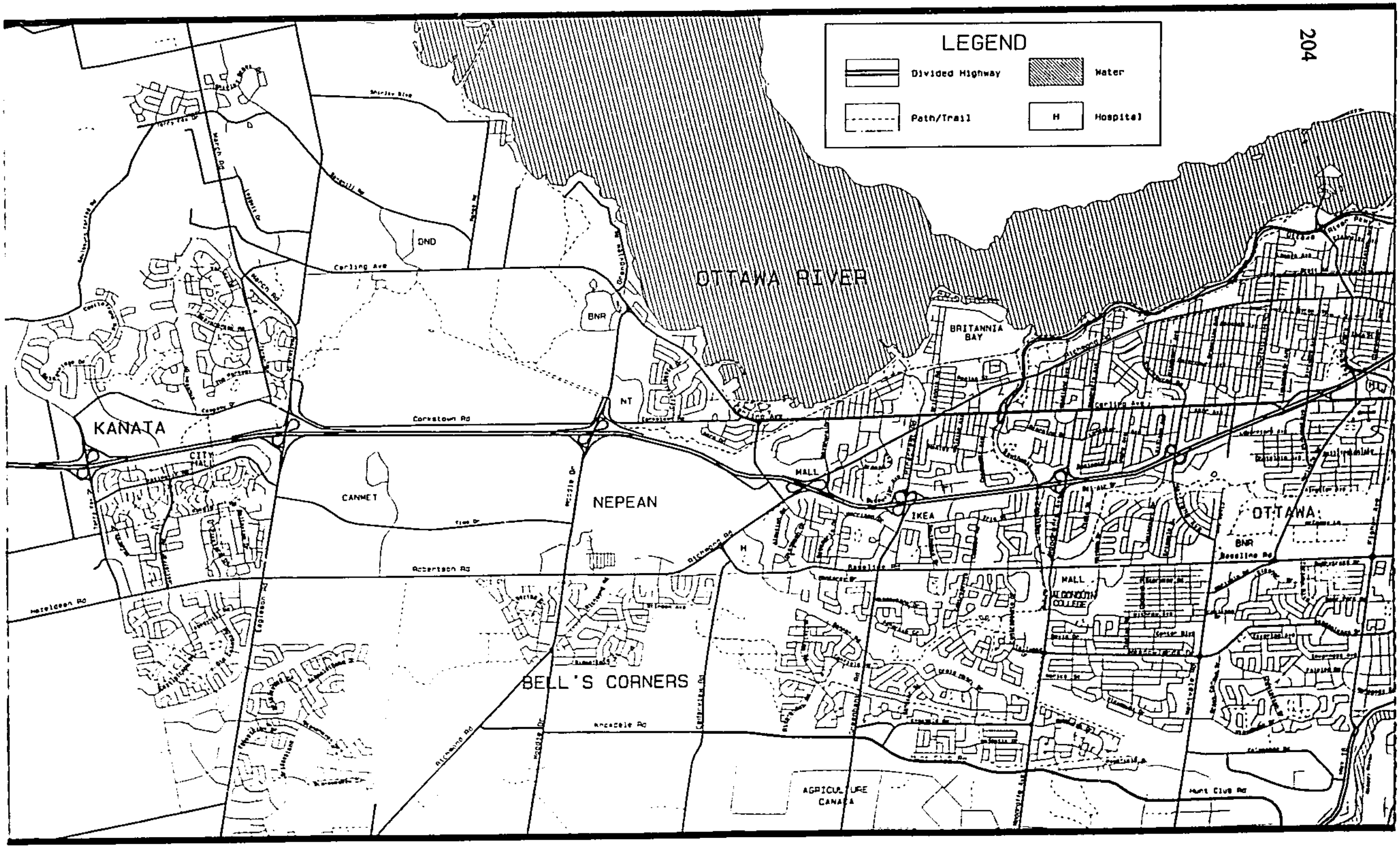
19. For how long have you been commuting by bicycle from any home location to any work or school location? __________years__________months

