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AN ANALYSIS OF CYCLING SAFETY PERCEPTIONS AND DEVELOPMENT OF A BICYCLE TRIP ASSIGNMENT METHODOLOGY

Anneka Ruth Lawson

A dissertation submitted to the University of Dublin in partial fulfilment of the requirements for the degree Doctor of Philosophy.

Department of Civil, Structural and Environmental Engineering
Trinity College Dublin

April 2015

DECLARATION

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Anneka Ruth Lawson

To Granny.

ABSTRACT

This thesis reports the outcome of research on the development of an alternative method to modelling the assignment of bicycle trips in multi-modal networks. The proposed methodology considers the effects of safety (or inversely risk) on cyclists' route choice behaviours. In developing this methodology, a survey and monitoring study of cyclists was conducted in order to gain greater understanding of cyclists' safety perceptions, behaviours and network interactions. Based on the findings of the survey analysis a number of policy recommendations are also presented that offer insight into cycling and safety for transport planners and policymakers. Dublin city was used as the study area for this research.

A sample of 1,595 cyclists responses to the questionnaire were analysed using ordinal logistic regression and principal component analysis. This study revealed cyclists to have had a poor perception of cycling, specifically in comparison with driving in the city. There exists a clear order of preference for cycling facilities; cycling on segregated cycle paths were most preferable, followed by kerbside cycle lanes and shared-use bus lanes, respectively. As one would expect, cycling on roads with no cycling facility was least preferred by cyclists, although those preferring to cycle here were found to have a much higher likelihood of considering cycling to be safer than driving. It was also found that those describing themselves as experienced and confident cyclists said they were less compliant with the rules of the road when cycling, yet self-reported compliance was also shown to produce a much higher likelihood of considering cycling to be safer. Cyclists who used helmets were also likely to have used other safety accessorises, but the use of this equipment was not found to be associated with an improved perception of safety. In addition to presentation of these results, a Cyclist Safety Index (CSI) is proposed based on the results of the Ordinal Logistic Regression (OLR) model. The CSI presents itself as a method by which safety perceptions can be measured and monitored in order to assess whether safety perceptions have improved.

The monitoring study was conducted to examine cyclists' route choice behaviour to ascertain whether cyclists travelled along the most direct route between their origin and destination - the 'shortest-path' route; and if not, to observe reasons for these deviations. This study was performed using Global Positioning System (GPS) information from anonymised cyclist trips collected via a smartphone application. It was established that cyclists generally do not follow the 'shortest-path' route. and The recorded cyclists' routes suggest that they deviate to avoid high traffic volumes, travelling instead in low-traffic, residential areas; to make use of the available cycling facilities, and where possible to make use of a high quality segregated cycle path. But

as not all cyclists detour to enter/leave the city centre via this segregated cycle path, there too remains travel time considerations.

Having established that the ‘shortest-path’ method is not appropriate to the assignment of cyclists in urban transport networks, an alternative method is proposed. This method supplements the ‘shortest-path’ method by adding a ‘risk exposure’ element. The magnitude of the risk exposure is dependent on the type of cycling facility on the link and the traffic volume, or more specifically on the flow-capacity ratio, relevant to this cycling facility. This value is indicative of the order of preference displayed by cyclists in the survey study i.e. a higher preference facility will have a lower risk exposure value. The risk exposure is also dependent on travel time. This reflects the cyclists desire to minimise their exposure to high risk situations.

In order to establish whether the proposed method was valid, it was initially tested within arbitrary network examples. Having achieved promising results from these tests, the method was applied to an area of Dublin city. The proposed method was compared with the ‘shortest-path’ method to establish if it was capable of producing different network flows. The trip assignment model with risk exposure was able to move bicycle flows from highly trafficked links with no facilities to adjacent segregated cycle facilities. These flows were more closely representative of actual cyclist flows than that of the ‘shortest-path’ model.

The research conducted in this thesis demonstrates that the ‘shortest-path’ method is not an accurate method for the assignment of bicycle trips in multi-modal transport networks. It fails to consider the risk avoidance of cyclists in their route choice decisions. The risk exposure methodology that has been developed in this thesis has been shown to be able to take these risk considerations into account. It produced more reliable bicycle flows for the study area than the ‘shortest-path’ method currently practised in Dublin. The research also demonstrates that considering cyclist safety perception data could be beneficial to evaluating cycling safety and policy suggestions are made based on the results of the survey analysis.

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LIST OF ABBREVIATIONS

Coef.	Coefficient
BCI	Bicycle Compatibility Index
BLOS	Bicycle Level of Service
BPR	Bureau of Public Roads
CA	Cellular Automate
CF	Car Following
CI	Confidence Interval
CO_2	Carbon Dioxide
CSI	Cyclist Safety Index
DOT	Department of Transport
DUE	Deterministic User Equilibrium
EU	European Union
FL	Factor Loading
GDA	Greater Dublin Area
GDP	Gross Domestic Product
GEH	Geoffrey E. Havers (The GEH statistic is a measure of comparability of observed and simulated traffic flows)
GIS	Geographical Information Systems
GPS	Global Positioning System
GPX	Global Positioning system file eXchange format
HGV	Heavy Goods Vehicle
LR	Likelihood Ratio
MAMIL	Middle Aged Men In Lycra
NCP	Nonlinear Complementary Problem
NCPF	National Cycle Policy Framework
NMT	Non-Motorised Transport
NO_2	Nitrogen Dioxide
$N0_x$	Nitrous Oxide
NRA	National Roads Authority
NTA	National Transport Authority
NTS	National Travel Survey

OD	Origin-Destination
OLR	Ordered Logistic Regression
OR	Odds Ratio
PC	Principal Component
PCA	Principal Component Analysis
PM10	Particulate Matter (<10 $\mu g/m^3$)
PMV	Private Motor Vehicle
POWSCAR	Place Of Work, School and College, Census of Anonymised Records
PT	Public Transport
RP	Revealed Preference
SP	Stated Preference
ST	Sustainable Transport
Std.	Standard
SUE	Stochastic User Equilibrium
TCD	Trinity College Dublin
TFI	Transport For Ireland
UK	United Kingdom
US	United States of America

CHAPTER 1

1. INTRODUCTION

It is estimated that in 2010 traffic congestion cost the Irish economy 4% of Gross Domestic Product (GDP) (IBM, 2010). This was over 6 million euro. Traffic congestion has consequences for businesses, human health and the environment; and pressure is being placed on relevant government departments and agencies to find solutions to these problems. It is usual that the solutions implemented to solve these problems involve the provision of public transport infrastructure. This is certainly the case in the Greater Dublin Area (GDA). At the time of this research a third light rail line (Luas Cross City) was under construction. This project is one of the largest capital investment projects undertaken by the Irish Government, costing €368 million (National Transport Authority, 2013b).

There are currently two other light rail lines (Luas Red and Luas Green) in operation in the city. Canal cordon counts from 2013 these lines transported 10,835 passengers into the city during the morning peak hour time period (7am to 10am) (Dublin City Council and National Transport Authority, 2014). This amounts to a 5.6% mode share. During this same time period 9,061 cyclists travelled across the canal cordon into Dublin city centre, more than doubling this mode share to 4.7% since 2006. These two modes carry similar numbers of travellers, yet investment in Luas services far exceeds that of cycling. Investment in both walking and cycling projects nationally over a similar time period to that of the Luas Cross City are estimated to be €65million (National Transport Authority, 2012b). Assuming number passenger numbers on the Luas Cross City line similar to that of the existing lines (which are operate close to capacity during the peak morning period (Melia, 2013)), the capacity of these three lines would be approximately 16,000 to 17,000 passengers over the morning period. These Luas lines also have a limited catchment. Cycling, as a mode of transport, is not affected by these constraints, and has the potential to reach commuter numbers far exceeding that of the Luas system and also requires a fraction of the investment of a project such as Luas Cross City. Therefore, investment in cycling would seem to make much more financial sense, yet cycling still fails to be considered as much more than a tourism mode in many Department of Transport (DOT), National Transport Authority (NTA) or National Roads Authority (NRA) documents. As discussed by (Aldred, 2012b) for the case of cycling policy in the UK, cycling is viewed by the state as an individual choice: for those conscious of their health, the environment and the costs of travel.

In 2006, the Government published the 'Smarter Travel' document (Department of Transport, 2006) with a strategic plan to reduce congestion by increasing sustainable transport mode shares. This resulted in the publication of the National Cycle Policy Framework (NCPF) (Department of Transport, 2009). This was the first commitment from the Government to cycling as a mode of transport.

Since then a public bicycle sharing scheme 'dublinbikes' and a number of new cycling facilities have been implemented in the city. This bicycle sharing scheme has been deemed a success with over 2.5 million rentals in its fourth year in operation (JCDecaux, 2014). Despite this, census data from 2006 and 2011 (before and after the 2009 introduction of the scheme), showed that motor vehicle mode shares continued to rise (Central Statistics Office, 2006b, Central Statistics Office, 2011b). The use of the scheme may then be associated with the 2.9% decrease in sustainable transport (other than cycling) mode share, which saw a 2% increase in cycling mode shares in Dublin city. A survey of 'dublinbikes' users was conducted in order to determine the extent of this transfer from other modes, showing that 78% of users previously used other forms of sustainable transport, with 45% having walked (Murphy and Usher, 2011).

The Irish Government appears to have approached cycling policy and cycling infrastructure from a 'build it and they will come' perspective, as has been the case elsewhere (Nelson and Allen, 1997). In doing so, there is very little understanding of where these cyclists will come from or whether they will come at all. Fortunately cycling mode share in Dublin has increased by 33% between 2006 and 2011, but without further significant increase in mode share in Dublin, the 2020 target of 10% of all commute trips nationwide by bicycle will not be reached (Department of Transport, 2009).

The lack of understanding of cycling as a mode of transport and of the cyclists needs is seen again in the bicycle trip assignment model created as part of the GDA cycle network plan (National Transport Authority, 2013a). This trip assignment considers cyclists to travel in a transport network in the same manner as motorised modes: travelling the shortest distance route (known as 'shortest-path') between origin and destination. Research has shown there are many attributes involved in the route choice decisions of cyclists, many of which are related to safety. (Sener et al., 2009) provides a detailed literature review on these studies.

Motorists are reluctant to convert to cycling because they find it 'too dangerous' (Keegan and Galbraith, 2005). Irish road safety statistics suggest cycling to be one of the safest modes of travel. This is due to the low numbers of reported fatalities and injuries relating to cycling. There exists much research into the extent of underreporting; one such study in Ireland estimated that cyclists are exposed to 8 times more risk than motorists (Short and Caulfield, 2014).

The research undertaken in this thesis considers factors of the safety perceptions, safety behaviours and network interactions of cyclists in order to develop a method of bicycle trip assignment which can better reflect the movements of cyclists in urban multi-modal transport networks. Previous efforts to provide for the safety of cyclists in trip assignment modelling have generally used a known cycling index (Ehrgott et al., 2012, Klobucar and Fricker, 2007, Smith and Haghani, 2012, Subhani et al., 2013) or similar regression model (Hood et al., 2011). These methods are data intensive, requiring information on many factors on the network, rendering them inaccessible to transport planning authorities for use in practise. This research proposes a method of bicycle trip assignment considering cyclist safety that makes use of data readily available to transport planning authorities. In order to develop this method a monitoring study and survey of cyclists was conducted. The 'risk exposure' methodology that is proposed was tested in arbitrary network examples and then applied for an area of Dublin city. The 'risk exposure' method was compared with the NTAs 'shortest-path' method to determine if the proposed method exhibited improvements over the 'shortest-path' currently applied for cycling in the GDA.

As well as this, policy recommendations relating to the findings of the survey are presented and a Cyclists Safety Index is proposed as a method to estimate cyclist safety perceptions, or changes in them based on a number of factors that transport planners can effect through policy and infrastructure provision.

Therefore, the research objectives of this thesis are as follows:

1. To conduct a detailed review of literature in the following areas: (i) cycling and cycling policy in Ireland and internationally, (ii) cycling safety – measurement of actual and perceived safety and (iii) transport modelling for cycling – the mode choice and trip assignment stages of the four stage model.
2. To conduct a survey among cyclists and analyse the results of this survey to determine the attributes related to cyclists' perceptions of safety, safety behaviours and experiences of network interactions.
3. To develop an index based on the survey respondents' perceptions to aspects of cycling which may aid transport planners in determining if infrastructural or policy changes have impacted on the safety perceptions of cycling.
4. To determine the appropriateness of 'shortest-path' methods for the assignment of cyclists in multi-modal transport networks and to investigate

what features of the transport network cause cyclists to deviate from the 'shortest-path', using a monitoring study.

5. To develop and test a methodology for the assignment of cyclists based on findings from the survey of cyclist safety perceptions and the monitoring study of cyclist route choices.

The remainder of the thesis is structured as follows. ***Chapter 2*** contains the research design which explains the logical progression of the thesis in terms of ensuring that the research questions are answered, and introduces the methodologies used in analysis.

The initial step of this research involved the examination of literature relating to the actual and perceived safety of cyclists and the methodologies used in transport planning to model the behaviours and movement of cyclists. ***Chapter 3*** presents a discussion of this literature and also provides a background on cycling policy in Dublin and internationally.

Chapter 4 reports on the research that was conducted on cyclist safety perceptions. The chapter details the findings of a survey of cyclists in Dublin city relating to their perceptions of cycling safety, cycling safety behaviours and interactions with the transport network. A cyclist safety index is also presented in this chapter. The chapter is concluded with a discussion of the policy implications of the findings.

The observed route choice decisions of cyclists are analysed in ***Chapter 5***. These observed cyclist routes were compared to the 'shortest-path' routes for the Origin-Destination (OD) pairs of each trip and the motives behind cyclists' deviations from the 'shortest-path' routes are discussed.

Based on the findings of the survey and the observations of cyclists route choice behaviours a methodology for considering the safety of cyclists in trip assignment modelling was proposed. The proposed method is presented in ***Chapter 6***, and its capabilities tested for arbitrary network examples.

Chapter 7 presents the findings from the application of the proposed methodology for cyclist trip assignment to a transport network for an area of Dublin city. The proposed methodology is compared with the 'shortest-path' methodology. The chapter concludes with a discussion of the value of the proposed method to improve upon the 'shortest-path' method in modelling the route choice behaviour of cyclists.

The final chapter, ***Chapter 8***, concludes the thesis with a discussion of the main findings of the research and its contribution to the body of knowledge. The chapter also discusses the shortcomings of the research and possible areas for further research.

CHAPTER 2

2. RESEARCH DESIGN

The purpose of a research design is to define the logical sequence of research that has been applied to answering the research question(s) (de Vaus, 2006). This ensures that the data collected and the methodologies used to analysis the data relate to the research question (Yin, 2006). This chapter presents the research design applied to this research.

The research question posed by this work has been divided into a number of sub-questions, or sub-problems. These sub-problems required different types of data and different methods of data analysis. The Research Design Chapter outlines the logical order used to solve this complex system of sub-problems and the methodologies used to address them.

As there are different methodologies applied in this thesis, each of these are introduced in this chapter, but in the interest of clarity, each are described in detail within the chapter in which the methodology is applied.

2.1. ORGANISATION OF THE THESIS

Figure 2.1 presents a flow chart diagram to aid the explanation and logical organisation of the research design. Each step involved in the process of answering the overall research question is explained in the following subsections; the reasons behind the need for the step, the methodologies used in the step and the main findings from the research undertaken as part of this step.

2.1.1. Step 1 – Define the Research Question

The initial step in the process was to pose research question(s) so as to define a direction for the remainder of the thesis. In its broadest sense the research was undertaken to consider the possibilities for improving cycling as a mode of transport in an urban setting. Ultimately, the aim was to do this by reconsidering how the bicycle is considered in transport modelling; but reaching this point required a greater understanding of the current situation for cycling. The research questions were defined in detail in Chapter 1.

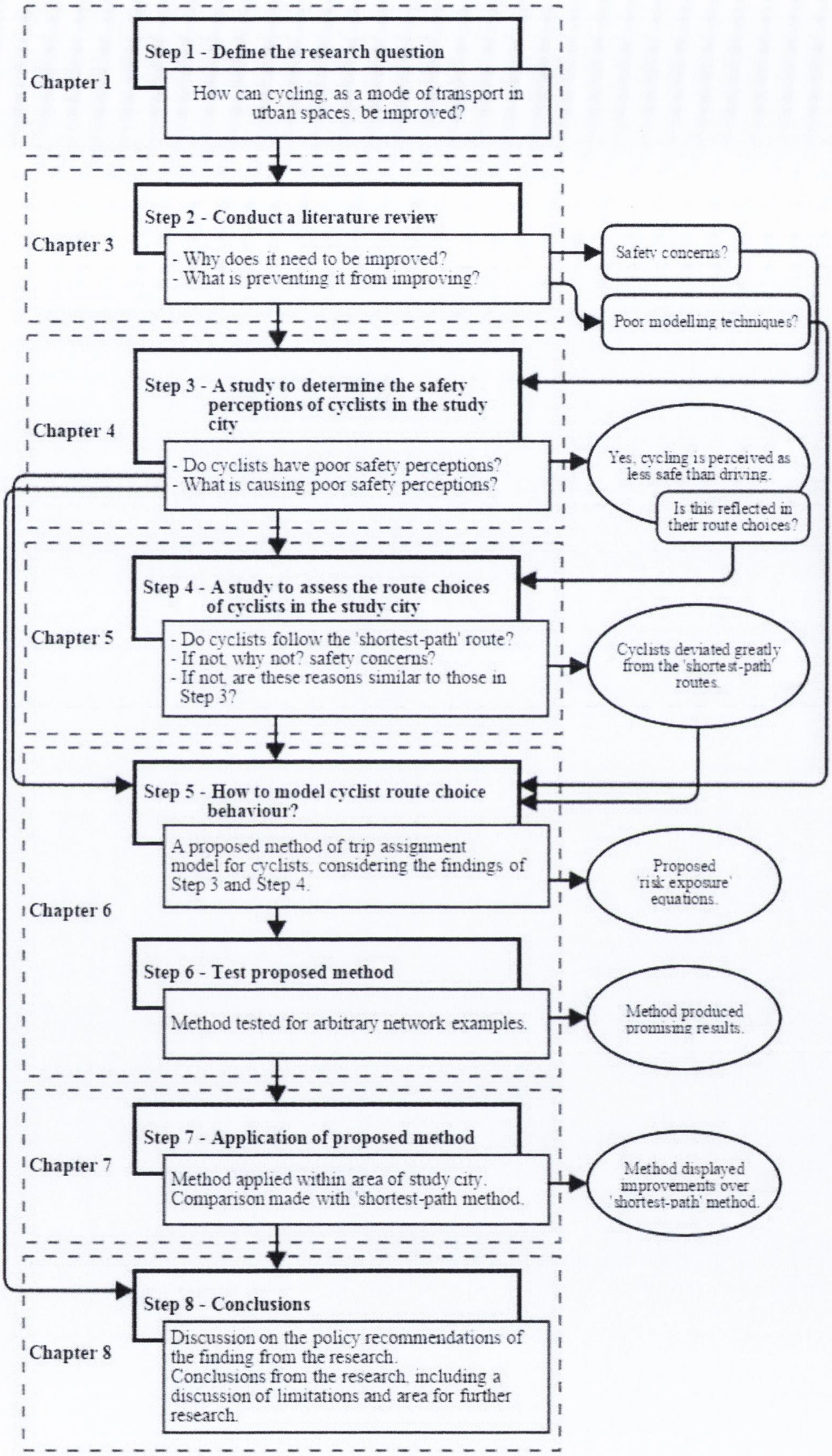

Figure 2.1 Research design flow chart

2.1.2. Step 2 – Conduct a Review of Literature

To gain a greater understanding of the current state of the art in cycling research an extensive literature review was undertaken. The literature included in this review was not only academic papers, but also information and reports from relevant organisations involved in the dissemination of policy, infrastructure etc. for cycling as a mode of transport. As Dublin city was used as a study city in this research much of the non-academic literature relates to Dublin and/or Ireland.

Within this literature review the following areas of research were investigated, to answer the research questions seen in Step 1 of the flow chart in Figure 2.1:

- The reasons behind the need to encourage cycling as a mode of transport;
- Current cycling trends in Dublin, Ireland and internationally;
- Cycling safety - the distinction between actual and perceived safety;
- Transport modelling for cycling.

2.1.3. Step 3 – A Study to Determine the Safety Perceptions of Cyclists

As a result of this review, cycling safety perceptions were raised as a possible barrier to improving cycling in urban areas. As there is little information available on the topic of perceived safety research related to the aspects which cyclist associate with their safety perceptions was undertaken. This was completed by survey questionnaire for the study city of Dublin, and considered aspects of cyclists' safety behaviour and their interactions with the transport network, as well as exploring what factors contribute to their safety perceptions. These survey responses were analysed using Ordered Logistic Regression (OLR) and Principal Component Analysis (PCA). The main findings are as follows:

- Cyclists perceive cycling as less safe than driving
- Cyclists who believe drivers to have poor attitudes to cyclists feel less safe
- Cyclists will alter their route to use quieter roads, routes perceived as safe and to make use of continuous cycling facilities
- Cyclists also believe they are likely to be involved in an incident during rush hour traffic
- Cyclists do have a clear order of preference for facility types.

2.1.4. Step 4 – A Study to Assess the Route Choices of Cyclists

Having established which attributes affect the safety perceptions of cyclists a monitoring study was devised in order to determine if these factors and/or other factors also affect how cyclists make route choice decisions. From the review of literature it was found that currently used methods tend to be overly simplistic, if they are used at all. In the case of the study city, the 'shortest-path' method was used. Observed routes used by cyclists were compared to the 'shortest-path' routes. In order to collect the information required for this study a smartphone application, 'Rothaim' (or 'I cycle' when translated from Irish to English) was developed as part of a Clarity, Centre for Web Sensor Technologies project run conjunction in this research (Gavin et al., 2011). This application allowed cyclists to anonymously upload a Global Positioning System (GPS) trace of their route to a secure server, from where the data could be taken for the purposes of this study. The study revealed that the routes used by cyclists differed from the 'shortest-path' routes and that cyclists preferred to travel quiet roads and on cycling facilities, and where possible to make use of higher quality cycling facilities.

2.1.5. Step 5 – How to Model Cyclist Route Choice Behaviour

With a greater understanding of the safety concerns of cyclists and how they chose their routes, the relevant findings from Steps 3 and 4 were considered in the development of a method which could improve upon the 'shortest-path' method used in the trip assignment stage of the four stage model.

A set of risk exposure equations were proposed. The equations consider the time a cyclist is exposed to a traffic volume (or more specifically the flow-capacity ratio), as well as the presence and type of cycling facility on which the cyclist is travelling. There are four risk exposure equations; each describe the risk associated with cycling on one of three types of cycling facility and on a link with no cycling facility, while considering the flow-capacity ratio in each case. It is anticipated that the risk exposure should increase with increasing time under certain conditions, with larger flow-capacity ratios and for travel on less preferred cycling facilities. The equations have been formulated to reflect cyclists' combined consideration of these attributes. For example under the same traffic conditions, a link with a kerbside cycle lane is higher preference to a link with no cycle facilities, therefore the risk exposure value for the link with no cycling facilities is higher; but where traffic flow is large on the link with a kerbside cycle lane and small on the link with no facilities (in comparison to the link capacities), the risk exposure associated with the link with kerbside cycle lanes will become larger than that of the link with no cycling facilities.

2.1.6. Step 6 - Test Proposed Methodology

This stage of the research involved testing the use of the proposed risk exposure equations. The initial step involved comparing the risk equation values with each other to determine if the values were demonstrative of the results of the studies in Steps 3 and 4. After this, the equations were applied within arbitrary network examples; a route-choice only assignment and a multi-modal mode and route choice assignment model. This was done using the Non-linear Complementarity Problem (NCP) technique, with a Stochastic User Equilibrium (SUE) assignment method. These preliminary tests produced promising results, suggestive of the effects of the variables considered (as described by Step 5).

2.1.7. Step 7 – Application of Proposed Methodology within an Exisitng Transport Network

With the equations displaying the desired properties in these previous tests, the next step was to determine if the method could be applied within an actual transport network with known traffic flows and capacities. This was done for an area of Dublin city, making comparison with the 'shortest-path' method.

The proposed method was found to produce different link flows for bicycles to that of the 'shortest-path' method. Bicycle flows in identified 'problem' areas within the study region showed improvements (from the 'shortest-path' model flow results), in line with bicycle flows expected from the use of the proposed risk exposure method.

2.1.8. Step 8 – Conclusions

Based on the findings of the research presented in the previous steps a discussion of the policy recommendations and conclusions of the research is presented. This step also discusses any limitations of the research and possible areas for further research.

2.2. METHODOLOGIES APPLIED

As mentioned in the introduction to this chapter, a separate methodology chapter is not included in this thesis due to the use of different methodologies appropriate to each particular step. Inclusion of the details of each of these methods outside the context of the study may cause confusion for the reader. As such this section serves as an introduction to each of the mathematical and statistical methods used in the thesis, while the formulations and further discussion of the methodologies are included within the chapter in which the methodology is applied.

2.2.1. Principal Component Analysis (PCA)

PCA has been used to analyse cyclist safety behaviours and network interactions in Chapter 4 to analyse the results collected in the cyclist safety study. It is a statistical method which uses an orthogonal transformation to convert a set of possibly correlated variables, to a new set of uncorrelated and ordered variables, known as Principal Components (PC). As such, the factors within a PC are correlated to each other, but are not correlated to factors in another PC. Each of the resulting PCs explains a certain proportion of the variance in the data, while each factor loading (FL) quantify the relationship between the factors in a PC. The use of this method with variables relating to cyclist safety behaviour and cyclist-network interactions offers insight into the behaviours and interactions which improve or impair a cyclists' safety. A detailed description of this method and its formulation are included in Chapter 4.

2.2.2. Ordered Logistic Regression (OLR)

Binary logistic regression is a statistical method used to measure the probability of a binary outcome (i.e. there can be two outcomes) based on the influence of a set of variables. OLR is based on this same principle, but in OLR the outcome may take multiple values, ordered from low to high. This method is used in the second study presented in Chapter 4. Its use is appropriate here in determining whether a cyclist perceives cycling to be less safe than, as safe as or more safe than driving in Dublin; three possible outcomes, which have a clear order. The likelihood or probability of a cyclist considering one of these three outcomes is determined based on a number of dependent variables. Using this model it is possible to ascertain which variables are relevant to this choice and how they influence this choice. Further information and details of the formulation of OLR are included in Chapter 4.

2.2.3. User Equilibrium Principles and the Non-linear Complementarity Problem

The objective of a trip assignment model is to reach an equilibrium state i.e. to reach a point where no traveller feels they can improve their trip cost by changing route. The most basic definition of this equilibrium assumes that all travellers have the same information available to them in making their route choice decisions. This is known as Deterministic User Equilibrium (DUE). This is very rarely the case in reality, as travellers will tend to have different network information, and therefore different perceptions of the minimum cost route. To account for this a stochastic user equilibrium is used. SUE is applied in all trip assignment models in this thesis to ensure valid model results are presented. SUE is applied within the trip assignment models presented in Chapters 6 and 7.

The non-linear complementarity problem is used in this thesis to solve the trip assignment model having SUE conditions. It is applied here as its formulation allows for easier solution than the SUE conditions are those defined by (Sheffi, 1985). Once an NCP has been formulated from the SUE conditions it is possible to efficiently optimise the network through the use of a gap function. Throughout this research, the Fischer gap function is used (Fischer, 1992, Fischer, 1997). This NCP methodology is used for the trip assignment models presented in Chapter 6.

2.2.4. Data Collection Methods

The research conducted in this thesis required the collection of data in order to inform the research questions. As part of the data collection processes the various methods by which the data could be collected where considered, so that the most appropriate methods could be selected.

In studying cycling safety two approaches have been considered; the analysis of incident data from road safety authorises, police incident reports or hospital admissions data i.e. observed safety; and the analysis of personal opinions towards cycling safety i.e. perceived safety. As will be discussed in Chapter 3, the underreporting of cycling incidents means that observed safety data can be unreliable, it can also fail to fully understand the reasons behind where cyclists cycle, why they cycle there and their feelings towards where they cycle. As such it was decided that a study of safety perceptions would be more appropriate to this research. Methodologies for the collection of data by survey where then considered; these included revealed and stated preference methods. Revealed preference methods examines situations where an option is actually made. This differs from stated preference methods, where a participant makes a decision based on a hypothetical situation. Stated preference studies have been widely used in the field of cycling research, particularly in studying route choices (Axhausen and Smith, 1986, Bovy and Bradley, 1985, Hunt and Abraham, 2007, Stinson and Bhat, 2003, Tilahun et al., 2007). While revealed preference studies have been used less for these purposes, recent improvements in GPS technology have made it possible (Broach et al., 2011, Hood et al., 2011, Menghini et al., 2010). For the data required of Chapter 4, it was thought that investigating a large number of network attributes by this method (rather than collecting overall perceptions of a route) would prove difficult and would involve long, time consuming and complicated routes for participants to follow. As such it was decided that a revealed preference study was not suitable. A stated preference survey asks participants to select from a list of alternatives that differ according to a number of attributes. A survey of this type would require a large number of questions to be asked in order to accurately and fully study all attributes. Therefore, a questionnaire type survey was chosen for this study. This allowed questions to be asked about a large number of attributes, although it does not allow the trade-offs between different attributes to be considered, as would be possible using stated preference methods.

In choosing this method, possible ethical issues where considered. The survey questions where based on a similar study conducted in Queensland, Australia (Haworth and Schramm, 2011). The authors of this study were consulted to ask about their experiences of how participants answered the questions and any improvements they thought would be beneficial. To ensure that the survey was relevant in the context of the study area (Dublin city), stakeholders from the NTA were also consulted. This ensured the questions were representative of the network the survey respondents used. Care was also taken to ensure that survey questions where not leading i.e. that they did not suggest that cycling safety perceptions in Dublin were good or bad or that any of the network attributes were safe or unsafe to use. As the responses to the majority of questions were controlled/fixed a Likert scale was used, for example question 18 in the survey used a 5 point Likert scale with possible positive and negative answers, and a mid-point answer: “Always”, “Usually”, “About half the time”, “Seldom” and “Never”. Other considerations in conducting the survey included ensuring the anonymity of respondents, as such no identifying personal information was collected, but IP addresses where used to ensure that the survey could not be answered more than once by any one person. This check was performed in case respondents tried to respond more than once if they believed their responses could influence results and policy recommendations based on these results. Also, questions relating to other personal details (age, gender etc.) were optional for respondents to complete.

In Chapter 5, data was required relating to the routes travelled by cyclists. Previous research in this area generally collected this information using stated preference methods, but with the emergence of widely available and low cost GPS technology it was possible to study the actual routes followed by cyclists. Similar studies of route choice have also applied GPS methods (Broach et al., 2011, Hood et al., 2011, Menghini et al., 2010). This method can lead to the collection of potentially sensitive user information. As such participation in this study was entirely voluntary; Rothaim, the application used to collect the GPS data was advertised, with the data being collected and how the data would be used clearly stated on the advertisment. There was also the option to opt-out after completing a trip, should the participant change their mind about submitting their data. This was necessary as participants may not wish to reveal the start/end locations of their trips. As well as this, participants were identifiable in the data collected only by a unique username, and not by their real name. This was to ensure the anonymity of participants.

CHAPTER 3

3. LITERATURE REVIEW

Through the centuries, transport systems have tried to keep pace with the growing demands of the private motor vehicle. The original thought process behind dealing with the issue was to further expand transport networks by increasing road capacities. New and wider roads were built to facilitate the increased demands. But as networks grew, so too did demand and cities worldwide found that their streets, originally designed to carry pedestrian, cyclist and horse carriage traffic, were now incapable of meeting vehicular traffic demands. Cities have become dominated by streets covered in grey thoroughfares; park and recreational areas removed to make space for these motorised vehicles. Cities are operating in excess of their capacities and thus face congestion and its negative side effects. Evidently this is not a sustainable situation, and one requiring investigation and discussion in order to implement change for the benefit of these cities and their inhabitants.

3.1. THE NEGATIVE EFFECTS OF MOTOR VEHICLE USE

These high volumes of motorised vehicle traffic are not sustainable from a number of perspectives; economic, environmental, health or social. The costs of congestion in cities are large; both for governments and for individuals. It is estimated that in 2010 traffic congestion in Dublin cost the economy 4% of GDP (IBM, 2010). This presents a huge threat to the competitiveness of Dublin in attracting investment to the city. Nitrous oxides (NO_x), carbon dioxide (CO_2) and particulate matter (PM10) are all pollutants associated with traffic emissions. While annual CO_2 and PM10 emission levels in Ireland are currently lower than the EU imposed safe limits, annual NO_x emission levels, particularly nitrogen dioxide (NO_2), are close to annual limit levels and have experienced exceedances of hourly emission levels (Environmental Protection Agency, 2013). These emissions can be dangerous to human and environmental health. The Environmental Protection Agency recommend increased walking, cycling and public transport (PT) use as an alternative to private motor vehicles in order to reduce NO_x emission levels in urban spaces. The World Health Organisation suggest the lack of physical activity can result in heart disease, stroke, obesity, type 2 diabetes, colon and breast cancer, poor musculoskeletal health and poor psychological well-being (Cavill et al., 2006). It recommends walking and cycling to work as a practical way to include physical activity in daily life (Cavill et al., 2006). In Ireland, 39% of adults are overweight and 18% are obese (Department of Health, 2011). It is estimated that in 2003 in-patient costs related to obesity were €30 million and that premature deaths related to obesity cost €4bn per annum in Ireland (Department of Health, 2011). Consequently it is clear, that there is a strong case from a number of perspectives to encourage a modal shift from private motor vehicles to non-motorised transport.

3.2. How Cycling, as a Mode of Transport, can Benefit a City

The reasons behind the necessity to promote cycling are mostly the same as why private motor vehicle use in urban space should be discouraged. This section discusses a number of additional arguments for the implementation of a strategy to increase cycling, and also walking (which together are referred to as Non-Motorised Transport (NMT)).

Increased NMT also has the potential to improve road safety. It is estimated that between 2000 and 2005 the total cost of traffic collisions in Ireland was €10.6 billion (Road Safety Authority, 2007c). There has been much research conducted in the area of 'safety in numbers' for both pedestrians and cyclists (Jacobsen, 2003, Robinson, 2005). Despite advances in the area of vehicle safety, motor vehicle incidents remain the main cause of road traffic incidents. In the seven year period between and including 2005 and 2011, 82.7% (35026 no.) of reported incidents (resulting in fatal, serious or minor injuries) involved a motorised vehicle on road in the Republic of Ireland; 12.5% (4307 no.) of which resulted in fatal or serious injuries (Road Safety Authority, 2007a, Road Safety Authority, 2007b, Road Safety Authority, 2008, Road Safety Authority, 2010b, Road Safety Authority, 2010a, Road Safety Authority, 2012, Road Safety Authority, 2013, Road Safety Authority, 2014).

A benefit to increasing NMT mode share would be its lower space requirements; NMT requires less road infrastructure and less provision of parking spaces for vehicles. A switch from motorised vehicles to public transport or NMT can hugely increase the capacity of a link in terms of the number of persons travelling on that link. Figure 3.1 is an image from Muenster, Germany used in a campaign to highlight the space requirements of private vehicles. The following text from the campaign explains the image:

> Bicycle: 72 people are transported on 72 bikes, which requires 90 square metres.
>
> Car: Based on an average occupancy of 1.2 people per car, 60 cars are needed to transport 72 people, which takes 1,000 square metres.
>
> Bus: 72 people can be transported on one bus, which only requires 30 square metres of space and no permanent parking space, since it can be parked elsewhere.

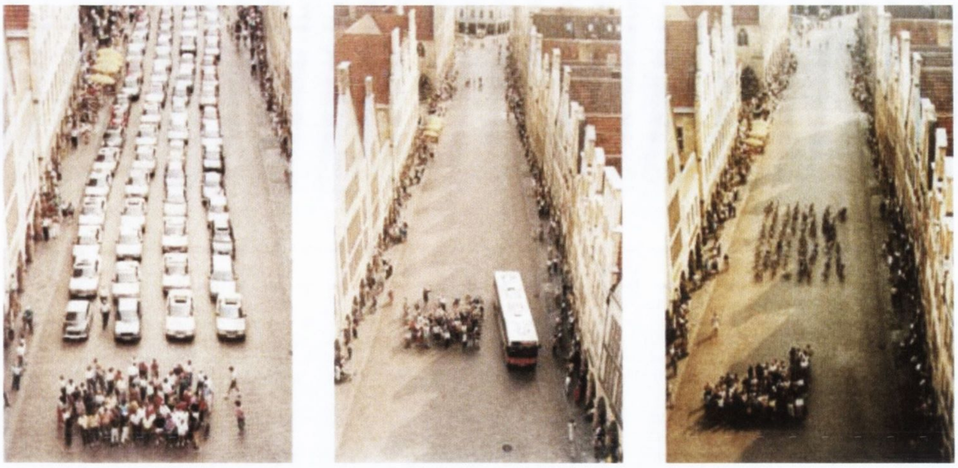

Figure 3.1 Photograph from "Program fahrradfreundliche Stadt Muenster" (Stadt Muenster, 1993)

With a significant reduction in motorised traffic, traffic lanes on roads operating sufficiently below capacity could be repurposed and redesigned to introduce 'green space' for walking, cycling and other recreational purposes (REBAR Group Inc., 2014). This aspiration to reacquire such spaces has been highlighted worldwide by campaigns such as 'Park(ing) Day', in which parking spaces are transformed for a day to usable public spaces (REBAR Group Inc., 2014). Reclaiming of road space from vehicles can already be seen in Dublin city as part of the 'Canal Cycle Way'. Here, approximately 270 parking spaces have been removed to facilitate the construction of a continuous segregated cycle lane along the Grand Canal (Roads and Traffic Planning, 2009). Maintenance of network infrastructures for NMT users would also be much easier as walking and cycling cause significantly less wear to road surfaces compared to much heavier vehicular traffic.

3.3. TRANSPORTATION AND TRAVEL IN THE CONTEXT OF IRELAND AND THE UK

Transport policy in Ireland prior to 2006 placed focus entirely on the improvement and expansion of the transport network to accommodate increasing vehicle numbers on the roads (Department of Transport, 2003). This was due to the growing 'Celtic Tiger' economy in the country which made ownership of a motor car possible for a large percentage of the population. Figure 3.2 presents a graphical representation of the numbers of persons travelling by each mode in Ireland between 1981 and 2011. In 1986 driving a private motor vehicle accounted for 37% of transport mode share in Ireland and walking and cycling modes were 13% and 6% respectively (Central Statistics Office, 1986). The twenty year period between 1986 and 2006, saw large changes in in these modes shares; 58% of commuters drove to their place of work and walking and cycling mode shares stood at 11% and 2% respectively (Central Statistics Office, 2006b). Despite the economic recession which hit Ireland between 2006 and

2011 the mode shares for private vehicle use continued to rise, amounting to over 60% of commuter trips (Central Statistics Office, 2011b). Cycling mode shares also increased by 0.3% during this same time period (Central Statistics Office, 2011b), while walking decreased by almost 1.3%. These figures would suggest a move from walking to both cycling and motorised vehicle modes. A survey of users of the public bicycle sharing scheme introduced in Dublin city in 2009 found that 45% of users had previously walked, while 19% had driven (Murphy and Usher, 2011). Dublin city, having benefited with receiving a lot of the investment in cycling, saw greater improvements in cycling mode shares than the national averages; in 2011 cycling modes shares was almost 8% of all commuter trips in the city. The rate of motor vehicle use was also much lower than the national figure at 36%, with much of the difference accounting to the higher rates of public transport use.

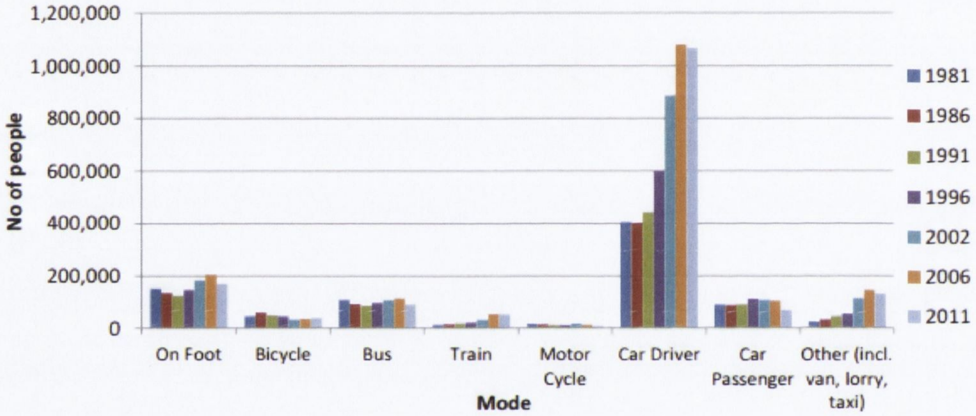

Figure 3.2 Number of persons travelling to work by travel mode between 1981 and 2011 (Department of Transport, 2014)

As the private motor vehicle mode share continues to rise, interest in alternatives has developed (Department of Transport, 2006). Ultimately the responsibility to achieve sustainable urban spaces falls to the local and national governments. NMT must be promoted by the relevant authorises through policy changes, economic incentive, adaption of infrastructure and protection of vulnerable road users (Department of Transport, 2006). The Irish Government has addressed these issues with the adoption of a new transport policy 'Smarter Travel-A Sustainable Transport Future' as the transport policy for Ireland for the period of 2009-2020 (Department of Transport, 2006). According to the policy document, "Alternatives such as walking, cycling and public transport will be supported and provided to the extent that these will rise to 55% of total commuter journeys to work." As a consequence, two new NMT related programs have been undertaken. 'Smarter Travel Workplaces' is a program which promotes walking, cycling, public transport, car-sharing and trip reduction as part of a workplace mobility management. Along with this, a 'National Cycle Policy

Framework, 2009-2020' (NCPF) has been adopted to promote a strong cycling culture in Ireland. This program aims to increase the bicycle mode share of all trips to 10% by 2020 (Department of Transport, 2009). A number of interventions, arising directly or indirectly from the publication of these documents, or even being implemented before this, have contributed to making urban spaces more pedestrian and cyclist friendly. At a National level:

- Campaigns such as 'Green Week' and the 'pedometer challenge' have attempted to highlight the benefits of NMT for the environment and physical fitness;
- the 'Bike to Work' scheme has offered tax free bicycle purchases to try encourage more commuters to use NMT;
- In 2012, the requirement for cyclists to use cycle lanes when they are present was abolished from road traffic law, except where the cycle lane is contra flow and within pedestrianised areas (Irish Statute Book, 2012). This was due to safety concerns related to the poor standard of cycle facilities and their lack of maintenance.

At a city level Dublin has experienced the most change:

- In 2007, a ban on 5+ axle goods vehicles was introduced in Dublin city (Irish Statute Book, 2006), due to safety concerns associated with the interaction of pedestrians and cyclists with heavy goods vehicles (HGVs). HGVs are now required circumnavigate the city and access the port through the purpose built Port Tunnel;
- In 2010, Dublin City Council introduced reduced speed limits within the city centre (Dublin City Council, 2013). This reduced the speed limit from 50 km/hr to 30 km/hr;
- Dublin city's cycling facilities now consists of approximately 120 km of on-road cycle lanes, 50 km of shared bus-cycle lanes and 25 km of off-road cycle paths, with further plans to extend the Canal Cycle Way (a segregated cycle facility) along the entirely of the canals surrounding Dublin to the north and south of the city centre;
- Dublin has also seen the introduction of a public bike sharing scheme; launching in 2009 'dublinbikes' consisted of 40 rental stations, in the city centre with 450 bicycles available for use. The scheme has been one of the most successful public bike schemes in the world with 36,000 active long-term subscribers, 6 million journeys having been made since its launch (JCDecaux, 2013). As such, expansion of the scheme to further part of the city

is currently in progress to bring the number of bicycles and stations to 1,500 and 102 respectively. Further public bike sharing schemes have now been approved for Cork, Galway and Limerick (National Transport Authority, 2014).

The experiences of cycling as a mode of travel in the UK may be described as similar to that of Ireland; with similarly low bicycle mode shares. Research into cycling related policy in the UK exposes cultural issues which do not arise from countries with a developed cycling culture. The perceptions of self associated with being a cyclist in the UK suppress mode shares (Pooley et al., 2011). Cycling is subject to social stigmas; it is perceived as a mode of travel for extremists such as environmentalists (Pooley et al., 2011, Anable, 2005, Aldred, 2012b) or cycling fanatics (Aldred and Jungnickel, 2014). Cyclists have been categorised, by cyclists and non-cyclists, into two distinct, but both uncomplimentary, groups: as incompetent or over competent (Aldred, 2012c). These opinions of cycling marginalise it as a subculture (Aldred and Jungnickel, 2014), perceived as a pursuit of the eccentric and not-normal (Pooley et al., 2013, Pooley et al., 2011, Aldred and Jungnickel, 2014). Cyclists and non-cyclists also demonstrated displeasure with being identified as a cyclist by their appearance; the 'MAMIL' ('middle aged men in lycra') is a term often used as a criticism, while the minimal use of a helmet is also identified as undesirable (Aldred, 2010, Aldred and Jungnickel, 2014). Two projects, 'Understanding Walking and Cycling' (Pooley et al., 2011) and 'Cycling Cultures' (Aldred, 2012a), (the umbrella projects to the majority of this UK research) both emphasise the requirement of cycling policy to normalise cycling, with (Pooley et al., 2011) acknowledging that restricting the opportunity to use motorised vehicles as the approach which must be taken in order to achieve this.

3.4. TRANSPORTATION AND TRAVEL IN AN INTERNATIONAL CONTEXT

Policy changes are necessary to increase NMT mode shares in Ireland. This section considers transport policies internationally, which have been successful in achieving significant amounts of NMT. Figure 3.3 and 3.4 present mode shares for sustainable transport (ST), NMT, private motor vehicles (PMVs) (Figure 3.3), walking, cycling and PT (Figure 3.4) from various cities in Europe, the U.S.A. and Australia. These cities have been ordered by increasing mode shares of private motor vehicles. Generally it can be seen that with increasing private motor vehicle shares sustainable transport shares decrease. A similar trend, but not as clear is seen for NMT shares.

Of the cities considered, Paris has the lowest PMV share and the highest sustainable and non-motorised transport shares (at 9%, 91% and 64% respectively); while Melbourne has the highest PMV share and lowest ST and NMT. Dublin falls within the less sustainable of these cities; having high PMV use (48%) and lower ST (52%) and NMT (27%). The breakdown of ST and NMT into walk, cycle and PT for these cities can be found in Figure 3.4. In terms of the sustainable modes, Paris has the highest walking mode share at 61%; while New York has the highest public transport share at 55%. Amsterdam has the highest cycling mode share of the cities considered in these two Figures, but other cities in the Netherlands, Denmark and Germany have achieved cycling mode shares higher than any other cities worldwide.

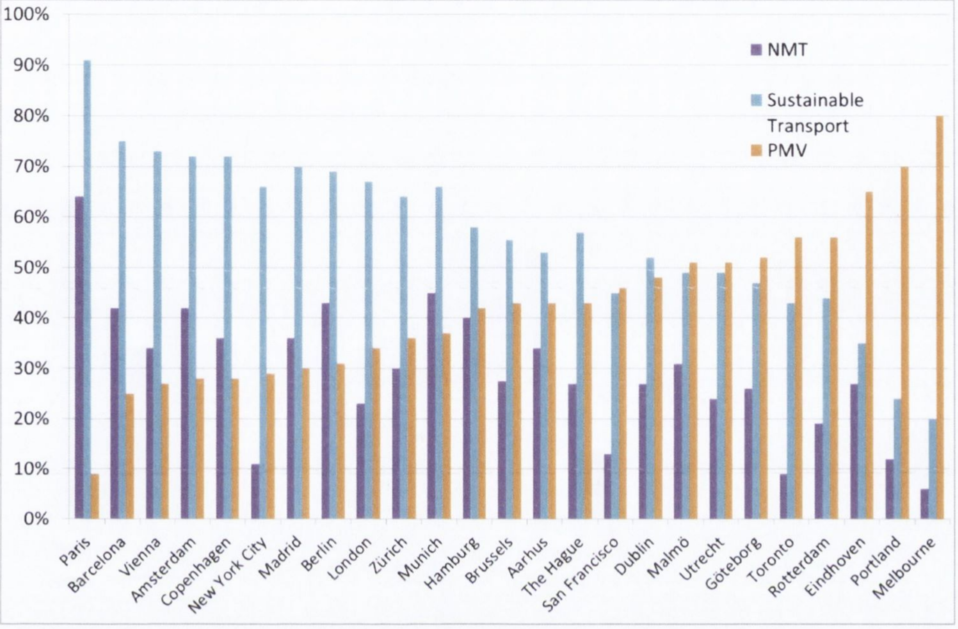

Figure 3.3 Proportions of NMT, ST and PMV in cities internationally (Transport for London, 2012b, Land Transport Authority Academy, 2011, OMNIL, 2012, Stadt Zürich, 2010, Bruxelles Mobilité, 2013, Data Management Group University of Toronto, 2006, Central Statistics Office, 2006a, U.S. Census Bureau, 2013).

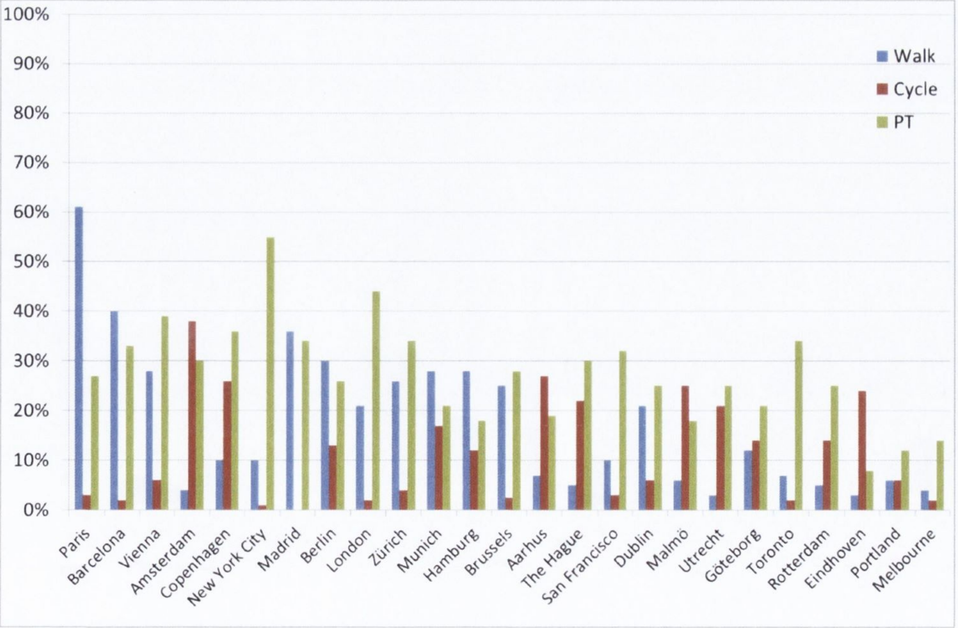

Figure 3.4 Proportions of walking, cycling and PT in cities internationally

(Transport for London, 2012b, Land Transport Authority Academy, 2011, OMNIL, 2012, Stadt Zürich, 2010, Bruxelles Mobilité, 2013, Data Management Group University of Toronto, 2006, Central Statistics Office, 2006a, U.S. Census Bureau, 2013).

There has been extensive research conducted into the transport policy which has resulted in these favourable walking and cycling mode shares in the Netherlands, Denmark and Germany. A review of literature on the topic suggests the following policies as important to increased NMT mode shares, but not in insolation, rather as a coordinated approach to integrated policy.

- Restrictions on motor vehicles and priority for NMT – vehicular traffic free/restricted zones in city centres and residential zones, reduced parking availability, traffic calming by road blocks, road narrowing, speed ramps and reduced speed limits (Buehler and Pucher, 2012, Pucher and Buehler, 2008, Pucher and Dijkstra, 2003, Pucher and Dijkstra, 2000, Pucher et al., 1999, Hull and O'Holleran, 2014);
- Cycling facilities – these cities generally consist of large networks of segregated cycle facilities, to physically separate cyclists from other traffic. Cycling facility networks need to be safe, convenient, comfortable and offer direct routes to cyclists (Pucher and Buehler, 2008, Pucher and Dijkstra, 2003, Pucher and Dijkstra, 2000, Pucher et al., 1999, Hull and O'Holleran, 2014);
- Complementary facilities – wide paths and sidewalks, well lit streets, signalled and clearly marked crossings, centre refuges on wide streets (Pucher and Dijkstra, 2003, Pucher and Dijkstra, 2000);
- Prioritisation of cyclists – advance green traffic signals, advance waiting positions at traffic signals and traffic signal timings which create 'green waves' to allow cyclists maintain momentum (Pucher and Buehler, 2008);
- Integration with public transport – this can benefit both walking, cycling and PT; considering and planning for the appropriate catchment areas that are accessible by foot/bicycle to allow for journeys to start and/or end with NMT (Buehler and Pucher, 2012, Pucher and Buehler, 2008);
- Bicycle parking – secure bicycle parking is provided at public transport depots, as well as in city centres and at workplaces (Buehler and Pucher, 2012, Pucher and Buehler, 2008, Pucher et al., 1999);
- Training – drivers in the Netherlands, Denmark and Germany receive training in collision avoidance with vulnerable road users (pedestrians and cyclists) and are taught how to walk and cycle defensively in order to anticipate possible dangers within the transport network (Buehler and Pucher, 2012, Pucher, 2001, Pucher and Buehler, 2008, Pucher and Dijkstra, 2003, Pucher and Dijkstra, 2000);

- Education – on the health and environmental benefits walking and cycling can offer (Garrard et al., 2011, Pucher et al., 1999);
- Taxation – the use of private motor vehicles can be decentivised through appropriate taxation of the costs associated with the use of cars e.g. fuel and motor taxation (Buehler and Pucher, 2012, Pucher et al., 1999);
- Traffic law – traffic regulations favour NMT users; responsibility is assumed to be with the motorist in the case of an incident involving child or elderly pedestrians and cyclists. There is also strict enforcement of traffic regulations for all road users, with large fines (Buehler and Pucher, 2012, Pucher and Buehler, 2008, Pucher and Dijkstra, 2003, Pucher and Dijkstra, 2000, Pucher et al., 1999);
- Spatial/development policy – encourage mixed use developments which require shorter trip distances that can be made more conveniently by NMT (Buehler and Pucher, 2012, Pucher, 2001, Pucher and Dijkstra, 2003, Pucher and Dijkstra, 2000, Hull and O'Holleran, 2014).

All policy implementations are recommended in order to increase the safety and convenience of cycling in these cities, which in turn encourages increased walking and cycling.

Dutch, Danish and German cycling cities contain vast networks of cycling facilities to enable cyclists to safely and conveniently traverse the city. These facilities can come in the form of segregated cycle paths, off-road shared use (pedestrians and cyclists) paths, on-road cycle lanes and on-road shared use (buses and cyclists) lanes. Much debate exists about which is most appropriate way to ensure the safety and efficiency of cycling in cities. Studies of cyclists within the carriage way have found vehicles drivers pay less attention and leave less space for cyclists when overtaking, creating a less safe environment for cyclists (de Lapparent, 2005, Parkin and Meyers, 2010). (Pucher and Buehler, 2008) recommend the need to separate cyclists from vehicular traffic at intersections and on high traffic volume roads to ensure the safety of cyclists. A number of other studies also recommend the separation of cyclists from other network users to increase safety and convenience for cyclists (Bíl et al., 2010, Hopkinson and Wardman, 1996, Parkin et al., 2007, Pucher, 2001, Tilahun et al., 2007, Wardman et al., 2007, Wegman et al., 2010). Although, there also exists research to the contrary; (Aultman-Hall and Hall, 1998), (Aultman-Hall and Kaltenecker, 1999), (Forester, 1993) and (Moritz, 1997) propose integration of cyclists within the vehicular carriageway. While, (Dill, 2009) and (Pucher et al., 2010) advise the need to provide a cycling network containing a variety of facility types, which caters for the differing need of cyclists. For further review on types of infrastructure for cyclists please refer to (Pucher et al., 2010).

In an effort to increase cycling mode shares in various cities and to reduce the environmental impacts of motorised modes of transport, a growing number of cities have introduced public bicycle sharing schemes. It is estimated that there are approximately 120 bicycle sharing schemes operating in cities around the world (DeMaio, 2009, Shaheen et al., 2010). (DeMaio, 2009) and (Shaheen et al., 2010) provide histories on the development of these bike schemes from the 1st generation schemes, to the current (3rd) generation schemes and discuss proposals for the next (4th) generation bicycle sharing schemes. A number of studies exist on the patterns of use of these schemes within cities where the schemes have been of great success. (Borgnat et al., 2009a), (Borgnat et al., 2009b) and (Borgnat et al., 2011) have analysed both temporal and spatial information collected in Lyon, while (Froehlich et al., 2009) and (Kaltenbrunner et al., 2010) preformed similar analyses in Barcelona. In terms of temporal patterns, morning and evening peaks on week days in the data show clear usage of both programs for utilitarian trips. During evenings and weekends, usage suggests more leisure and recreational trips. Spatial patterns suggest the use of the bicycles for short range trips. A similar result is also found in a study of the London bicycle sharing scheme (Lathia et al., 2012); bicycle usage patterns form interconnecting concentric circles around London's city centre. (Froehlich et al., 2009) used the spatial information to determine whether a locality was residential, commercial or a downtown area from the usage patterns. (Borgnat et al., 2011) suggests that depending on the time of the week some of the bicycle stations in Lyon alternated between being a sink or a source, rather than the expected diurnal pattern. A number of these studies have also produced models to predict bicycle rentals and returns from stations in these cities, based on previous rental and return data (Borgnat et al., 2009a, Borgnat et al., 2011, Kaltenbrunner et al., 2010, Froehlich et al., 2009). (Borgnat et al., 2009a) exploits a number of explanatory variables to improve prediction capabilities; number of subscribers to the bicycle sharing scheme, the time of the week, public holidays, average daily temperature and average daily rainfall. A study of Dublin city's bicycle sharing scheme takes an alternative approach, to gain insight into why the scheme is used instead of how, as in the previous studies (Murphy and Usher, 2011). A questionnaire completed by 360 bike scheme users revealed them to be from middle and upper class socioeconomic groups, who used the bicycle sharing scheme as for part of their trip in conjunction with other modes. This study revealed that trips now taken using the bicycle sharing scheme where previously taken using other forms of NMT and not motorised modes.(Fishman et al., 2013) also note the use of these schemes has not been from the intended motorised modes and in a review of literature relating to these schemes around the world recognises a gap in understanding why this has been so.

A number of EU countries offer incentives to encourage commuting by bicycle; some of these benefit the commuter directly, while others incentivise employers to provide equipment for employees. In Belgium, the Netherlands, the UK, employers can offer tax free rental or hire purchase-type schemes to employees for bicycle and bicycle safety equipment for commuting purposes (Department of Transport, 2011, Schiøtt Stenbæk Madsen, 2010) (a similar scheme to these is currently in place in Ireland). Employers in these same EU countries can also pay their employees a tax-free mileage rate for commuting by bicycle; typically approximately €0.20/km. Other incentives offer rewards for bicycle commuting; for example the "Bike to Work" scheme in Belgium allows cyclists to collect points based on their commute by bicycle which can be redeemed for vouchers for use in shops and cafes etc. (Fietsersbond and Gracq, 2009). In Demark, a month long campaign encourages teams of employees to commute by bicycle, offering prizes to teams for the largest number of days cycling and distances travelled (Danish Cyclists' Federation, 1998).

In addition to these cycling tax schemes, complementary taxation of motorised modes may also incentivise cycling; these taxes include sales taxes on motor vehicles and motor fuels, annual motor taxes related to use of the transport network, parking charges and the costs associated with drivers licence registration fees.

3.5. CYCLING SAFETY

Understanding the safety issues associated with cycling in a mixed-mode transport network is vital to transport policy creation and prioritisation for the needs of cyclists. Identifying the physical and environmental threats to cyclist's safety within the network allows important insight for the design of new facilities and the improvement of existing facilities. Traditionally the estimation of bicycle safety has been approached from two perspectives; actual safety and perceived safety. Actual safety involves the study of cycle incident histories, whereas perceived safety studies analyse factors which cyclists (and non-cyclists) believe may lead to them being involved in an incident. The actual and perceived safety related to a city, road link or cycling facility type can be quite different. Winters et al. (2012) performed a study to compare the real and subjective risk associated with different types of cycling route. It was found that generally routes that were perceived as high risk by the cyclists, were the routes the posed the greatest real injury risk, although cyclists placed a higher perceived risk on cycle paths than observed risk, while they saw mixed-use (walk and cycle) paths to have a lower injury risk than observed. The following sub-sections present studies of both actual and perceived safety and discusses their findings.

3.5.1. Actual Safety

Generally, studying actual safety involves the analysis of data collected in incident records complied by police, hospital or other associated authorities. These records are used in determining factors contributing to two areas related to actual safety; injury severity and incident rates, as shown in Tables 3.1 and 3.2. Studies of injury severity have shown factors such as not wearing a helmet (Moore et al., 2011, de Lapparent, 2005), consumption of alcohol (by driver or cyclist) (Moore et al., 2011, Kim et al., 2007), inappropriate motorist speeds (Bíl et al., 2010, Klop and Khattak, 1999, Kim et al., 2007) and steep grades (Allen-Munley et al., 2004, Moore et al., 2011, Allen-Munley and Daniel, 2006, Klop and Khattak, 1999) to be associated with increased injury severity. The profile of those most at risk of severe injury is that of older and male cyclists (Chong et al., 2010, Bíl et al., 2010, Welander et al., 1999, Kim et al., 2007).

In terms of incident rates, males are also at higher risk (Welander et al., 1999, Wessels, 1996, Wachtel and Lewiston, 1994), but there exist conflicting views of which age groups are more at risk of involvement in an incident while cycling; (Wachtel and Lewiston, 1994) has shown older cyclists to be more at risk, while (Munster, 2001) stated in a report of cyclists in New Zealand that younger cyclists were more at risk. (Petritsch et al., 2006) obtained some seemingly counter-intuitive results when investigating crash rates using reported incident data; proposing that lower roadway and side-path widths incur lower incidence rates. It is suggested that this is because narrower roadways and side-paths reduce the speeds of vehicular and cyclist traffic. (Mindell et al., 2012) has considered the risk of cycling in comparison with walking and driving, finding that for young males cycling was lower risk than driving and that risk increases with the age of cyclists. Each of these studies displayed in Table 3.1 measured incident rates as the number of incidents occurring over the time period of the study, this is with the exception of Aultman-Hall and Adams (1998), Doherty et al. (2000) and Turner et al. (2006).

Studies investigating incidence rates using reported incident data are less popular due to their unreliability, as they can tend to underestimate the true number of cycling accidents. The extent of the underestimation has been estimated through comparison with other sources of incident information. These studies which compare incident report data to survey data collected on the past incident experiences of cyclists have revealed that only a small percentage of incidences are reported each year (Hendrie and Ryan, 1994, Veisten et al., 2007, Doherty et al., 2000, Broughton et al., 2010, Short and Caulfield, 2014). Underreporting has been shown to occur for all locations and all levels of injury severity, although the percentage of underreporting decreases as the severity of an incident increases (Veisten et al., 2007, Hendrie and Ryan, 1994). Frequently, it is accidents which occur off-road, which do not involve motor-vehicles and which do not result in injuries requiring hospital admission that remain unreported and are therefore largely underrepresented in official incident report data.

Table 3.1 Studies related to actual cyclist safety.

Author(s)	Location of study	Data considered	Type of measurement	Type of incident	Involved parties	Purpose of trip
(Allen-Munley and Daniel, 2006)	New Jersey	Incident reports	Injury severity	Collisions	Vehicles	
(Allen-Munley et al., 2004)	New Jersey	Incident reports	Injury severity	Collisions	Vehicles	
(Aultman-Hall and Adams, 1998)	Ottawa & Toronto, Canada	Survey	Crash rate (/10^5 km)	Falls, collisions	Vehicles, pedestrians	Commute, Non-Commute
(Aultman-Hall and Hall, 1998)	Ontaria, Canara	Survey	Crash, injury rate	Falls, collisions	Vehicles, pedestrians	Commute
(Bíl et al., 2010)	Czech Republic	Incident data	Fatality rates	Collisions	Vehicle	
(Chong et al., 2010)	New South Wales, Australia	Incident data	Injury severity	Collisions	Vehicle, pedestrians, animals	
(de Lapparent, 2005)	French urbanisations	Incident data	Injury severity	Collisions	Vehicle	
(Doherty et al., 2000)	Ottawa & Toronto, Canada	Survey	Crash rate (/month, /hr, /location)	Falls, collisions	Vehicles, pedestrians	Commute
(Klop and Khattak, 1999)	North Carolina	Incident data	Injury severity	Collisions	Vehicle	
(McInerney, 1998)	Western Australia		Incident attributes			
Mindell et al. (2012)	England	Incident data	Fatality rates (/10^5 hr use)	Falls, collisions	Any type	Commute, Non-commute
(Moore et al., 2011)	Ohio	Incident data	Injury severity	Collisions	Vehicle	
(Munster, 2001)	New Zealand	Survey	Incident attributes	Falls, collisions	Non-vehicles	Transport, Leisure, Sport
(Petritsch et al., 2006)	Florida	Incident data	Crash rate	Collisions	Vehicles	
(Schepers et al., 2011)	The Netherlands	Incident reports	Crash rate	Collisions	Vehicle, pedestrians	
(Turner et al., 2006)	New Zealand	Incident data	Event rate (/yr)	Collisions		
(Welander et al., 1999)	Western Sweden	Incident data	Crash rate			Work Related, Non-Work Related
(Wessels, 1996)	Washington State	Incident data	Injury severity	Collisions	Vehicle	

Table 3.2 Attributes considered by studies related to actual cyclist safety.

Author(s), year	**Gender**	**Age**	**Helmet**	**Alcohol**	**Location Within Network**	**Presence/ Type Of Facility**	**Cycle Volume**	**Traffic Volume**	**Traffic Speed**	**Road Type**	**One-Way Streets**	**No Of Lanes**	**Lane Width**	**Intersections**	**Roundabout**	**Bicycle Crossing**	**Road Surface**	**Bus Route/ Truck Route**	**Parking**	**Grade/Curve**	**Time Of Year**	**Time Of Day**	**Weather/Visibility**	**Daylight**	**Type Of Collision**	**Party At Fault**	**Overtaking**	**Fail To Yield**	**Turning Manoeuvres**	**Pop Density/ Surrounding Area Use**
(Allen-Munley and Daniel, 2006)		*						*	*	*	*		*	*			*	*	*	*			*	*						*
(Allen-Munley et al., 2004)								*			*		*				*	*		*				*						*
(Aultman-Hall and Adams, 1998)	*	*			*					*																				
(Aultman-Hall and Hall, 1998)	*	*			*			*																					*	
(Bíl et al., 2010)	*	*		*											*					*			*	*	*	*	*			
(Chong et al., 2010)	*	*																							*					
(de Lapparent, 2005)		*	*			*						*				*							*	*	*					
(Doherty et al., 2000)					*									*			*				*	*								
(Klop and Khattak, 1999)								*	*				*	*						*			*	*						
(McInerney, 1998)					*	*	*	*	*	*				*					*											*
Mindell et al. (2012)	*	*			*																									
(Moore et al., 2011)	*	*	*	*					*					*						*	*			*	*					
(Munster, 2001)		*	*		*			*	*					*			*						*	*						
(Petritsch et al., 2006)					*				*			*	*																	
(Schepers et al., 2011)					*	*	*	*			*		*	*		*							*						*	
(Turner et al., 2006)	*	*			*		*	*						*	*						*	*	*	*					*	
(Welander et al., 1999)	*	*																												
(Wessels, 1996)	*	*		*						*				*							*	*	*	*	*			*	*	

As such, studies have used data collected from surveys to gain a more comprehensive understanding on the factors contributing to actual cyclist safety. (Aultman-Hall and Hall, 1998) and (Aultman-Hall and Adams, 1998) make an argument against moving cyclists off the road and onto side-walks. Both studies have shown higher event and injury rates for side-walk accidents. This result is opposed to the recommendations of a number of studies which believe in the segregation of cyclists from vehicular traffic, including by (Bíl et al., 2010) following analysis of reported incident data. Tables 3.1 and 3.2 give an overview of these and further analyses in the area of actual safety measurement. (Reynolds et al., 2009) reviewed 23 peer reviewed literatures to assess the impact of network infrastructure on injury severity and crash rates. It concluded that multi-lane roundabouts increase risk, unless a separated path is included, mixed use pedestrian-cycle paths or trials pose a high risk and the presence of bicycle facilities revealed the lowest risk. However, (Reynolds et al., 2009) acknowledge that bicycle facilities of potentially different levels of risk have been grouped within these studies. It is also stated that measures such as street lighting, pavement surfaces and gradient can impact cyclist safety.

In the EU, road safety is measured by the number of fatalities per million inhabitants. In 2013, Ireland ranked among the safest countries in the EU with less than 40 deaths per million inhabitants (Jost et al., 2013). This report also provides a rating of deaths per billion vehicle kilometres travelled; in which Ireland was ranked second (after Sweden) with less than 5 deaths per billion vehicle kilometres. A similar rating system to that mentioned previously is used in the EU to measure cycling safety. In 2010, Ireland experienced 1 death per million inhabitants (Candappa et al., 2012). This was the lowest number of deaths per million inhabitants of the 20 countries considered, but as the cycling mode share in Ireland is low than the majority of the countries considered this may be an inaccurate method of measuring cyclist safety. Due to the difficulty in calculating the exposure of cyclists, there has been no EU wide attempt to measure cyclist safety by other methods. (Short and Caulfield, 2014) have attempted to calculate such a figure for cycling in Ireland based census information on commuter trips (Central Statistics Office, 2011b), the National Travel Survey (Central Statistics Office, 2011c) and road fatality statistics (Road Safety Authority, 2012, Road Safety Authority, 2010b, Road Safety Authority, 2010a). These calculations found there to be approximately 3.5 fatalities per 100 million km cycled. This is 8 times the value risk exposure value for motor vehicle users. (Short and Caulfield, 2014) also estimate that cyclists are 40 times more likely to be injured or killed in a collision per km cycled, than motor vehicle users, while recognising the underestimation of this figure due to underreporting arising from the data sources.

Within the area of actual cyclist safety a popular topic of research is related to cycling helmets; their use (or failure of use) and their benefits in injury prevention/reduction. Much debate exists for (Cameron et al., 1994, Curnow, 2005, Depreitere et al., 2004, Ekman et al., 1997, Povey et al., 1999, Scuffham et al., 2000, Welander et al., 1999) and against (Hagel and Barry Pless, 2006, Robinson, 2001, Robinson, 1996, Robinson, 2007) the promotion, or even mandatory use, of helmets for cyclists. The argument for helmet use maintains that use of a helmet will reduce injury severity in an incident. While those against helmet use argue that requiring helmet use will inhibit the grow of cycling as a transport mode, therefore not maximising the potential health and economic benefits it can offer, which they suggest far outweigh the hazards due to accidents. Other research related to cycling helmets looks into their effectiveness at injury severity minimisation (McIntosh et al., 1998).

3.5.2. Perceived Safety

A poor perception of cycling safety can impede the growth of cycling as a practical mode of transport. (Noland, 1995) found that regardless of the mode used (motor vehicle, transit, bicycle or pedestrian), cycling was perceived as the highest risk travel mode. Motorists in Dublin listed cycling being too dangerous as a reason they do not cycle (Keegan and Galbraith, 2005). It is therefore clear that perceptions of cycling safety need to change both among cyclists and other network users in order for cycling mode shares to benefit.

The existing research and the attributes associated with safety that they attempt to identify are presented in Table 3.3.[1] With the exception of (Møller and Hels, 2008), each of these studies considers only network attributes in evaluating the perception of cycling safety. Transport for London (2012a), (Møller and Hels, 2008) and (Parkin et al., 2007) also consider the characteristics of the cyclist; Transport for London (2012a) and (Parkin et al., 2007) considered age, gender, and how often they cycle, while Møller and Hels also consider helmet use, distance travelled, if they have had previous accidents while cycling and whether they hold a licence to drive a vehicle. Generally each of these studies consulted only cyclists in their analysis. Although (Parkin et al., 2007) also consulted non-cyclists, while (Leden et al., 2000) surveyed 'cycling experts'. Data for these studies were collected by interview (Møller and Hels, 2008), completion of a questionnaire (Leden et al., 2000, Transport for London, 2012a), by providing a rating after watching video clips (Harkey et al., 1998, Hughes and Harkey, 1999, Parkin et al., 2007, Sorton and Walsh, 1994) and after riding through test routes

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[1] Within these studies, the following terms were used which are all understood, from review of the studies to imply what is referred to here as 'safety perceptions': 'risk perceptions', 'safety perceptions', 'hazard perceptions', 'comfort perceptions' and 'stress perceptions'.

(Landis et al., 1997, Landis et al., 2003, Winters et al., 2012) representative of various scenarios. These studies also differed in the location with which they were concerned; the majority of the research consider link segments, while (Parkin et al., 2007) considers a route as a whole, (Landis et al., 2003) consider intersection locations and (Møller and Hels, 2008) consider roundabouts only.

The results of these studies suggest that traffic volume had a large and adverse effect on cyclists' safety perceptions. The perception of on road cycle facilities varied between studies according to cycle-lane width and facility type; generally as the lane becomes wider the perception of the facility improved and while lane markings were found to be important there was little difference in the on road facility types in improving safety perceptions, but off road facilities were perceived as much safer. While roundabouts where perceived as less safe than other junction types; this perception was improved slightly with the addition of a cycle facility. Other attributes which were found by these studies to be important to improving safety perceptions included good pavement surface quality and the presence of other cyclists.

Table 3.3 Attributes considered by studies related to perceived cyclist safety.

Author(s)	Location	Cyclist Volume	Cyclist speed	Traffic Volume	Motorist speed	Presence of a cycling facility	Type of cycling facility	Type of road	Continuity of cycling facility	Outside lane width	Lane markings	Number of junctions (on route)	Traffic signals	Intersection crossing distance	Intersection advanced stop lines	Turning vehicles	Roundabouts	Pavement surface	Right turns	Link length	Number of lanes	Number of side roads	Parked cars	Pedestrians	Traffic mix	Traffic Calming	Trip creation of surrounding area
(Møller and Hels, 2008)	Roundabout	*		*	*	*										*	~										
(Parkin et al., 2007)	Route			*			*		*			*	*		*	*	*		*				*	*			
(Landis et al., 2003)	Intersection			*	*					*				*		*				~	*						
(Leden et al., 2000)	Bicycle crossing	*	*		*											*				~							
(Hughes and Harkey, 1999)	Link			*	*					*	*																
(Harkey et al., 1998)	Link			*	*					*								*			*	*					*
(Landis et al., 1997)	Link			*	*					*	*		*					*			*				*		*
(Landis, 1994)	Link			*	*					*								*			*	*			*		*
(Sorton and Walsh, 1994)	Link			*	*		*																				
Transport for London (2012a)	Route	*		*	*	*	*	*				*															
Winters et al. (2012)	Route					*	*	*										*					*			*	

3.6. CYCLING IN TRANSPORT MODELLING

Traditional transport modelling methods follow the Four Stage Modelling technique: trip generation, trip distribution, mode choice and trip assignment (McNally, 2007). The focus of this section of the review is on mode choice and route choice studies incorporating cycling within the transport network. As interest in increasing cycling mode shares has only become popular in more recent years, little research in the area pre-dates 1990. For a review of mode and route choice literature prior to this, please refer to (Barff et al., 1982, Noland, 1995) and (Hopkinson et al., 1989) respectively.

3.6.1. Mode Choice

Travel mode choice models aim to discover the attributes network users consider important when deciding which mode(s) of transport they will use between their origin and destination of travel. These models also allow estimates of demand for certain travel modes and therefore such models are vital to transport planners. If a mode has been targeted for increased mode share it is of interest to planners to discover which attributes will most substantially increase their appeal. These models may also be used to determine if there is a large demand for a specific travel mode, enabling them to provide the necessary infrastructure etc. for this mode.

With focus moving to increasing sustainability within the transport sector a number of studies concentrating on the characteristics encouraging the use of non-motorised modes of transport have emerged. Table 3.4 displays a number of this type of study categorised as either aggregate (census and National Travel Survey (NTS) data etc.) or disaggregate studies (Stated Preference (SP) and Revealed Preference (RP) data etc.). The majority of these studies consider a number of personal characteristics; age, gender, car ownership, income and socioeconomic class are largely considered in these studies, although hours of exercise and bicycle competency (Noland, 1995, Noland and Kunreuther, 1995) have also been considered. Other areas studied include characteristics of the transport network; the major variables being travel time/distance, en-route facilities and terrain (hilliness), however road type (Wardman et al., 2000, Wardman et al., 2007) road surface condition (Parkin, 2004), network density (Parkin, 2004), speed of traffic in relation to bicycles (Rietveld and Daniel, 2004) have also been found significant, and characteristics of the origin or destination region; population densities (Buehler, 2011, Parkin, 2004, Rietveld and Daniel, 2004, Rodríguez and Joo, 2004), urban/rural area (Crespo Diu, 2000) and neighbourhood type (Cervero and Radisch, 1996, Siu et al., 2000). Certain studies concentrate on a particular area which they have shown have an influence on travel mode choice; (Rietveld and Daniel, 2004) investigate the influence of municipal policies, although the results of modelling are more based on neighbourhood characteristics such as population size, proportion of 15 to 19 year olds, presence of a higher vocational training school, proportion of foreigners, number of cars per capita; (Noland, 1995) and (Noland and Kunreuther, 1995) look at the effect of various safety factors on choosing cycling as a travel mode. Perceived risk, perceived injury severity, perceived convenience, perceived comfort, perceived cost, bicycle competency, risk due to lack of hard shoulder are shown within these researches to affect the probability of selecting cycling as a viable transport mode.

Table 3.4 Mode choice studies relating to cycling.