20. The following will assist researchers in estimating the risk of cycling accidents for different groups .

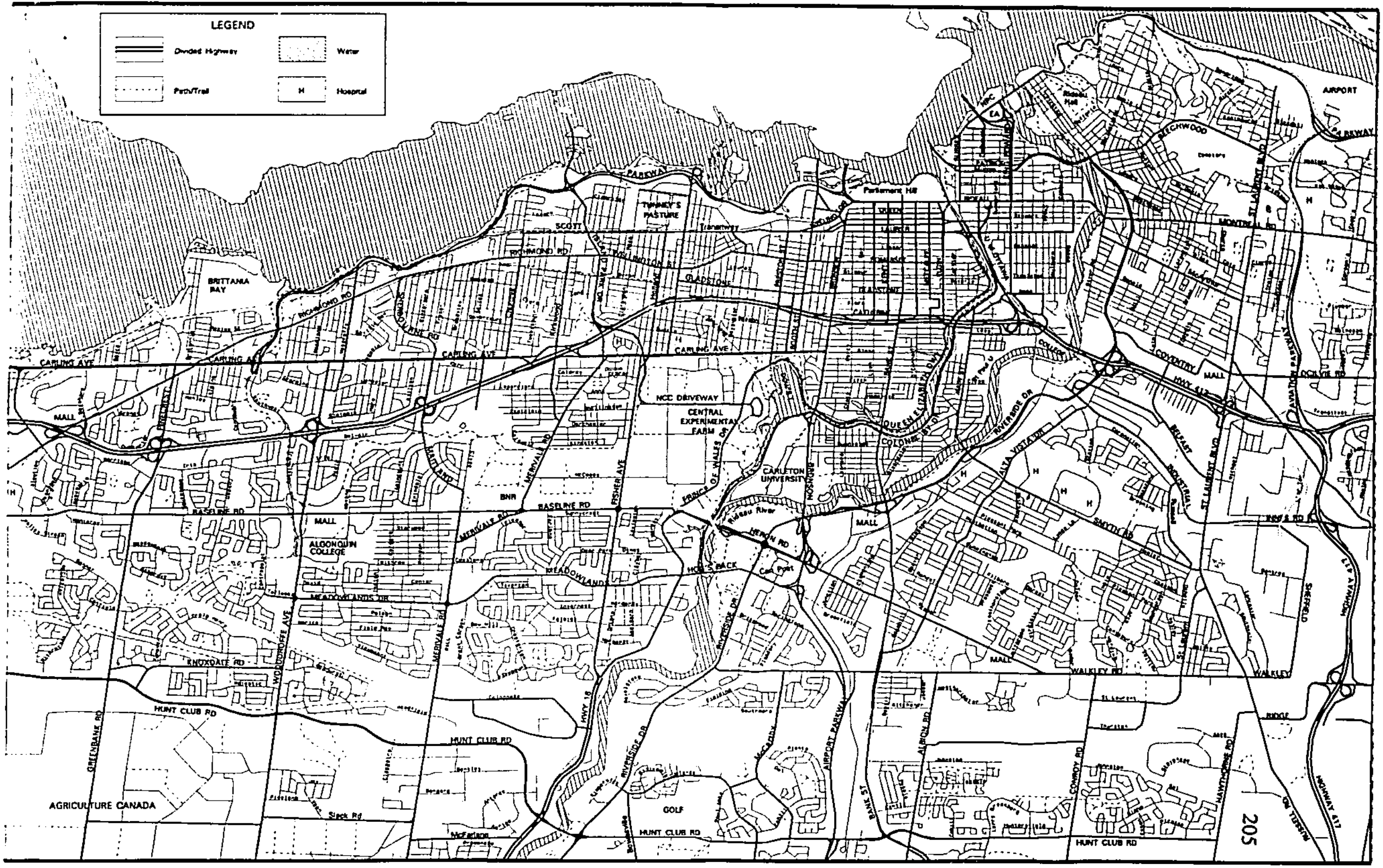
Year of Birth: _____ Sex:_____

THANK YOU for your assistance.
Please indicate in the space below any other comments you wish to make.