Author(s)	Data Sources	Factors Found Significant to Mode Choice
Aggregate Studies		
(Waldman, 1977)	UK Census	Hilliness, rainfall, trip length, socio-economic class
(Ashley and Banister, 1989)	UK Census	Hilliness, car ownership, link lengths
(Crespo Diu, 2000)	UK Census	Gender, trip length, rainfall, safety, terrain, urban/rural, car ownership
(Rietveld and Daniel, 2004)	NTS & Dutch Cyclists' Union surveys	Population size, human activity indicator, proportion of 15-19 years old, presence of a higher vocational training school, proportion of liberal party voters, proportion of foreigners, number of cars per capita, hilliness, stop frequency, parking costs, hindrance frequency, speed compared to a car, degree of satisfaction, safety level
(Parkin, 2004)	UK Census	Age, level of qualification, car ownership, socio-economic class, ethnicity, trip length, road surface conditions, network density, population density, hilliness, rainfall, mean temperature
(Buehler, 2011)	NTS	Germany/US, income, gender, age, car access, Population density, work/shopping trip
Disaggregate Studies		
(Noland, 1995)	SP survey	Perceived risk, perceived injury severity, perceived cost, perceived comfort, car ownership, bicycle parking, bicycle competency, gender, income, hours of exercise per week, available modes
(Noland and Kunreuther, 1995)	SP survey	Available modes, perceived cost, perceived convenience, travel time, perceived risk, weather, lack of hard shoulder risk factor, perceived comfort, car ownership, bicycle parking, bicycle competency, gender, income, hours of exercise per week
(Cervero and Radisch, 1996)	Survey	Neighbourhood, destination, car ownership, gender, age, persons per household, income
(Wardman et al., 1997)	SP survey	Travel time, costs, segregation/integration with traffic, trip end facilities, weather
(Wardman et al., 2000)	NTS, RP & SP surveys	Travel time, gender, age, socio-economic class, income, car ownership, incentive (payment to cycle), trip end facilities, en-route facilities, road type, available modes
(Ortúzar et al., 2000)	SP survey	Travel time, access/walking/waiting time, costs, weather, available modes
(Siu et al., 2000)	Surveys	Gender, age, current mode, neighbourhood, hilliness
(Rodríguez and Joo, 2004)	Survey	Travel time, costs, car ownership/licence holder, gender, student, use of sidewalk, time effect of slopes, population density in home region, available modes
(Wardman et al., 2007)	NTS, RP & SP surveys	Travel time, gender, age, socio-economic class, income, car ownership, incentive (payment to cycle), trip end facilities, en-route facilities, road type, available modes

3.6.2. Route Choice

Route choice modelling is performed in order to gain better understanding of how network users choose their routes between origin and destination. This information is vital to transport planners so the necessary infrastructure or improvement to infrastructure for a mode can be provided along preferred routes. Due to the differing requirements of various modes, the characteristics of a route considered by users vary drastically according to mode.

(Hopkinson et al., 1989) and (Sener et al., 2009) provide detailed reviews of past literature in the area of bicycle route choice. A large amount of these studies apply descriptive analysis only, while those who have used methods of quantitative analysis techniques have done so using information collected from stated preference survey sources (this includes the work of Sener et al. (2009)), with the exception of (Landis et al., 1997) who analyses the experiences of cyclists who have ridden through a test track. Since (Sener et al., 2009) a number of revealed preferences studies of bicycle route choice have appeared. A study of travel routes in Zurich (Menghini et al., 2010), has used GPS units to collect actual route information which is then compared to a set of viable alternatives to determine why the actual route was selected over the suggested alternatives. This study has a number of drawbacks in that there was no personal information collected with the data, nor was the mode which collected the data specified. A mode detection algorithm (Schüssler and Axhausen, 2009) is used to separate cyclist trips from this data; although Menghini et al. (2010) state that it is not possible to estimate the amount of false positive or wrong negatives which may have arisen. A further two studies in Portland OR, US (Broach et al., 2011) and San Francisco CA, US (Hood et al., 2011) used GPS devices to collect trip information uniquely from cyclists. Similar to previous analysis both studies highlight the importance of distance, slope, bicycle facilities and turn frequency consideration to the route choice of cyclists, although these studies disagree on the importance of traffic volume; (Broach et al., 2011) has found it relevant to route choice decisions, while (Hood et al., 2011) suggests it is not relevant. Each of these studies recognises the difference occurring in route choice characteristics among cyclists; between commute and non-commute trips, male and female and across cycling frequencies.

3.6.3. Traffic Assignment

Due to the dominance of motorised vehicles in transport networks, the assignment of traffic within these networks has historically only considered motorised travel mode and public transport. Where bicycle trip assignment models have been implemented in transport planning they are limited; assigning cyclists within congested multi-modal networks by 'shortest-path' approaches (National Transport Authority, 2013a, U.S. Department of Transportation, 1999, Ridgway, 1997, Hill and Stefan, 2014). This approach was traditionally developed for the assignment of motorised modes and was not sufficient to consider the requirements of cyclists.

More recently, owing to the more heavily mixed traffic situations which arise in developing countries, traffic assignment models which also consider cyclists have appeared (Si et al., 2008a, Si et al., 2008b, Si et al., 2011, Jiang and et al., 2004, Oketch, 2000, Gao and Si, 1998, Li et al., 2007, Li et al., 2009a, Yulong and Junyi, 1997, Zhou, 2001). These traffic situations tend not to be representative of the situation in developed countries and will not be considered further. Traffic assignment models have taken two distinct approaches to the problem; the traditional approach, using Wardropian Principles and its extensions; and microscopic modelling approaches.

Microscopic traffic flow simulation models offer an alternative approach to modelling traffic systems. This type of model simulates each individual vehicle within a network, thus at any timestep the location, velocity and other characteristics of the vehicle are known. There are two main types of microscopic model used in traffic flow analysis; Car Following (CF) models and Cellular Automata (CA) models. Both sets of models follow a set of rules updated at each time step for each vehicle. CF models are based on the speed, acceleration and deceleration rates and position of the lead and following car to monitor the progress of a vehicle in the network. CA models divide a network into a set of cells and progress of a vehicle is dependent on whether the subsequent cell is available for the vehicle to move into. Examples of the use of these models with bicycle in the network include (Faghri and Egyháziová, 1999) (CF), (Jia et al., 2007) (CA), (Gould and Karner, 2009) (CA), (Xie et al., 2009) (CF) and (Vasic and Ruskin, 2011) (CA).

Models based on Wardropian principles generally involve assigning network flow in order to optimise, or more specifically minimise, the costs to either the user (user equilibrium) or the transport network operator (system optimal) based on a set of criteria generally referred to as travel costs or travel disutility. Researches into the development of these types of models, which include cyclists in the network, are limited.

While (Hood et al., 2011) uses the results of a multinomial logit model of cyclist routes with a volume delay function, a number of studies have based assigned cyclists within the network based on Bicycle Level of Service (BLOS), Bicycle Compatability Index (BCI) or similar type indexes of link suitability (Klobucar and Fricker, 2007, Smith and Haghani, 2012, Subhani et al., 2013, Ehrgott et al., 2012). The BCI was developed by (Harkey et al., 1998) based on the safety perceptions of cyclists having watched video clips of roadway segments of varying traffic conditions and geometry, while the BLOS (Landis et al., 1997) was developed based on cyclist ratings having ridden various test routes. In two of these studies (Klobucar and Fricker, 2007, Smith and Haghani, 2012) trip distance was considered with the respective index. (Ehrgott et al., 2012) assigned trips using a suitability rating developed by (Palmer et al., 1998) and a travel time function. This suitability rating considers similar factors to the BCI and BLOS, but is not based on safety perceptions. (Subhani et al., 2013) use the BLOS estimated for cyclists of different levels of experience.

Each of these models is a single modal bicycle trip assignment model with deterministic demand. (Zhou, 2001), (Si et al., 2008a, Si et al., 2008b, Si et al., 2011), (Mesbah and Thompson, 2011), (Si et al., 2012) and (Li et al., 2014) each consider multiple modes and mode choice. (Zhou, 2001), (Mesbah and Thompson, 2011) and (Si et al., 2012) assign bicycle trips to the networks using only travel time or travel distance. (Si et al., 2008a, Si et al., 2008b) and (Si et al., 2011) apply a system optimal approach. As such the network is optimised in order to reduce the overall network cost for costs such as congestion, emissions, fees or energy (fuel) consumption. (Li et al., 2014) presents a multimodal network model which considers costs that may be considered representative to the actual costs felt by travellers. These costs include travel time, access/parking time, tolls and fairs. This model considers only cyclists who use a public bicycle rental scheme; for these cyclists the costs considered are travel time, walking time to rental station, rider fatigue, bicycle rental costs, time taken to return rental bicycle to station.

It can be seen that there is no comprehensive multi-modal network modal which takes into account modal choice, the decision not to travel (elastic demand) and trip assignment for all cyclists in a network model representative of an actual transport network. As safety is a major factor to the decision, both to cycle and in which route to take once the decision to cycle is made it should be included in these traffic assignment models.

CHAPTER 4

4. AN ANALYSIS OF THE SAFETY PERCEPTIONS OF CYCLISTS

This chapter aims to investigate the perceptions associated with cycling in Dublin city to improve understanding and identify attributes of network design and transport network user attitudes which influence these perceptions. The research presented in this chapter of the thesis is based on the results presented in (Lawson et al., 2013) and (Lawson et al., 2014).

4.1. CYCLING SAFETY SURVEY

In order to investigate the determinants associated with cycling safety perceptions a survey was conducted. This survey collected information from cyclists in Dublin city, in 2012. As discussed within the review of literature, cycling is generally viewed largely as an unsafe mode of travel. This is dispite the low rates of road traffic incidents involving cyclists, compared to other travel modes. This study, therefore, aims to collect information relating to the perceptions of cycling which lead perceptions of cycling being unsafe. The following sections describe the study region, methods of data collection and present a profile of the survey respondents. A copy of the questionnaire is included in Appendix I.

4.1.1. Study Region

Dublin City (Figure 4.1) is the capital of Ireland and the largest city in terms of residing and working population of the country (Central Statistics Office, 2011a). Private motor vehicles are the main mode of transport in the city with 38.7% commuting by this mode in 2011 (Central Statistics Office, 2011b). As such Dublin city contains a large network of roads to carry this traffic. Other main modes of motorised transportation in Dublin City are Dublin Bus, Luas (light rail), Dublin Area Rapid Transport (heavy rail) and Commuter trains (suburban railway networks). In 2011, nearly 12% of the commuter trips were made using NMT (Central Statistics Office, 2011a). However, the percentage of persons walking to their workplaces was much higher than that using bicycle as their preferred mode of commuter travel. The cycling network in Dublin City contains facilities mainly in the form of cycle lanes; approximately 120 km of on-road cycle lanes, 50 km of shared bus-cycle lanes and 25 km of off-road cycle paths exist in the network (Dublin City Council, 2013). Examples of each of these types of facilities can be seen in Figure 4.2.

Figure 4.1 Cycling facilities in Dublin City (National Transport Authority, 2013a)

Cycle lane

Shared-use bus lane

Segregated cycle path

Figure 4.2 Examples of cycling facilities available in Dublin.

4.1.2. Data Collection

Before commencing this study of cyclists' safety perceptions, the methods that would be appropriately applied, were considered; revealed preference and stated preference type studies. A revealed preference method refers to a situation where an option is actually made; whereas stated preference refers to a situation where an option is selected based on a hypothetical situation. A revealed preference study may be able to provide a more realistic description of the safety perceptions when using the network, as the choices that are actually made by cyclists, rather than the choices they may believe they would make (this would be the outcome of a stated preference survey), would be collected. It was thought that investigating a large number of network attributes by this method (rather than collecting overall perceptions of a route) would prove difficult and would involve long, time consuming and complicated routes for participants to follow. As such it was decided that a revealed preference study was not suitable. A stated preference survey generally asks participants to select from a list of alternatives, differing in terms of their attributes. Again, a survey of this type would require a large number of questions to be asked to be able to study all attributes. This may reduce response rates due to the time that would be required. Therefore, a questionnaire type survey was chosen for this study. This allowed questions to be asked about a large number of attributes, although this does not allow the trade-offs between different attributes to be considered as would be possible using the stated preference method described above.

The questionnaire was conducted in order to gather information, previously unavailable in Dublin, on the perceived safety and safety behaviours of cyclists, with regards to the available cycling infrastructures, the use of safety accessories, the effect of prevalent road and weather conditions, as well as various other aspects of traveling by bicycle in Dublin's multi-modal network. The survey, conducted over a 3 month period between 7th March and 1st June, 2011, receiving 1,954 responses, collected information from existing cyclists, who regularly cycled in Dublin within the previous 12 months. The questionnaire was distributed among major Irish and multi-national companies, major Universities in Dublin (Trinity College Dublin, University College Dublin, Dublin Institute of Technology, Dublin City University), governmental departments and through word of mouth. The questionnaire was available on-line; the link to which was circulated via e-mail, posts on cycle club and group websites, cycling forums, and posts on social networking web-sites. Hardcopies of the questionnaire were available from local cycle repair shops.

The survey questions have been based on those from a broader study of cycling (considering both on- and off-road and urban and rural cycling) conducted in Queensland, Australia (Haworth and Schramm, 2011). Attempts were made to minimise bias in the data collection methods; this included consulting with stakeholders from the NTA and the researchers involved in the study in Queensland about the questions and format of the survey. Questions were also worded so as not to be leading. Despite this, a certain amount of bias may still remain; as this was a self-reporting survey respondents may exaggerate responses or answer dishonestly because of how they feel they might be perceived. The survey collection process was anonymised in order to reduce the possibilities of this occurring. Respondents may also exaggerate responses if they believe that results may benefit their vision for cycling safety; the occurrence of such bias may be encouraged by the anonymity of the survey. As such a large number of survey responses were collected to reduce the effects of this. The adequacy of the survey sample size was checked using the equation from (Dillman, 2000) to estimate the minimum survey sample size required:

$$N_s = \frac{N_p pq}{(N-1)D + pq} \qquad \textbf{Eq. (4.1)}$$

where

$$q = 1 - p \qquad \textbf{Eq. (4.2)}$$

$$D = \left(\frac{B}{C}\right)^2 \qquad \textbf{Eq. (4.3)}$$

and where N_s is the sample size required for the desired level of precision, N_p is the size of the population, p is the proportion of the population expected to choose one of two response catagories, B is the acceptable amount of sample error and C is the Z statistic associated with the confidence level.

The population of cyclists in Dublin was calculated from the most recently collected census data prior to the survey being conducted. The 2006 census showed that there were 18,028 persons over the age of five in Dublin city who cycled as their main mode of travel to work, school or college (Central Statistics Office, 2006a). In order to get the most conservative sample population size and allow for maximum variation in the sample, a 50/50 split was chosen which represents a 50% chance of an individual choosing one option and 50% chance that they would choose the other option. This results in values for p and q of 0.5 and 0.5 respectively. For these values, allowing a 5% sampling error at a 95% level of confidence, the following sample population is estimated as

$$N_s = \frac{(18,082)(0.5)(1-0.5)}{(18,082-1)\left(\frac{0.05}{1.96}\right)^2 + (0.5)(1-0.5)} = 377 \qquad \textbf{Eq. (4.4)}$$

Therefore, the minimum sample size for this survey should be 377 responses. This value is much lower than the sample population used for this survey.

The survey collected information on socio-demographics, trip purposes, trip distance, trip time, cycling infrastructure preferences, safety equipment preferences, information on the effects of adverse road and weather conditions as well as information on effects of interaction with other travel modes. At the beginning of each section of the survey, a short explanation of the focus of the section was given so that respondents were aware of why the questions were being asked. In particular, models related to safety behaviour and cyclist-network interaction involved questions based on extensive literature review and discussions with cycling experts from the city council, National Transport Authority and cycling forums. These bodies were considered influential to the focus of the section. For the perception of safety model, the perceived safety was measured by asking specific questions on how safe the cyclist feels compared to driving in Dublin on a Likert scale (Jambu, 1991).

4.1.3. Profile of Cyclists and Description of Data Collected

The profile 1,732 cyclists who gave eligible responses to the survey has been presented in Tables 4.1 and 4.2. The profile has been summarised according to the self-reported experience of the cyclists ('inexperienced', 'competent', or 'highly skilled'), socio-demographic characteristics (e.g., 'age') and cyclists' trip characteristics (e.g., 'regularity of cycling') with a count and the corresponding percentage given for each combination of self-reported experience and characteristic (e.g., 'male'). The percentage is calculated by dividing the count by the total number of eligible responses, 1732, and multiplying the resulting quotient by 100%. Hence, the sum of all the percentages under the same characteristic (e.g. gender) equals 100%. This is with the exception of the trip purpose characteristic as cyclists may cycle for more than one trip purpose.

As can be seen in Table 4.1 the majority of the respondents were male (63.7%) and were aged less than 45 years. As the majority of the cyclists in Dublin City were male and less than 40 years of age (Central Statistics Office, 2011a), these responses are representative of the cycling population in the city. The majority of respondents were either students (46.1%) or in full-time employment (44.4%). Respondents were mainly single, living in shared accommodation (35.8%), couples with resident child(ren) (24.1%) or couples with no resident child(ren) (17.0%). All respondents live within the Dublin area, as this is the study area of interest and 51.8% of respondents have a car that can be used on a day-to-day basis.

The survey showed that on average the respondents cycled 9.54 km on a weekday and 6.85 km on a weekend day. In 2006, commuters in Dublin travelled an average distance of 4.83 km (Central Statistics Office, 2006b) (data relating to distance was not collected as part of the 2011 Place Of Work, School or College – Census of Anonymised Records (POWSCAR) dataset, therefore only 2006 data is presented).

Other studies of cyclists observed that the average distances for utilitarian trips are between 3.5 km and 7 km (Broach et al., 2011, Howard and Burns, 2001, Nankervis, 1999, Winters et al., 2010a, Winters et al., 2010b). These figures may be lower than what have been observed here as these studies do not include exercise trips or social and recreational trips. In terms of time spent cycling, the respondents cycle 42.6 min on a weekday and 31.9 min on a weekend day on average. Travel times recorded by census are much lower than this; in 2011 a cyclist spent on average 21.3 minutes travelling in Dublin (Central Statistics Office, 2011b), but this census data considers only commute trips. Table 4.2 also shows that generally the cyclists travel at speeds of 10-20 km/hr. Although a large number of respondents describing themselves as highly skilled cyclists travel at higher speeds. In the survey, nearly 98% of the respondents describe themselves as being either competent or highly skilled cyclists. This may present a bias in the survey sample; it is not known if inexperienced cyclists have been underrepresented by the survey or whether cyclists do not tend to believe themselves to be inexperienced. It has also been observed that, over 85% of the respondents are regular cyclists and cycle at least 3 days per week. The survey reveals that bicycles are used for social and recreational trips by the greatest number of respondents (65.4%), and such trips consume on average 7.6% of their total time spent cycling. Bicycles are used for commuting trips by 58.2% of the respondents and on average such trips take 37.8% of their total cycling time. In 2006, only 45% of these respondents cycled in Dublin; this figure grew each year to 90.9% in 2010. Over 90% of the respondents, cycle from spring to autumn and 74.1% continue to cycle during the winter months. Almost 94% of the respondents owned a bicycle; it is thought that the remaining respondents make use of the bicycle sharing scheme available in the city. This high percentage of bicycle ownership may be misrepresentative of the proportion of cyclists the make use of the public bicycle sharing scheme but there has been no information collected by the census to inform the proportions using their own bicycle or a public bicycle. Nearly 54% of the respondents claim to wear a helmet and 88% use lights or reflective accessories while cycling at night. While helmet use has not been made mandatory by Irish road traffic law, the use of lights during night time hours is compulsory. Similar international studies suggest lower rates of safety accessory use; 2.2% of the cyclists in Paris, 31.5% in Boston (Osberg et al., 1998) and 44% in Victoria (Robinson, 1996) wear helmets while cycling and 14.8% of the cyclists in Boston, 46.8% in Paris (Osberg et al., 1998), 40-60% in Christchurch (Ferguson and Blampied, 1991) and 50% in Edmonton (Hagel et al., 2007) use lights or reflective accessories while cycling at night. These lower rates in international cities may suggest a bias in the survey data but these differences may be due to the legal, cultural and social differences among the various cities and countries.

Table 4.1 Description of survey respondent attributes.

	Inexperienced		**Competent**		**Highly Skilled**		**Total**	
	No.	%	No.	%	No.	%	No.	%
Total Persons	36	2.1	871	50.3	825	47.6	1732	
Gender								
Male	4	0.2	445	25.7	654	37.8	1103	63.7
Female	32	1.9	418	24.1	167	9.6	617	35.6
Age								
Less than 25 years old	19	1.1	283	16.3	255	14.7	557	32.1
25 to 44 years old	11	0.6	400	23.1	423	24.4	834	48.1
45 to 64 years old	0	0.0	98	5.7	90	5.2	188	10.9
More than 64 years old	0	0.0	7	0.4	4	0.2	11	0.6
Not Stated	6	0.3	75	4.3	46	2.7	127	7.3
Employment status								
Full time	7	0.4	360	20.8	399	23.0	766	44.2
Part-time	0	0.0	31	1.8	29	1.7	60	3.5
Student	26	1.5	419	24.2	350	20.2	795	45.9
Unemployed	0	0.0	12	0.7	7	0.4	19	1.1
Other	3	0.2	49	2.8	40	2.3	92	5.3
Household structure								
Single person - shared	14	0.8	327	18.9	276	15.9	617	35.6
Single person - unshared	1	0.1	62	3.6	65	3.8	128	7.5
Lone parent with resident	3	0.2	21	1.2	22	1.3	46	2.7
Couple with resident	4	0.2	195	11.3	216	12.5	415	24.0
Couple with no resident	7	0.4	147	8.5	138	8.0	292	16.9
Other	7	0.4	119	6.9	108	6.2	234	13.5
Regularity of cycling								
1 to 2 days every week	14	0.8	170	9.8	56	3.2	240	13.8
3 to 5 days every week	20	1.2	519	30.0	419	24.2	958	55.4
6 to 7 days every week	2	0.1	182	10.5	350	20.2	534	30.8
Time spent on cycling on an average weekday								
Less than 30 min	17	1.0	325	18.8	209	12.1	551	31.9
30 min to 1 hour	17	1.0	418	24.1	415	24.0	850	49.1
More than 1 hour	2	0.1	128	7.4	201	11.6	331	19.1
Time spent on cycling on an average weekend day								
Less than 30min	30	1.7	585	33.8	429	24.8	1044	60.3
30 min to 1 hour	6	0.3	145	8.4	155	9.0	306	17.7
More than 1 hour	0	0.0	141	8.1	241	13.9	382	22.0

Table 4.2 Description of survey respondent attributes continued.

	Inexperienced		Competent		Highly Skilled		Total	
	No.	%	No.	%	No.	%	No.	%
Distance cycled on an average weekday								
Less than 5 km	26	1.5	372	21.5	225	13.0	623	36.0
5.1 to 10 km	6	0.4	224	12.9	209	12.1	439	25.4
10.1 to 15 km	2	0.1	124	7.2	137	7.9	263	15.2
More than 15 km	2	0.1	151	8.7	254	14.7	407	23.5
Distance cycled on an average weekend day								
Less than 5 km	32	1.9	619	35.7	425	24.5	1076	62.1
5.1 to 10 km	2	0.1	74	4.3	102	5.9	178	10.3
10.1 to 15 km	1	0.1	50	2.9	47	2.7	98	5.7
More than 15 km	1	0.1	128	7.4	251	14.5	380	22.0
Average travel speed								
Less than 10 km/hr	5	0.3	45	2.6	11	0.6	61	3.5
10 to 20 km/hr	15	0.9	409	23.6	317	18.3	741	42.8
More than 20 km/hr	0	0.0	148	8.6	334	19.3	482	27.9
Don't know	16	0.9	269	15.5	163	9.4	448	25.8
Trip purpose								
Commute to/from work	16	0.9	502	29.0	545	31.5	1063	61.4
Commute to/from school or	24	14	458	26.4	408	23.6	890	64.0
Travel to other forms of public	7	0.4	130	7.5	134	7.7	271	15.6
Shopping	19	1.1	443	25.6	423	24.4	885	51.1
Social/recreation	24	1.4	561	32.4	557	32.2	1142	66.0
Health/fitness training	13	0.8	412	23.8	460	26.6	885	51.2
Organised racing	1	0.1	37	2.1	130	7.5	168	9.7
Driver's attitude (as perceived by the cyclists)								
Always reckless	3	0.2	25	1.4	40	2.3	68	3.9
Usually reckless	6	0.3	151	8.7	134	7.7	291	16.8
Reckless about half the time	12	0.7	260	15.0	238	13.7	510	29.4
Seldom reckless	12	0.7	417	24.1	395	22.8	824	47.6
Never reckless	3	0.2	18	1.0	18	1.0	39	2.3

An initial analysis of the survey data looked at the travel behaviour of the respondents while cycling in the city. In the questionnaire, the respondents were presented with various alternative route choice scenarios and they were asked whether they would alter their routes under these scenarios. A qualitative Likert scale, with 5 options, was used to measure the likelihood of route alteration. Of the respondents, 57.8% stated that they would alter their routes to make use of continuous cycle lanes, while 50.4% and 50.6% of the respondents would alter their routes to use quiet roads and routes perceived as safe by the cyclists, respectively. Cyclists also showed a clear order of preference for the cycling facilities available in Dublin city; with segregated paths being most preferable, followed by kerbside cycle lanes and shared-use bus lanes respectively. Cycling where no facilities were present was least preferable. The strongest aversion felt by the respondents was for roads with higher speed limits and for roads with poor quality surfaces, with 32.9% and 31.7% of the respondents respectively, stating they would alter their routes in order to avoid these roads. Only 10.9% of the respondent cyclists stated that they would alter their routes to avoid inconvenient right turn movements. Infrastructure to allow easier right turn movements for cyclists have recently been introduced to Dublin; however, such implementation may not improve the attractiveness of a route according to the results. The respondents were also asked if they would consider changing to another mode of transportation under various weather conditions; 79.8% would change to an alternative mode under icy road conditions; 55.6% in heavy rain and 30.3% in temperatures below freezing. A study on students in three universities in Melbourne, Australia found that 40% of the respondent cyclists would change to another mode in rain and 66% would do the same in icy and snowy conditions (Nankervis, 1999). In Dublin, more survey respondents are likely to change their mode of travel under adverse weather conditions as they may have better access to alternative modes, such as private cars, than a student-only population.

4.2. METHODOLOGIES

Principal component analysis and ordered logistic regression were the methods used to analyse the survey responses. PCA is a multivariate data analysis methodology in which the dimensionality of a large dataset is reduced (Jambu, 1991, Jolliffe, 2002). This allows the identification of variables which are related (i.e. if there is a change to a variable in a principle component, there is a change to each variable in that principle component; the magnitude and direction of change for these variables can differ). OLR, on the other hand, establishes the likelihood of an event which is dependent on the outcome of a number of independent variables (Semmlow, 2009, Hosmer and Lemeshow, 2000). OLR is applied here to determine the variables related to cyclists' perception of cycling as less safe than, as safe as or more safe than driving.

Both of these methodologies are applied within this research to gather more information than either method alone could provide. An understanding of which variables should be addressed together by policy in order to maximise their impact is beneficial; PCA allows the identification of these groups. But it is also necessary in the study of safety to understand which variables are associated with cyclists' perceptions of safety and how these associated variables affect this perception; in this case OLR is required.

The PCA analysis was conducted using MATLAB version 7.12.0.635 (MathWorks, 2011) and the OLR analysis was performed in Stata 10 (StataCorp LP, 2007).

4.2.1. Principal Component Analysis (PCA)

PCA reduces the dimensionality of a data set containing a large number (*p)* of possibly correlated random variables ($X_1, X_2, ..., X_p$) by transforming the variables to a new set of variables called principal components ($F_1, F_2, ..., F_p$), which are uncorrelated and ordered so as the first principal component retains the most of the variance present in the original variables. The random variables X_i forming the matrix $\mathbf{X}$ can be expressed as a linear combination of the factor components $F_1, F_2, ..., F_p$ as follows,

$$X_i = \left(\sum_{k=1}^{p} a_{ik} F_k \right) + R_i \qquad i = 1, 2, ..., p \qquad \textbf{Eq. (4.5)}$$

where R_i is the disturbance term (Jambu, 1991, Jolliffe, 2002) and a_{ik} are the linear coefficients related to the factors. As the variables used in this thesis are heterogeneous with regard to their means and dispersions (measured in different units, across different ranges) they must be standardised. The elements of the matrix $\mathbf{X}$ are denoted by X_{ij} (*j* = the number of units in X_i) which are replaced by,

$$\Pi_{ij} = \frac{X_{ij} - \bar{X}_i}{\sigma_i} \qquad \textbf{Eq. (4.6)}$$

where $\bar{X}_i$ and σ_i are the arithmetic mean and the standard deviation of the random variable X_i respectively. The next step of the PCA is to calculate the covariance matrix, from which the eigenvalues[2] and corresponding eigenvectors[3] (or principal components) are found. In this thesis, the latent root criterion is followed in the analysis, where eigenvectors with corresponding eigenvalues greater than 1 are considered as significant, while eigenvectors with corresponding eigenvalues less than

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[2] An eigenvalue gives the variation of the data in the direction of the eigenvector.

[3] An eigenvector is a variable created following the orthogonal transformation of the original data.

1 are considered as insignificant and are disregarded. Λ is the matrix formed by ordered principal components with their eigenvalues greater than 1.

A rotation criteria is now applied in order to make the structure of Λ as simple as possible, to create a matrix B where the elements are either 'close to zero' or 'far from zero' (Jolliffe, 2002). An orthogonal rotation method is applied here. The varimax rotation maximises the sum of the variances of the squared loadings to create the matrix

$$B = \Lambda T \qquad \textbf{Eq. (4.7)}$$

where B is the matrix with elements b_{il}, $i = 1,2,...,p; l = 1,2,...,m$ and m $(\leq p)$ is the number of principal components in Λ. T is the rotation matrix used to create B in order to maximise the varimax criterion, Q defined as;

$$Q = \sum_{l=1}^{m}\left[\sum_{i=1}^{p} b_{il}^{4} - \frac{1}{p}\left(\sum_{i=1}^{p} b_{il}^{2}\right)^{2}\right] \qquad \textbf{Eq. (4.8)}$$

The elements in B which are 'far from zero', more specifically with a magnitude greater than 0.3, are known as the factor loadings for each variable (Jolliffe, 2002). These factors loadings are grouped according to principal components. Those variables with factor loadings considered significant in the first principal component are related and explain the most of the variation present in the original data.

4.2.2. Ordered Logistic Regression (OLR)

The second method chosen for analysis of the survey data, OLR, is similar to other logistic regression methods as it models the probability of an outcome (***Y***) based on the influence of the independent variables. OLR differs from binary logistic regression analysis in how the dependent variable (***Y***) is presented in the model; the outcome can have multiple values (1, 2…*N*), ordered from low to high. In OLR, the conditional probability of an outcome can be expressed as,

$$\pi(\mathbf{y} = q|\mathbf{x}) = \frac{e^{g_q^{(\mathbf{x})}}}{\sum_{r=1}^{N} e^{g_r^{(\mathbf{x})}}} \qquad \textbf{Eq. (4.9)}$$

where $\pi(\mathbf{y} = q|\mathbf{x})$ is the probability of the outcome assuming a value q, $g(\mathbf{x})$ denotes the attractiveness of this outcome $(\mathbf{y} = q)$ and $\mathbf{x}$ denotes the vector of the factors or independent variables which influence this choice. The logit transformation, which is the transformation of $\pi(\mathbf{y}=q|\mathbf{x})$, is defined as,

$$g(\mathbf{x}) = \ln \frac{\pi(\mathbf{y}=q|\mathbf{x})}{1-\pi(\mathbf{y}=q|\mathbf{x})} = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \ldots + \beta_N x_N + \varepsilon$$

Eq. (4.10)

where $\beta_1, \beta_2, \ldots, \beta_N$ denote the relative importance of the independent variables $x_1, x_2, \ldots, x_N$ and ε is the independently distributed error term with mean zero. A maximum likelihood estimation technique is used to estimate the values of $\beta_1, \beta_2, \ldots, \beta_N$. For the OLR model to be valid the proportional odds assumption[4] must hold. This is tested using the Brant test (UCLA Statistical Consulting Group, 2015). If this test does not hold, multinomial logistic regression should be implemented. The odds ratio (OR) is the measure used to interpret the results of logistic regression. In the case of OLR the OR is the ratio of the conditional probability of an outcome to the sum of conditional probabilities of all other possible outcomes. For the possible values $\{a,b,c\}$ of an outcome ***Y*** the OR is defined as,

$$\text{OR} = \frac{\pi(\mathbf{y}=a|\mathbf{x})}{\pi(\mathbf{y}=b|\mathbf{x})+\pi(\mathbf{y}=c|\mathbf{x})} = \frac{\pi(\mathbf{y}=c|\mathbf{x})}{\pi(\mathbf{y}=a|\mathbf{x})+\pi(\mathbf{y}=b|\mathbf{x})} = \frac{\pi(\mathbf{y}=b|\mathbf{x})}{\pi(\mathbf{y}=a|\mathbf{x})+\pi(\mathbf{y}=c|\mathbf{x})}$$

Eq. (4.11)

Three models, namely the Safety Behaviour Model, the Cyclist-Network Interaction Model and the Perceived Safety Model, were developed to analyse the survey responses using the above-mentioned methods. The Safety Behaviour Model was developed to investigate the safety behaviour of the cyclists in an urban multi-modal network. PCA was used to develop the model to analyse survey responses related to their attitudes and behaviours towards safety while cycling. The Cyclist-Network Interaction Model was built via PCA to investigate the interaction between the cyclist and the elements of the shared multi-modal transportation network of Dublin City and to understand the perception of safety of the cyclists in relation to the existing infrastructures. The Perceived Safety Model was developed using OLR to investigate the determinants which influence a cyclist's perception of safety as compared to driving in the shared multi-modal transportation network of Dublin City. There are two different methodologies applied to the analysis of this survey data in order to gain a greater benefit from the information available in this dataset; while PCA can inform on factors that are interdependent - in the direction and magnitude of change of these

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[4] The proportion odds assumption assumes the relationship between each pair of outcome groups is the same.

variables; OLR allows the probabilities (or likelihoods) of an event, in this case of the perceived safety, to be calculated based on particular values of variables found to be dependent on the precieved safety.

4.3. SAFETY BEHAVIOUR MODEL

This model was developed to analyse the survey responses related to attitudes and behaviour towards safety while cycling in a shared urban multimodal network of Dublin City. PCA was used to reveal the guiding factors. The PCA analysis was preformed, included 26 variables related to cyclists' safety behaviours. This analysis produced 8 eigenvectors which remained significant after the latent root criterion was taken into account, explaining 55% of the variance of the original data set.

In interrupting the results of PCA within this thesis, a significant positive (>0.3) FL is taken to imply an increase in likelihood for that variable. For example, from Table 4.3 eigenvector 3, a FL of 0.326 associated with cyclist confidence implies an increasing level of cyclist confidence described by the cyclist. The opposite is true where the FL is significant and negative i.e. <-0.3; an example of this can be seen in eigenvector 3 where a FL of -0.324 is associated with the occurrence of an incident due to their belief that they are lacking in cycling skills, which implies that the cyclist feels they are less likely to be involved in an incident due to a lack of cycling skills. As these variables are found to be significant within the same eigenvector they are assumed to move together i.e. as the level of confidence described by the cyclist increases they believe they are less likely to be involved in an incident due to a lack of cycling skills. A larger magnitude of the FL is also taken to imply a larger effect on that variable, with the effect of FLs with magnitude less than 0.3 taken to be insignificant.

As discussed in the methodology section the matrix Λ produced by the PCA is transformed through varimax rotation to produce a matrix with FLs very close to, or far away from, zero. But before rotation is applied, preliminary results can be seen in matrix Λ. This matrix is displayed in Table 4.3. As the majority of these results will remain after varimax rotation is applied, only results which are not present after rotation are discussed below. The FLs relating to these results are marked in Table 4.3 in bold print (in eigenvectors 2, 3, 5, 6, 7 and 8).

- In eigenvector 2, increased self-reported compliance with the rules of the road (indicated by a positive FL of 0.34) was associated with increased use of hi-visibility clothing, helmets and reflective accessories (FLs of 0.44, 0.45 and 0.37 respectively) and increases in cycling for commuting purposes (FL of 0.31).

- In eigenvector 3, a decrease in the likelihood of an incident due to lack of cycling skills (as indicated by a negative FL of -0.32) was associated with increased levels of experience (FL of 0.46) and confidence (FL of 0.33) and regularity of cycling (FL of 0.45) being described by cyclists.
- In eigenvector 5, a FL of -0.30 implies a decrease in the likelihood of an incident due to a lack of cycling skills which was seen to be associated with an increase in the use of bicycles for social/recreational (FL of 0.46) and health/fitness purposes (FL of 0.47).
- In eigenvector 6, negative FLs of -0.44 and -0.38, indicating less cycling for shopping and social/recreational purposes, respectively, was associated with decreased likelihoods of perceiving drivers as reckless (FL of -0.38) or careless (FL of -0.40) towards cyclists.
- In eigenvector 7, increased health/fitness cycling (FL of 0.35) and increased cyclist confidence (FL of 0.31) were associated with low use of bicycles to connect to public transport (FL of -0.34) and for shopping purposes (FL of -0.56).
- In eigenvector 8, increased belief that drivers are reckless and carless (FLs of 0.32 respectively) and increased belief of involvement in an incident involving a bus in a shared-use bus lane (FL of 0.35) were associated with decreasing likelihoods of incidents resulting from a poorly maintained bicycle and a lack of cycling skills (FLs of -0.42 respectively).

As a number of variables were found to be significant within more than one eigenvector a varimax rotation was applied to the matrix. These significant FLs resulting from this rotation are displayed in Table 4.4.

Table 4.3 Factor loadings for all variables before matrix rotation is applied.

	Eigenvector No.							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Experience of cyclist	0.082	-0.124	0.464*	-0.026	0.202	-0.103	0.189	-0.012
Familiarity with cycling in Dublin	0.029	0.060	0.024	0.391*	0.192	0.087	-0.024	0.041
Regularity of cycling	0.079	-0.166	0.451*	0.099	-0.067	-0.186	-0.150	-0.155
Bright coloured/hi-visibility clothing use	-0.088	0.442*	0.092	-0.041	0.126	-0.033	0.220	-0.161
Helmet use	-0.130	0.446*	0.091	-0.040	0.027	-0.004	-0.024	-0.206
Reflective accessory and/or light use	-0.034	0.371*	0.187	-0.018	0.021	-0.178	-0.159	-0.048
Use of cycle lanes while cycling at night	0.012	0.051	-0.038	0.583*	0.177	0.101	0.012	0.017
Use of roads with street lights while cycling at night	-0.009	0.010	-0.054	0.593*	0.179	0.140	0.041	0.031
Compliance with rules of the road	-0.119	**0.340***	-0.103	-0.065	0.098	-0.047	-0.098	0.196
Confidence of cyclist	0.129	-0.283	0.326*	-0.006	0.096	-0.047	**0.312***	-0.123
Incident due to rush hour traffic	-0.324*	-0.043	0.039	0.008	-0.048	-0.055	0.112	0.143
Incident involving a bus in a shared cycle lane	-0.372*	-0.125	-0.009	-0.041	-0.014	0.119	-0.061	**0.345***
Incident involving a taxi in a shared cycle lane	-0.394*	-0.110	0.123	-0.007	-0.008	0.071	-0.060	0.252
Incident due to poor quality road surfaces	-0.340*	0.054	0.061	0.070	-0.078	-0.151	0.052	0.153
Incident due to vehicles parked along road-side	-0.349*	-0.060	0.159	0.140	-0.146	-0.193	-0.004	0.044
Incident due to pedestrians	-0.282	-0.032	0.221	0.112	-0.122	-0.188	0.079	-0.135
Incident due to a poorly maintained bicycle	-0.168	-0.122	-0.192	0.145	-0.237	-0.102	0.247	-0.416*
Incident due to a lack of cycling skills	-0.176	-0.027	**-0.324***	0.079	**-0.302***	-0.082	0.095	-0.417*
Reckless vehicle driver attitude	0.278	0.115	-0.008	0.136	-0.285	-0.381*	0.166	**0.315***
Careless vehicle driver attitude	0.237	0.131	-0.097	0.148	-0.283	-0.404*	0.167	**0.318***
Cycling for commuting purposes	0.024	0.309*	0.294	0.077	-0.146	0.115	-0.228	-0.169
Cycling to public transport	0.063	-0.099	-0.079	0.051	0.018	-0.088	-0.344*	-0.007
Cycling for shopping purposes	-0.032	-0.144	-0.039	0.051	0.108	**-0.444***	-0.557*	-0.135
Cycling for social/recreational purposes	-0.062	-0.094	-0.239	-0.028	0.458*	**-0.376***	-0.062	-0.090
Cycling for health/fitness and training	-0.107	0.074	-0.102	-0.133	0.472*	-0.278	**0.345***	-0.007

* factor loading of magnitude greater then 0.3

Table 4.4 gives the eigenvalues and percentage of variance for each eigenvector, where the eigenvectors are presented in order so that the first group of variables explains the largest amount of variation. The loading factors and standard errors for each variable are also included in this Table. As there is no R^2 type measure of fit defined for PCA models, the goodness of fit is established from the cumulative variance explained by the model (Jambu, 1991); in this case, the first 8 eigenvectors where able to explain 55% of the variance in the original data. This would indicate that the model has been reasonably able to explain the variance in the dataset, but due to the large variability of the data 45% of the variance in the original dataset was not captured by the PCA when the latent root criterion is applied.

The likelihood of an incident due to pedestrians, rush-hour traffic, road surface quality, parked vehicles along road sides, buses and taxis in shared lanes are grouped together according to the similarity of the perceived risk that they present to the cyclists. This grouping indicates that if a cyclist feels the threat of an incident due to the presence of one of these factors, they will feel similarly about the other factors within this group. For example if a cyclists feels there was large chance of involvement in an incident with a pedestrian (a loading factor of -0.30), they were more likely to believe there was a chance of an incident involving a bus or taxi because of the more negative factor loadings of -0.44 and -0.46 respectively. This result may be a cause of concern as these elements are encountered by cyclists on a regular basis within the transportation network. These above-mentioned factors move independently of the likelihood of an incident due to poor bicycle maintenance and lack of cycling skills. Table 4.4 shows that safety accessory use is not associated with the confidence of cyclists, regularity of cycling or the level of experience of cyclists, as the group containing variables related to safety accessory use moves independently from all other groups. A lack of self-reported compliance with the rules of the road is associated with the cyclists who described themselves as being more experienced and confident and who tend to cycle more regularly within the network, as all these factors move together within a group. Another interesting point revealed by PCA is that the trip purposes are not related to any of the safety aspects or variables considered within the model. This is shown by the fifth and seventh eigenvectors which move independently of all other variables. Finally, Table 4.4 indicates that the cyclists feel motorists to be both reckless and careless with regard to the presence of cyclists in Dublin's transportation network. This is a major cause for concern; as it is vital that all the modes cooperate with each other to ensure the safety of the shared space. The overall ranked scores for the variables of the model are presented in Figure 4.3. The bar graph shows the magnitude and direction of the effect of the variables. The factoring loadings signify that the variables of similar signs are interpreted to be of similar influence in a binary sense.

Table 4.4 Eigenvalues, percentage variance explained, factor loadings, means and standard errors of the variables of the Safety Behaviour Model

Eigen-value	% variance explained	Loading	Variable	Mean	Std. Error
3.06	12.22	-0.304	Incident due to pedestrians	2.335[b]	0.024
		-0.366	Incident due to rush hour traffic	1.924[b]	0.021
		-0.403	Incident due to poor quality road surfaces	2.386[b]	0.024
		-0.425	Incident due to vehicles parked along road-side	2.574[b]	0.023
		-0.439	Incident involving a bus in a shared cycle lane	2.237[b]	0.024
		-0.459	Incident involving a taxi in a shared cycle lane	2.611[b]	0.025
2.28	9.10	0.499	Bright coloured/hi-visibility clothing use	3.641[c]	0.037
		0.460	Helmet use	3.234[c]	0.044
		0.449	Reflective accessory and/or light use	4.463[c]	0.025
1.78	7.12	0.521	Experience of cyclists	2.478[a]	0.013
		0.520	Confidence of cyclists	3.052[c]	0.025
		0.478	Regularity of cycling	4.636[d]	0.041
		-0.301	Compliance with rules of the road	2.539[c]	0.020
1.65	6.61	0.636	Use of roads with street lights while cycling at night	1.194[a]	0.018
		0.621	Use of cycle lanes while cycling at night	1.378[a]	0.022
		0.445	Familiarity with cycling in Dublin	3.231[c]	0.039
1.57	6.29	0.652	Cycling for health/fitness and training	17.904[e]	0.658
		0.580	Cycling for social/recreational purposes	15.283[e]	0.515
		-0.350	Cycling for commuting purposes	37.846[e]	0.912
1.23	4.92	-0.677	Reckless attitude of drivers	3.279[c]	0.023
		-0.688	Careless attitude of drivers	2.615[c]	0.022
1.18	4.70	-0.363	Cycling to public transportation facilities	3.124[e]	0.273
		-0.736	Cycling for shopping purposes	7.558[e]	0.294
1.02	4.09	-0.625	Incident due to a poorly maintained bicycle	3.379[b]	0.022
		-0.631	Incident due to lack of cycling skills	3.695[b]	0.016

[a] range of values: 1-3 [b] range of values: 1-4 [c] range of values: 1-5 [d] range of values: 1-7
[e] range of values: 0-90% [f] range of values: 7.5-75 min [g] range of values: 0.5-20 km

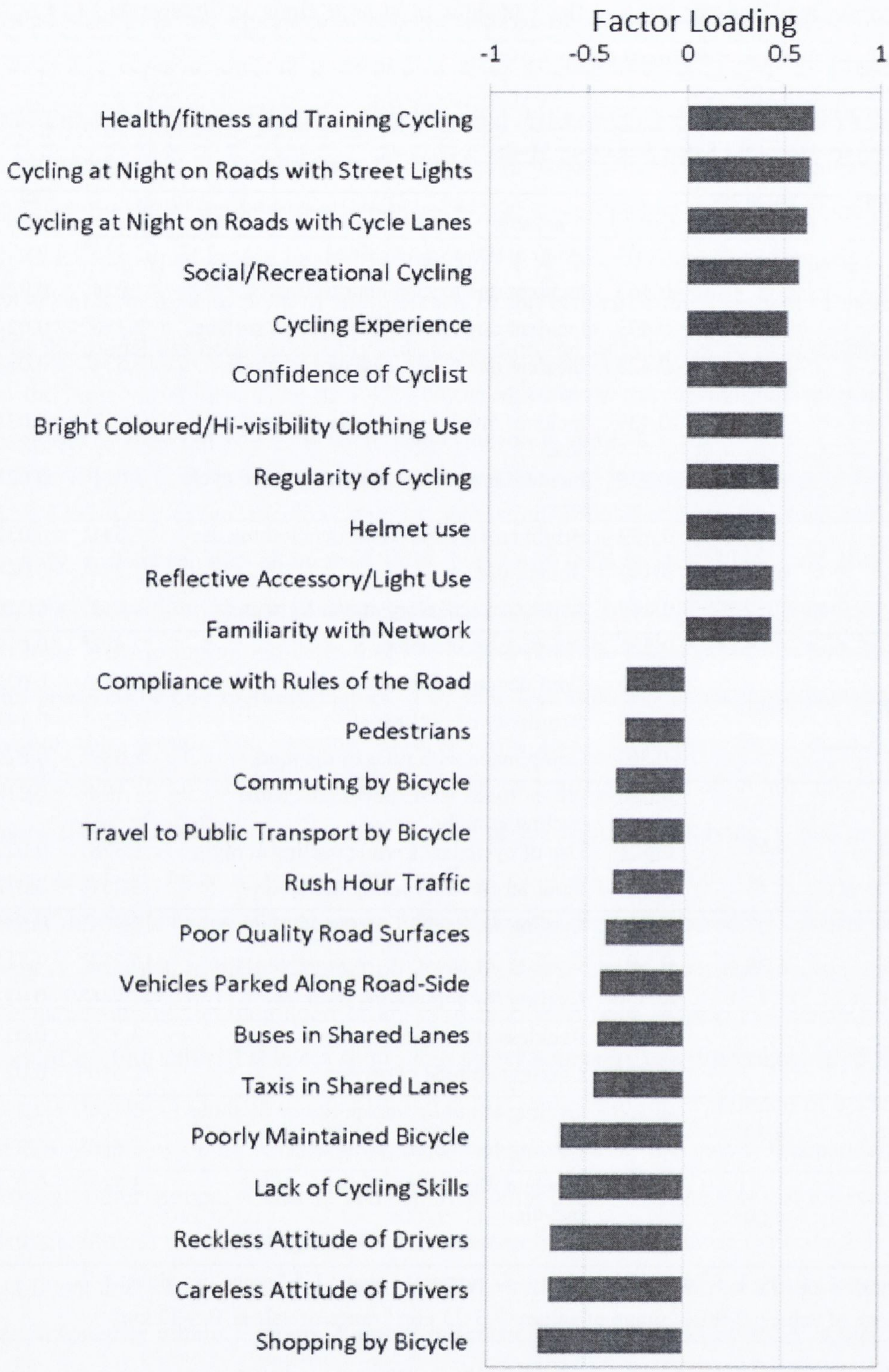

Figure 4.3 Scores for each variable of the safety behaviour model

4.4. CYCLIST-NETWORK INTERACTION MODEL

The interaction between the cyclists and the elements of the shared multi-modal transportation network of Dublin was investigated through PCA to understand the perception of safety of the cyclists in relation to the existing infrastructures. Initially, the Cyclist-Network Interaction Model included 25 variables. Performing PCA with these variables, 7 eigenvectors were found to remain significant after taking the latent root criterion into account, explaining 52% of the variance of the original data set. This value shows the model to be a reasonable fit but there remains 48% of the variance of the original data unexplained by the PCA model using the latent root criterion. This suggests there is a large amount of variance in this dataset.

The matrix of loading factors for this model did not reveal any results that were not included following the rotation of the matrix; therefore the matrix of loading factors prior to rotation is not included here. Table 4.5 presents the significant eigenvalues, the percentage of variance explained, factor loadings, means and standard errors of the variables following varimax rotation. Respondents were asked if they would alter their routes to avoid or make use of various factors encountered within the network that are often described as hindrances or beneficial to cyclists. The results reveal that the likelihood of cyclists altering their routes to make use of routes perceived as safe, quiet roads, well-lit streets, continuous cycle lanes and amenities are grouped together. This means that the cyclists who tend to (or not to) alter their routes for one of these factors will do similarly for all other factors within the group. Interestingly, all factors studied, and viewed as beneficial to the cyclists are contained within this group, explaining the largest amount of variance within the data modelled. This indicates that the presence of one or more of these factors may improve the attractiveness of a route. Factors considered as hindrances move in two separate groups; the first of these groups includes stop signs and traffic lights, while the second includes steep gradients, roads with high speed limits, traffic congestion, right turns, parked cars along road-side and roundabouts. This implies that those cyclists who will change their route to avoid stop signs and traffic lights will not necessarily do the same for the second group of factors considered as hindrances.

In terms of road types studied, urban, residential and suburban roads are grouped together. Off-road paths and trails were found to be insignificant in this analysis, this may be due to the relatively low occurrence of types of facilities within Dublin city. In terms of bicycle infrastructure, the cyclists preferring to use kerb-side cycle lanes also prefer to use shared bus-cycle lanes, while those who prefer roads without cycling facilities prefer not to cycle on cyclepaths. These cyclists will also alter their routes to avoid roads with poor quality surfaces. The final point displayed by the PCA model of cyclist network interactions shows that with increased regularity of cycling, the tendency to change to alternative modes in adverse weather conditions decreases.

Table 4.5 Eigenvalues, percentage variance explained, factor loadings, means and standard errors of the variables of the Cyclist-Network Interaction Model

Eigen-value	% variance explained	Loading	Variable	Mean	Std. Error
3.44	13.76	0.531	Alter route to use routes perceived as safe	3.936[b]	0.032
		0.507	Alter route to use quite roads	3.956[b]	0.032
		0.416	Alter route to use roads with street lights	3.864[b]	0.032
		0.390	Alter route to use continuous cycle lanes	4.005[b]	0.033
		0.320	Alter route to use amenities (e.g. Shops and cafes)	2.509[b]	0.040
2.19	8.74	0.675	Alter route to avoid stop signs	2.171[b]	0.034
		0.662	Alter route to avoid traffic lights	2.498[b]	0.036
1.92	7.69	0.630	Use of residential streets	1.763[a]	0.022
		0.620	Use of suburban roads	1.726[a]	0.021
		0.320	Use of urban roads	1.278[a]	0.016
1.61	6.43	0.471	Regularity of cycling	4.636[c]	0.041
		-0.453	Icy road conditions	4.115[b]	0.027
		-0.504	Heavy rain conditions	3.236[b]	0.035
		-0.539	Temperatures below 0°	2.605[b]	0.032
1.40	5.60	0.474	Use of roads with no cycling facilities	1.469[a]	0.020
		0.391	Alter route to avoid poor quality road surfaces	3.469[b]	0.033
		-0.503	Use of cycle lanes on the footpath	2.122[a]	0.021
1.24	4.94	-0.325	Alter route to avoid steep gradients	1.823[b]	0.038
		-0.334	Alter route to avoid roads with high speed limits	2.161[b]	0.039
		-0.408	Alter route to avoid traffic congestion	1.898[b]	0.038
		-0.409	Alter route to avoid right turns	1.498[b]	0.036
		-0.431	Alter route to avoid parked cars along road-side	1.885[b]	0.032
		-0.441	Alter route to avoid roundabouts	1.681[b]	0.037
1.11	4.45	0.649	Use of curb-side cycle lanes	1.998[a]	0.023
		0.603	Use of shared bus-cycle lanes	1.481[a]	0.020

[a] range of values: 1-3 [b] range of values: 1-5 [c] range of values: 1-7

Figure 4.4 represents the ranked scores for the variables of this model. The Figure shows the magnitude and direction of effect of each variable within the model and the factor loadings signify that the variables of similar signs are interpreted to be of similar influence in a binary sense.

Figure 4.4 Scores for each variable of the cyclist network interation model

4.5. PERCEIVED SAFETY MODEL

The Perceived Safety Model was developed using the OLR technique to investigate the determinants which influence a cyclist's perception of safety as compared to driving in the shared multi-modal transportation network of Dublin City. Generally it has been incident data that has been used in conducting statistical analysis of cycling safety. But the use of a subjective measure (such as that used here) allows additional insight, beyond the causes of incidents which result in the injury or death of cyclists, to the factors related to the perceptions of safety, which may otherwise not be revealed and hence cannot be addressed in improving the situation for cycling and cycling safety. This subjective measure of safety is the cyclists' own opinions on cycling safety, rather than the actual safety of cycling as would be measured by incident related data. Considering only incident data would show cycling to be much safer than driving; in 2012 15 cyclists were killed or seriously injured in Dublin, compared to 61 drivers/passengers using private motor vehicles (Road Safety Authority, 2014). Yet, it is known that safety issues are preventing increases in cycling mode shares (Keegan and Galbraith, 2005). This analysis is an attempt to further investigate how the perceptions of various aspects related to cycling in Dublin (infrastructure, network users etc.) affect the perceptions of cycling safety.

This OLR analysis differs from the previous PCA models presented; rather than determining which variables change together, OLR is used is used to determine the relationship of variables to a particular dependent variable, in this case safety perceptions. This is not possible with PCA. In addition to this model of all participants, further analysis was conducted to analyse and compare responses according to age (under 25 years of age, and 25 years of age or older), gender and vehicle access.

Odds ratios and probabilities are used to describe the effect of variables on the dependent variable. These measures represent the likelihoods by which the overall safety perception is improved or worsened based on changes in this variable (when all other variables are held constant). These results cannot be interpreted to infer any improvements in the actual safety of cyclists (i.e. changes in incident rates).

McFadden's R^2 values have been displayed for each of the OLR models presented in this thesis; it will be seen that these values are low. Despite the significance of a number of variables in each of the OLR models presented, these McFadden's R^2 values may be low as there may be other factors not considered by the survey which are related to the safety experiences of cyclists in Dublin city. The appropriateness of the various pseudo R^2 measures of fit in logistic regression modelling are much debated (Hosmer and Lemeshow, 2000, UCLA Statistical Consulting Group, 2011). Pseudo R^2 statistics are comparable only with other pseudo R^2 of the same type, on the same data, predicting the same outcome (UCLA Statistical Consulting Group, 2011). As such, the McFadden's R^2 values presented are the highest values received under these conditions. In order to confirm that these models offer a better fit than the intercept only models the Likelihood Ratio (LR) test is also included; the significance of these test statistics confirm that the models presented do offer improvements over the intercept only models.

4.5.1. Perceived Safety Model for All Respondents

Initially, 13 variables were included as explanatory variables in the OLR model. Following the creation of dummy variables to cater for categorical variables, there were 23 variables included in the model, 10 of which were found to be significant at a level of confidence of 90%. In Table 4.6, the coefficients, odds ratios, standard errors of the coefficients, indicative significance according to p-values and 95% Confidence Interval (CI) of the coefficients are presented for each of these variables. Based on the results of the model, the probabilities of describing cycling as safer than, as safe as, or less safe than driving, are calculated as per Eq. (4.9), were calculated for each outcome of the significant variables, while the other explanatory variables were assumed constant. The resulting probabilities for the 3 possible outcomes (cycling is less safe than, as safe as, safer than driving) of the variable found to be significant at 95% confidence are displayed in Figures 4.3 and 4.4.

Table 4.6 Coefficients, odds ratios, the standard errors & the 95% CI of these coefficients of the Perceived Safety Model

Is cycling safer than driving in Dublin?	Coef.	Odds Ratio		Std. Error	95% CI	
Gender (Male)	-0.194	0.823		0.141	-0.471	0.082
Age	0.015	1.015	**	0.006	0.003	0.027
Regularity of bicycle use	0.149	1.161	***	0.041	0.069	0.229
Cyclist's experience	0.130	1.139		0.134	-0.132	0.393
Balanced cyclists	0.030	1.031		0.145	-0.254	0.315
Confident cyclists	-0.105	0.901		0.364	-0.819	0.610
Distance travelled	0.001	1.002		0.002	-0.003	0.006
Use of urban roads	0.537	1.711	***	0.183	0.178	0.896
Use of suburban roads	0.007	1.007		0.155	-0.297	0.311
Use of residential streets	0.206	1.229		0.149	-0.086	0.498
Use of park/scenic trials	0.020	1.021		0.163	-0.300	0.340
Use of cycle lanes on footpath	-0.124	0.884		0.139	-0.396	0.149
Use of off-road scenic cycle paths	0.023	1.023		0.169	-0.308	0.354
Use of kerbside cycle lanes	-0.212	0.809		0.133	-0.473	0.048
Use of shared bus-cycle lanes	0.160	1.174		0.157	-0.147	0.467
Use of roads with no cycling facilities	0.576	1.779	***	0.155	0.271	0.880
Use of helmets	-0.238	0.788	*	0.142	-0.516	0.040
Use of bright coloured/hi-visibility clothing	-0.440	0.644	***	0.141	-0.716	-0.164
Use of reflective accessories/lights	-0.142	0.868		0.196	-0.526	0.243
General compliance with rules of the road	0.642	1.900	**	0.281	0.092	1.192
Full compliance with rules of the road	0.791	2.205	**	0.334	0.135	1.446
Attitude of drivers towards cyclists is usually reckless	-0.457	0.633	***	0.145	-0.742	-0.172
Attitude of drivers towards cyclists is always reckless	-0.446	0.640	**	0.174	-0.787	-0.106

N. 1,595

McFadden R^2 0.06

LR χ^2 132.07 (p=0.000)

*** represents a *p* value of 0.01, ** represents a *p* value of 0.05, * represents a *p* value of 0.1

From Table 4.6 it can be see that the use of helmets and bright coloured or hi-visibility safety accessories were significant in this model; while the use of lights/reflective accessories were not found to be relevant. The odds ratio for the use helmets and of bright coloured /hi-visibility safety accessories are 0.79 and 0.64, indicating a worsened safety experience with their use. The cyclists who prefer to cycle on urban roads and on-road with no cycling facilities are nearly 1.71 and 1.78 times more likely to consider cycling to be safer than driving. With more regular cycling there is an increased likelihood of improved perceptions of cycling safety; for an additional day cycled each week cyclists are 1.16 times more likely to feel safer. The results of the OLR model also indicate a perception of reckless driver behaviour is a major factor in cycling being perceived as less safe than driving. In all cases the respondent cyclists are highly probable to perceive cycling to be less safe than driving in Dublin, except with regard to their self-reported compliance with the rules of the road. In this exceptional case, it is quite interesting to see that cyclists who claim to always follow the rules of the road are much more likely to describe cycling as safer than or as safe as driving in Dublin.

These results can also be visualised through calculation of the probabilities of each outcome (perceiving cycling as less safe than, as safe as or safer than driving in Dublin). These probabilities are calculated from the coefficient values using Eq. (4.9) and (4.10). For variables significant at 95% confidence, the probability of each outcome (or event) is present in Figures 4.5 and 4.6. From Figure 4.5 it can be seen that there are high probabilities of finding cycling less safe than driving for each variable, with the exception of those who stated they always comply with the rules of the road. In this case, there is probability of 0.26 of finding cycling less safe than driving, with the combined probability of finding cycling at least as safe as driving being 0.74. For both the use of urban roads and roads with no cycle facilities, a preference for their use reduces the probability of considering cycling less safe than driving, with probabilities of 0.69 and 0.70, respectively, compared to 0.79 and 0.80 respectively for non-preference. In either the case of preference or non-preference for these facilities the probability of finding cycling at least as safe as driving is low; a probability of 0.31 or less in each case. Comparison of the probabilities of those with a preference and non-preference to the use of bright/hi-visibility clothing, shows that while both groups are highly unlikely to view cycling as safer than driving in Dublin, those who prefer not to use bright/hi-visibility clothing had a higher probability of finding cycling at least as safe; 0.28, compared to 0.20 for those preferring their use. With increasing number of days cycled per week the probabilities of finding cycling safer than and as safe as driving increase, although the former increases at a much slower rate; with the probability of finding cycling safer than driving increaseing from 0.04 for one day cycled per week to 0.09 for seven days, while the probability of finding cycling as safe as driving increases from 0.10 to 0.20. A perception of reckless driver attitudes (always and about half the time) produces the worst probabilities of both finding cycling safer than and as safe as driving in Dublin, with each probability less than 0.8.

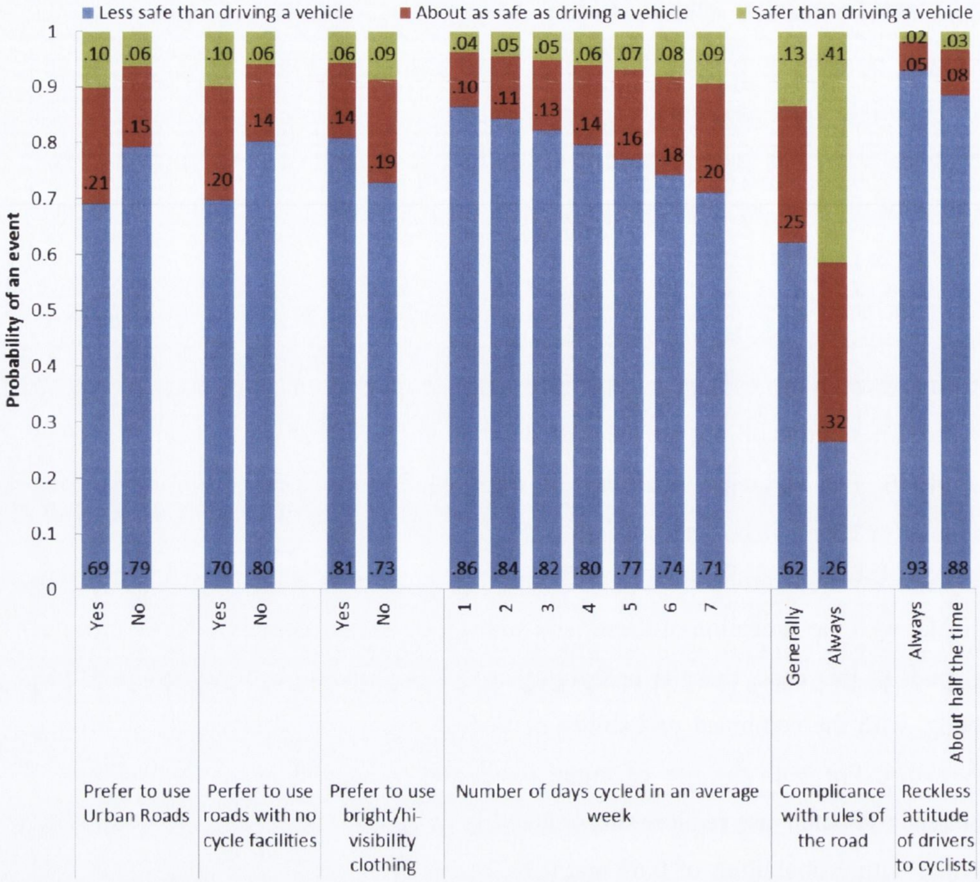

Figure 4.5 Probability of perceiving cycling as less safe than, as safe as or more safe than driving for significant variables in the OLR model of all survey respondents.

As the age of respondent cyclists increased, their likelihood of having a higher perception of safety also increased; for a unit increase in the age of respondents there was a 0.02 increase in the value of the dependent variable. Figure 4.6 presents the probability of cycling being perceived as a safe mode when compared with driving in Dublin according to the age of the cyclists.

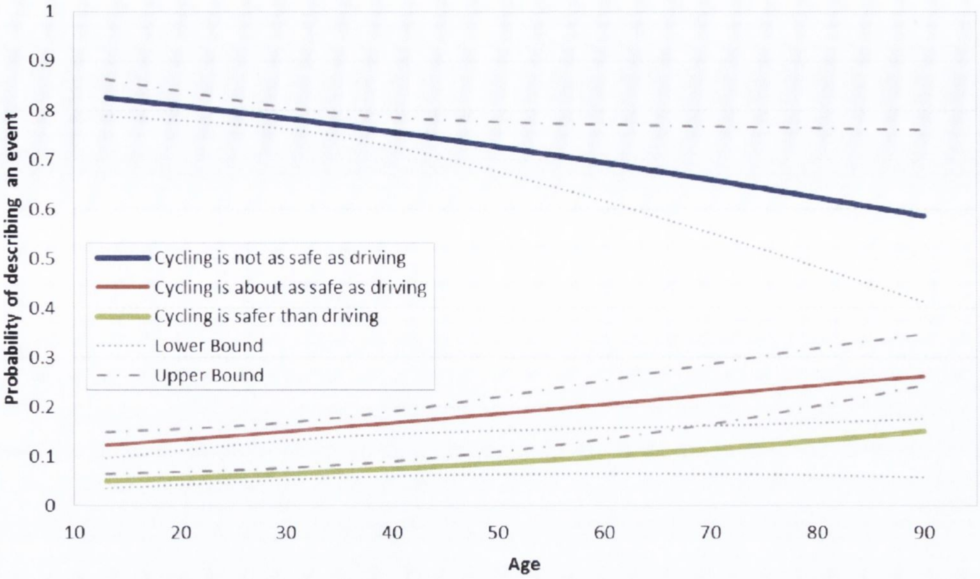

Figure 4.6 Probability of perceiving cycling as less safe than, as safe as or more safe than driving by age.

4.5.2. Perceived Safety Model by Age of Respondents

In order to compare cyclists by age the OLR method was used. Table 4.7 shows the odds ratios of the variables for the models. These models indicate that the factors that improve the perceived safety of cycling are quite different between the two age groups, except in two cases; first, the respondent cyclists of both age groups who tend to use safety accessories are more likely to describe cycling to be less safe than driving and second, the respondent cyclists of both age groups associated reckless attitude of drivers with a reduced perception of safety. Compliance with the rules of the road is another factor, where both age groups show similar choice behaviour. Reporting of full compliance with the rules of the road among the older age group increases their perceived safety by 2.5 times compared to the older cyclists who do otherwise, while self-reported general compliance with the rules among the younger cyclists increases their perceived safety by 3.3 times compared to others.

From the results in Table 4.7, it can be seen that the older cyclists experience an increased feeling of safety with a greater number of days cycled within a week. Among the younger age group, the more experienced cyclists are 1.8 times more likely to describe cycling as safe, than their less experienced colleagues. The cyclists aged under 25, who prefer to cycle on urban roads tend to describe cycling in Dublin city to be safer than those who prefer to avoid this type of road. Older cyclists who prefer to cycle on roads with no cycling facilities also tend to describe cycling in Dublin city to be safer than those who prefer otherwise.

Table 4.7 Odds ratios of the variables of the Perceived Safety Models, categorised by age.

Is cycling safer than driving in Dublin?	**Under 25**	**25 and over**
Gender (Male)	1.257	0.719 **
Age	-	-
Regularity of bicycle use	1.156 *	1.173 ***
Cyclist's experience	1.786 **	0.972
Balanced cyclists	0.852	1.070
Confident cyclists	0.420	2.032
Distance travelled	0.999	1.003
Use of urban roads	1.640	1.524 *
Use of suburban roads	0.881	1.126
Use of residential streets	1.102	1.268
Use of park/scenic trials	0.999	1.033
Use of cycle lanes on footpath	1.046	0.859
Use of off-road scenic cycle paths	0.933	0.982
Use of kerb-side cycle lanes	0.709	0.830
Use of shared bus-cycle lanes	0.900	1.324
Use of roads with no cycle facilities	1.369	1.824 ***
Use of helmets	1.080	0.673 **
Use of bright coloured/hi-visibility clothing	0.587 **	0.671 **
Use of reflective accessories/lights	1.173	0.717
General compliance with rules of the road	1.426	2.564 **
Full compliance with rules of the road	3.324 **	2.508 *
Attitude of drivers towards cyclists is usually reckless	0.543 **	0.631 ***
Attitude of drivers towards cyclists is always reckless	0.930	0.486 ***
N.	511	1,084
McFadden R^2	0.06	0.08
LR χ^2 (p)	35.7 (0.032)	124.2 (0.000)

*** represents a *p* value of 0.01, ** represents a *p* value of 0.05, * represents a *p* value of 0.1

4.5.3. Perceived Safety Model by Respondent Gender

The gender specific model presented in Table 4.8 shows that older female cyclists tend to perceive cycling to be safer than the younger ones. The regularity of cycling is significant to both male and female groups in increasing their perception of safety. The preference for cycling on urban roads for male cyclists and for cycling on shared bus-cycle lanes for female cyclists improve their tendency of describing cycling to be as safe as or safer than driving in Dublin city. A preference for using roads with no cycling facilities is also significant in improving the likelihood of describing cycling to be as safe as or safer than driving for both genders. Similar to age specific model, both male and female cyclists who tend to use safety accessories are more likely to describe cycling to be less safe than driving.

Table 4.8 Odds ratios of the variables of the Perceived Safety Models, categorised by age and gender

Is cycling safer than driving in Dublin?	**Male**	**Female**
Age	1.009	1.024**
Regularity of bicycle use	1.161***	1.149**
Cyclist's experience	1.207	1.025
Balanced cyclists	0.969	1.175
Confident cyclists	0.769	3.786
Distance travelled	1.001	1.003
Use of urban roads	1.989***	0.779
Use of suburban roads	1.146	0.813
Use of residential streets	1.322	1.104
Use of park/scenic trials	0.942	1.149
Use of cycle lanes on footpath	0.896	0.740
Use of off-road scenic cycle paths	0.963	1.181
Use of kerbside cycle lanes	0.889	0.689*
Use of shared bus-cycle lanes	0.983	1.890*
Use of roads with no cycle facilities	1.604***	2.444***
Use of helmets	0.906	0.591**
Use of bright coloured/hi-visibility clothing	0.644**	0.753
Use of reflective accessories/lights	1.047	0.496*
General compliance with rules of the road	1.756	3.118
Full compliance with rules of the road	1.742*	4.517*
Attitude of drivers towards cyclists is usually reckless	0.633**	0.558**
Attitude of drivers towards cyclists is always reckless	0.735	0.507**
N.	1025	570
McFadden R^2	0.06	0.08
LR χ^2 (p)	91.3 (0.000)	61.7 (0.000)

*** represents a *p* value of 0.01, ** represents a *p* value of 0.05, * represents a *p* value of 0.1

4.5.4. Perceived Safety Model by Respondent Access to a Vehicle

Although cyclists were not explicitly asked whether they had any driving experience, they were asked if they had a private motor vehicle at their disposal, which they could drive, on a day to day basis. The models in this section make comparison between the respondents with, and without access to a vehicle. Although there may be respondents with no access to a vehicle who have driving experience, it is assumed that the majority will not have previous driving experience. Therefore, comparing cyclists who travel within the road network by both private motor vehicle and bicycle with those who travel only by bicycle can reveal the differences and similarities in these types of network users.

The odds ratios for each model are displayed in Table 4.9. From the Table it can be seen that the significant variables for each group are different. For respondents with no vehicle access there are three significant variables: age and the use of urban and residential roads. For respondents with vehicle access the significant variables are gender, regularity of bicycle use, the use of roads with no cycling facilities, the use of bright coloured/hi-visibility clothing and driver attitudes.

With increasing age cyclists with no vehicle available to them had a greater chance of a positive perception of safety. This group of respondents were also likely to have a better perception of safety if they preferred to cycle on urban and residential roads; inversely, they are likely to feel less safe if they do not like to cycle on these types of roads. As cities are made up of urban and residential roads this result is detrimental to these cyclists.

Male respondents who had access to a vehicle (therefore assumed to have driving experience) are much less likely to rate cycling highly in terms of safety. These cyclists with vehicle access received similar results to the model of all respondent for the use of bright coloured/hi-visibility clothing and the driver attitude variables; each found to reduce the likelihood of perceiving cycling as safer than driving in Dublin. The final relevant variable for this group was the use of roads with no cycling facilities; preferring to cycle here could more than double how safe they felt while cycling.

Table 4.9 Odds ratios of the variables of the Perceived Safety Models, categorised by access to a vehicle.

Is cycling safer than driving in Dublin?	No access		Access	
Gender (Male)	1.139		0.589	**
Age	1.035	***	1.007	
Regularity of bicycle use	1.091		1.239	***
Cyclist's experience	1.231		1.049	
Balanced cyclists	1.077		1.010	
Confident cyclists	0.745		1.514	
Distance travelled	1.000		1.002	
Use of urban roads	1.706	**	1.685	*
Use of suburban roads	0.832		1.222	
Use of residential streets	1.505	**	0.940	
Use of park/scenic trials	0.825		1.185	
Use of cycle lanes on footpath	0.954		0.795	
Use of off-road scenic cycle paths	1.211		0.983	
Use of kerb-side cycle lanes	0.823		0.831	
Use of shared bus-cycle lanes	1.350		0.991	
Use of roads with no cycle facilities	1.500	*	2.118	***
Use of helmets	0.929		0.694	*
Use of bright coloured/hi-visibility clothing	0.718	*	0.562	***
Use of reflective accessories/lights	1.073		0.625	
General compliance with rules of the road	1.658		2.385	
Full compliance with rules of the road	2.300	*	2.365	
Attitude of drivers towards cyclists is usually reckless	0.679		0.574	***
Attitude of drivers towards cyclists is always reckless	0.799		0.516	**
N.	772		823	
McFadden R^2	0.08		0.09	
LR χ^2	124.2	(0.000)	102.3	(0.000)

*** represents a *p* value of 0.01, ** represents a *p* value of 0.05, * represents a *p* value of 0.1

4.6. CYCLIST SAFETY INDEX

To quantify the perceived safety of cyclists in Dublin city, a Cyclist Safety Index (CSI) was formulated using an OLR model of all respondent cyclists. Whereas in the previous sections the OLR models consisted of cyclist and network attributes, the variables included in the OLR model presented within this section considers only network attributes, cycling regularity, self-reported rule compliance and driver attributes. Each of these variables are elements that transport planners, to some extent, may control; be it through policy and campaigns or through infrastructural changes. The CSI is proposed as a measure to gauge the safety perceptions of cyclists. As safety perceptions have been shown to have a large effect on cyclists' experience such a measure may prove beneficial to transport planners in assessing whether infrastructural and policy changes have influenced safety perceptions. Monitoring the safety perceptions of cyclists over time, using the CSI would offer valuable insight into cycling beyond the measurement of mode share.

The OLR considers 20 variables, two of which (compliance with the rules of the road, driver attitudes) are a categorical variable, which was transformed into dummy variables, to give a total of 22 variables presented in Table 4.10. For the purposes of this model variables were considered significant at a probability of inclusion of 0.2, in accordance with (Hosmer and Lemeshow, 2000). As such, 8 variables were found to be significant as described in the equations of the resulting OLR model:

$$\pi_1 = \frac{1}{1+\exp(Z-2.044)} \qquad \textbf{Eq. (4.12)}$$

$$\pi_2 = \frac{1}{1+\exp(Z-3.428)} - \frac{1}{1+\exp(Z-2.044)} \qquad \textbf{Eq. (4.13)}$$

$$\pi_3 = 1 - \frac{1}{1+\exp(Z-3.428)} \qquad \textbf{Eq. (4.14)}$$

$$\begin{aligned} Z = {} & 0.190x_1 - 0.188x_2 + 0.599x_3 - 0.415x_4 \\ & +0.504x_5 + 0.467x_6 - 0.508x_7 - 0.404x_8 \end{aligned} \qquad \textbf{Eq. (4.15)}$$

where Z is the perceived safety, π_1 is the probability of considering cycling to be less safe than driving, π_2 is the probability of considering cycling to be as safe as driving, π_3 is the probability of considering cycling to be more safe than driving, x_1 is the average number of days cycled per week, x_2 is a preference to cycle on cycle paths, x_3 is a prefer to cycle with no cycle lanes, x_4 is the preference to avoid roundabouts, x_5 is a general compliance with the rules of the road, x_6 is a full compliance with the rules of the road, x_7 is a belief that rush hour traffic is likely to cause an incident and x_8 is a belief that a bus is likely to cause an incident.

These results suggest increases in the likelihood of finding cycling safer than driving in Dublin for an increased number of days cycled per week (OR 1.21), a preference for cycling where no cycle facilities are preset (OR 1.82) and for both general (OR 1.66) and full (OR 1.60) self-reported compliance with the rules of the road; while the likelihood of finding cycling safer is decreased with a preference for cycling on cycle paths (OR 0.83), to avoid roundabouts (OR 0.66) and when viewing both rush hour traffic (OR 0.60) and buses in shared-use lanes (OR 0.67) are likely causes of an incident involving them. For variables $x_2, x_3, x_4, x_5, x_6, x_7$ and x_8, which were binary variables (yes/no), the effect of answering "yes" to preferring to cycle where no cycle lane is present has the largest impact on the dependent variable; increasing the dependent variable by 0.6, when all over variables are held constant. The variable which causes the largest negative change in the dependent variable is x_7 (a belief that rush hour traffic is likely to cause an incident involving them); reducing the dependent variable by 0.51.

Table 4.10 OLR model of all variables considered for development of CSI.