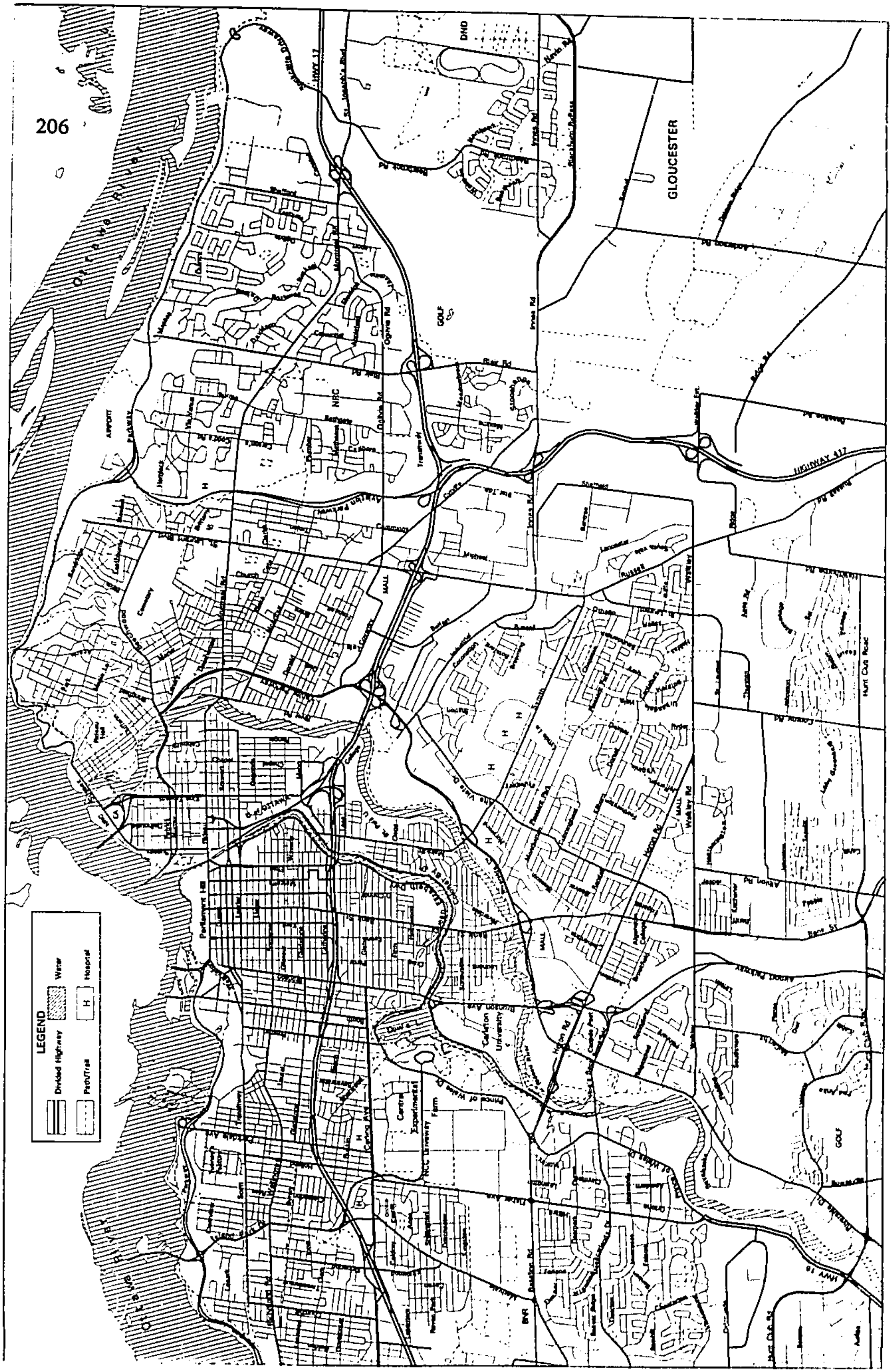
BLUE


204
LEGEND
Divided Highway
Water
Path/Trail
H
Hospital
OTTAWA RIVER
BRITANNIA BAY
DND
BNR
NT
KANATA
CITY HALL
CANMET
NEPEAN
MALL
IKEA
H
OTTAWA
BNR
MALL
ALGONQUIN COLLEGE
BELL'S CORNERS
AGRICULTURE CANADA
Carling Ave
March Rd
Corkstown Rd
Robertson Rd
Hazeldean Rd
Eagleson Rd
Moodie Dr
Richmond Rd
Baseline Rd
Hunt Club Rd
Fisher Ave

YELLOW


LEGEND
Divided Highway
Water
Path/Trail
Hospital
H
AIRPORT
PARKWAY
BEECHWOOD
ST LAURENT BLVD
MONTREAL RD
Parliament Hill
RIDEAU
SCOTT
TUNNEY'S PASTURE
RICHMOND RD
GLADSTONE
BRITTANIA BAY
CARLING AVE
COVENTRY
MALL
OGILVIE RD
AVIATION PARKWAY
HWY 417
NCC DRIVEWAY
CENTRAL EXPERIMENTAL FARM
QUEEN ELIZABETH DRWY
COLONEL BY DR
CARLETON UNIVERSITY
RIVERSIDE DR
ALTA VISTA DR
BELFAST
INDUSTRIAL
INNES RD
SMYTH RD
BASELINE RD
FISHER AVE
MERIVALE RD
BNR
PRINCE OF WALES DR
BRONSON
Rideau River
HERON RD
HOG'S BACK
ALGONQUIN COLLEGE
MEADOWLANDS DR
WOODROFFE AVE
KNOXDALE RD
HUNT CLUB RD
GREENBANK RD
AGRICULTURE CANADA
Slack Rd
McFarlane
HWY 16
GOLF
AIRPORT PARKWAY
BANK ST
ALBION RD
CONROY RD
HAWTHORNE RD
WALKLEY RD
SHEFFIELD
RIDGE
RUSSELL RD
HIGHWAY 417

GREEN


LEGEND
Divided Highway
Water
Path/Trail
Hospital
H
GLOUCESTER
HIGHWAY 417
AIRPORT
NRC
GOLF
MALL
Parliament Hill
Carleton University
Central Experimental Farm
HWY 16

Appendix F: Ottawa Organizations that Gave Permission for Questionnaire Distribution

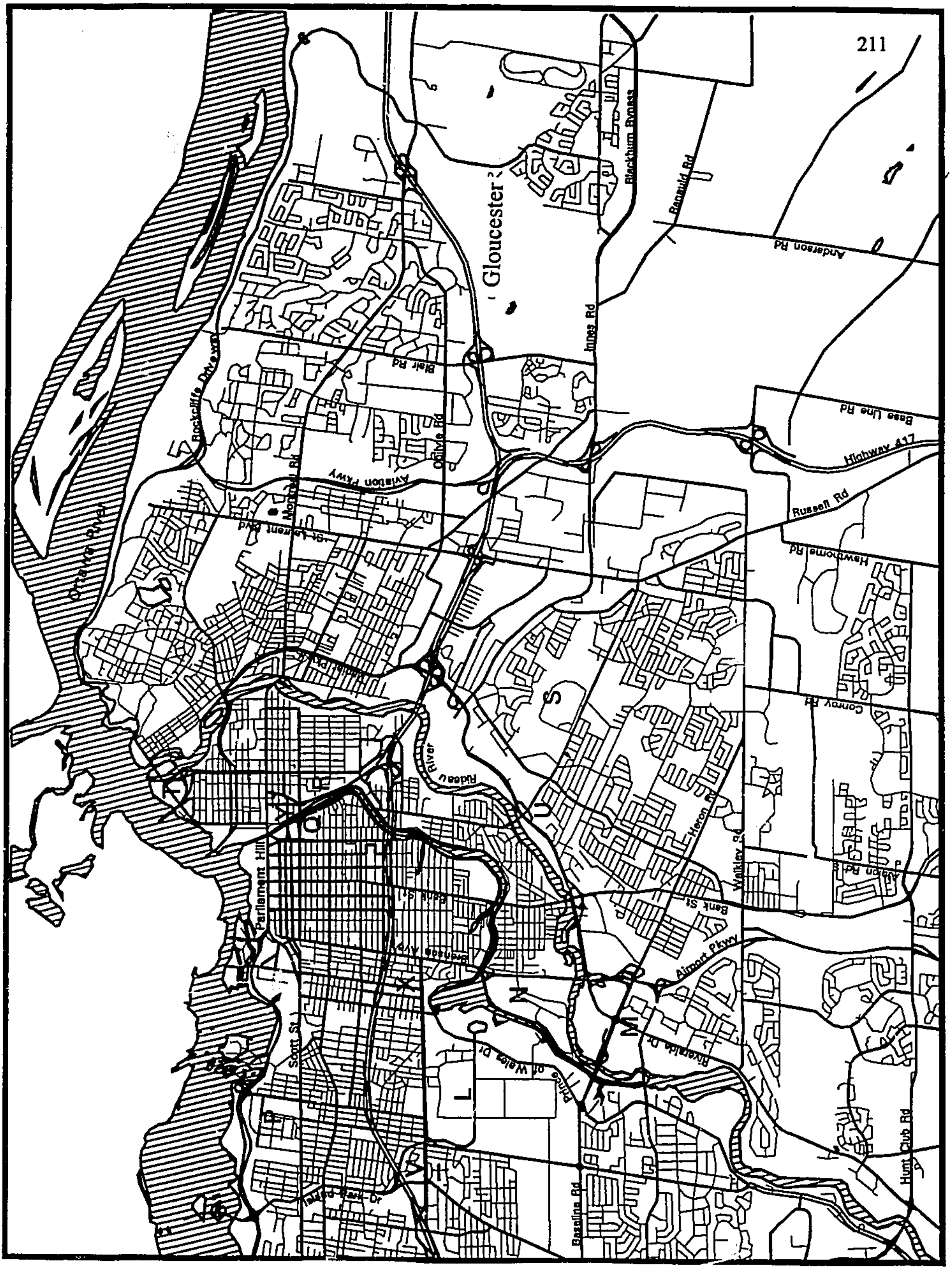
The following organizations gave their permission for bicycle route and safety study questionnaires to be placed on the crossbars of parked bicycles on their property in the Regional Municipality of Ottawa-Carleton.