Is cycling safer than driving in Dublin?	Coef.	Odds Ratio	Std. Error	95% CI	
Average number of days cycled per week	0.190	1.209 ***	0.039	0.114	0.266
Prefer to cycle on cycle path	-0.188	0.828 *	0.132	-0.448	0.071
Prefer to cycle on off road trails	0.076	1.079	0.127	-0.173	0.325
Prefer to cycle on kerb-side lanes	-0.061	0.941	0.128	-0.311	0.189
Prefer to cycle on shared bus lanes	0.191	1.210	0.150	-0.104	0.485
Prefer to cycle with no cycle lane	0.599	1.820 ***	0.142	0.320	0.877
Avoids stop signs	-0.296	0.744	0.441	-1.159	0.568
Avoids traffic lights	-0.188	0.829	0.298	-0.772	0.396
Avoids poor quality road surfaces	-0.139	0.871	0.138	-0.409	0.131
Avoids right turns	0.039	1.040	0.214	-0.380	0.457
Avoids traffic congestion	0.079	1.082	0.161	-0.236	0.394
Avoids roads with higher speed limits	0.130	1.139	0.134	-0.134	0.394
Avoids roads with parked vehicles	0.196	1.217	0.236	-0.267	0.659
Avoids roundabouts	-0.416	0.660 **	0.196	-0.800	-0.032
Generally compliant with the rules of the road	0.504	1.656 **	0.262	-0.010	1.019
Fully compliant with the rules of the road	0.467	1.595 *	0.310	-0.141	1.076
Rush hour traffic likely to cause an incident	-0.508	0.602 ***	0.132	-0.766	-0.249
Bus likely to cause an incident	-0.404	0.668 ***	0.152	-0.702	-0.105
Taxi likely to cause an incident	-0.090	0.914	0.198	-0.478	0.298
Poor road surface likely to cause an incident	0.090	1.094	0.161	-0.226	0.405
Parked cars likely to cause an incident	0.174	1.190	0.211	-0.239	0.588
Pedestrians likely to cause an incident	-0.095	0.909	0.159	-0.407	0.217
Cutpoint 1[5]	2.045			1.291	2.799
Cutpoint 2[5]	3.428			2.657	4.199

N. 1595

McFadden R^2 0.05

LR χ^2 120.56 (p=0.000)

*** represents a *p* value of 0.01, ** represents a *p* value of 0.1, * represents a *p* value of 0.2

The CSI has been developed from this model by calculating the probabilities of an individual considering cycling to be safer than (π_3), as safe as (π_2) or less safe than driving (π_1).

$$\text{CSI}=\phi_1\pi_1+\phi_2\pi_2+\phi_3\pi_3 \qquad \textbf{Eq. (4.16)}$$

where ϕ_1,ϕ_2,ϕ_3 are the weights applied to π_1,π_2,π_3. The weights are chosen in this manner as this is representative of the way the categorical outcome variable of 'perceived safety' was coded in the logistic regression model. Accordingly, the CSI

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[5] The cutpoints indicate where the latent variable is cut to make the three groups observed in the data. These values are required for the probability calculations in Eq. (4.8) to (4.10).

value for an individual cyclist can range between 1 (lowest safety rating) and 3 (highest safety rating).

Figure 4.7 graphs the CSI values calculated for 1,595 survey respondents. The maximum CSI obtained for these respondents was 1.95 and the minimum was 1.06, with the majority of CSI values between approximately 1.1 and 1.5. Figure 4.8 presents the histogram of the unweighted probabilities (π_1, π_2, π_3) that form CSI. It is observed that apart from the mean value, the skewedness of the distribution of CSI is also a good indicator of the tendency of the population in terms of perceived safety. Clearly, this is more on the unsafe side for Dublin. Also important to note is that the respondent population with a feeling of perceived safety higher than car, represented by π_3, forms a distribution not only separate from the other two categories of lesser perceived safety, but is also skewed more on the safe side. CSI is thus observed to be a beneficial, quantitative marker at an individual and at a population level. The effects of implementation of a policy may be measured by assessing the statistical properties of the distribution of CSI. Additionally, different mixed mode cycling networks may be benchmarked and compared through the statistical properties of the distribution of CSI.

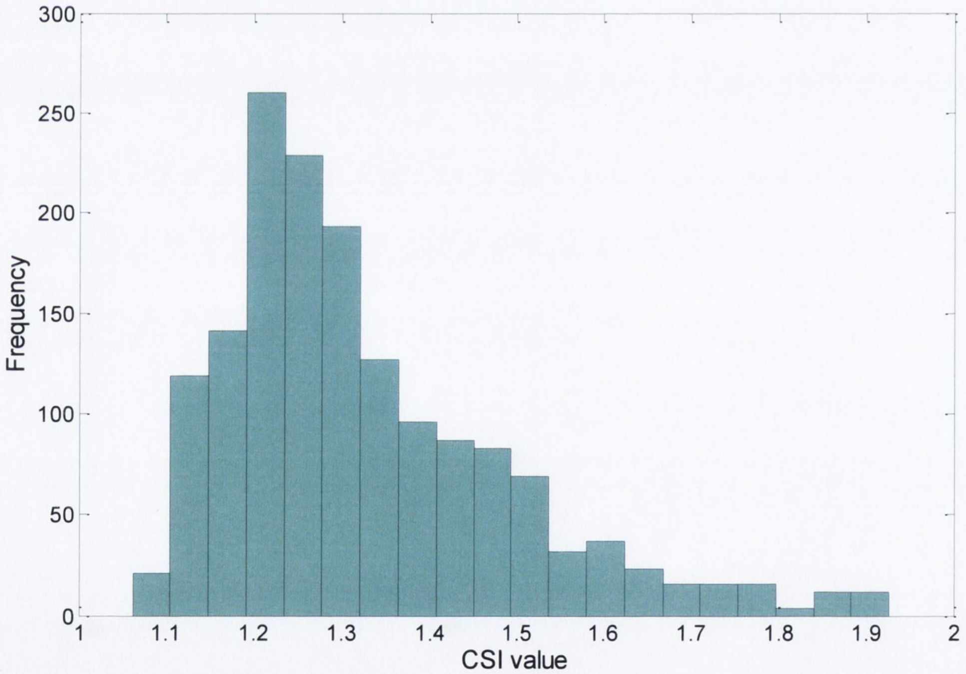


Figure 4.7 Histogram of CSI values calculated for each respondent.

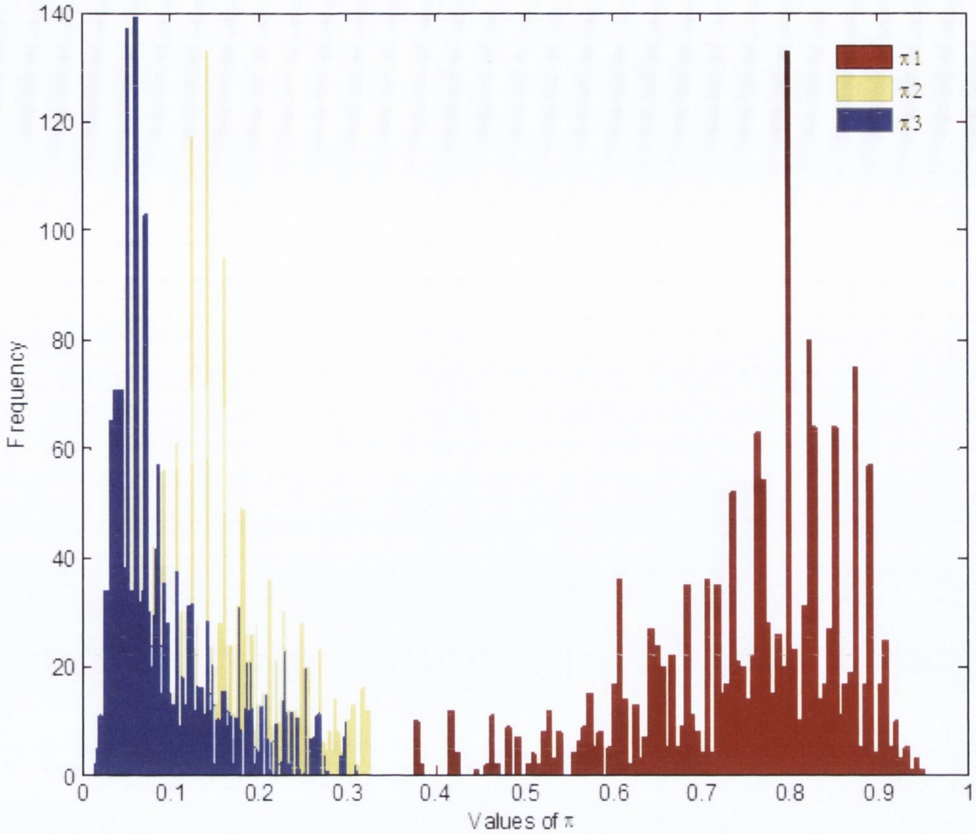
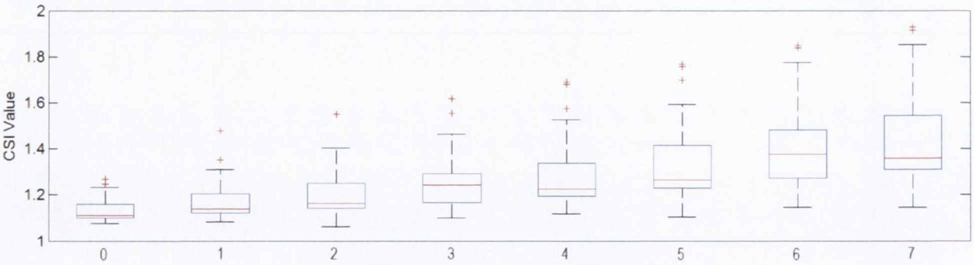


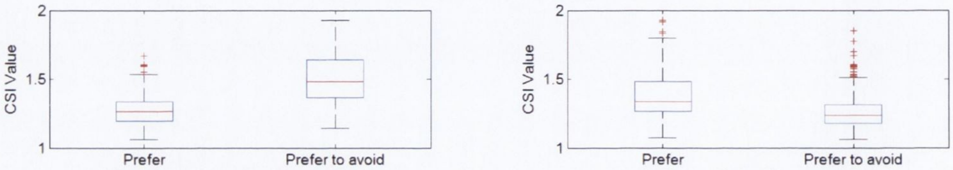
Figure 4.8 Histogram of the π values.

Figure 4.9 presents the variation of CSI values for factors that have an effect on perceived safety for all of the respondent cyclists. All subfigures are presented as boxplots. The upper and the lower edge of each box represent the 75th and 25th percentile respectively, the horizontal line in the middle of the box is the median (50th percentile) and the whiskers represent the extreme points in the dataset that are not considered as outliers. The outliers are the plus signs at the extreme of each box. When the median is not at the middle of the box, it indicates skewedness present in the plotted dataset.

The relationship between the experience of a cyclist and the higher perception of safety is illustrated in Figure 4.9a where a consistent increase in CSI is observed for cyclists with the number of days cycled per week. Cyclists who preferred no cycle lane (Figure 4.9b) and or preferred cycle paths (Figure 4.9c) perceived cycling in Dublin to be safer than those who did not. Avoidance of cycle lanes can often be related to poor maintenance and the lack of integration of the design requirements of cyclists as a mode of travel in a mixed mode network, within a shared space. The perception of safety increased consistently with a decreased likelihood of getting involved in a rush hour traffic incident (Figure 4.9d) or a bus incident (Figure 4.9e). Confident cyclists, who would not alter their routes due to the presence of roundabouts (Figure 4.9f) experience a higher level of safety than those who would. However, confidence is not related to non-compliance with the rules of the road, since the cyclists who state they are compliant report a higher safety experience (Figure 4.9g). CSI values are essential to quantify these differences.

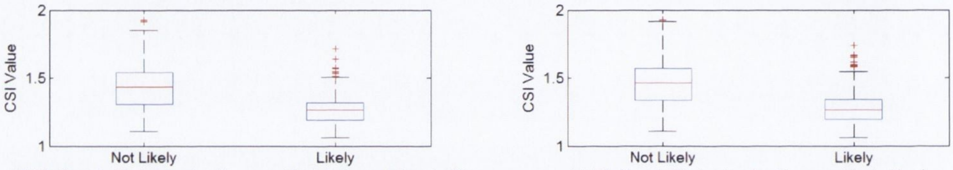


(a) Average number of days cycled per week



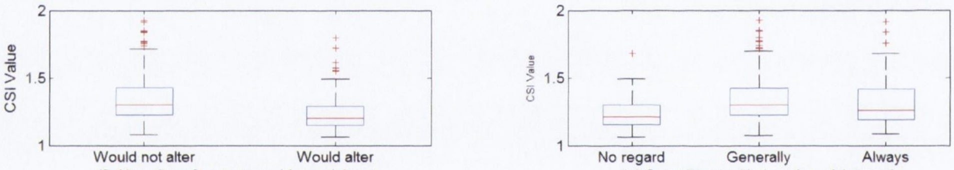
(b) Preference for cycling with no cycle lane

(c) Preference for cycling on a cycle path



(d) Likelihood of being involved in an accident during rush hour traffic

(e) Likelihood of being involved in an accident with a bus



(f) Alteration of route to avoid roundabouts

(g) Compliance with the rules of the road

Figure 4.9 CSI values calculated for each respondent plotted against their response to various factors considered

4.7. CONCLUSIONS

This chapter presents a comprehensive study on cyclists' perception of safety while using a shared multi-modal urban transportation network. A questionnaire based survey of 1,954 existing cyclists was carried out in Dublin to obtain an overall view of how the network, its users and their attitudes impact on the perceptions of safety of cyclists. The study considered a wide range of variables from all parts of the network, such as cyclists' self-reported compliance with the rules of the road, attitudes of bus/taxi/vehicle drivers, weather conditions, presence of incident blackspots on the route, etc. These are variables that may be expected to be important in influencing the perception of safety among cyclists but were not studied in the past. The analysis showed many of these variables are critical in improving the perceived safety of cyclists. Here, possible policy recommendations from these findings are presented.

To promote cycling as a major mode of transportation it is important to improve the perceived safety of the mode to be at least comparable to the level of other existing major modes of travel, such as driving. Analysis has shown that the cyclists who claim to be fully compliant with the rules of the road had a 74% likelihood of considering cycling as safer than or at least as safe as driving in Dublin, yet the survey has revealed that 87.5% of the participants admit to breaking the rules of the road. Road safety initiatives encouraging improved compliance among cyclists can therefore be beneficial in improving the perceived safety of cycling. Increased compliance with the rules of the road could also be achieved through enforcement as is done for cars in the form of fines and 'points' on offenders. However, such enforcement may decrease the attraction of the mode. It is important to note, regular and confident cyclists were seen to have lower self-reported compliance with the rules of the road.

The analysis has shown that the use of safety accessories (helmets, high visibility/bright coloured clothing and lights/reflective accessories) is not associated with an improvement in perception of safety among cyclists' compared to driving in Dublin, but instead is shown to be associated with a decreased safety experience. The presence of situations perceived by cyclists as potentially unsafe has most probably led the cyclists to make use of such safety accessories, but has not helped them to overcome their fear of such situations. Therefore, making their use mandatory among cyclists may be of little or no benefit to the improvement of the perceived safety of cyclists which is required to promote cycling as a viable mode of transportation in Dublin. Such a measure may even prove counteractive to improving cycle mode share, as has been presented by a before-and-after study of the mandatory helmet use for Australian cyclists (Robinson, 1996).

Analysis has revealed the perceived safety of cycling increases with regularity of use and with an increasing number of days cycled per week, the probability of considering cycling as less safe than driving in Dublin falls. Therefore, it is suggested that transportation policies which encourage regular cycling activities such as the 'Bike to Work' scheme should be expanded and further encouraged. Further provision of incentives which encourage regular bicycle use for additional activities would broaden the scope of the scheme to other areas of bicycle use, and hence to a larger population of cyclists and potential cyclists.

Careless and reckless driver behaviour have has been shown by analysis to have a major detrimental effect on the safety experience of cyclists. Campaigns to encourage cyclist-driver cooperation within the network may help combat Dublin's 'road rage' problems.

Respondents have been shown to associate the chances of being involved in an incident during rush hour traffic or with a bus with a lower safety experience.

Research into the reporting of cycling accidents has shown that as the severity of an incident involving a cyclist decreases, so does the likelihood of the incident being reported (Stutts and Hunter, 1998). The Irish Road Safety Authority reported 376 minor accidents involving cyclists in 2011 (Road Safety Authority, 2013). It is possible, that these accidents are only a fraction of the total number of such cases and hence, the importance of improving the safety of cyclists in the network may appear as a less critical consideration. Research studies have attempted to estimate the extent of underreporting, including studies in Ireland (Short and Caulfield, 2014), but creation of concepts which incentivise public participation in the reporting of minor incidents would create a more reliable database. More accurate identification of the types, and situations which lead to an incident may allow design, or redesign of the network to minimise the risk of such an incidence occurring again.

CHAPTER 5

5. A STUDY OF ROUTE CHOICES MADE BY CYCLISTS

The previous chapters have shown safety issues to have large and damaging effects on the perceptions of cycling. Elements related to cyclists' interactions with the transport network were highlighted as important to the cyclists' safety; these included the presence of cycling facilities and interactions with other transport modes. In this chapter, the route choice behaviour of cyclists is studied to explore if the factors affecting safety perceptions also affect cyclists' route choice behaviours.

In order to do this, a monitoring study was undertaken. This allowed network elements, shown by Chapter 4 to be relevant to cyclist safety, to be further examined. The aim was to investigate if cyclists would alter their routes to avoid perceived risks or to make use of more favourable environments, i.e. would they deviate from the shortest distance/time route between their origin and destination. If cyclists are found to deviate, the reasoning behind these deviations needs to be better understood so as transport planning and modelling methods reflect this behaviour. Incorporation of these attributes in cycle route planners may also produce more appropriate route choices for travellers. As will be shown in the work contained in this chapter and Chapter 7, traditional 'shortest-path' methods currently in use are not suitable.

5.1. DATA COLLECTION

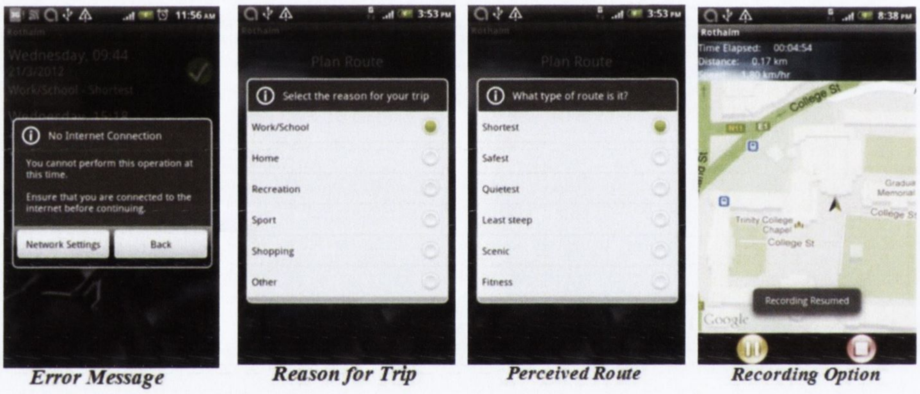
An Android smartphone application 'Rothaim' was developed as part of a Clarity, Centre for Web Sensor Technologies project in conjunction with this research in order to facilitate the collection of cyclist route choice behaviour (Gavin et al., 2011). The application used GPS to collect information about participants' routes. The application worked similarly to other applications developed for this platform to allow sportspersons track their workouts, for example Map My Ride (MapMyFitness Inc, 2014) or Strava (Strava Inc, 2014).

In addition to these GPS capabilities that, before a cyclist began a trip they were requested to enter the purpose of their type (i.e. travel to work/education, recreational etc.) and the type of route on which they will travel (i.e. shortest, safest etc.). On completion of the trip the users were given the option to upload their trip information to a secure server. The trip information provided could then be securely, and solely, accessed by the involved researchers from this secure server.

The GPS information collected by this application was potentially sensitive as users may be travelling between their place of work and/or home etc. As such no information relating to the identity of participating individuals was collected. In advertising the application, potential participants where made aware of what information was and was not being collected by the application, how this information was stored on a sercure server and would be used only for the purposes of this research.

In order to encourage the use of the application the interface was designed much like other applications previously mentioned, to provide statistics (such as distance, time and speed) related to the travellers trip and a map of the route travelled. Figure 5.1 includes screenshots from the Rothaim app.

The application was made freely available on the Google Play store, from where it could be downloaded for use on any Android device. The availability of the application was advertised on Trinity College Dublin (TCD) campus and in the Dublin Cycling Campaign members newsletter (via email).



No Internet Connection

You cannot perform this operation at this time.

Ensure that you are connected to the internet before continuing.

Select the reason for your trip

- ● Work/School
- ○ Home
- ○ Recreation
- ○ Sport
- ○ Shopping
- ○ Other

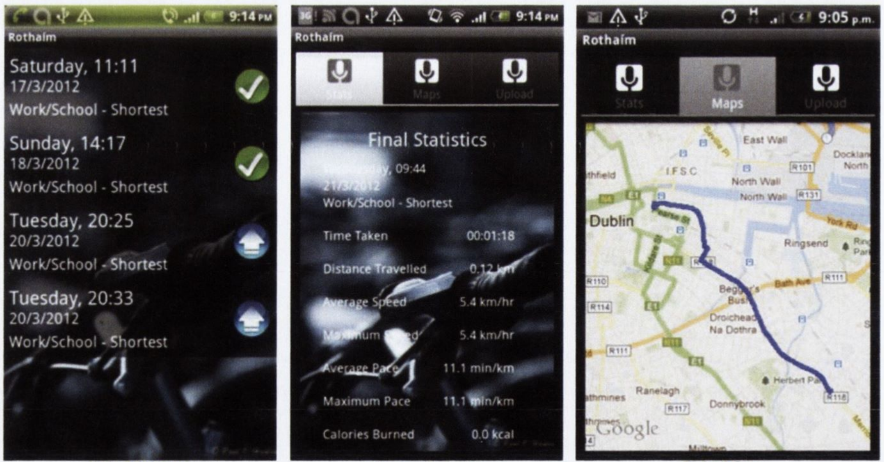
What type of route is it?

- ● Shortest
- ○ Safest
- ○ Quietest
- ○ Least steep
- ○ Scenic
- ○ Fitness

Time Elapsed: 00:04:54
Distance: 0.17 km

Recording Resumed

Error Message *Reason for Trip* *Perceived Route* *Recording Option*



Saturday, 11:11
17/3/2012
Work/School - Shortest

Sunday, 14:17
18/3/2012
Work/School - Shortest

Tuesday, 20:25
20/3/2012
Work/School - Shortest

Tuesday, 20:33
20/3/2012
Work/School - Shortest

Final Statistics

Work/School - Shortest

Time Taken	00:01:18
Distance Travelled	0.12 km
Average Speed	5.4 km/hr
Maximum Speed	5.4 km/hr
Average Pace	11.1 min/km
Maximum Pace	11.1 min/km
Calories Burned	0.0 kcal

Trip History *Trip Statistics* *Trip Map*

Figure 5.1 Rothaim app design and layout

5.2. DATA DESCRIPTION

Between March 12 and April 21 2012, 117 trips were submitted from 23 anonymous contributors. It was found that 54 of these trips had either their origin or destination on

TCD campus and the majority of trips took place in the south area of Dublin city. Table 5.1 provides information relating to the trip purposes, route type and trip times. No demographic information relating to age or gender was collected.

Table 5.1 Observed cyclist trip characteristics

	No of trips	% of trips
Total no. of trips	117	
Trip purpose		
Work/Education	62	53.0
Home	37	31.6
Social/Recreation	11	9.4
Shopping	4	3.4
Sport	2	1.7
Unknown	1	0.9
Route type		
Shortest	102	87.2
Quietest	5	4.3
Safest	5	4.3
Scenic	4	3.4
Least steep	1	0.9
Day trip taken		
Monday	20	17.1
Tuesday	28	23.9
Wednesday	21	17.9
Thursday	15	12.8
Friday	11	9.4
Saturday	9	7.7
Sunday	13	11.1
Trip start time		
Between 00:00 and 07:00	2	1.7
Between 07:00 and 10:00	29	24.8
Between 10:00 and 13:00	19	16.2
Between 13:00 and 14:00	2	1.7
Between 14:00 and 17:00	16	13.7
Between 17:00 and 19:00	22	18.8
Between 19:00 and 24:00	27	23.1
Trip duration		
Less than 10 mins	15	87.2
10 to 20 mins	24	4.3
20 to 30 mins	38	4.3
30 to 40 mins	22	3.4
More than 40 mins	18	0.9

Over 80% of these trips were taken on week days and 53% of trips made were trips to work or education, although only 27 of these trips commenced between 07:00 and 10:00. This low number of trips during the peak commute time period, and the frequency in which TCD campus features as a trip destination, would suggest that a large number of these trips were submitted by TCD students. This was anticipated, due to the application advertisement on the campus. Almost all trips were described by the travel as being the shortest distance route, yet the analysis in the following section showed only 10% of the routes actually followed the shortest-path route. The average travel time for these trips was 27.9 minutes, with the longest trip taking 76.1 minutes and the shortest 5.1 minutes. It is highly likely that these travel times are over estimated due to the time required to set up and store the device before commencing the trip, and similarly at the trip end. As such trip distance is thought to be a more accurate measure for the trip. The average trip distance was found to be 5.8 km, while the minimum and maximum distances travelled were 1.5 and 11.0 km.

5.3. ROUTE CHOICE BEHAVIOUR – 'SHORTEST-PATH' VERSUS OBSERVED PREFERENCE

Although there were 117 trips collected, the users tended to follow the same routes each time they travelled. This is likely due to participants travelling on a 'regular' or 'routine' route, suggesting these routes to be the routes on which they feel most comfortable to travel. This resulted in 26 different routes being collected; 15 of which were travelled once, while the remainder of routes where travelled multiple times. The number of times these repeated routes were travelled are given in Table 5.2. Two of the routes collected are between the same OD pair, but follow different paths; routes 9 and 10. Also, due to the one-way systems operating in Dublin routes in which the OD pair is simply swapped are considered separately i.e. a home to work trip will generally follow a different route to the trip from work to home for that person. This situation where OD pairs are swapped arises for 3 sets of routes; routes 2 and 3, routes 8 and 9 (or 10) and routes 21 and 24.

Table 5.2 Number of times an observed route was repeated.

Route ID	No. of times route was used
2	2
3	2
4	20
9	4
10	5
12	15
13	14
17	10
20	14
25	4
26	12

A Geographical Information Systems (GIS) mapping tool, ArcMap (ESRI, 2010) was used to display and analyse the routes. This allowed the NTA map of cycling facilities in Dublin (National Transport Authority, 2013a) to be added as a base map to aid analysis. The 'shortest-path' routes were calculated using the Dublin Cycle Planner (Transport for Ireland, 2013) for each OD pair. GPS exchange (GPX) files of the routes were downloadable from the Transport for Ireland (TFI) website which were converted to be displayed in ArcMap. The observed cyclist routes were also collected using this file format. The maps showing the comparisons between each of the observed cyclist routes and TFI calculated 'shortest-path' routes can be found in Appendix II. Figure 5.2 shows an example of one of these route comparisons, where the observed route is presented in purple or pink (trip 9 only) and the TFI route is green. The origin for the route is displayed in blue. Where trips extended beyond the boundary of the NTA cycle facility map the remainder of the trips are overlaid on OpenStreetMap maps (OpenStreetMap, 2014).

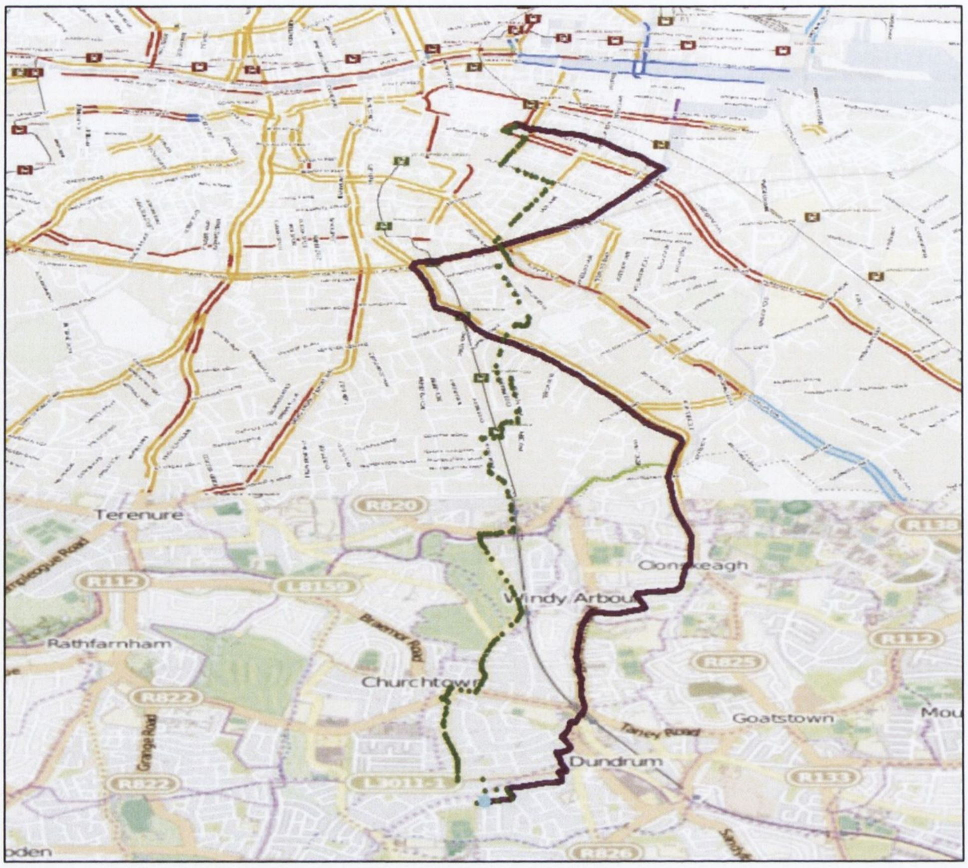


Figure 5.2 Observed cyclist route (purple) and TFI 'shortest-path' route for Trip 9

Inspection of the route comparisons in Table 5.3 show six of the routes to be similar to that of the 'shortest-path' route, while 10 of the routes appear to be substantially different of the TFI route. Using ArcMap's measurement tools it was possible to calculate the lengths of the routes and the distances travelled on each type of cycling facility. These distances and their proportion of total trip length for each OD pair are displayed in Table 5.3. The distances of travel on cycling facilities are measured only within the extents of the NTA cycling facility map (the percentage of distance spent of these facilities also only considers the trip distance within the NTA map). Information relating the distance and proportion of overlap between the observed cyclist route and 'shortest-path' route are also presented in Tables 5.4 and 5.5.

Table 5.3 Comparison of the route lengths and overlap.

Route ID	**TFI route length** km	**Observed route length** km	**Difference in length** km	%	**Overlap Distance** km	%
1	1.16	1.50	0.33	22.2	0.19	12.5
2	5.74	6.19	0.44	7.2	0.58	9.4
3	5.96	6.94	0.98	14.1	0.30	4.4
4	4.19	4.19	0.00	0.0	4.19	100.0
5	5.37	5.37	0.00	0.0	5.37	100.0
6	9.77	10.69	0.92	8.6	6.13	57.3
7	6.79	7.00	0.21	3.0	4.41	63.0
8	8.06	9.45	1.39	14.7	0.88	9.4
9	8.17	8.82	0.66	7.5	0.39	4.4
10	8.17	9.31	1.14	12.2	0.39	4.2
11	3.76	3.76	0.00	0.1	3.57	94.9
12	8.79	8.43	-0.36	-4.2	4.55	53.9
13	9.02	9.27	0.25	2.7	1.73	18.6
14	5.57	6.22	0.65	10.5	2.79	44.9
15	4.92	5.84	0.93	15.8	0.59	10.0
16	5.29	5.94	0.65	11.0	0.59	9.9
17	1.45	1.45	0.00	0.0	1.45	100.0
18	6.07	5.93	-0.14	-2.4	3.44	58.0
19	11.26	11.00	-0.27	-2.4	10.07	91.5
20	4.24	5.14	0.89	17.4	1.37	26.7
21	3.33	3.33	0.00	0.0	3.33	100.0
22	3.42	3.64	0.22	6.0	1.77	48.5
23	3.63	3.77	0.13	3.5	1.99	52.9
24	3.14	3.70	0.57	15.3	0.50	13.4
25	1.81	1.81	0.00	0.0	1.81	100.0
26	5.24	5.20	-0.04	-0.7	3.73	71.8
Average	5.55	5.92	0.37	6.23	2.54	48.45

From Table 5.3 and Figure 5.3 it can be seen that four of the routes used by cyclists were shorter than the TFI route. In three of these cases it was found that cyclists had made choices not allowed by the route planner. This was due to cyclists use of exits or turns not coded within the TFI planner; in trip 12 the cyclist used a non-vehicular exit from a residential area; in trip 18 the cyclists travelled for a short distance in the wrong direction along a one-way street; and in trip 19 the cyclist travelled through a park not coded within the cycle planner map. There were seven trips which showed little or no difference in length to the ‘shortest-path’ route, although only five of these followed the same routes; trip 11 differed only over a small segment of the route (less than 0.2 km), while trip 26 differed from the TFI route over a much larger amount.

The largest proportion of difference in the length of the trips was 22% for trip 1, but this trip was also the shortest distance trip made resulting in an actual difference in length of only 0.33 km. The largest difference in distance was seen for trip 8, where the cyclists travelled 1.39 km (14.7%) further than the 'shortest-path' route. As previously mentioned five of the observed cyclist trips followed the 'shortest-path' route; overlapping 100%. As can be seen in Figure 5.4, none of the trips were completely different from the shortest route path; overlapping for at least 4.2% of the trip, with half of the observed routes overlapping the shortest distance path by less than 50%.

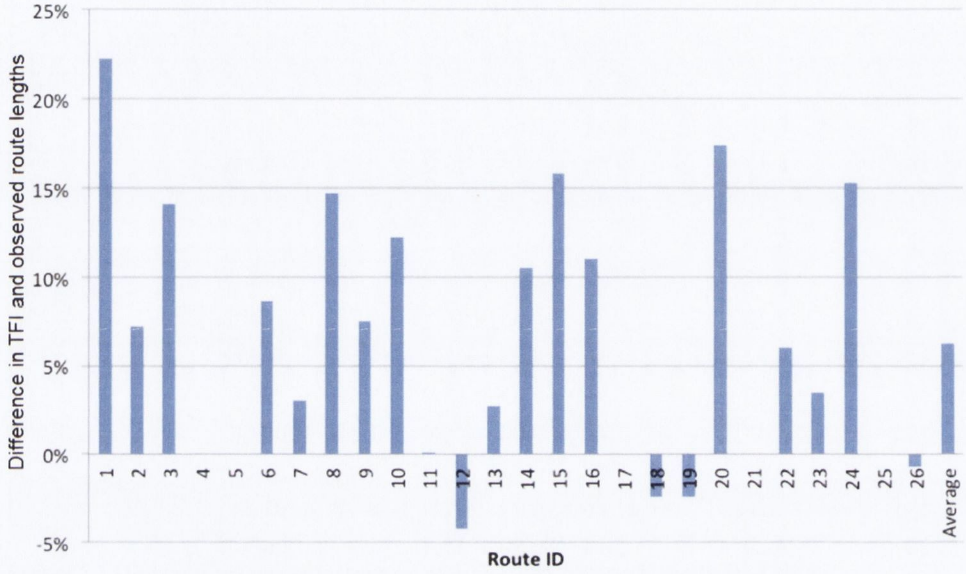


Figure 5.3 Difference in TFI and observed route lengths.

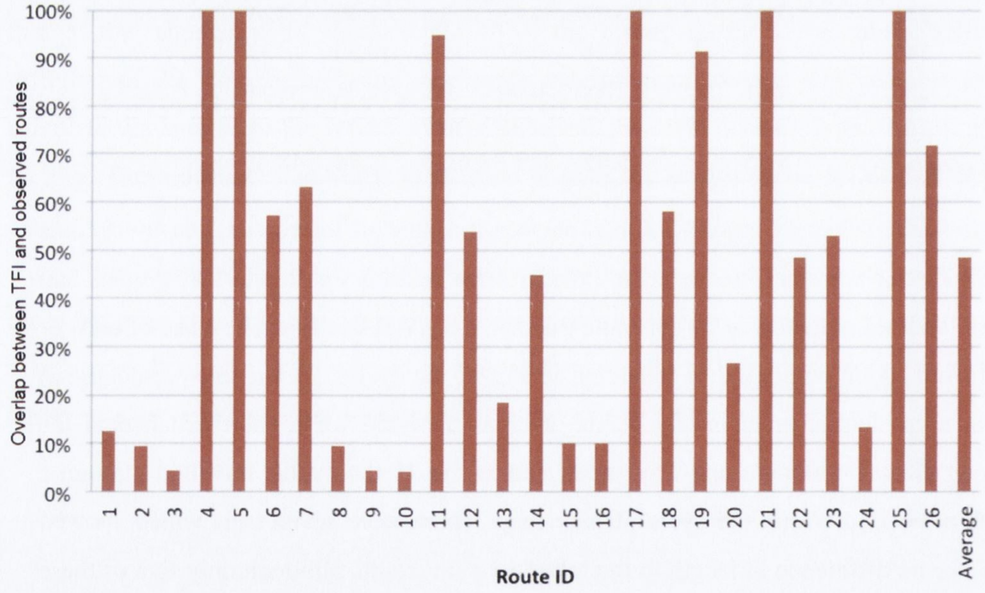


Figure 5.4 Overlap between TFI and observed routes.

From Table 5.4 it can be seen that both trips 17 and 25 recorded by cyclists used no cycling facilities; they both follow the 'shortest-path' routes. Alternative routes lying adjacent to the observed routes have kerbside cycle lanes and/or bus lanes, but carry much higher traffic volumes. Each of the other 24 cyclist routes spent at least 35% of their distance on cycling facilities; 22 spending at least 50% on cycling facilities; while 3 trips made entirely on cycling facilities. In comparison, 8 of the TFI shortest path routes (Table 5.5) were over 65% on road (i.e. where no cycling facility was present), 12 were over 50% on road and 2 trips made use of cycling facilities for the entire trip distance. Generally, where cyclists have not travelled on links with cycling facilities they are travelling within residential areas or on lower traffic volume links adjacent to highly trafficked links. Exceptions to this do arise close to the city centre area, where a uni-directional system of links offers little alternative to travelling on streets with no cycling facilities. These findings would suggest that cyclists have a high preference for low trafficked links and for the use of cycling facilities that the 'shortest-path' methods has been unable to provide for.

The proportion of travel on shared-use bus lanes is much lower than that of kerb-side cycle lanes, but this is mainly due to the greater availability of kerbside cycle lanes in the network (also, if a kerb-side cycle lane runs alongside a bus lane the cycling facility is classified by the NTA as a kerb-side lane). The amount both of these facilities types were used as part of a route varies depending on the route, with the TFI 'shortest-path' routes presenting lower average percentage use for both. These averages were 9.4% and 12.7% on shared-use bus lanes, and 39.5% and 46.5% on kerbside cycle lanes for the TFI and observed cyclist routes respectively.

Segregated cycle paths where used in twice as many of the recorded cyclist routes, and for longer distances then the TFI 'shortest-path' routes. The high quality segregated cycle path located along the east part of the Grand Canal was used in 8 of the trips taken by cyclists. Only two of the TFI 'shortest-path' routes use any part of this facility; one of these routes having its destination located along the canal facility. Where the TFI 'shortest-path route did not assign cyclists to this segregated facility, cyclists where assigned to lower quality facilities and along links with higher traffic volumes. The proportions presented in Tables 5.4 and 5.5 are also displayed in the graphs in Figures 5.5 and 5.6, for easy comparison between routes and TFI and observed trips.

Table 5.4 Distance and proportion of distance travelled on each type of cycling facility for each observed cyclist route.