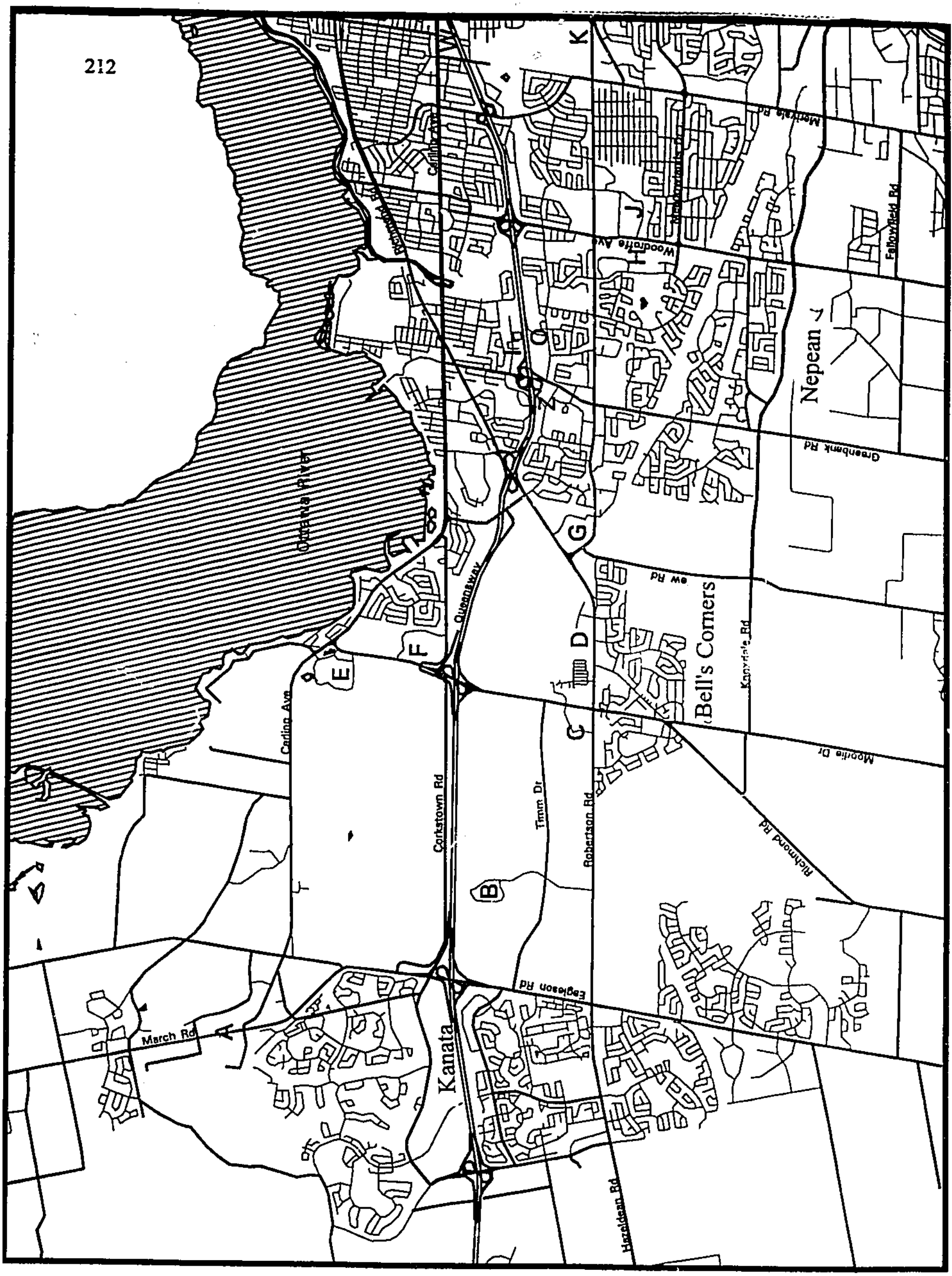
Agriculture Canada
Algonquin College
Bell Canada
Bell Northern Research
Betz
CANMET
Canada Post
Canadian Marconi
Carleton University
Children's Hospital of Eastern Ontario
City of Nepean
City of Ottawa
Computing Devices
Corel
Department of Justice
Department of National Defense
Digital
External Affairs and International Trade
Lockheed
Mitel
National Defense Medical Centre
National Research Council
Newbridge
Nordion
OC Transpo
Ottawa Citizen
Ottawa Civic Hospital
Ottawa General Hospital
Public Works Canada
Regional Municipality of Ottawa-Carleton
Riverside Hospital
Royal Ottawa Hospital
Transport Canada
University of Ottawa