	No cycle facility		**Shared-use bus lane**		**Kerbside cycle lane**		**Segregated cycle path**	
Route ID	km	%	km	%	km	%	km	%
1	0.53	35.7	0.30	20.1	0.45	29.9	0.22	14.4
2	2.41	39.0	0.09	1.5	3.69	59.6	0.00	0.0
3	4.25	61.3	0.00	0.0	2.69	38.7	0.00	0.0
4	1.28	30.4	0.28	6.7	2.63	65.2	0.00	0.0
5	0.52	13.6	0.00	0.0	3.29	86.4	0.00	0.0
6	0.00	0.0	1.24	28.8	3.06	71.2	0.00	0.0
7	0.75	16.9	2.47	55.5	0.81	18.1	0.43	9.6
8	0.00	0.0	0.00	0.0	3.29	74.9	1.10	25.1
9	1.44	28.8	0.43	8.7	2.92	58.6	0.19	3.9
10	0.92	18.2	0.00	0.0	2.44	48.4	1.69	33.4
11	1.87	49.7	0.46	12.3	1.43	38.0	0.00	0.0
12	0.00	0.0	1.10	24.2	3.44	75.8	0.00	0.0
13	0.35	8.1	0.18	4.1	3.79	87.8	0.00	0.0
14	2.85	45.8	0.00	0.0	2.85	45.9	0.52	8.4
15	2.86	64.3	0.86	19.2	0.73	16.5	0.00	0.0
16	2.26	49.4	0.00	0.0	0.59	13.0	1.71	37.5
17	1.45	100.0	0.00	0.0	0.00	0.0	0.00	0.0
18	0.66	12.9	0.70	13.6	3.76	73.5	0.00	0.0
19	3.38	43.2	1.60	20.4	0.00	0.0	2.85	36.4
20	1.64	31.9	0.71	13.8	2.29	44.5	0.50	9.8
21	0.16	4.7	1.20	36.1	1.97	59.2	0.00	0.0
22	1.42	39.1	0.52	14.1	1.70	46.8	0.00	0.0
23	1.22	32.4	0.30	7.9	1.72	45.7	0.53	14.0
24	0.90	24.4	0.69	18.6	1.58	42.8	0.53	14.2
25	1.81	100.0	0.00	0.0	0.00	0.0	0.00	0.0
26	0.26	5.5	1.13	24.3	3.27	70.2	0.00	0.0
Average	1.35	32.9	0.55	12.7	2.09	46.6	0.40	7.95

Table 5.5 Distance and proportion of distance travelled on each type of cycling facility for each TFI 'shortest-path' route.

	No cycle facility		Shared-use bus lane		Kerbside cycle lane		Segregated cycle path	
Route ID	km	%	km	%	km	%	km	%
1	1.00	85.8	0.00	0.0	0.17	14.2	0.00	0.0
2	3.80	66.1	0.00	0.0	1.23	21.4	0.72	12.4
3	2.78	46.7	0.44	7.3	2.74	46.0	0.00	0.0
4	1.28	30.4	0.28	6.7	2.63	65.2	0.00	0.0
5	0.52	13.6	0.00	0.0	3.29	86.4	0.00	0.0
6	3.12	62.2	0.44	8.8	0.84	16.7	0.62	12.3
7	2.05	45.9	1.07	23.9	0.74	16.6	0.61	13.6
8	3.21	90.0	0.12	3.5	0.23	6.5	0.00	0.0
9	3.91	90.3	0.42	9.7	0.00	0.0	0.00	0.0
10	3.91	90.3	0.42	9.7	0.00	0.0	0.00	0.0
11	1.87	49.6	0.46	12.3	1.43	38.0	0.00	0.0
12	0.00	0.0	0.29	5.8	4.76	94.2	0.00	0.0
13	1.49	29.8	0.29	5.8	3.23	64.5	0.00	0.0
14	1.12	20.2	0.38	6.9	3.54	63.6	0.52	9.3
15	0.54	15.1	0.00	0.0	3.04	84.9	0.00	0.0
16	0.76	17.9	0.00	0.0	3.49	82.1	0.00	0.0
17	1.45	100.0	0.00	0.0	0.00	0.0	0.00	0.0
18	0.00	0.0	0.52	10.1	4.61	89.9	0.00	0.0
19	3.38	43.2	1.60	20.4	0.00	0.0	2.85	36.4
20	2.38	56.1	0.56	13.1	1.31	30.7	0.00	0.0
21	0.16	4.7	1.20	36.1	1.97	59.2	0.00	0.0
22	0.94	27.6	0.47	13.7	2.01	58.7	0.00	0.0
23	2.70	74.3	0.42	11.4	0.52	14.3	0.00	0.0
24	1.72	54.9	0.46	14.6	0.96	30.5	0.00	0.0
25	1.81	100.0	0.00	0.0	0.00	0.0	0.00	0.0
26	1.46	31.1	1.13	24.1	2.10	44.8	0.00	0.0
Average	1.82	47.92	0.42	9.38	1.72	39.55	0.20	3.23

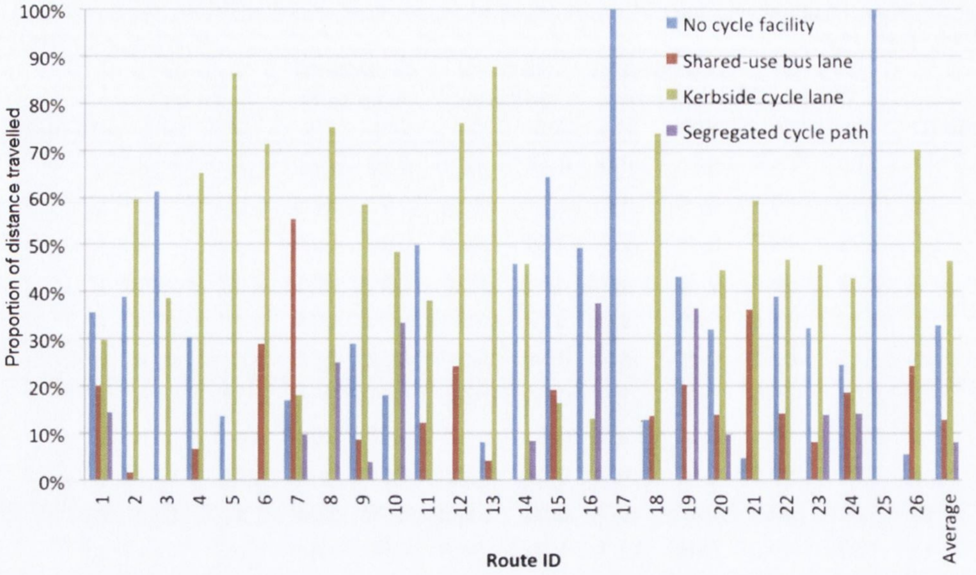


Figure 5.5 Proportion of distance travelled on each type of cycling facility for each observed cyclist route.

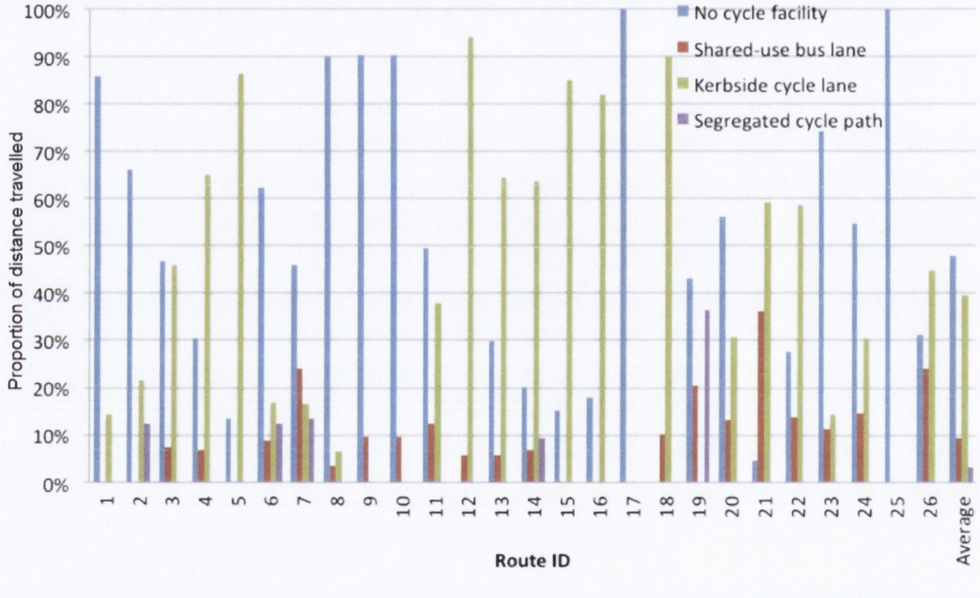


Figure 5.6 Proportion of distance travelled on each type of cycling facility for each TFI 'shortest-path' route.

5.4. CONCLUSIONS

In this chapter the revealed choice route preferences of cyclists were explored to investigate whether the 'shortest-path' method of trip assignment is sufficient for the assignment of cyclists within urban transport networks. A comparison of 26 routes travelled by cyclists in Dublin city has shown that cyclists generally will not follow the 'shortest-path' route; therefore considering attributes other than travel time/distance.

Although it cannot be explicitly stated from the monitoring study that the safety concerns of cyclists are the only reasons behind the differences seen from the 'shortest-path' routes, the elements of the network that the cyclists divert to avoid or make use of factors shown in Chapter 4 to be attributed to safety perceptions.

Based on the results of this study it would appear that cyclists consider the presence and type of cycling facility available, as well as the volume of traffic. They appear act to maximise their travel time on these facilities or in low traffic conditions, to the detriment of their travel distance, and hence their travel time. But as not all trips diverted to follow the highest quality cycling facilities or to travel 100% of the trip distance on cycling facilities, there must still remain a travel time/distance element involved in these route choice decisions i.e. these cyclists make a compromise between the safety elements of their trip and the trip travel time. It may also be the case that a cycling facility (or a cycling facility of higher quality than the one in use) may not be available within a practical distance to enable its use. The consideration of travel time by this method would prevent a trip assignment model from assigning cyclists along impractically long routes in order to make use of cycling facilities (or higher quality cycling facilities).

CHAPTER 6

6. MODELLING CYCLIST ROUTE CHOICE BEHAVIOUR – A RISK EXPOSURE METHOD

Previous research has shown that safety contributes largely to the perceptions of cycling; both in choosing to cycle; and after the decision to cycle is made, in choosing which route to cycle. The research presented in Chapter 4 finds that although cyclists have made the decision to cycle, they still feel unsafe. Previous efforts to improve upon transport modelling methods for cyclists have been outlined in Chapter 2; but few consider safety, and those that do require large amounts of network design data and where not originally developed for the purposes of assigning cyclists within transport networks. The work presented in this chapter aims to progress beyond 'shortest-path' methods currently in use in to assign cyclists within networks; to consider risk exposure, based on data that is already being collected for transport modelling purposes.

The remainder of the chapter is organised as follows: section 6.1 describes the modelling methodologies used within the rest of the chapter; section 6.2 presents the equations proposed to model cyclist risk; and section 6.3 provides a justification for the use of the proposed equations through examples.

6.1. METHODOLOGY

The trip assignment problem is essentially an optimisation (or equilibrium) problem; travellers act to minimise their travel costs between an OD pair. There are a number of assumptions which may be made in this regard as to the amount of information a traveller has when they make this decision and assignment methods differ slightly based on this.

6.1.1. User Equilibrium Principles

Deterministic user equilibrium - also known as Wardropian equilibrium - principles were first proposed by Wardrop in 1952 (Wardrop, 1952). DUE assumes that all network users have perfect information about network conditions. Wardrop's first principle for DUE is stated as follows

> The journey times in all routes actually used are equal or less than those which would be experienced by a single vehicle on any unused road.

In other words, no traveller is able to reduce his or her travel time by choosing an alternative route.

Stochastic user equilibrium is an extension to DUE, in which travellers do not have perfect network information, but choose their route based on what they perceive to be the minimum cost route. These perceived costs are generally considered to be randomly distributed across the population of users (Sheffi, 1985). As such, SUE presents a more realistic representation of transport networks; unlike for DUE where all travellers are assigned to the minimum cost route. In SUE travellers are distributed across the routes perceived by them to have the minimum cost.

6.1.2. User Equilibrium Formulations

Deterministic User Equilibrium

The DUE problem is formulated as a mathematical problem to find the link flows $\mathbf{x}$ that satisfy the user equilibrium criterion when all OD entries $\mathbf{q}$ have been assigned appropriately (Sheffi, 1985). Sheffi formulates this problem as the minimisation of the objective function:

$$\min \sum_{s} \int_{0}^{x_s} t_s(\omega) d\omega \qquad \textbf{Eq. (6.1)}$$

subject to

$$x_s = \sum_{w} \sum_{s} f_p^w \delta_s^p , \forall s \qquad \textbf{Eq. (6.2)}$$

$$\sum_{p} f_p^w - q_w = 0, \forall w, \qquad \textbf{Eq. (6.3)}$$

$$f_p^w \geq 0, \forall p, w \qquad \textbf{Eq. (6.4)}$$

where t_s is the travel time on link s, x_s is the flow on link s, f_p^w is the flow on path p between OD pair w, $\delta_s^p = 1$ if link s is on path p, $\delta_s^p = 0$ otherwise, q_w is the OD demand, which is assumed to be fixed for any OD pair w in DUE. These conditions ensure that the resulting flows are viable: Eq. (6.2) implies that the flow on a link is equal to the sum of the route flows making use of the link, while Eq. (6.3) and Eq. (6.4) are flow conservation and non-negativity constraints. These constraints ensure that all of the demand is assigned to the network and that the flows are meaningful.

The first order optimality conditions for this optimisation problem are as follows:

$$f_p^w (c_p^w - \mu^w) = 0, \forall p, w \qquad \textbf{Eq. (6.5)}$$

$$c_p^w - \mu^w \geq 0, \forall p, w$$ **Eq. (6.6)**

where $c_p^w = \sum_s t_s(x_s)\delta_s^p, \forall p, w$ **Eq. (6.7)**

and where c_p^w is the route travel time and μ^w is a Lagrange multiplier associated with Eq. (6.3) and $\mu^w \geq 0$. The first order optimality conditions in Eq. (6.8) and (6.9) imply Wardrop's first principle:

$$f_p^{w}* > 0 \Rightarrow c_p^w = \mu^w, \forall p, w$$ **Eq. (6.8)**

$$f_p^{w}* = 0 \Rightarrow c_p^w \geq \mu^w, \forall p, w$$ **Eq. (6.9)**

Eq (9) and (10) imply that when there is flow on a path the travel time is equal to the minimum path travel time; when there is no flow on the path the travel time is greater than the minimum path travel time (Sheffi, 1985).

Stochastic User Equilibrium

SUE is a more general equilibrium than DUE; if the perceived travel times are accurate the SUE case becomes the same as DUE. According to (Sheffi, 1985), the conditions for SUE can be stated as follows:

$$f_p^w = q_p^w P_p^w, \forall p, w$$ **Eq. (6.10)**

where Eq. (6.3) still holds and P_p^w is probability that path p between OR pair w is chosen, when $P_p^w = P_p^w(\mathbf{t}) = \Pr(C_p^w \leq C_k^w, \forall k \neq p \mid \mathbf{t})$, where C_p^w is the perceived route travel time such that:

$$C_p^w = c_p^w + \xi_p^w$$ **Eq. (6.11)**

where ξ_p^w is a random error term. The SUE flow distribution is subject to the probability distribution of the error term. It can be specified by logit-based or probit-based models. The study in this thesis is based on a logit-based SUE model and therefore only it is given here.

The route choice probability in a logit-based SUE is the probability that a given path is used based on the difference in the measure travel time on the path to that of all alternative paths. It can be expressed as follows (Sheffi, 1985):

$$P_p^w = \frac{\exp(-\theta c_p^w)}{\sum_k \exp(-\theta c_k^w)}, \forall p, w \qquad \textbf{Eq. (6.12)}$$

6.1.3. The Non-Linear Complementary Problem (NCP)

(Aashtiani, 1979) realised the equivalence between the DUE conditions and the Non-Linear Complementary Problem. Therefore, according to Aashtiani, the DUE optimisation problem can be reformulated as:

$$\mathbf{x} \geq \mathbf{0} \qquad \textbf{Eq. (6.13)}$$

$$\mathbf{F(x)} \geq \mathbf{0} \qquad \textbf{Eq. (6.14)}$$

$$\mathbf{x}^{\mathbf{T}}\mathbf{F(x)} = \mathbf{0} \qquad \textbf{Eq. (6.15)}$$

where $\mathbf{x} = \begin{pmatrix} \mathbf{f} \\ \mathbf{u} \end{pmatrix}$ **Eq. (6.16)**

$$\mathbf{F(x)} = \begin{pmatrix} \mathbf{F^f(x)} \\ \mathbf{F^u(x)} \end{pmatrix} \qquad \textbf{Eq. (6.17)}$$

where $\mathbf{f}$ is the vector of $(..., f_p^w, ...)$, $\mathbf{u}$ is the vector of $(..., \mu^w, ...)$, $\mathbf{F^f(x)}$ is the vector of $(c_p^w - \mu^w, \forall p, w)$ and $\mathbf{F^u(x)}$ is the vector of $(f_p^w - q^w, \forall w)$.

Extending this NCP formulation to SUE Eq. (6.13)-(6.15) remain the same, while $\mathbf{x}$ is the vector of $(..., f_p^w, ...)$and $\mathbf{F(x)}$ is the vector of $(f_p^w - q^w P_p^w, \forall p, w)$ (Aashtiani, 1979).

6.1.4. Gap Function - Fischer function

In order to solve the NCP, the minimisation of a gap (or merit) function is required. Minimising the gap function causes the network to reach the equilibrium required. The gap function G must satisfy the following conditions

- $G(\mathbf{x}) \geq 0$,
- $G(\mathbf{x}) = 0 \Leftrightarrow \mathbf{x} \in \Omega$
- $\min_{x \in \Psi} G(\mathbf{x}) = 0$ is a global minimum

where Ω is the set of all solutions to the NCP formulation and $\Psi = \{\mathbf{x} \geq 0, \mathbf{F(x)} \geq 0\}$ (Aashtiani, 1979). The gap function in use in this thesis is based on the Fisher Function (Fischer, 1992, Fischer, 1997)[6].

$$\phi(a,b) = \sqrt{a^2 + b^2} - (a + b) \qquad \textbf{Eq. (6.18)}$$

$$\varphi(a,b) = \frac{1}{2}\phi^2(a,b) \qquad \textbf{Eq. (6.19)}$$

where Eq.(6.18) is the Fisher function and Eq. (6.19) is the gap function. Applying to the NCP formulation for an SUE (the user equilibrium conditions used in this thesis) model the gap function is as follows:

$$G(\mathbf{x}) = \sum_i \varphi(\mathbf{x}_i, \mathbf{F(x)}_i) \qquad \textbf{Eq. (6.20)}$$

$$G(\mathbf{x}) = \sum_w \sum_p \varphi(f_p^w, f_p^w - q^w P_p^w) \qquad \textbf{Eq. (6.21)}$$

$$G(\mathbf{x}) = \sum_w \sum_p \left\{ \sqrt{(f_p^w)^2 + (f_p^w - q^w P_p^w)^2} - (f_p^w + (f_p^w - q^w P_p^w)) \right\}^2$$

Eq. (6.22)

6.2. NOTATION

This subsection presents notation used throughout the remainder of the Chapter and in subsequent chapters for the presentation of methods and formulation of trip assignment models. This notation is presented in Tables 6.1 to 6.4.

Table 6.1 Trip assignment notation – travel modes.

Notation	Definition
m	mode, $m = \{a, b, c\}$
a	auto mode
b	bus mode
c	bicycle mode

Table 6.2 Trip assignment notation – sets.

Notation	Definition
G_m	sub-network for mode m, on multi-modal network G
N_m	set of nodes in sub-network G_m
S_m	set of links connecting N_m

---

[6] The squared norm of the Fischer function (Eq. (6.19)) is used as the gap function in NCP applications because of the continuity of its gradient; ensuring the minimisation of the equilibrium problem.

S_{b1}	set of in-vehicle links on sub-network G_b
S_{b2}	set of wait links on sub-network G_b
W	set of OD pairs
P_w^m	set of routes between OD pair w by mode m
L	set of bus lines

Table 6.3 Trip assignment notation – variables.

Notation	Definition
g_p^b	in-vehicle crowding discomfort of passengers in bus on route p
g_{ls}^b	in-vehicle crowding discomfort of passengers in bus line l on link s
h_p^m	flow of mode m on route p
q_w	actual travel demand between OR pair w
q_w^m	travel demand for mode m between OR pair w
R_p^c	risk associated with cycling on route p
r_s^c	risk associated with cycling on link s
T_p^m	travel time by mode m on route p
t_s^m	travel time by mode m on link s
u_p^m	travel disutility by mode m on route p
v_s^m	traffic volume of mode m on link s
W_s^b	average waiting time of passengers for a bus on link s
W_p^b	average waiting time of passengers for a bus on route p
x_s^b	passenger flow on bus link s
x_{ls}^b	passenger flow on bus line l on link s
λ_w^m	expected travel disutility by mode m between OD pair w
λ_w	expected travel disutility between OD pair w
δ_{sp}	indicator variable; if link s is on route p $\delta_{sp} = 1$, 0 otherwise
δ_{sp}^l	indicator variable; if line l link s is on route p $\delta_{sp}^l = 1$, 0 otherwise

Table 6.4 Trip assignment notation – constants.

Notation	Definition
F_s^b	bus services frequency on link s
F_s^b	bus services frequency of line l
$g_{ls}^{b,0}$	baseline in-vehicle crowding discomfort of passengers in bus line l on link s
$r^{c,0}$	baseline risk associated with choosing bicycle as travel mode
κ_l	vehicle capacity of bus line l
K_l	capacity of bus line l
K_s	capacity of bus link s
q_w^0	potential (latent) travel demand between OR pair w
$\overline{V}_s^m$	free flow travel speed by mode m on link s
Z_p^m	walking time for access and egress from mode m on route p
Γ_p	length of route p
Γ_s	length of link s
Λ_p^a	monetary cost by auto for route p
Λ_p^b	bus fare for route p
α_t	value of travel time
α_z	value of walking time
α_w	value of waiting time
α_g	value of in-vehicle crowding discomfort
α_r	value of cycling risk
θ_1, θ_2	parameter representing the importance of travel disutility in route and mode choices respectively
η	parameter that reflects demand sensitivity to OD travel disutility
σ	factor to convert buses into auto equivalent vehicle units
γ	calibration parameter for bus waiting times, depends on bus headway and passenger arrival
ρ_1, β_1	parameters that reflect the importance of traffic volumes to travel times (in the BPR function)
ρ_2, β_2	parameters that reflect the importance of passenger volumes in in-vehicle crowding discomfort
$\rho_{cf_i}, \beta_{cf_i}$	parameters that reflect the importance of traffic volumes to cyclist risk for cycling facility types $i = 1, \ldots, 4$

6.3. CYCLIST SAFETY IN NETWORK DESIGN

Transport planning is based on the four-stage model; these stages involve collecting and modelling information on how many persons want to travel (trip generation), where these persons want to travel to/from (trip distribution), by which mode of transport these persons wish to travel (mode choice) and on which route will they travel by this mode (trip assignment). Each of these modelling stages is completed for public, private and commercial travel, with the exception of walking and cycling modes, where trip assignment is generally not preformed. In the cases where cyclist trip assignment has been completed it is generally assumed that cyclists follow the shortest distance path between their origin and destination (National Transport Authority, 2013a, Hill and Stefan, 2014, Ridgway, 1997, U.S. Department of Transportation, 1999).

A number of studies, as discussed in the review of literature, have attempted to improve on these methods by considering attributes such as congestion, emissions, bicycle rental costs and rider fatigue (Si et al., 2008a, Si et al., 2011, Si et al., 2008b, Li et al., 2014). In the existing research which considers safety in trip assignment models for cyclists (Klobucar and Fricker, 2007, Smith and Haghani, 2012, Ehrgott et al., 2012), the authors have considered safety through the use of various indexes; BCI (Harkey et al., 1998), BLOS (Landis et al., 1997) index and a suitability index developed by (Palmer et al., 1998). However, these indices were not originally developed for use in trip assignment models, and require a large amount of information; much of which would not be available to transport authorities, therefore requiring expensive data collection to be applicable.

The BCI and BLOS are similar in their formulation; they are regression equations based on attributes of the network which were considered as important to the safety/compatibility/suitability of a route. Below are the formulas for the BCI and BLOS:

BCI (Bicycle Compatibility Index),

$$\begin{aligned} BCI = c - a_1 BL - a_2 BLW - a_3 CLW + a_4 CLV \\ + a_5 OLV + a_6 SPD + a_7 PKG - a_8 AREA + AF \end{aligned} \quad \textbf{Eq. (6.23)}$$

where a_i are the coefficients, BL indicates the presence of a bicycle lane or paved shoulder, PKG indicates the presence vehicle parking, BLW is the bicycle lane or paved shoulder width, AREA indicates the whether it is residential area, CLW is the curb lane width, CLV is traffic volume is this lane, OLV is the traffic volume is the other lanes, SPD is the traffic speed, AF is an adjustment factor for truck volumes, parking and right turns and c is a constant (Harkey et al., 1998).

BLOS (Bicycle Level of service),

$$\begin{aligned}&\mathrm{BLOS}=\mathrm{a}_1\ln\left(\frac{\mathrm{Vol}_{15}}{L}\right)+\mathrm{a}_2\ln[\mathrm{SPD}_p(1+\mathrm{HV}\%)]\\&+\mathrm{a}_3\ln\left(\mathrm{COM}_{12}{*}\mathrm{NCA}\right)+\mathrm{a}_4(\mathrm{PC}_5)^{-2}+\mathrm{a}_5(\mathrm{W}_e)^2+\mathrm{c}\end{aligned} \qquad \textbf{Eq. (6.24)}$$

where a_i are the coefficients, COM_{15} is the trip generation intensity of the land adjoining the road segment, PC_5 is the pavement surface condition rating, Vol_{15} is the volume of directional traffic, W_e is the effective width of outside lane, L is the number of lanes, SPD_p is the speed limit, HV% is percentage of heavy vehicles, NCA is a measure of the frequency of uncontrolled access to a link (e.g. driveways and on-street parking spaces), and c is a constant (Landis et al., 1997) .

The work in this thesis uses an alternative approach to considering safety in trip assignment for cyclists. This approach is based on methods currently applied to the assignment of vehicles in transport networks. This means it would be easily interrupted by those with a knowledge of vehicle trip assignment methods. The method also allows its use in existing softwares developed for the assignment of vehicles (as will be demonstrated in Chapter 7). The method was developed in order to provide a much less data intensive, but reliable, method for the realistic assignment of bicycle trips. As will be explained in the following sections, the commonly used travel time variable is used in conjunction with the 'perceived risk' variable, which is developed and demonstrated in this Chapter. The basis for the structure of this equation is found in the Bureau of Public Roads (BPR) equation (U.S. Department of Commerce and Bureau of Public Roads, 1964), which is a volume-delay function used widely for the assignment of vehicular traffic as the travel time consideration.

$$t_s = t_s^0\left(1+\rho\left(\frac{x_s}{C_s}\right)^{\beta}\right) \qquad \textbf{Eq. (6.25)}$$

where t_s is the travel time on link s, t_s^0 is the free flow travel time on link s, x_s is the flow on link a, C_s is the capacity of link s, and ρ, β are parameters. Generally, the values of ρ and β are 0.15 and 4 respectively (U.S. Department of Commerce and Bureau of Public Roads, 1964).

This equation structure has already previously been used as the basis for similar equations related to traffic assignment. (Lo et al., 2003), (Li et al., 2009b) and (Li et al., 2011) use a BPR-type function to describe the crowding discomfort occurring on transit modes.

$$g_{ls}^{m} = t_{s}^{m}\left(g_{ls}^{m,0} + \rho\left(\frac{x_{s}^{ml} + \bar{x}_{s}^{ml}}{K_{l}} \right)^{\beta} \right) \qquad \textbf{Eq. (6.26)}$$

where g_{ls}^{m} is the in-vehicle crowding discomfort cost (in time units) for line l of mode m on link s, t_{s}^{m} is the travel time of mode m on link s, $g_{ls}^{m,0}$ is the baseline in-vehicle crowding discomfort cost (in time units) for line l of mode m on link s, x_{s}^{ml} is the passenger flow for line l of mode m on link s, x_{s}^{ml} is the passenger flow competing with x_{s}^{ml} for the same common capacity of line l on mode m for link s, K_{l} is the capacity of line l and ρ, β are parameters (not necessarily of the same values are in Eq. (6.25)).

6.3.1. BPR-Type Equations for Cyclist Risk

To be able to capture the risk (or inversely, safety) perceptions of cyclists in order to be better able to assign cyclists within transport networks would offer an improvement over current 'shortest path' methods, which have been shown to fall short in their understanding of cyclist route choice decisions. This section proposes four equations (relating to four types of cycling facility) which build on previous assignment methods in an attempt to do this. These equations must reflect the preferences of cyclists for the types of cycling facility and the varying traffic conditions that may arise in an urban transport network. Table 6.5 presents the order of preference for the four types of cycling facility considered in question 13 of the cycling survey presented in Chapter 4. Here, it can be seen that the majority of respondents gave their first preference to segregated cycle paths; while they gave their second, third and fourth preference to kerbside cycle lanes, shared-use bus lanes and no cycle facilities, respectively. The same order of preference can be seen for these same cycle facility types in (Caulfield et al., 2012).

Table 6.5 Survey respondent order of preference according to Q13.

	Segregated path		**Kerbside cycle lane**		**Shared-use bus lane**		**No cycle facility**	
Preference	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**
1st	**640**	**52.8%**	371	30.6%	67	5.5%	135	11.1%
2nd	177	14.6%	**662**	**54.6%**	266	21.9%	108	8.9%
3rd	129	10.6%	154	12.7%	**638**	**52.6%**	292	24.1%
4th	267	22.0%	26	2.1%	242	20.0%	**678**	**55.9%**

Travellers will move within the network so as to minimise their perceived travel costs or travel time; in other words to minimise their disutility; whereas they will act to maximise their perceived safety. For safety to be considered alongside other attributes which must be minimised would require inversion of the safety attribute and possible loss of meaning/understanding of the resulting values. Instead, rather than maximising perceived safety; here, the perceived risk is minimised, where risk is understood to be the opposite (or inverse) of safety. As such the proposed equations estimate the perceived risk r to which cyclists are exposed.

As previously mentioned, the equations proposed here are based on the BPR-type structure. They are dependent on cyclist travel time, traffic flows and traffic capacities. These traffic flows and capacities are different depending on the type of cycling facility present and are explained for each facility below. The equations also contain a parameter known as baseline perceived risk. This parameter describes the perceived risk associated with choosing cycling as a travel mode; similar to how the baseline discomfort in Eq. (6.26) describes the discomfort associated with choosing to travel by that mode. The parameter has no unit as it is a proportion, which in the equations is multiplied by travel time to add this proportion of travel time to the risk associated with cycling. As such, this parameter is equal to zero for trip assignment models which do not include mode choice.

Equations (6.27) to (6.30) below have been developed as part of this research in an effort to better describe the perceived risk of cycling in an urban environment with mixed traffic, where there are a number of different cycling facilities available for the use of cyclists. These equations have not been presented previously in any other research and were formulated by the researcher. For the purposes of clarity, where 'risk' is mentioned, in the remainder of this chapter and in the following chapters (unless otherwise stated), it should be taken to mean 'perceived risk'.

<u>No cycling facilities on link</u> (cf_1)

If there is no cycle facility, the cyclist is considered to be exposed to the full effect of the vehicular traffic using the link. In Eq. (6.27) both auto and bus traffic is considered in relation to link capacity.

$$r^c_{s,cf_1} = t^c_s \left[r^{c,0} + \rho_{cf_1} \left(\frac{v^a_s + v^b_s}{K_s} \right)^{\beta_{cf_1}} \right] \qquad \textbf{Eq. (6.27)}$$

where r_{s,cf_1}^{c} is the perceived risk (measured in time units) associated with cycling on cycle facility cf_1 on link s, $r^{c,0}$ is the baseline perceived risk, t_s^c is the travel time for cycling on link s, v_s^a and v_s^a are the flows of autos and buses on link s, K_s is the capacity of link s and $\rho_{cf_1}, \beta_{cf_1}$ are parameters.

Shared-use bus lane (cf_2)

If there is a shared use bus lane on the, the cyclist is considered to be exposed to the effects of the bus traffic in this bus lane, therefore the flow-capacity ratio is the ratio of the flow of buses to the capacity of the bus lane.

$$r_{s,cf_2}^{c} = t_s^c \left[r^{c,0} + \rho_{cf_2} \left(\frac{v_s^b}{K_{s,cf_2}} \right)^{\beta_{cf_2}} \right] \qquad \textbf{Eq. (6.28)}$$

where r_{s,cf_2}^{c} is the perceived risk associated with cycling on cycle facility cf_2 on link s, K_{s,cf_2} is the capacity of the bus lane on link s and $\rho_{cf_2}, \beta_{cf_2}$ are parameters.

Kerbside cycle lane (cf_3)

If there is a dedicated kerbside lane on the link, the effect of the traffic on the cyclist is considered to be less than that of when there is no cycle facility, this effect is captured by parameters $\rho_{cf_3}, \beta_{cf_3}$. The traffic volumes and capacities considered are the same as for the equation where no cycle lane is present.

$$r_{s,cf_3}^{c} = t_s^c \left[r^{c,0} + \rho_{cf_3} \left(\frac{v_s^a + v_s^b}{K_s} \right)^{\beta_{cf_3}} \right] \qquad \textbf{Eq. (6.29)}$$

where r_{s,cf_3}^{c} is the perceived risk associated with cycling on cycle facility cf_3 on link s and $\rho_{cf_2}, \beta_{cf_2}$ are parameters.

Segregated cycle path (cf_4)

If there is a segregated cycle path, the effect of vehicular traffic is considered to be irrelevant due to the physical separation of cyclists from other traffic. This equation instead considers the presence of other cyclists on the path with respect to the capacity of the facility.

$$r^{c}_{s,cf_4} = t^{c}_{s}\left[r^{c,0} + \rho_{cf_4}\left(\frac{v^{c}_{s}}{K_{s,cf_4}}\right)^{\beta_{cf_4}}\right]$$ **Eq. (6.30)**

where r^{c}_{s,cf_4} is the perceived risk associated with cycling on cycle facility cf_4 on link s, v^{c}_{s} is the flow of bicycles on link s and K_{s,cf_4} is the capacity of the segregated path on link s.

6.3.2. Risk Equation Values

Values for each ρ_{cf_i} and β_{cf_i} must be chosen to reflect the cycle facility preference of cyclists, but also to reflect traffic conditions, for example a cyclist would most likely prefer to travel on a link with no cycle facility in low vehicle traffic volumes, than on a shared-use bus lane with high bus flows; despite the preference for shared-use bus lanes over links with no cycle facilities. In order to demonstrate that these equations are capable of reflecting these conditions, reasonable values (based, wherever possible, on values used by similar trip assignment examples in literature (Li et al., 2014)) for each of these parameters have been chosen. Values for each risk equation were calculated for a range of values of link length Γ_s (km), auto flow v^{a}_{s} (auto-vehicles/hr), bus flow v^{b}_{s} (bus-vehicles/hr), bicycle flow v^{b}_{s} (bicycles/hr) and link capacity K_s (auto- and bus-vehicles/hr). As altering values of bus lane capacity K_{s,cf_2} (bus-vehicles/hr) and K_{s,cf_4} (bicycles/hr) would present similar results to altering v^{b}_{s} and v^{b}_{s}, respectively, these values are not included. Each is varied in value one at a time (i.e. all other variables held constant) to investigate the effect on risk costs and disutility. The parameter values required by the equations involved in these calculations are given in Table 6.6, this includes the values for ρ_{cf_i}, β_{cf_i} and $r^{c,0}$, where $\overline{V}^{c}$ is the average cyclist speed and σ is the factor which converts buses to equivalent autos. The values for auto flow, bus flow, bicycle flow, link capacity, shared-use bus lane capacity and link length, when each are held constant are given in Table 6.7. As this is a route choice only model the value of baseline risk $r^{c,0}$ is zero. Due to the funding limitations, the values of ρ_{cf_i} and β_{cf_i} could not be calibrated to real-world network connections. Instead they have been arbitrarily chosen to produce reasonable values, so that for the same link length and flow-capacity ratio on each type of cycling facility, the resultant values of perceived risk reflect the order of preference as shown by the cyclist safety survey and produce perceived risk values that were considered reasonable under various conditions described below. Therefore, further research would be required to calibrate these parameters before such a method might be applied in to an actual transport network. As this analysis into the behaviour of the proposed equations is somewhat arbitrary, it is meant only for the purpose of showing that the equations behave in the expected manner.

Table 6.6 Parameter values for Eq (27) to (32).

Average cyclist speed (km/hr)	Conversion factor	Baseline risk	Parameter values for risk exposure equations							
$\overline{V}^c$	σ	$r^{c,0}$	ρ_{cf_1}	ρ_{cf_2}	ρ_{cf_3}	ρ_{cf_4}	β_{cf_1}	β_{cf_2}	β_{cf_3}	β_{cf_4}
12	4	0	1.5	1	0.8	0.4	1	1	2	4

Table 6.7 Values used for each variable for testing risk exposure equations.

Auto flow	Bus flow	Bicycle flow	Link capacity	Shared-use Bus lane capacity	Segregated cycle path capacity	Link length
v_s^a	v_s^b	v_s^c	K_s	K_{s,cf_2}	K_{s,cf_4}	Γ_s
auto-veh/hr	bus-veh/hr	bicycle /hr	auto equil.-veh/hr	bus-veh/hr	bicycle /hr	km
500	15	1000	3000	90	6000	1

Tables 6.8 to 6.12 present the resulting values for cyclist travel time t_s^c, risk on each facility type r_{s,cf_i}^c, and total disutility u_s^c. The values of each variable (when that variable was not being varied) were chosen so that the flow-capacity ratios were similar. This is to allow easier comparison of risk values for each type of cycling facility. For these flow and capacities values, the flow-capacity ratios are 0.19 for no cycling facility and kerbside cycle lane, and 0.17 for shared-use bus lane and segregated cycle path, respectively.

As assignment models are generally used to assign traffic within cities during high traffic time periods i.e. during the commute time period, the majority of cyclists will consider minimising their commute time/distance as well as minimising risk. Therefore, a total disutility u_s^c equal to the sum of travel time and risk is calculated (in time units) as:

$$u_s^c = t_s^c + r_{s,cf_i}^c \qquad \textbf{Eq. (6.31)}$$

for the relevant type of cycling facility, where cyclist travel time is calculated as link length Γ_s divided by average cycling speed $\overline{V}^c$.

$$t_s^c = \frac{\Gamma_s}{\overline{V}^c} \qquad \textbf{Eq. (6.32)}$$

The resulting risk exposure values for changes in auto flow are presented in Table 6.8. The risk values r^c_{s,cf_2} and r^c_{s,cf_4} are not dependent on auto flows; their values are 0.83 and 0.002 minutes, respectively, regardless of the value of auto flow. When increasing auto flow from zero to capacity it can be seen that initially a shared-use bus lane presents the highest risk, due to its much larger flow-capacity ratio. At an arbitrary flow between 200 and 400 auto/hr (or a flow-capacity ratio between 0.09 and 0.17) the risk associated with a link with no cycling facilities becomes larger and at a flow between 1200 and 1500 auto/hr (or a flow-capacity ratio between 0.40 and 0.52) the risk associated with a kerbside cycle lane also becomes larger than that of the shared-use bus lane. Figure 6.1 shows how the risk values for the four types of cycling facility vary with changes in auto flow. For zero auto flow (but, a flow of 15 bus/hr) the risk associated with no cycling facility and kerbside cycle lanes are 0.15 and 0.002 minutes respectively. At capacity these increase to 7.5 and 4 minutes, accounting for 60.0% and 44.4% of total disutility. This is the maximum possible contribution of risk to disutility of these facilities.