Appendix G: Ottawa-Carleton Questionnaire Distribution Areas

Letter on Map (follows Table)	Area	Survey Day (s)	Number of Sites (Approx)	Map Colour (See App E)	Number of Surveys Distributed
A	Kanata North Industrial Park	Monday Tuesday Thursday	8	Blue	101
B	Bell's Corner's Complex (CANMET)	Tuesday	1	Blue	4
C	Fitzgerald Drive	Thursday	1	Blue	6
D	Computing Devices	Wednesday	1	Blue	17
E	Bell Northern Research	Wednesday	1	Blue	203
F	Bell Northern Research / Northern Telecom	Wednesday	1	Blue	42
G	Queensway Carleton Hospital and Area	Wednesday Thursday	2	Blue	17
H	Nepean Civic Centre and Area	Wednesday Thursday	4	Blue	41
I	Queensview Drive	Thursday	2	Blue	6
J	Algonquin College	Monday	1	Blue	25
K	Bell Northern Research	Thursday	1	Yellow	97
L	Central Experimental Farm and Civic Hospital	Tuesday Thursday	2	Yellow	148
M	Canada Post and Sir Charles Tupper Building	Monday	2	Yellow	84
N	Carleton University	Tuesday	1	Yellow	367
O	Ottawa Citizen and Area	Thursday	2	Blue	21
P	Tunney's Pasture	Thursday	1	Yellow	354
Q	Downtown Core	Monday Wednesday	*	Green	580
R	University of Ottawa	Wednesday	1	Green	165
T	NRC, City Hall and External Affairs	Monday Wednesday	3	Green	232
S	Riverview Medical Centre	Tuesday Wednesday	3	Green	179
U	Riverside Hospital	Monday	1	Green	24
V	Royal Ottawa Hospital	Monday	1	Yellow	19
W	Corel	Thursday	1	Yellow	39
X	Booth Street Complex (CANMET)	Tuesday	1	Yellow	205
Y	Department of National Defense	Wednesday	1	Green	70
Z	Morrison Drive	Thursday	3	Blue	7

* The downtown core in this case refers to the area west of the Rideau Canal, South of the Ottawa River, North of Lisgar and East of Bay Street. There were far more bicycles in this area than questionnaires could be distributed on. Questionnaires were placed on bicycles at many large parking areas, in racks on the street and in one indoor bicycle room. Tourist areas were avoided.


Gloucester
Blackburn Bypass
Renauld Rd
Anderson Rd
Innes Rd
Blair Rd
Base Line Rd
Highway 417
Russell Rd
Hawthorne Rd
Conroy Rd
Albion Rd
Walkley Rd
Heron Rd
Bank St
Airport Pkwy
Riverside Dr
Hunt Club Rd
Baseline Rd
Prince of Wales Dr
Island Park Dr
Scott St
Parliament Hill
Bronson Ave
Rideau River
Ottawa River
Rockcliffe Driveway
Montreal Rd
Aviation Pkwy
Ogilvie Rd
St Laurent Blvd
Vanier Pkwy
S
U
R
Q
X
N
M
O
L


Ottawa River
Nepean
Bell's Corners
Kanata
Richmond Rd
Carling Ave
Woodroffe Ave
Meadowlands Dr
Merivale Rd
Fallowfield Rd
Greenbank Rd
Knoxdale Rd
Moodie Dr
Robertson Rd
Timm Dr
Corkstown Rd
Queensway
Eagleson Rd
March Rd
Hazeldean Rd
ew Rd
Carling Ave
A
B
C
D
E
F
G
H
J
K
N
O

Appendix H: Indoor and Caged Distribution Locations in Toronto

The following locations provide indoor or caged bicycle parking for their employees. A map of the locations follows within this appendix.