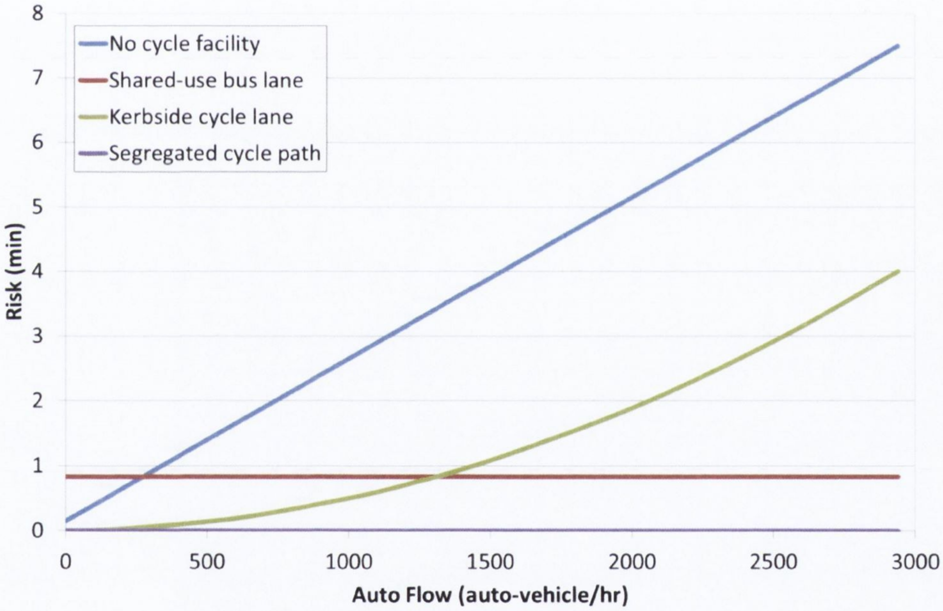


Figure 6.1 Relationship between risk and auto flow for 4 types of cycling facility.

Table 6.8 Demonstration of the use of the proposed risk equations for changes in auto flow.

Auto flow	Flow-Capacity ratios				Travel time	Link risk exposure				Link disutility				Percentage Of Disutility			
v_s^a	$\frac{v_s^a + v_s^b}{K_s}$	$\frac{v_s^b}{K_{s,cf_2}}$	$\frac{v_s^a + v_s^b}{K_s}$	$\frac{v_s^c}{K_s}$	t_s^c	r_{s,cf_1}^c	r_{s,cf_2}^c	r_{s,cf_3}^c	r_{s,cf_4}^c	$u_s^{cf_1}$	$u_s^{cf_2}$	$u_s^{cf_3}$	$u_s^{cf_4}$	$\frac{r_{s,cf_1}^c}{u_s^{cf_1}}$	$\frac{r_{s,cf_2}^c}{u_s^{cf_2}}$	$\frac{r_{s,cf_3}^c}{u_s^{cf_3}}$	$\frac{r_{s,cf_4}^c}{u_s^{cf_4}}$
auto-veh/hr					min	Min	min	min	min	min	min	min	min	%	%	%	%
0	0.02	0.17	0.02	0.17	5	0.150	0.833	0.002	0.002	5.150	5.833	5.002	5.002	2.9	14.3	0.0	0.0
100	0.05	0.17	0.05	0.17	5	0.400	0.833	0.011	0.002	5.400	5.833	5.011	5.002	7.4	14.3	0.2	0.0
200	0.09	0.17	0.09	0.17	5	0.650	0.833	0.030	0.002	5.650	5.833	5.030	5.002	11.5	14.3	0.6	0.0
400	0.15	0.17	0.15	0.17	5	1.150	0.833	0.094	0.002	6.150	5.833	5.094	5.002	18.7	14.3	1.9	0.0
600	0.22	0.17	0.22	0.17	5	1.650	0.833	0.194	0.002	6.650	5.833	5.194	5.002	24.8	14.3	3.7	0.0
800	0.29	0.17	0.29	0.17	5	2.150	0.833	0.329	0.002	7.150	5.833	5.329	5.002	30.1	14.3	6.2	0.0
1000	0.35	0.17	0.35	0.17	5	2.650	0.833	0.499	0.002	7.650	5.833	5.499	5.002	34.6	14.3	9.1	0.0
1200	0.40	0.17	0.40	0.17	5	3.150	0.833	0.706	0.000	8.150	5.833	5.706	5.000	38.7	14.3	12.4	0.0
1500	0.52	0.17	0.52	0.17	5	3.900	0.833	1.082	0.002	8.900	5.833	6.082	5.002	43.8	14.3	17.8	0.0
2000	0.69	0.17	0.69	0.17	5	5.150	0.833	1.886	0.002	10.150	5.833	6.886	5.002	50.7	14.3	27.4	0.0
2500	0.85	0.17	0.85	0.17	5	6.400	0.833	2.913	0.002	11.400	5.833	7.913	5.002	56.1	14.3	36.8	0.0
2940	1.00	0.17	1.00	0.17	5	7.500	0.833	4.000	0.002	12.500	5.833	9.000	5.002	60.0	14.3	44.4	0.0

For changes in bus flow (Table 6.9) each of r^{c}_{s,cf_1} r^{c}_{s,cf_2} r^{c}_{s,cf_3} vary, while r^{c}_{s,cf_4} is not dependent on bus flows and its value is as before. Initially, when bus flow is zero, shared-use bus lanes are the safest type of cycling facility, but as soon as bus flow is introduced segregated paths become lower risk and once 3 bus/hr are travelling the link the kerbside cycle lane also becomes lower risk. This can be seen clearly from Figure 6.2 where the lines on the graph intersect. For the given auto flow, links with no cycling facilities presented the highest risk at low bus flows. But as the flow-capacity ratio associated with shared-use bus lanes increased at a higher rate than that of no cycle facility at a flow-capacity ratio of 0.27 to 0.33 (approximately 26-29 bus/hr), shared-use bus lanes became the highest risk option. At this point the flow capacity ratio for a link with no cycle facilities is between 0.20 and 0.21. At bus flow equal to bus lane capacity (flow-capacity ratio equal to 1), 5 minutes are added to disutility, accounting for 50% of disutility costs, the maximum proportion this type of facility can contribute to risk.

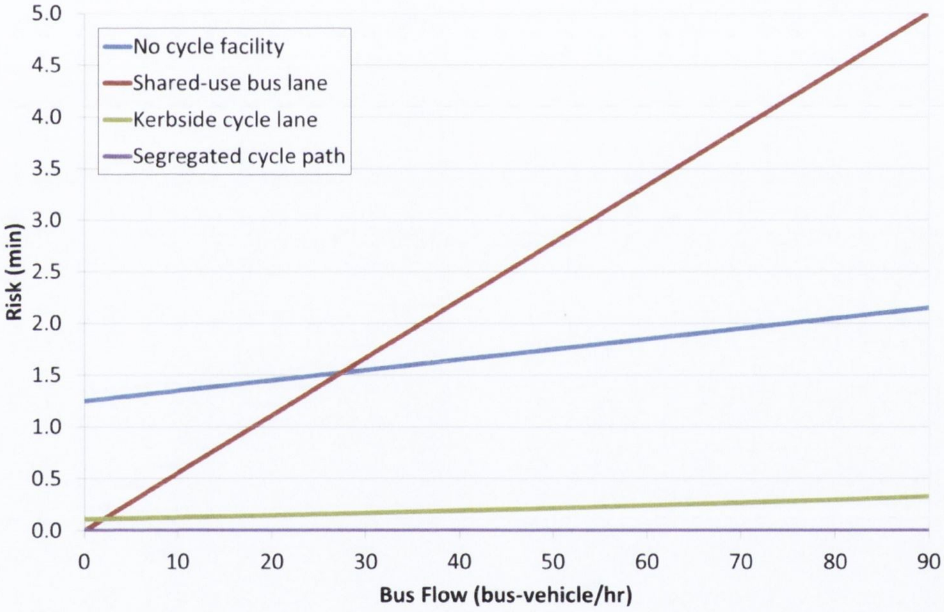


Figure 6.2 Relationship between risk and bus flow for 4 types of cycling facility.

Table 6.9 Demonstration of the use of the proposed risk equations for changes in bus flow.

Bus flow	Flow-Capacity ratios				Travel Time	Link risk exposure				Link disutility				Percentage Of Disutility			
v_s^b	$\frac{v_s^a+v_s^b}{K_s}$	$\frac{v_s^b}{K_{s,cf_2}}$	$\frac{v_s^a+v_s^b}{K_s}$	$\frac{v_s^c}{K_s}$	t_s^c	r^c_{s,cf_1}	r^c_{s,cf_2}	r^c_{s,cf_3}	r^c_{s,cf_4}	$u_s^{cf_1}$	$u_s^{cf_2}$	$u_s^{cf_3}$	$u_s^{cf_4}$	$\frac{r^c_{s,cf_1}}{u_s^{cf_1}}$	$\frac{r^c_{s,cf_2}}{u_s^{cf_2}}$	$\frac{r^c_{s,cf_3}}{u_s^{cf_3}}$	$\frac{r^c_{s,cf_4}}{u_s^{cf_4}}$
bus-veh/hr					Min	min	min	min	min	min	min	min	min	%	%	%	%
0	0.17	0.00	0.17	0.17	5	1.250	0.000	0.111	0.002	6.250	5.000	5.111	5.002	20.0	0.0	2.2	0.0
3	0.17	0.03	0.17	0.17	5	1.280	0.167	0.117	0.002	6.280	5.167	5.117	5.002	20.4	3.2	2.3	0.0
6	0.17	0.07	0.17	0.17	5	1.310	0.333	0.122	0.002	6.310	5.333	5.122	5.002	20.8	6.3	2.4	0.0
9	0.18	0.10	0.18	0.17	5	1.340	0.500	0.128	0.002	6.340	5.500	5.128	5.002	21.1	9.1	2.5	0.0
12	0.18	0.13	0.18	0.17	5	1.370	0.667	0.134	0.002	6.370	5.667	5.134	5.002	21.5	11.8	2.6	0.0
15	0.19	0.17	0.19	0.17	5	1.400	0.833	0.139	0.002	6.400	5.833	5.139	5.002	21.9	14.3	2.7	0.0
18	0.19	0.20	0.19	0.17	5	1.430	1.000	0.145	0.002	6.430	6.000	5.145	5.002	22.2	16.7	2.8	0.0
21	0.19	0.23	0.19	0.17	5	1.460	1.167	0.152	0.002	6.460	6.167	5.152	5.002	22.6	18.9	2.9	0.0
24	0.20	0.27	0.20	0.17	5	1.490	1.333	0.158	0.002	6.490	6.333	5.158	5.002	23.0	21.1	3.1	0.0
30	0.21	0.33	0.21	0.17	5	1.550	1.667	0.171	0.002	6.550	6.667	5.171	5.002	23.0	21.1	3.1	0.0
40	0.22	0.44	0.22	0.17	5	1.650	2.222	0.194	0.002	6.650	7.222	5.194	5.002	23.7	25.0	3.3	0.0
50	0.23	0.56	0.23	0.17	5	1.750	2.778	0.218	0.002	6.750	7.778	5.218	5.002	25.9	35.7	4.2	0.0
75	0.27	0.83	0.27	0.17	5	2.000	4.167	0.284	0.002	7.000	9.167	5.284	5.002	28.6	45.5	5.4	0.0
90	0.29	1.00	0.29	0.17	5	2.150	5.000	0.329	0.002	7.150	10.000	5.329	5.002	30.1	50.0	6.2	0.0

When changing the values of bicycle flow as shown in Table 6.10, only r^{c}_{s,cf_4} is affected. The risk values r^{c}_{s,cf_1} , r^{c}_{s,cf_2} and r^{c}_{s,cf_3} stood at 1.40, 0.83 and 0.14 minutes. It is not until the flow-capacity ratio for segregated paths exceeds 0.5 that segregated paths present a higher risk than kerbside-cycle lanes, adding 0.23 minutes for a flow of 4000 bicycle/hr. Although this is a flow rate unlikely to be reached at a single point in a network the bicycle flow values are increased to capacity in order to demonstrate the structure and interactions of the proposed method. This ratio exceeds 0.75 before shared-use bus lanes also become lower risk and exceeds 0.83 before cycling on a link with no facilities is safer (bearing in mind the relatively low flow-capacity ratios of 0.19 and 0.17 for no cycle facility and shared-use bus lanes, respectively). Figure 6.3 shows how the risk of cycling on a segregated cycle path is very close to zero for values below 2000 bicycle/hr and only becomes less safe than all other facility types for flows greater than approximately 5500 bicycle/hr, a value close to capacity. At bicycle flow equal to capacity, the risk associated with segregated paths adds 2 minutes, accounting for 28.6% of disutility. This contribution of risk to total disutility is the maximum; occurring at capacity.

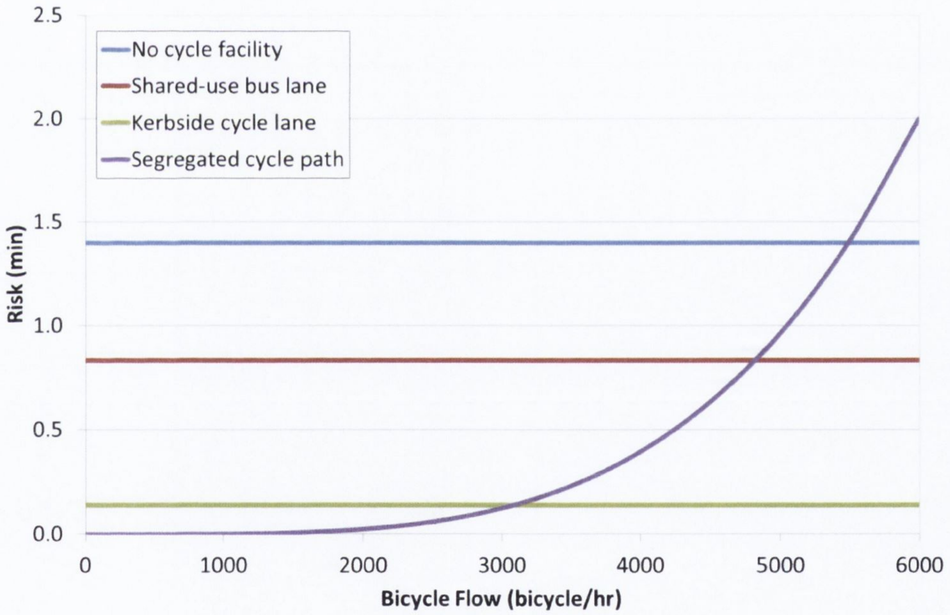


Figure 6.3 Relationship between risk and bicycle flow for 4 types of cycling facility.

Table 6.10 Demonstration of the use of the proposed risk equations for changes in bicycle flow.

Bicycle flow	Flow-Capacity ratios				Travel time	Link risk exposure				Link disutility				Percentage Of Disutility			
v_s^c	$\frac{v_s^a+v_s^b}{K_s}$	$\frac{v_s^b}{K_{s,cf_2}}$	$\frac{v_s^a+v_s^b}{K_s}$	$\frac{v_s^c}{K_s}$	t_s^c	r_{s,cf_1}^c	r_{s,cf_2}^c	r_{s,cf_3}^c	r_{s,cf_4}^c	$u_s^{cf_1}$	$u_s^{cf_2}$	$u_s^{cf_3}$	$u_s^{cf_4}$	$\frac{r_{s,cf_1}^c}{u_s^{cf_1}}$	$\frac{r_{s,cf_2}^c}{u_s^{cf_2}}$	$\frac{r_{s,cf_3}^c}{u_s^{cf_3}}$	$\frac{r_{s,cf_4}^c}{u_s^{cf_4}}$
bicycle /hr					Min	min	min	min	min	min	min	min	min	%	%	%	%
0	0.19	0.17	0.19	0.00	5	1.400	0.833	0.139	0.000	6.400	5.833	5.139	5.000	21.9	14.3	2.7	0.0
200	0.19	0.17	0.19	0.03	5	1.400	0.833	0.139	0.000	6.400	5.833	5.139	5.000	21.9	14.3	2.7	0.0
500	0.19	0.17	0.19	0.08	5	1.400	0.833	0.139	0.000	6.400	5.833	5.139	5.000	21.9	14.3	2.7	0.0
800	0.19	0.17	0.19	0.13	5	1.400	0.833	0.139	0.001	6.400	5.833	5.139	5.001	21.9	14.3	2.7	0.0
1000	0.19	0.17	0.19	0.17	5	1.400	0.833	0.139	0.002	6.400	5.833	5.139	5.002	21.9	14.3	2.7	0.0
1200	0.19	0.17	0.19	0.20	5	1.400	0.833	0.139	0.003	6.400	5.833	5.139	5.003	21.9	14.3	2.7	0.1
1500	0.19	0.17	0.19	0.25	5	1.400	0.833	0.139	0.008	6.400	5.833	5.139	5.008	21.9	14.3	2.7	0.2
2000	0.19	0.17	0.19	0.33	5	1.400	0.833	0.139	0.025	6.400	5.833	5.139	5.025	21.9	14.3	2.7	0.5
2500	0.19	0.17	0.19	0.42	5	1.400	0.833	0.139	0.060	6.400	5.833	5.139	5.060	21.9	14.3	2.7	1.2
3000	0.19	0.17	0.19	0.50	5	1.400	0.833	0.139	0.125	6.400	5.833	5.139	5.125	21.9	14.3	2.7	2.4
3500	0.19	0.17	0.19	0.58	5	1.400	0.833	0.139	0.232	6.400	5.833	5.139	5.232	21.9	14.3	2.7	4.4
4000	0.19	0.17	0.19	0.67	5	1.400	0.833	0.139	0.395	6.400	5.833	5.139	5.395	21.9	14.3	2.7	7.3
4500	0.19	0.17	0.19	0.75	5	1.400	0.833	0.139	0.633	6.400	5.833	5.139	5.633	21.9	14.3	2.7	11.2
5000	0.19	0.17	0.19	0.83	5	1.400	0.833	0.139	0.965	6.400	5.833	5.139	5.965	21.9	14.3	2.7	16.2
5500	0.19	0.17	0.19	0.92	5	1.400	0.833	0.139	1.412	6.400	5.833	5.139	6.412	21.9	14.3	2.7	22.0
6000	0.19	0.17	0.19	1.00	5	1.400	0.833	0.139	2.000	6.400	5.833	5.139	7.000	21.9	14.3	2.7	28.6

The next set of data was varied according to link capacity (Table 6.11). This caused changes to the risk associated with links with no cycling facilities and kerbside cycle lanes only. With combined auto and bus flow equal to capacity i.e. flow-capacity ratio equal to 1, risk values are 7.5 and 4 minutes for no cycle facility and kerbside cycle lanes. Continuing to increase the link capacity causes the same decrease in the flow-capacity ratios, for both of these cycling facilities, but due to the different parameters involved, the risk values fall at a faster rate for kerbside cycle lanes, than for links with no cycling facilities. At a flow-capacity ratio between 0.14 and 0.12 kerbside lanes became safer than shared-use bus lanes and between 0.11 and 0.08 use of a link with no cycling facilities became safer. This can be seen clearly in Figure 6.4. It can also be seen in Table 6.11 that the risk associated with kerbside cycle lanes approaches that of segregated paths at a capacity of 12000 auto- equivalent vehicles/hr, or a flow-capacity ratio of 0.05. The capacity would need to be much larger (flow-capacity ratio much lower) for cycling on a link with no facilities to present a risk value as low as that of a segregated path.

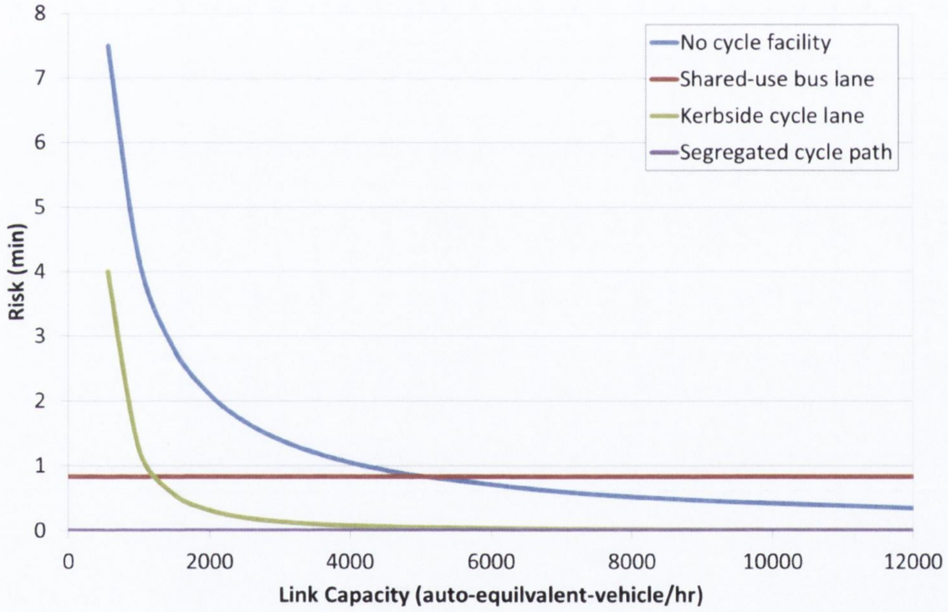


Figure 6.4 Relationship between risk and link capacity for 4 types of cycling facility.

Table 6.11 Demonstration of the use of the proposed risk equations for changes in link capacity.

Link capacity	Flow-Capacity ratios				Travel time	Link risk exposure				Link disutility				Percentage Of Disutility			
K_s	$\frac{v_s^a + v_s^b}{K_s}$	$\frac{v_s^b}{K_{s,cf_2}}$	$\frac{v_s^a + v_s^b}{K_s}$	$\frac{v_s^c}{K_s}$	t_s^c	r_{s,cf_1}^c	r_{s,cf_2}^c	r_{s,cf_3}^c	r_{s,cf_4}^c	$u_s^{cf_1}$	$u_s^{cf_2}$	$u_s^{cf_3}$	$u_s^{cf_4}$	$\frac{r_{s,cf_1}^c}{u_s^{cf_1}}$	$\frac{r_{s,cf_2}^c}{u_s^{cf_2}}$	$\frac{r_{s,cf_3}^c}{u_s^{cf_3}}$	$\frac{r_{s,cf_4}^c}{u_s^{cf_4}}$
auto equil.-veh/hr					min	min	min	min	min	min	min	min	min	%	%	%	%
0	~	0.17	~	0.17	5	~	0.833	~	0.002	~	5.833	~	5.002	~	14.3	~	0.0
560	1.00	0.17	1.00	0.17	5	7.500	0.833	4.000	0.002	12.500	5.833	9.000	5.002	60.0	14.3	44.4	0.0
1000	0.56	0.17	0.56	0.17	5	4.200	0.833	1.254	0.002	9.200	5.833	6.254	5.002	45.7	14.3	20.1	0.0
1500	0.37	0.17	0.37	0.17	5	2.800	0.833	0.558	0.002	7.800	5.833	5.558	5.002	35.9	14.3	10.0	0.0
2000	0.28	0.17	0.28	0.17	5	2.100	0.833	0.314	0.002	7.100	5.833	5.314	5.002	29.6	14.3	5.9	0.0
2500	0.22	0.17	0.22	0.17	5	1.680	0.833	0.201	0.002	6.680	5.833	5.201	5.002	25.2	14.3	3.9	0.0
3000	0.19	0.17	0.19	0.17	5	1.400	0.833	0.139	0.002	6.400	5.833	5.139	5.002	21.9	14.3	2.7	0.0
3500	0.16	0.17	0.16	0.17	5	1.200	0.833	0.102	0.002	6.200	5.833	5.102	5.002	19.4	14.3	2.0	0.0
4000	0.14	0.17	0.14	0.17	5	1.050	0.833	0.078	0.002	6.050	5.833	5.078	5.002	17.4	14.3	1.5	0.0
4500	0.12	0.17	0.12	0.17	5	0.933	0.833	0.062	0.002	5.933	5.833	5.062	5.002	15.7	14.3	1.2	0.0
5000	0.11	0.17	0.11	0.17	5	0.840	0.833	0.050	0.002	5.840	5.833	5.050	5.002	14.4	14.3	1.0	0.0
7000	0.08	0.17	0.08	0.17	5	0.600	0.833	0.026	0.002	5.600	5.833	5.026	5.002	10.7	14.3	0.5	0.0
9000	0.06	0.17	0.06	0.17	5	0.467	0.833	0.016	0.002	5.467	5.833	5.016	5.002	8.5	14.3	0.3	0.0
12000	0.05	0.17	0.05	0.17	5	0.350	0.833	0.009	0.002	5.350	5.833	5.009	5.002	6.5	14.3	0.2	0.0

The final set of data, displayed in Table 6.12, show how risk values change with the link length. Here, all risk values change with changes in link length. The relationship of link length to the other variables in these equations is linear. Therefore changes in length cause linear changes in risk, but the rate of change (or the slope) is different depending on the type of cycling facility. These relationships can be clearly seen in Figure 6.5. For the given values of flows and capacities (which result in similar flow-capacity flows), at any link length, the highest risk is associated with a link with no cycling facilities, followed by shared-use lane lanes, kerbside cycle lanes and finally segregated paths. For these values, these cycling facilities account for 21.88, 14.29, 2.71 and 0.03% of total link disutility. Changing a flow or capacity value will result in different proportions of disutility and these changes in proportions are not linearly related, as can be seen when looking at the percentages of disutility presented in the other parts of Tables 6.8 to 6.11.

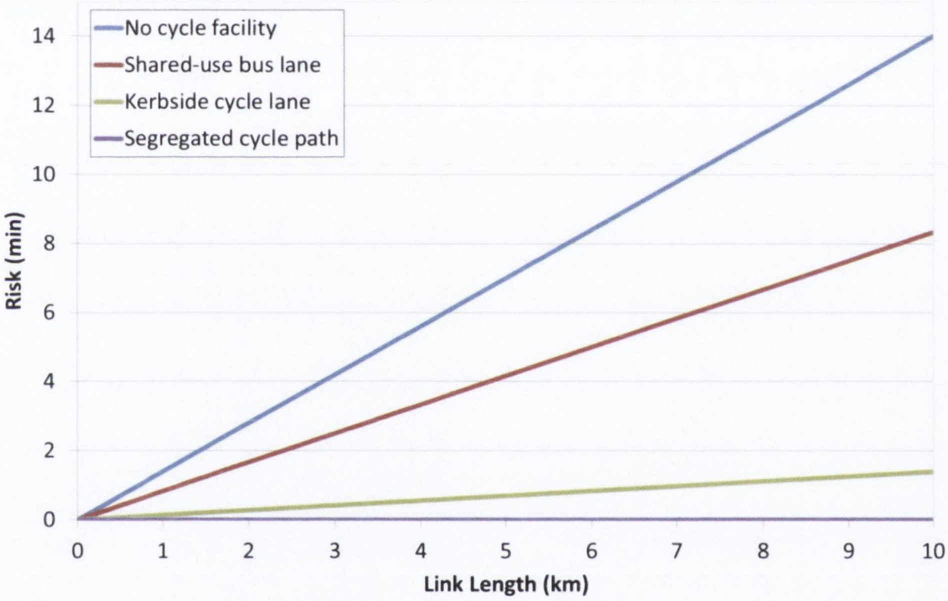


Figure 6.5 Relationship between risk and link length for 4 types of cycling facility.

Table 6.12 Demonstration of the use of the proposed risk equations for changes in link length.

Link length	Flow-Capacity ratios				Travel time	Link risk exposure				Link disutility				Percentage Of Disutility			
Γ_s	$\frac{v_s^a + v_s^b}{K_s}$	$\frac{v_s^b}{K_{s,cf_2}}$	$\frac{v_s^a + v_s^b}{K_s}$	$\frac{v_s^c}{K_s}$	t_s^c	r_{s,cf_1}^c	r_{s,cf_2}^c	r_{s,cf_3}^c	r_{s,cf_4}^c	$u_s^{cf_1}$	$u_s^{cf_2}$	$u_s^{cf_3}$	$u_s^{cf_4}$	$\frac{r_{s,cf_1}^c}{u_s^{cf_1}}$	$\frac{r_{s,cf_2}^c}{u_s^{cf_2}}$	$\frac{r_{s,cf_3}^c}{u_s^{cf_3}}$	$\frac{r_{s,cf_4}^c}{u_s^{cf_4}}$
km					min	min	min	min	min	min	min	min	Min	%	%	%	%
0	0.19	0.17	0.19	0.17	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	~	~	~	~
1	0.19	0.17	0.19	0.17	5	1.400	0.833	0.139	0.002	6.400	5.833	5.139	5.002	21.9	14.3	2.7	0.0
2	0.19	0.17	0.19	0.17	10	2.800	1.667	0.279	0.003	12.800	11.667	10.279	10.003	21.9	14.3	2.7	0.0
3	0.19	0.17	0.19	0.17	15	4.200	2.500	0.418	0.005	19.200	17.500	15.418	15.005	21.9	14.3	2.7	0.0
4	0.19	0.17	0.19	0.17	20	5.600	3.333	0.558	0.006	25.600	23.333	20.558	20.006	21.9	14.3	2.7	0.0
5	0.19	0.17	0.19	0.17	25	7.000	4.167	0.697	0.008	32.000	29.167	25.697	25.008	21.9	14.3	2.7	0.0
6	0.19	0.17	0.19	0.17	30	8.400	5.000	0.836	0.009	38.400	35.000	30.836	30.009	21.9	14.3	2.7	0.0
7	0.19	0.17	0.19	0.17	35	9.800	5.833	0.976	0.011	44.800	40.833	35.976	35.011	21.9	14.3	2.7	0.0
8	0.19	0.17	0.19	0.17	40	11.200	6.667	1.115	0.012	51.200	46.667	41.115	40.012	21.9	14.3	2.7	0.0
9	0.19	0.17	0.19	0.17	45	12.600	7.500	1.254	0.014	57.600	52.500	46.254	45.014	21.9	14.3	2.7	0.0
10	0.19	0.17	0.19	0.17	50	14.000	8.333	1.394	0.015	64.000	58.333	51.394	50.015	21.9	14.3	2.7	0.0

In summary of the results presented above, it is seen that

- As flow approaches link capacity, the value of risk exposure is much larger than for the risk exposure on other facilities (for the values given);
- As bus flows approach shared-use bus lane capacity, the risk associated with the use of shared-use bus lanes exceeds that of other cycle facilities (for the values given);
- The flow-capacity ratio associated with segregated cycle paths must exceed 0.5 before it becomes higher risk than any other cycle facilities (for the values given);
- If link capacities are small, the risk associated with no cycle facilities and kerbside cycle lanes are larger than that of shared-use bus lanes (for the values given);
- For the reasonable flows and capacity values presented here, the values for risk represent the order of cycle facility preference according to the responses to question 13 of the survey presented in Chapter 4;
- For the given parameter values in Table 6.6, the maximum contribution of risk to disutility for no cycle facility, shared-use bus lane, kerbside cycle lane and segregated cycle path are 60%, 50%, 44.4% and 28.57% respectively;
- The risk value for a kerbside cycle lane will always be lower than that of no cycle facilities as they both depend on the same flow-capacity ratio (for networks working below or at capacity);
- When the capacity value used in the calculation of the flow-capacity ratio is zero, no risk value for that cycle facility can be calculated; essentially that facility does not exist.

6.4. NETWORK EXAMPLES

In order to demonstrate how the risk exposure equations can be applied both in a simple bicycle only assignment model, and in a multi-modal mode choice and assignment model, this section presents two examples. The first example is for a multimodal network which assigns only bicycles to a network in the presence of known autos and buses flows and where bicycle demand is fixed. The second example is a multimodal network with auto, bus and bicycle modes, where travellers can choose between the available modes but can also choose not to travel i.e. the network demand is elastic. The next subsections present each of the models and their results. The networks used in these examples have been based upon similar network examples found in literature relating to trip assignment modelling (Li et al., 2014). It is noted, as is normal for similar models, that these trip assignment models consider ‘peak-hour’ traffic situations i.e. the purpose of these trip assignment models is to be able to describe the situation during the worst-case traffic scenario. This 'peak-hour' traffic is generally taken to occur during morning rush-hour traffic (between 07:00 and 10:00).

6.4.1. Single-Mode, Route Choice Only Example

In this section, a worked example of a trip assignment model using the proposed equations for risk is presented. This model assigns only cyclists, based on known flows of autos and buses. The travel demand for cyclists is also known. Cyclists are assigned assuming they do not have perfect network information i.e. using SUE as described in section 6.1.1.

The travel disutility for bicycles in this network is calculated as the sum of the route travel time and route risk (in time units).

$$u_p^c = T_p^c + R_p^c, \forall p \in P_w^c, w \in W \qquad \textbf{Eq. (6.33)}$$

where u_p^c is the travel disutility by bicycle on route p, measured in time units.

The travel time T_p^c by bicycle on route p is the sum of link travel times along that route

$$T_p^c = \sum_{s \in S_c} t_s^c \delta_{sp}, \forall p \in P_w^c, w \in W \qquad \textbf{Eq. (6.34)}$$

The travel time t_s^c by bicycle on link s is calculated as link length Γ_s divided by average cycling speed $\overline{V}^c$

$$t_s^c = \frac{\Gamma_s}{\overline{V}_s^c}, \forall s \in S_c \qquad \textbf{Eq. (6.35)}$$

The risk R_p^c of cycling on route p is the sum of the risk on each link along that route

$$R_p^c = \sum_{s \in S_c} r_{s,cf_i}^c \delta_{sp}, \forall p \in P_w^c, w \in W \qquad \textbf{Eq. (6.36)}$$

where $i = 1,2,3,4$ represents the type of cycling facilities on the link as no cycling facility, shared-use bus lane, kerbside cycle lane and segregated cycle path respectively. The risk equations for each of these facilities were developed within section 6.3.1, but are restated here for completeness.

$$r_{s,cf_1}^c = t_s^c \left[r^{c,0} + \rho_{cf_1} \left(\frac{v_s^a + v_s^b}{K_s} \right)^{\beta_{cf_1}} \right] \qquad \textbf{Eq. (6.37)}$$

$$r^c_{s,cf_2} = t^c_s \left[r^{c,0} + \rho_{cf_2} \left(\frac{v^b_s}{K_{s,cf_2}} \right)^{\beta_{cf2}} \right] \qquad \textbf{Eq. (6.38)}$$

$$r^c_{s,cf_3} = t^c_s \left[r^{c,0} + \rho_{cf_3} \left(\frac{v^a_s + v^b_s}{K_s} \right)^{\beta_{cf3}} \right] \qquad \textbf{Eq. (6.39)}$$

$$r^c_{s,cf_4} = t^c_s \left[r^{c,0} + \rho_{cf_4} \left(\frac{v^c_s}{K_{s,cf_4}} \right)^{\beta_{cf4}} \right] \qquad \textbf{Eq. (6.40)}$$

where r^c_{s,cf_i} is the risk (measured in time units) associated with cycling on cycle facility cf_i on link s, $r^{c,0}$ is the baseline risk, v^a_s, v^b_s and v^c_s are the flows of autos, buses and bicycle on link s, K_s is the capacity of link s, K_{s,cf_2} is the capacity of the bus lane on link s, K_{s,cf_4} is the capacity of the segregated path on link s and ρ_{cf_i}, β_{cf_i} are parameters.

Figure 6.6 displays the network used in this example. It is made up of 12 links, connecting 9 nodes, for travel between 2 OD pairs (nodes 1 to 9 and 5 to 9). Links 1, 3, 9 and 10 have segregated cycle paths; links 5, 6 and 12 contain kerbside cycle lanes; links 2 and 7 have bus lanes; and links 4, 8 and 11 have no cycle facilities. Trips between OD pair (1,9) are greater in distance than trips between OD pair (5,9). Table 6.13 lists all possible routes for this network and Table 6.14 gives the link length, relevant capacities, auto and bus flows for each link. The demands for OD pairs (1,9) and (5,9) are each 3,000 bicycle/hr. The average speed of bicycles is taken to be 12 km/hr. Other network parameter values are: σ=4, ρ_{cf_1}=1.5, ρ_{cf_2}=1, ρ_{cf_3}=0.8, ρ_{cf_4}=0.4, β_{cf_1}=1.0, β_{cf_2}=1.0, β_{cf_3}=2.0, β_{cf_4}=4.0 and $r^{c,0}$=0.

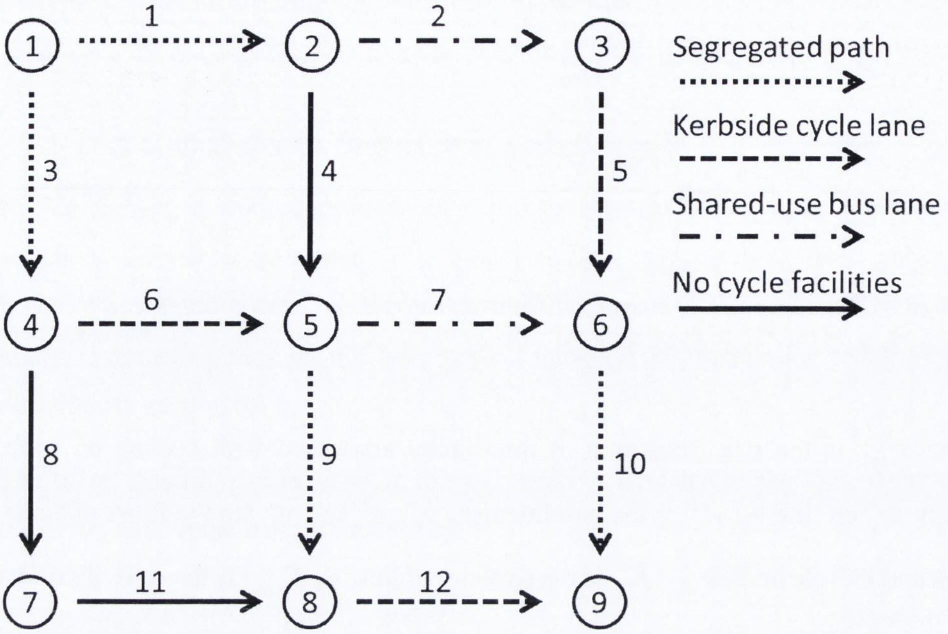


Figure 6.6 Cycling network map.

Table 6.13 Possible bicycle routes.

OD pair	Route No	Links
(1,9)	1	1,2,5,10
(1,9)	2	1,4,7,10
(1,9)	3	1,4,9,12
(1,9)	4	3,6,7,10
(1,9)	5	3,6,9,12
(1,9)	6	3,8,11,12
(5,9)	7	7,10
(5,9)	8	9,12

Table 6.14 Known variable values for route choice only model.

	Cycling facility type cf_i	Link length Γ	Link capacity K_s	Bus lane capacity K_{s,cf_2}	Segregated path capacity K_{s,cf_4}	Auto flow v_s^a	Bus flow v_s^b
1	4	5	~	~	6000	~	~
2	2	4	~	60	~	~	10
3	4	4	~	~	6000	~	~
4	1	3	3000	~	~	800	0
5	3	4	3000	~	~	600	15
6	3	6	3000	~	~	500	15
7	2	4	~	90	~	~	15
8	1	5	3000	~	~	600	12
9	3	5	~	~	6000	~	~
10	4	5	~	~	6000	~	~
11	1	3	3000	~	~	1200	12
12	3	6	3000	~	~	1500	12

The model was run in 'Risk Solver' (FrontlineSolvers, 2014) using an Intel® Core™ i3-2120 CPU at 3.30GHz and 8GB of RAM. The gap function converged (from an empty (zero flow) network) to 4.68×10^{-16}, after a single iteration, taking 0.01 seconds. The resulting link and route flows are presented in Tables 6.15 and 6.16.