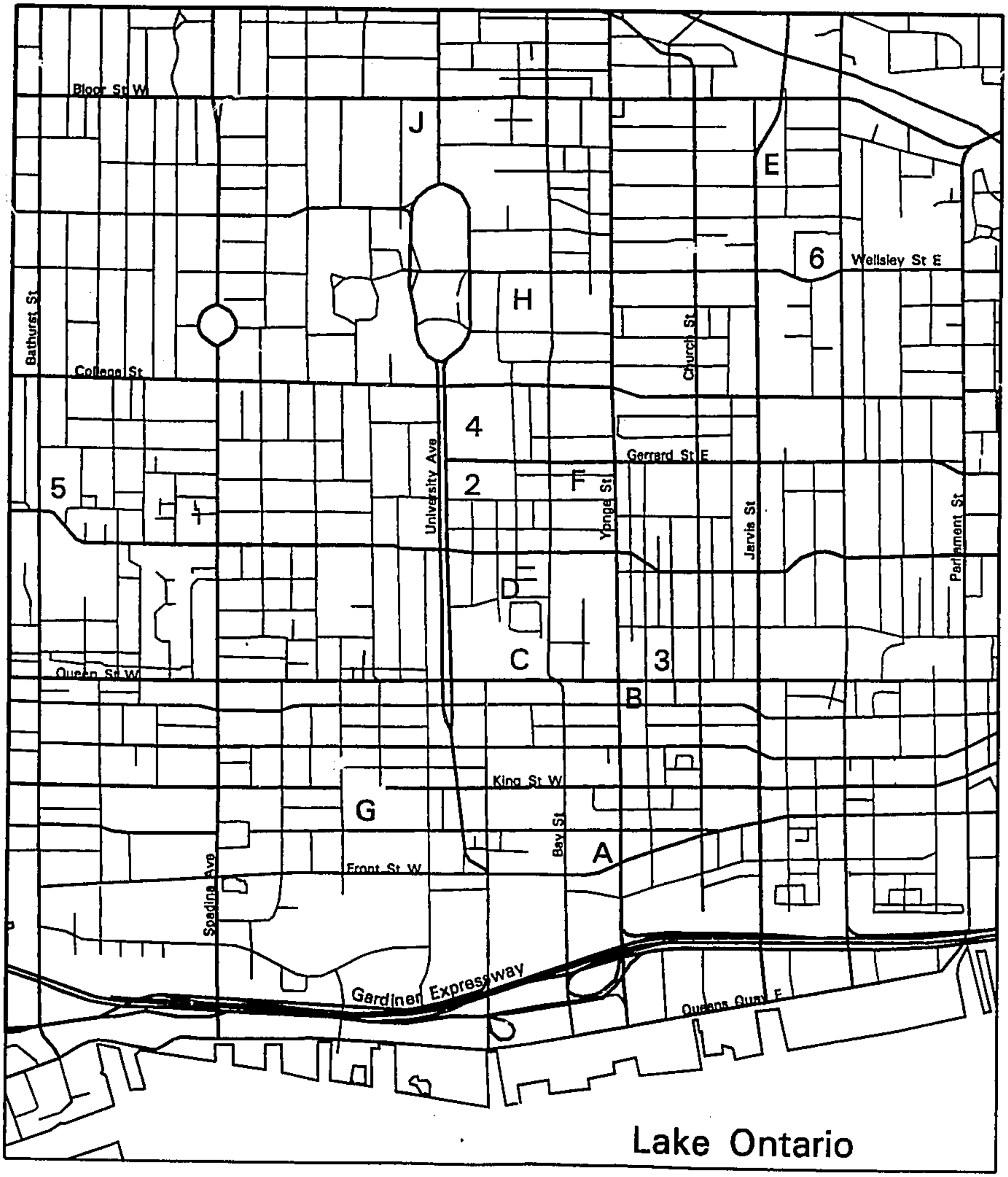
Indoors

Location	Map Location	Number Distributed
BCE Place	A	23
Cambridge Suites Hotel	B	3
City Hall	C	30
Colony Hotel	D	6
Confederation Life	E	3
Delta Chelsea Inn	F	1
Metro Hall	G	20
Queen's Park	H	5
Royal Ontario Museum	J	15

Cages

Location	Map Location	Number Distributed
Hospital for Sick Children	2	97
St. Michael's Hospital	3	14
The Toronto Hospital	4	20
Toronto Western Hospital	5	15
Wellsley Hospital	6	25

Map of the indoor and caged bicycle parking areas at which questionnaires were distributed in Toronto. Letters correspond to the letters provided in the table on the previous page of this appendix.



Appendix I: Organizations in Toronto that Granted Permission for Survey Distribution

The following organizations gave permission for questionnaires to be distributed on their property in Toronto.

Art Gallery of Ontario
BCE Place
Bell Trinity Square
Cambridge Suites Hotel
Canadian Broadcasting Corporation
Citibank Place
Toronto City Hall
Colony Hotel
Commerce Court
Confederation Life
Delta Chelsea Inn
Guardian Tower
Hospital for Sick Children
Legislative Building
Metro Hall
Mount Sinai Hospital
National Bank Building
Ontario Hydro
Ontario Court House
Osgood Hall
Queen Elizabeth Hospital
Queen's Park
Royal Ontario Museum
Ryerson Polytechnical Institute
Scotia Bank Centre
St. Michael's Hospital
Sun Life Building
The Toronto Hospital
Toronto Board of Education
Toronto Western Hospital
University of Toronto
Waterpark Place
Wellesley Hospital
Xerox Centre

Appendix J: Ottawa-Carleton Event Rates Subdivided by Personal Variables

Unweighted Relative Event Rates for Men Versus Women

Relative Rate for ...	Event	Relative Rate	Statistical Significance[8] (level)	Lower 95% Confidence Interval[9]	Upper 95% Confidence Interval
Men versus Women	Collision	0.7	(0.05)	0.5	1.0
	Fall	1.1	No Diff (0.5)	0.7	1.5
	Injury	0.9	No Diff (0.5)	0.6	1.2
	Major Injury	1.8	No Diff (0.25)	0.4	5.0

Unweighted Relative Event Rates for Different Age Categories

Relative Rate for ...	Event	Relative Rate	Statistical Significance (level)	Lower 95% Confidence Interval	Upper 95% Confidence Interval
30-39 year olds versus 18-29 year olds	Collision	0.7	No Sign. Diff (0.1)	0.5	1.1
	Fall	0.5	0.001	0.4	0.7
	Injury	0.5	0.01	0.4	0.8
	Major Injury	0.6	No Sign. Diff (0.5)	0.2	1.6
over 40 year olds versus 18-29 year olds	Collision	0.5	0.001	0.3	0.7
	Fall	0.7	0.05	0.5	0.9
	Injury	0.7	No Sign. Diff (0.1)	0.5	1.0
	Major Injury	0.6	No Sign. Diff (0.5)	0.2	1.5
over 40 year olds versus 30-39 year olds	Collision	0.6	0.005	0.5	0.9
	Fall	1.3	No Sign. Diff (0.1)	0.9	1.7
	Injury	1.2	No Sign. Diff (0.25)	0.9	1.7
	Major Injury	0.9	No Sign. Diff (0.75)	0.4	2.3

---

[8] This result is based on the Hauer hypothesis test software described in section 5.5.1.

[9] Confidence intervals derived from Cox's F-test described in section 5.5.1.

Unweighted Relative Event Rates for Different Number of Years Commuting

Relative Rate for ...	Event	Relative Rate	Statistical Significance (level)	Lower 95% Confidence Interval	Upper 95% Confidence Interval
>9 years commuting versus 6-9 years commuting	Collision	0.9	No Diff (0.5)	0.6	1.3
	Fall	0.9	No Diff (0.5)	0.6	1.4
	Injury	1.0	No Diff (0.75)	0.6	1.5
	Major Injury	2.0	No Diff (0.25)	0.5	5.9
> 9 years commuting versus 3-6 years commuting	Collision	1.0	No Diff (0.5)	0.7	1.5
	Fall	1.0	No Diff (0.5)	0.7	1.5
	Injury	0.9	No Diff (0.5)	0.6	1.3
	Major Injury	0.9	No Diff (0.75)	0.4	2.4
6-9 years commuting versus 3-6 years commuting	Collision	1.1	No Diff (0.5)	0.8	1.7
	Fall	1.0	No Diff (0.5)	0.7	1.5
	Injury	0.9	No Diff (0.5)	0.6	1.4
	Major Injury	0.5	No Diff (0.25)	0.2	1.9
> 9 years commuting versus 0-3 years commuting	Collision	0.6	(0.05)	0.4	1.0
	Fall	0.7	No Diff (0.1)	0.5	1.1
	Injury	0.8	No Diff (0.25)	0.5	1.2
	Major Injury	1.3	No Diff (0.5)	0.4	3.7
6-9 years commuting versus 0-3 years commuting	Collision	0.7	No Diff (0.1)	0.5	1.1
	Fall	0.7	No Diff (0.25)	0.5	1.2
	Injury	0.8	No Diff (0.25)	0.5	1.2
	Major Injury	0.7	No Diff (0.5)	0.2	2.8
3-6 years commuting versus 0-3 years commuting	Collision	0.6	(0.05)	0.4	0.9
	Fall	0.8	No Diff (0.1)	0.5	1.1
	Injury	0.9	No Diff (0.5)	0.6	1.3
	Major Injury	1.4	No Diff (0.5)	0.4	4.1

Unweighted Relative Event Rates for Different Categories of Weekly Bicycle Travel

Relative Rate for ...	Event	Relative Rate	Statistical Significance (level)	Lower 95% Confidence Interval	Upper 95% Confidence Interval
...those who travel 40-80 km per week in peak season versus those who bicycle 0-40 km	Collision on a road	1.1	No Diff (0.5)	0.5	2.0
	Collision on a Path/trail	1.1	No Diff (0.75)	0.2	3.3
	Collision on a Sidewalk	0.9	No Diff (0.75)	0.02	9.2
	Fall on a road	1.1	No Diff (0.5)	0.6	1.8
	Fall on a Path/trail	0.5	No Diff (0.1)	0.2	1.2
	Fall on a Sidewalk	0.8	No Diff (0.25)	0.2	2.7
	Injury on a Road	0.8	No Diff (0.5)	0.4	1.4
	Injury on a Path/trail	0.6	No Diff (0.25)	0.2	1.5
	Injury on Sidewalk	0.5	No Diff (0.25)	0.1	2.1
	Major Injury on Road	0.8	No Diff (1.0)	0.1	7.3
	Major Injury on Path	0.5	No Diff (0.5)	0.0	2.8
...those who travel > 120 km per week in peak season versus those who bicycle 80-120 km	Collision on a road	1.0	No Diff (0.5)	0.6	1.6
	Collision on a Path/trail	0.7	No Diff (0.25)	0.3	1.4
	Collision on a Sidewalk	0.2	No Diff (0.25)	0.0	6.8
	Fall on a road	0.8	No Diff (0.5)	0.5	1.3
	Fall on a Path/trail	0.6	No Diff (0.1)	0.3	1.1
	Fall on a Sidewalk	1.3	No Diff (0.75)	0.2	4.4
	Injury on a Road	0.9	No Diff (0.5)	0.5	1.5
	Injury on a Path/trail	0.6	No Diff (0.1)	0.3	1.1
	Injury on Sidewalk	0.8	No Diff (0.5)	0.2	2.8
	Major Injury on Road	0.9	No Diff (0.75)	0.3	2.4
	Major Injury on Path	1.0	No Diff (0.75)	0.0	10.7
...those who travel >120 km per week in peak season versus those who bicycle 0-40 km	Collision on a road	0.9	No Diff (0.5)	0.5	1.5
	Collision on a Path/trail	0.5	No Diff (0.25)	0.1	1.5
	Collision on a Sidewalk	0.2	No Diff (0.5)	0.0	9.3
	Fall on a road	0.4	(0.005)	0.2	0.7
	Fall on a Path/trail	0.4	(0.05)	0.2	0.7
	Fall on a Sidewalk	0.5	No Diff (0.25)	0.1	1.7
	Injury on a Road	0.6	No Diff (0.1)	0.3	1.1
	Injury on a Path/trail	0.4	No Diff (0.1)	0.2	1.0
	Injury on Sidewalk	0.4	No Diff (0.25)	0.1	1.5
	Major Injury on Road	2.1	No Diff (0.75)	0.2	7.4

	Major Injury on Path	0.1	No Diff (0.1)	0.0	1.3
...those who travel 80-120 km per week in peak season versus those who bicycle 40-80 km	Collision on a road	0.8	No Diff (0.25)	0.5	1.3
	Collision on a Path/trail	0.7	No Diff (0.25)	0.3	1.6
	Collision on a Sidewalk	1.6	No Diff (0.5)	0.2	9.9
	Fall on a road	0.5	(0.005)	0.3	0.9
	Fall on a Path/trail	1.1	No Diff (0.5)	0.6	2.0
	Fall on a Sidewalk	0.5	No Diff (0.25)	0.1	2.6
	Injury on a Road	0.9	No Diff (0.5)	0.5	1.6
	Injury on a Path/trail	1.3	No Diff (0.5)	0.6	2.7
	Injury on Sidewalk	1.1	No Diff (0.75)	0.3	5.0
	Major Injury on Road	3.2	No Diff (1.0)	0.4	14.3
	Major Injury on Path	0.3	No Diff (0.5)	0.0	11.4
...those who travel 80-120 km per week in peak season versus those who bicycle 0-40 km	Collision on a road	0.9	No Diff (0.5)	0.4	1.6
	Collision on a Path/trail	0.8	No Diff (0.5)	0.2	2.4
	Collision on a Sidewalk	1.4	No Diff (0.75)	0.0	10.0
	Fall on a road	0.5	(0.05)	0.3	1.0
	Fall on a Path/trail	0.6	No Diff (0.25)	0.3	1.2
	Fall on a Sidewalk	0.4	No Diff (1.0)	0.1	2.3
	Injury on a Road	0.7	No Diff (0.25)	0.3	1.3
	Injury on a Path/trail	0.8	No Diff (0.5)	0.3	1.8
	Injury on Sidewalk	0.5	No Diff (0.5)	0.1	2.4
	Major Injury on Road	1.2	No Diff (0.75)	0.1	5.2
	Major Injury on Path	0.1	No Diff (0.25)	0.0	5.2
...those who travel > 120 km per week in peak season versus those who bicycle 40-80 km	Collision on a road	0.8	No Diff (0.25)	0.5	1.2
	Collision on a Path/trail	0.5	(0.05)	0.2	1.0
	Collision on a Sidewalk	0.3	No Diff (0.5)	0.0	10.8
	Fall on a road	0.4	(0.001)	0.3	0.6
	Fall on a Path/trail	0.7	No Diff (0.25)	0.4	1.2
	Fall on a Sidewalk	0.6	No Diff (0.5)	0.2	1.8
	Injury on a Road	0.8	No Diff (0.25)	0.5	1.3
	Injury on a Path/trail	0.7	No Diff (0.25)	0.3	1.5
	Injury on Sidewalk	0.9	No Diff (0.75)	0.2	3.2
	Major Injury on Road	2.2	No Diff (0.5)	0.3	7.6
	Major Injury on Path	0.3	No Diff (0.25)	0.0	2.7

Unweighted Relative Event Rates for Those Who Do and Do Not Use the Left Turn Lane At Busy Intersections

Relative Rate for ...	Event	Relative Rate	Statistical Significance (level)	Lower 95% Confidence Interval	Upper 95% Confidence Interval
...those who do not use the left turn lane versus those who do	Collision on a road	0.8	No Diff (0.25)	0.5	1.4
	Collision on a Path/trail	0.8	No Diff (0.5)	0.4	1.9
	Collision on a Sidewalk	0.3	No Diff (0.5)	0.1	13.4
	Fall on a road	0.8	No Diff (1.0)	0.5	1.3
	Fall on a Path/trail	0.6	No Diff (0.1)	0.4	1.2
	Fall on a Sidewalk	1.2	No Diff (0.5)	0.5	3.1
	Injury on a Road	1.0	No Diff (0.1)	0.7	1.7
	Injury on a Path/trail	0.6	No Diff (0.25)	0.3	1.3
	Injury on Sidewalk	1.3	No Diff (0.5)	0.5	3.5
	Major Injury on Road	1.3	No Diff (1.25)	0.5	4.3
	Major Injury on Path	1.1	No Diff (0.75)	0.2	9.3

Unweighted Relative Event Rates for Those Who Answered Yes and No to the Busy Street Question

Relative Rate for ...	Event	Relative Rate	Statistical Significance (level)	Lower 95% Confidence Interval	Upper 95% Confidence Interval
...those who answered yes versus those who answered no	Collision on a road	1.0	No Diff (0.5)	0.6	1.4
	Collision on a Path/trail	1.3	No Diff (1.0)	0.5	2.5
	Collision on a Sidewalk	0.2	No Diff (1.0)	0.0	1.2
	Fall on a road	1.1	No Diff (0.5)	0.8	1.6
	Fall on a Path/trail	0.8	No Diff (0.5)	0.5	1.3
	Fall on a Sidewalk	8.1	No Diff(.0)	0.2	32.8
	Injury on a Road	1.3	No Diff (0.25)	0.8	1.9
	Injury on a Path/trail	1.3	No Diff (0.5)	0.6	2.5
	Injury on Sidewalk	1.3	No Diff (0.1)	0.4	10.4
	Major Injury on Road	0.8	No Diff (0.5)	0.3	1.9
	Major Injury on Path	0.9	No Diff (0.75)	0.1	3.6

Unweighted Relative Event Rates for Those Who Have or Have not Participated in a Bicycle Club or Course

Relative Rate for ...	Event	Relative Rate	Statistical Significance (level)	Lower 95% Confidence Interval	Upper 95% Confidence Interval
...those who have participated in a club or course versus those who have not	Collision on a road	0.9	No Diff (0.5)	0.6	1.7
	Collision on a Path/trail	0.6	No Diff (0.25)	0.2	2.2
	Collision on a Sidewalk	1.4	No Diff (0.75)	0.3	54.3
	Fall on a road	0.8	No Diff (0.25)	0.5	1.5
	Fall on a Path/trail	0.9	No Diff (1.0)	0.0	1.9
	Fall on a Sidewalk	1.5	No Diff (0.5)	0.5	7.5
	Injury on a Road	1.4	No Diff (0.25)	0.9	2.3
	Injury on a Path/trail	1.2	No Diff (0.5)	0.6	2.7
	Injury on Sidewalk	2.6	No Diff (0.1)	1.0	10.0
	Major Injury on Road	2.7	No Diff (1.0)	1.1	8.0
	Major Injury on Path	2.1	No Diff (0.5)	0.5	18.2