From the link based results in Table 6.15, it can be seen that generally, the lowest risk facilities are the segregated paths and the highest risk are links with no cycle facilities. However, link 12, which has a shared-use bus lane, does in fact show a higher risk value than that of link 4, which has no cycling facility. This is due in part to the longer length of link 12 (6km) compared to link 4 (3km); this relates the desired effects of risk exposure within the proposed assignment model. This is also due in part to the flow-capacity ratios involved; this ratio for link 12 is 0.52 and for link 4 is 0.27, reflecting the effect the desired effect of the proposed equations to consider both the preference for various types of cycling facility, but also consider the effects of the volumes of other relevant modes.

Table 6.15 Link flow, travel time and risk results for the route choice only trip assignment model.

Link No.	Flow v_s^c	Travel time t_s^c	Risk r_{s,cf_i}^c
1	1525	0.417	0.001
2	516	0.333	0.056
3	1475	0.333	0.000
4	1009	0.250	0.100
5	516	0.333	0.013
6	993	0.500	0.014
7	2554	0.333	0.056
8	482	0.333	0.108
9	2449	0.417	0.005
10	3070	0.417	0.011
11	482	0.333	0.208
12	2930	0.500	0.107

Table 6.16 displays the results for the network in terms of route flows and disutility. It can be seen that the lowest disutility for OD pair (1,9) occurs on routes 1 and 2, with route 6 having the highest disutility. Table 6.17 contains the details of these three routes to allow comparison of their details. Despite route 6 being the same length as route 1, it presents has a higher disutility value due to the small amount of time/distance spent on lower risk cycling facilities and greater amount on higher risk facilities. Routes 1 and 2 result in similar disutility values; although travel time on route 2 is less than that on route 1, route 2 does have a higher disutility than route 1. As both routes use links 1 and 10, and links 2 and 7 are both shared-use bus lanes of the same length the differences in this disutility values for routes 1 and 2 arise in the

differences in links 4 and 5; link 4 is a link with no cycling facility, 3 km in length, while link 5 has a kerbside cycle lane and is 4 km in length. Although a link with no cycling facilities is less preferable under similar flow-capacity conditions and equal distance, the higher flow-capacity ratio and greater distance were sufficient to increase the risk associated with route 1 above that of route 2.

Table 6.16 Route flow, travel time, risk and disutility results for the route choice only trip assignment model.

Route No.	Flow h_p^c	Travel time T_p^c	Risk R_p^c	Disutility u_p^c
1	516	1.500	0.081	1.581
2	515	1.417	0.168	1.584
3	494	1.583	0.212	1.795
4	507	1.583	0.081	1.665
5	486	1.750	0.126	1.876
6	482	1.500	0.423	1.923
7	1532	0.750	0.067	0.817
8	1468	0.917	0.111	1.028

Table 6.17 Comparison of routes 1, 2 and 6.

Route No	% of OD flow	Distance on each type of cycling facility				Total distance	Travel time	Risk	Flow-capacity ratio	Disutility
		cf_1	cf_2	cf_3	cf_4		T_p^c	R_p^c		u_p^c
1	17.19	0	4	4	10	18	1.500	0.081	0.27	1.581
2	17.18	3	0	4	10	17	1.417	0.168	0.22	1.584
6	16.05	8	6	0	4	18	1.500	0.423	0.52	1.923

In order to confirm that the trip assignment model which includes risk attributes displays different behaviour to that of the trip assignment model considering travel time only, the model was rerun for the same network where disutility is equal to travel time only i.e. the shortest-path method. Table 6.18 shows the flows and disutility values for disutility equal to travel time only and for disutility equal to the sum of travel time and risk. It can be seen from the resulting flows, the modelled behaviour of travellers is different according to the definition of disutility. The final two columns of Table 6.18 arrange the route numbers for each model from smallest to largest values of disutility; showing that there has been a change in which route will be used by more of the cyclists in the network. In order to ensure that these equations correctly model this behaviour associated with risk, the proposed risk equations require calibration against observed cyclist route choice data, but this confirms that the proposed equations are capable of capturing behaviour different to the shortest-path method.

Table 6.18 Comparison of route flows for different definitions of disutility.

	$u_p^c = T_p^c$			$u_p^c = T_p^c + R_p^c$				
	h_p^c	% of OD flow	u_p^c	h_p^c	% of OD flow	u_p^c	$u_p^c = T_p^c$	$u_p^c = T_p^c + R_p^c$
OD pair (1,9)								
1	505	16.8	1.500	516	17.2	1.581	**2**	**1**
2	514	17.1	1.417	515	17.2	1.584	**1**	**2**
3	497	16.6	1.583	494	16.5	1.795	**6**	**4**
4	497	16.6	1.583	507	16.9	1.665	**3**	**3**
5	481	16.0	1.750	486	16.2	1.876	**4**	**5**
6	505	16.8	1.500	482	16.1	1.923	**5**	**6**
OD pair (5,9)								
7	1525	50.8	0.750	1532	51.1	0.817	**7**	**7**
8	1475	49.2	0.917	1468	48.9	1.028	**8**	**8**

6.4.2. Assumptions and Formulation of the Multimodal, Mode and Route Choice Example

This section presents a worked example of a multi-modal, mode and route choice, trip assignment model using the proposed equations for the risk. The network is modelled by dividing a multi-modal network into uni-modal sub-networks for each mode. There are three modes by which travellers can complete their trips: auto, bus or bicycle. For clarity, assumptions made by this model are stated below.

A It is assumed that travellers will decide on their mode of travel before deciding on which route to take.

B All travellers are assumed to have the same value of time and perception of disutility.

C The effect of congestion due to the interaction of modes is considered in the model. Auto and bus flows only are considered in congestion interaction. The only case within the model where there is no congestion interaction is when a segregated cycle path is present.

D To represent the response of travellers to network conditions, i.e. deciding not to make a trip, an elastic demand function is used (Zhou et al., 2005, Li et al., 2008).

E Bus traveller discomfort is modelled used a discomfort cost function (Lo et al., 2003, Li et al., 2011, Li et al., 2009b).

In accordance with assumption **A**, where a hierarchical structure implies that travellers will first choose their mode before deciding which route to take, the logit-based mode choice model defines the travel demand of mode m between OD pair w as:

$$q_w^m = q_w \frac{\exp(-\theta_2 \lambda_w^m)}{\sum_{m\in\{a,b,c\}} \exp(-\theta_2 \lambda_w^m)}, \forall m \in \{a,b,c\}, w \in W \qquad \textbf{Eq. (6.41)}$$

where expected travel disutility λ_w^m between OD pair w for mode m is expressed as (Ben-Akiva and Lerman, 1985):

$$\lambda_w^m = -\frac{1}{\theta_1} \ln\left(\sum_{p\in P_w^m} \exp\left(-\theta_1 u_w^m\right) \right), \forall m \in \{a,b,c\}, w \in W \qquad \textbf{Eq. (6.42)}$$

The expected travel disutility λ_w between OR pair w is calculated as (Ben-Akiva and Lerman, 1985):

$$\lambda_w = -\frac{1}{\theta_2} \ln\left(\sum_{m\in\{a,b,c\}} \exp\left(-\theta_2 \lambda_w^m\right) \right), w \in W \qquad \textbf{Eq. (6.43)}$$

The logit-based route choice equilibrium problem (SUE based assignment) (Sheffi, 1985) is given by:

$$h_w^m = q_w^m \frac{\exp(-\theta_1 u_p^m)}{\sum_{p\in P_w^m} \exp(-\theta_1 u_p^m)}, \forall m \in \{a,b,c\}, p \in P_w^m, w \in W \qquad \textbf{Eq. (6.44)}$$

To reflect the sensitivities of traffic conditions on a traveller's choice to decide whether or not to travel, demand is considered to be elastic. The total demand q_w between OR pair w is defined as:

$$q_w = q_w^0 \exp(-\eta \lambda_w), \forall w \in W \qquad \textbf{Eq. (6.45)}$$

where q_w^0 is the potential network demand (Li et al., 2014).

This network can be solved using the NCP formulation for SUE described in section 6.1.3., with the gap function described section 6.1.4. Below the travel disutility and all components of that disutility for each mode is defined.

Below the travel disutilities for each of the travel modes is defined. The auto and bus disutilities are based on the definitions of auto and bus disutilities used by (Li et al., 2014) modified to fit the purposes of this research.

<u>*Travel disutility for autos*</u>

The travel disutility for autos consists of in-vehicle travel time, access and egress walking time and monetary travel cost.

$$u_p^a = \alpha_t T_p^a + \alpha_z Z_p^a + \Lambda_p^a, \forall p \in P_w^a, w \in W \qquad \textbf{Eq. (6.46)}$$

where u_p^a is the travel disutility by auto on route p, measured in money units, Z_p^a is the walking time and Λ_p^a is the monetary costs (parking costs etc) associated with auto mode. α_t and α_z are the values of travel time and walking time respectively.

The in-vehicle travel time T_p^a by auto on route p is the sum of link travel times along that route:

$$T_p^a = \sum_{s \in S_a} t_s^a \delta_{sp}, \forall p \in P_w^a, w \in W \qquad \textbf{Eq. (6.47)}$$

The in-vehicle travel time $t_s^a(v_s^a, v_s^b)$ by auto on link s is affected by both the auto and bus volumes on the link. It is given by the BPR function (U.S. Department of Commerce and Bureau of Public Roads, 1964):

$$t_s^b = \frac{\Gamma_s}{\overline{V}_s^a}\left[1 + \rho_1 \left(\frac{v_s^a + v_s^b}{K_s}\right)^{\beta_1}\right], \forall s \in S_a \qquad \textbf{Eq. (6.48)}$$

where v_s^b will be defined later and

$$v_s^a = \sum_{w \in W} \sum_{p \in P_w^a} h_p^a \delta_{sp}, \forall s \in S_a \qquad \textbf{Eq. (6.49)}$$

<u>*Travel disutility for bus*</u>

The travel disutility for buses consists of in-vehicle travel time, access and egress walking time, waiting times at bus stops, in-vehicle crowding discomfort and monetary travel cost (bus fare).

$$u_p^b = \alpha_t T_p^b + \alpha_z Z_p^b + \alpha_w W_p^b + \alpha_g g_p^b + \Lambda_p^b, \forall p \in P_w^b, w \in W \qquad \textbf{Eq. (6.50)}$$

where u_p^b is the travel disutility by bus on route p, measured in money units, Z_p^b is the walking time and Λ_p^b is the monetary costs (bus fair) associated with bus mode. α_w and α_g are the values of waiting time and crowding discomfort respectively.

The in-vehicle travel time T_p^b by bus on route p is the sum of link travel times along that route:

$$T_p^b = \sum_{s \in S_b} t_s^b \delta_{sp}, \forall p \in P_w^b, w \in W \qquad \textbf{Eq. (6.51)}$$

The in-vehicle travel time $t_s^b(v_s^a, v_s^b)$ by bus on link s is affected by both the auto and bus volumes on the link. It is given by the BPR function (U.S. Department of Commerce and Bureau of Public Roads, 1964):

$$t_s^b = \frac{\Gamma_s}{\overline{V}_s^b}\left[1+\rho_1\left(\frac{v_s^a+v_s^b}{K_s}\right)^{\beta_1}\right], \forall s \in S_{b1} \qquad \textbf{Eq. (6.52)}$$

where $v_s^b = \sigma F_s^b, \forall s \in S_{b1}$. **Eq. (6.53)**

The bus frequency F_b^s on link s is the sum of the service frequencies of all attractive lines on link s:

$$F_s^b = \sum_{l\in\Theta_s} F_l^b, \forall s \in S_b \qquad \textbf{Eq. (6.54)}$$

The average waiting time W_p^b of passengers on route p is the sum of average waiting time of passengers on all links along that route:

$$W_p^b = \sum_{s\in S_{b2}} W_s^b \delta_{sp}, \forall p \in P_w^b, w \in W \qquad \textbf{Eq. (6.55)}$$

The average waiting time W_s^b of passengers on link s is:

$$W_s^b = \frac{\gamma}{F_s^b}, \forall s \in S_{b2} \qquad \textbf{Eq. (6.56)}$$

where $\gamma = 0.5$ implies a uniform random passenger arrival distribution and a constant bus headway (Lam and Morrall, 1982).

The in-vehicle crowding discomfort g_p^b on route p is calculated as:

$$g_p^b = \sum_{l\in L}\sum_{s\in S_{b1}} g_{ls}^b \delta_{sp}^l, \forall p \in P_w^b, w \in W \qquad \textbf{Eq. (6.57)}$$

where in-vehicle crowding discomfort g_{ls}^b of travelling on line l on link s is calculated as (Li et al., 2009b, Li et al., 2014, Lo et al., 2003):

$$g_{ls}^b = t_s^b\left[g_{ls}^{b,0}+\rho_2\left(\frac{x_{ls}^b}{K_l}\right)^{\beta_2}\right], \forall l \in L, s \in S_{b1} \qquad \textbf{Eq. (6.58)}$$

where $K_l = \kappa_l F_l^b, \forall l \in L$. **Eq. (6.59)**

The bus passenger flow x_{ls}^b of line l on link s is expressed as:

$$x_{ls}^{b} = \sum_{w \in W} \sum_{p \in P_w^b} h_p^b \delta_{sp}^l, \forall l \in L, s \in S_{b1}$$ **Eq. (6.60)**

Travel disutility for bicycles

The travel disutility for bicycles consists of travel time and cyclist risk exposure costs.

$$u_p^c = \alpha_t T_p^c + \alpha_r R_p^c, \forall p \in P_w^c, w \in W$$ **Eq. (6.61)**

where u_p^c is the travel disutility by bicycle on route p, measured in money units and α_r is the value of risk; this value allows the risk value to be converted from time units to monetary units for inclusion within the disutility equation.

The in-vehicle travel time T_p^c by bicycle on route p is the sum of link travel times along that route:

$$T_p^c = \sum_{s \in S_c} t_s^c \delta_{sp}, \forall p \in P_w^c, w \in W$$ **Eq. (6.62)**

The in-vehicle travel time t_s^c by auto on link s is calculated as:

$$t_s^c = \frac{\Gamma_s}{\overline{V}_s^c}, \forall s \in S_c$$ **Eq. (6.63)**

The risk R_p^c of cycling on route p is the sum of link risks along that route:

$$R_p^c = \sum_{s \in S_c} r_{s,cf_i}^c \delta_{sp}, \forall p \in P_w^c, w \in W$$ **Eq. (6.64)**

where $i = 1, 2, 3, 4$ represents the type of cycling facilities on a link as no cycling facility, shared-use bus lane, kerbside cycle lane and segregated path respectively. The risk associated with cycling on a link is the same as that developed in section 6.3.1 of this thesis.

The risk associated with cycling on a link with no cycle facility is formulated as:

$$r_{s,cf_1}^c = t_s^c \left[r^{c,0} + \rho_{cf_1} \left(\frac{v_s^a + v_s^b}{K_s} \right)^{\beta_{cf_1}} \right]$$ **Eq. (6.65)**

where r_{s,cf_1}^c is the risk (measured in time units) associated with cycling on cycle facility cf_1 on link s, $r^{c,0}$ is the baseline risk, t_s^c is the travel time for cycling on link s, v_s^a and v_s^a are the flows of autos and buses on link s, K_s is the capacity of link s and $\rho_{cf_1}, \beta_{cf_1}$ are parameters.

The risk associated with cycling on a shared-use bus lane is formulated as:

$$r_{s,cf_2}^{c} = t_s^c \left[r^{c,0} + \rho_{cf_2} \left(\frac{v_s^b}{K_{s,cf_2}} \right)^{\beta_{cf_2}} \right] \qquad \textbf{Eq. (6.66)}$$

where r_{s,cf_2}^{c} is the risk associated with cycling on cycle facility cf_2 on link s, K_{s,cf_2} is the capacity of the bus lane on link s and $\rho_{cf_2}, \beta_{cf_2}$ are parameters.

The risk associated with cycling on a kerbside cycle lane is formulated as:

$$r_{s,cf_3}^{c} = t_s^c \left[r^{c,0} + \rho_{cf_3} \left(\frac{v_s^a + v_s^b}{K_s} \right)^{\beta_{cf_3}} \right] \qquad \textbf{Eq. (6.67)}$$

where r_{s,cf_3}^{c} is the risk associated with cycling on cycle facility cf_3 on link s, and $\rho_{cf_2}, \beta_{cf_2}$ are parameters.

The risk associated with cycling on a segregated cycle path is:

$$r_{s,cf_4}^{c} = t_s^c \left[r^{c,0} + \rho_{cf_4} \left(\frac{v_s^c}{K_{s,cf_4}} \right)^{\beta_{cf_4}} \right] \qquad \textbf{Eq. (6.68)}$$

where r_{s,cf_4}^{c} is the risk associated with cycling on cycle facility cf_4 on link s, v_s^c is the flow of bicycles on link s and K_{s,cf_4} is the capacity of the segregated path on link s.

6.4.3. Input Data for Multimodal, Mode and Route Choice Example

The multi-modal network used in this example is shown Figure 6.7. It is made up of 12 links, connecting 9 nodes, for travel between 2 OD pairs (nodes 1 to 9 and 5 to 9). Trips between OD pair (1,9) are greater in distance than trips between OD pair (5,9). Travellers can complete their journeys by auto, bus or bicycle.

The network of cycle facilities is shown in Figure 6.8 for this model. Links 1, 3, 9 and 10 have segregated cycle paths; links 5, 6 and 12 contain kerbside cycle lanes; links 2 and 7 have bus lanes; and links 4, 8 and 11 have no cycle facilities. Tables 6.19 to 6.21 show the routes by each mode in terms of the links they follow; and for bus mode the lines used and wait links (expressed by the node in which a transfer is made) are given. Both auto and bicycle can use all links in the network, but buses may not use links 4, 8 and 11. There are also 4 bus lines operating on this network. L1 and L2 operate between OD pair (1,9) and L3 and L4 operate between OD pair (5,9). The nodes that each line run thru are as follows:

L1 $N_1 - N_2 - N_3 - N_6 - N_9$

L2 $N_1 - N_4 - N_5 - N_8 - N_9$

L3 $N_5 - N_6 - N_9$

L4 $N_5 - N_8 - N_9$

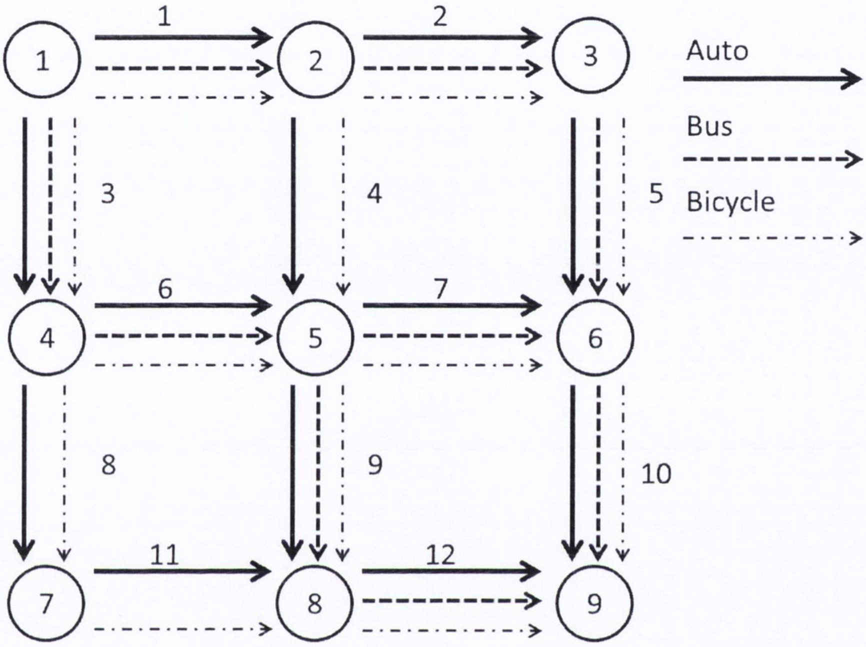


Figure 6.7 Links usage by auto, bus and bicycle modes.

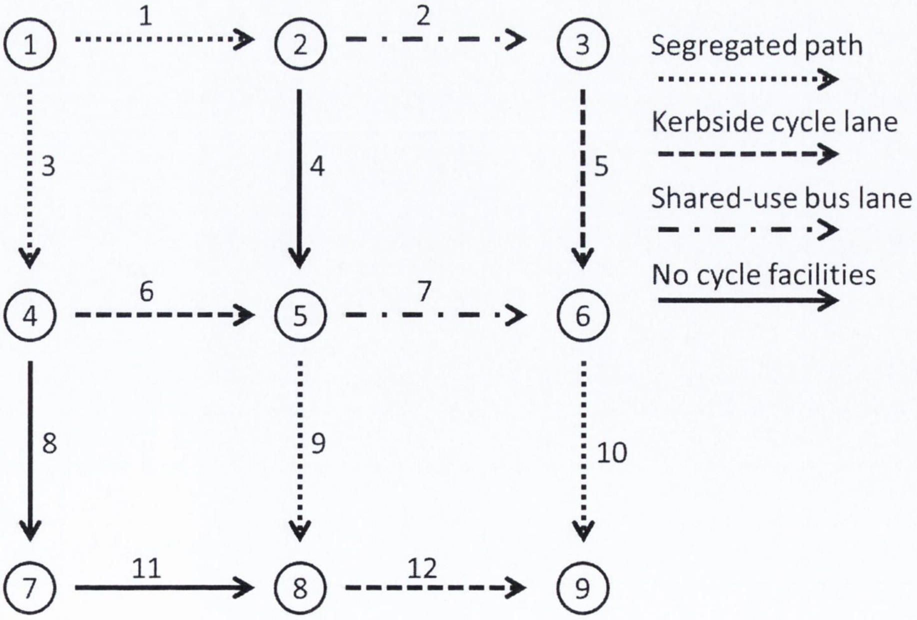


Figure 6.8 Cycle facilities on each network link.

Table 6.19 Auto routes for multi-modal trip assignment example.

OD pair	Route No	Links
(1,9)	1	1,2,5,10
(1,9)	2	1,4,7,10
(1,9)	3	1,4,9,12
(1,9)	4	3,6,7,10
(1,9)	5	3,6,9,12
(1,9)	6	3,8,11,12
(5,9)	7	7,10
(5,9)	8	9,12

Table 6.20 Bus routes for multi-modal trip assignment example.

OD pair	Route No	Lines & Links	Wait Links
(1,9)	1	**L1**(1,2,5,10)	N1, N9
(1,9)	2	**L2**(3,6,9,12)	N1, N9
(1,9)	3	**L1**(1,2,5), **L3**(10)	N1, N6, N9
(1,9)	4	**L2**(3,6,9), **L4**(12)	N1, N8, N9
(1,9)	5	**L2**(3,6), **L3**(7,10)	N1, N5, N9
(1,9)	6	**L2**(3,6), **L2**(9,12)	N1, N5, N9
(1,9)	7	**L2**(3,6), **L3**(7), **L1**(10)	N1, N5, N6, N9
(1,9)	8	**L2**(3,6), **L4**(9), **L2**(12)	N1, N5, N8, N9
(5,9)	9	**L3**(7,10)	N5, N9
(5,9)	10	**L2**(9,12)	N5, N9
(5,9)	11	**L4**(9,12)	N5, N9
(5,9)	12	**L3**(7), **L1**(10)	N5, N6, N9
(5,9)	13	**L2**(9), **L4**(12)	N5, N8, N9
(5,9)	14	**L4**(9), **L2**(12)	N5, N8, N9

Table 6.21 Bicycle routes for multi-modal trip assignment example.

OD pair	Route No	Links
(1,9)	1	1,2,5,10
(1,9)	2	1,4,7,10
(1,9)	3	1,4,9,12
(1,9)	4	3,6,7,10
(1,9)	5	3,6,9,12
(1,9)	6	3,8,11,12
(5,9)	7	7,10
(5,9)	8	9,12

The values chosen for link lengths and relevant link, shared-use bus lane and segregated cycle path capacities are presented in Table 6.22. Other input data and parameter values required were arbitrarily choosen as reasonable values (based on values which might be expected in a real-world network) as follows:

- Potential demand for each of the OD pairs (1,9) and (5,9) are each 10,000 persons/hr;
- Average speeds for auto, bus and bicycle are 45, 20 and 12 km/hr respectively;
- Bus fare is €3 between OD pair;
- Auto costs between OD pair (1,9) and (5,9) are €10 and €6 respectively;
- The bus service frequency for L1 and L3 are 15 buses/hr and for L2 and L4 are 20 buses/hr;
- Value of travel time is €10/hr[7];
- Value of waiting time is €20/hr[7];
- Value of in-vehicle crowding discomfort is €20/hr[7];
- Value of cyclist risk is €10/hr[7];
- Value of walking time is €20/hr[7];
- Walking time associated with auto and bus modes are 6 and 15 minutes respectively;
- Bus capacity is 120 passengers/bus;
- Factor to convert buses to equivalent auto vehicle units is 4.0 autos/bus.

The values for other model parameter are: $g_{ls}^{b,0}$=0.1, ρ_1=0.15, β_1=4.0, ρ_2=0.05, β_2 =2.0, ρ_{cf_1}=1.5, ρ_{cf_2}=1, ρ_{cf_3}=0.8, ρ_{cf_4}=0.4, β_{cf_1}=1.0, β_{cf_2}=1.0, β_{cf_3}=2.0, β_{cf_4}=4.0, $r^{c,0}$=0.2, θ_1=0.2, θ_2=0.2 and η=0.1.

---

[7] The values of travel time, waiting time, in-vehicle crowding discomfort, cyclist risk and walking risk are arbitrary values, but based on closely on established values used for these purposes.

Table 6.22 Link lengths and relevant link, shared-use bus lane and segregated cycle path capacities.

Link No.	Cycling facility type cf_i	Link length Γ km	Link capacity K_s auto- equil-vehicle/hr	Bus lane capacity K_{s,cf_2} bus/hr	Segregated path capacity K_{s,cf_4} bicycle/hr
1	4	3	5000	~	6000
2	2	6	3000	25	~
3	4	4	5000	~	6000
4	1	6	3000	~	~
5	3	3	3000	~	~
6	3	7	3000	~	~
7	2	5	3000	25	~
8	1	6	3000	~	~
9	3	5	3000	~	6000
10	4	5	5000	~	6000
11	1	4	3000	~	~
12	3	4	5000	~	~

6.4.4. Results of the Multimodal, Mode and Route Choice Example

This model was optimised suing 'Risk Solver' (FrontlineSolvers, 2014) on an Intel® Core™ i3-2120 CPU at 3.30GHz and 8GB of RAM. Figure 6.9 shows the change in the gap G as defined by Eq. (6.20)-(6.22). The gap function converges (from an empty (zero flow) network) to 1.02×10^{-8}, after 19 iterations, taking 0.05 seconds.

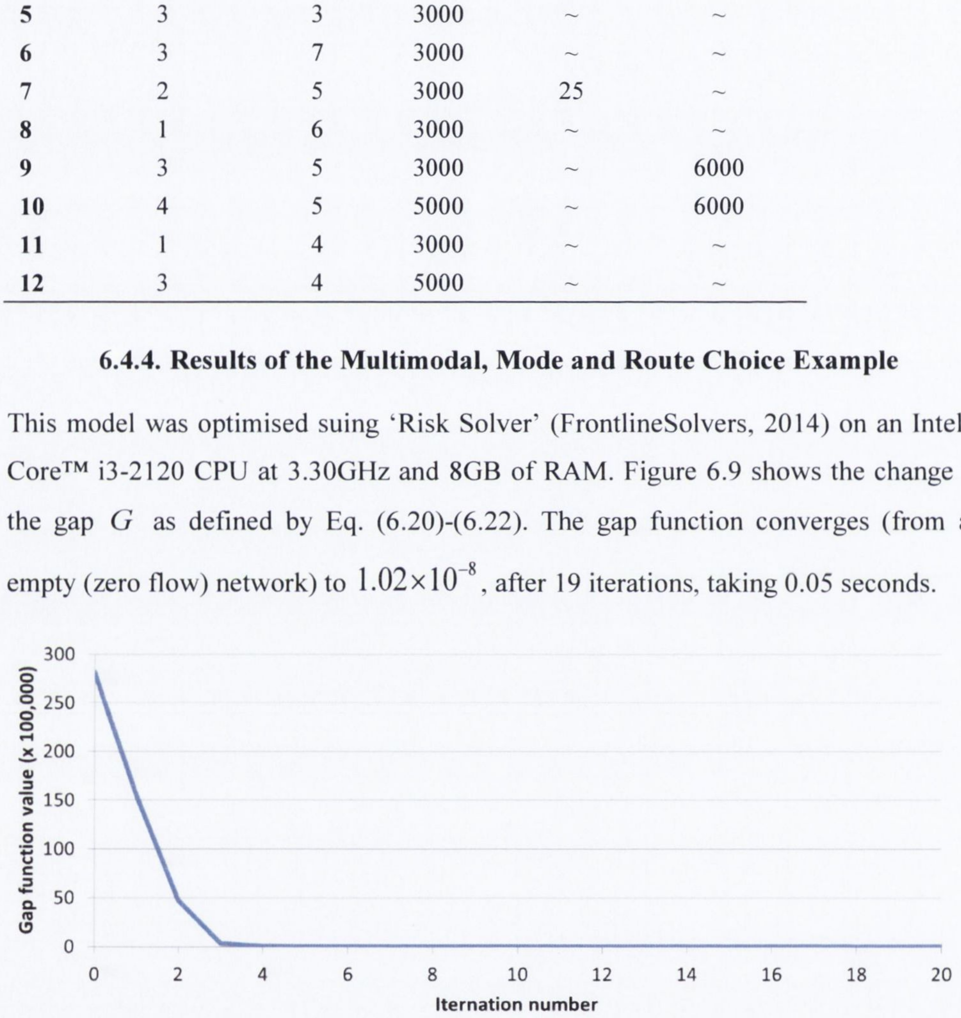


Figure 6.9 Converge on Gap function.

Table 6.23 presents the travel total demands for each OD pair and by travel mode. The resulting demands represent 70.3% and 94.6% of potential OD demand for OD pairs (1,9) and (5,9) respectively. It can be seen that bicycle mode shares in this network are smaller than for auto and bus modes and that auto mode share is larger than bus mode share for OD pair (1,9), it is smaller for OD pair (5,9). The mode share of bicycles for OD pair (1,9) is less than that of OD pair (5,9). This is related to the greater distances involved for OD pair (1,9), as it influences both travel time and risk to increase the overall disutility cost of cycling.

Table 6.23 Network demands from multi-modal model.

	OD pair			
	(1,9)		(5,9)	
OD travel demand	7033		9465	
Auto demand	3301	46.94%	2737	28.91%
Bus demand	2451	34.85%	4074	43.04%
Bicycle demand	1281	18.21%	2654	28.05%

Only information related to bicycle flows are presented here (Tables 6.24 and 6.25). The link and route flows, disutility and each component of disutility are given in Appendix III for each mode. Based on link flows it is difficult to make inferences about the network, as some links are part of more routes than others, but it can be seen from the values of risk that the proposed equations behave as anticipated.

Table 6.24 Bicycle mode link results from multimodal modal.

Link No.	**Type of cycling facility** cf_i	**Flow** v_s^c bicycle/hr	**Travel time** t_s^c hr	**Risk** r_s^c hr	**Flow-capacity ratio**
1	4	738	0.250	0.050	0.12
2	2	399	0.500	0.175	0.15
3	4	542	0.333	0.067	0.09
4	1	339	0.500	0.377	0.37
5	3	399	0.250	0.060	0.22
6	3	350	0.583	0.179	0.36
7	2	1583	0.417	0.146	0.15
8	1	193	0.500	0.244	0.19
9	4	1760	0.417	0.085	0.29
10	4	1982	0.417	0.085	0.33
11	1	193	0.333	0.163	0.19
12	3	1953	0.333	0.177	0.64

Table 6.25 Bicycle mode route results from multimodal modal

Route No.	**Flow** h_p^c person/hr	**Travel time** T_p^c hr	**Risk** R_p^c hr	**Disutility** u_p^c €	**% OD flow**
1	399	1.417	0.370	17.868	31.2%
2	161	1.583	0.658	22.415	12.5%
3	179	1.500	0.688	21.885	13.9%
4	166	1.750	0.477	22.265	12.9%
5	184	1.667	0.507	21.735	14.4%
6	193	1.500	0.651	21.505	15.1%
7	1257	0.833	0.231	10.645	47.3%
8	1398	0.750	0.261	10.114	52.7%

Link 8 had the highest risk value for this network at 0.24hr (or 14.6 minutes). This is despite having a relatively low flow-capacity ratio compared to other links; it is its longer length (6 km) and not having a cycle facility that result in this high value of risk. Link 1, on the other hand, has the lowest risk associated with it at 0.05hr or 3 minutes. This link is only 3 km in length and has a segregated cycle path, which contribute to the resulting low value.

For a link with no cycling facility to have the highest risk and a segregated path to have the lowest risk, reflects how the proposed risk equations consider the preference of cyclists to these types of facility; but there are also situations within the example that interrupt this order of preference due to the effects of distance and traffic volumes on risk values, as is also desired by this method. For example link 5, a link with a kerbside cycle lane, had a lower risk than both links 3 and 9, which both have segregated cycle paths. Although link 3 had a lower flow-capacity ratio than that of link 5, it was found to be a higher risk because its longer length was sufficient to outweigh the contribution of this lower flow-capacity ratio. For link 9, both a higher flow capacity ratio and longer link length contributed to why link 9 was found to be a higher risk than link 5.

It can also be seen in this network that link 11, despite having no cycling facility has a lower risk associated with it than links 2, 6 and 12, which have cycling facilities. Link 2 has a shared-use bus lane, while links 6 and 12 both have segregated paths. Even though links 2 and 6 have a shared-use bus lane and kerbside cycle lane respectively, they are both longer than link 11 and have higher flow-capacity ratios which prevent them from having lower risk values than link 11. Link 12, on the other hand, is the same length as link 11; it is therefore the large flow-capacity ratio of 0.64 which makes this link a higher risk than link 11.

Despite this large flow-capacity ratio of link 12, it is not found to be the highest risk. Both links 6 and 8 have higher risk values. This is because link 8 is a relatively long link (6km) with no cycle facility and because link 6, although having the same type of cycling facility, is much longer (7 km) than link 12 (4 km).

Looking at the routes in the network, it can be seen that for OD pair (1,9) route 1 has the lowest disutility cost (€17.87) and therefore carries the highest proportion of cyclists, 31.2% of OD demand for bicycles. While route 2, carrying 12.5% of bicycle OD demand and having a disutility cost of €22.42, is the least preferred route for OD pair (1,9). For these routes 1 and 2, risk accounts for 20% and 29%, respectively, of the disutility costs. In comparing the reasons behind these differences it that both of these routes use links 1 and 10, this higher proportion of risk associated with route 2 is due to 4 km travelled on link 4 with no facility and a further 5 km travelled on link 7 on a shared-use bus lane; whereas route 1 travels 6 km on link 2 with a shared-use bus lane and 3 km on link 5 with a kerbside cycle lane. These results again show that the proposed equations behave as anticipated.

The two possible routes for OD pair (5,9) are routes 7 and 8; they carry 47.3% and 52.7% of the bicycle demand for this OD pair. As link 10 on route 7 and link 9 on route 8 are both 4 km and both have segregated cycle paths with similar flows-capacity ratios they both have risk values of 0.09, therefore the differences in the disutility costs and hence proportions travelling on routes 7 and 8 arise due to differences in links 7 and 12. Although link 7 has a lower risk value than link 12, link 7 is 2 km longer than link 12 resulting in a larger travel time for link 7 and therefore a larger overall disutility cost for route 7. This result also confirms that travel time is a large consideration and that sacrifices are made in order to reduce the overall trip cost, again a characteristic desired from the method.

6.5. CONCLUSIONS

The research undertaken in this chapter aimed to improve upon trip assignment methods for cyclists. Generally, trip assignment models are not used for cyclists, but where they are they tend to fall short in modelling attributes of cyclists' route choices. The literature review in Chapter 2 outlines previous studies which have attempted to improve upon 'shortest-path' methods.

As safety/risk is a major consideration in choosing to cycle, and once a decision to cycle is made, on which route to cycle, this work aims to add to 'shortest-path' methods by including risk considerations. To do this, four equations are proposed; each describing the perceived risk associated with a cycling facility; segregated cycle paths, kerbside cycle lanes, shared-use bus lanes and where no cycle facility is provided. These equations reflect the order of preference of cyclists for these four types of cycling facility (listed above in order of most preferred to least preferred) as found by the survey of cyclists presented in Chapter 3. As well as this, these equations consider the effects of distance travelled (or time spent) on the cycle facility type and the traffic conditions effecting the cyclist while on the cycle facility.

The proposed equations are based on a BPR-type format. They therefore consider travel time, traffic flow and traffic capacity variables and each contain two parameters of differing magnitudes which reflect the cyclists' order of preference for the cycling facilities. The equations also differ from each other in the traffic flows and capacities they consider; for segregated cycle path the risk equation takes into account bicycle flow and the capacity of the segregated cycle path; for shared-use bus lanes the bus flow and capacity of the bus lane is used; while for kerbside cycle lanes and where no cycling facility is present auto and bus flows are included, with link capacity. This allows the risk values calculated from the proposed equations to deflect from the expected order of preference. This may occur should there be more favourable traffic conditions on a low preference facility to make it a lower risk option than adverse traffic conditions on a higher preference facility.

The examples provided in this chapter were selected for the purposes of demonstrating how the proposed risk equations work in an arbitrary network. Further work is required to correctly calibrate the parameters within the equations to the observed route choices of cyclists.

CHAPTER 7

7. APPLICATION OF THE PROPOSED METHODOLOGY FOR CONSIDERING CYCLIST RISK IN TRIP ASSIGNMENT MODELLING

Following the application of the equations proposed in Chapter 6 to modelling the risk exposure of cyclists in single- and multi- modal trip assignment examples to produce results in line with those expected for these equations, the next step was to apply these methods within an actual (existing) transport network. This would make it possible to assess whether the proposed method could better describe actual bicycle flows than 'shortest-path' methods. In order to do this, trip assignment models for both the 'shortest-path' method and the newly proposed method were evaluated for an area of Dublin City.

The 'shortest-path' method is the method currently in use by the NTA to assign bicycle flows within the GDA. With the permission of the NTA, it is this model that has been adapted for the applications required of this study.

7.1. THE NTA TRIP ASSIGNMENT MODEL FOR DUBLIN

In 2013, the NTA published the GDA Cycle Network Plan (National Transport Authority, 2013a). As part of this report, a trip assignment model for cycling was developed, assigning bicycle flows within the network using the 'shortest-path' method. This is the method also recommended for use in the U.S. and Canada (Ridgway, 1997, U.S. Department of Transportation, 1999, Hill and Stefan, 2014). The NTA trip assignment model is a route choice only assignment model. This means that all travellers considered in the model have already chosen to cycle i.e. the OD demands are known and fixed. The model also uses stochastic assignment methods as described by (Sheffi, 1985) (see section 6.1.2) to incorporate the variation in the perceptions of information available to travellers. The OD demands for the NTA model are based on data from POWSCAR 2011 (Central Statistics Office, 2011b), NTA 2006 demand data (Steer Davies Gleave, 2009), 2006 NTA Household Survey (Dublin Transportation Office, 2006) and 2011 NTA Canal Cordon Traffic Count (National Transport Authority, 2012a); these account for work, education and 'other' trip types made over the 3 hour time period between 07:00 and 10:00.

The NTA model produced the directional bicycle flows represented in Figure 7.1 by green bars, where a bar of greater width represents a higher bicycle flow. The Geoffrey E. Havers (GEH) statistic, as described in (Oketch and Carrick, 2005), was used to compare the fitted model to observed data. The GEH statistic is a modified chi-squared statistic that uses both relative and absolute differences to compare modelled and observed hourly traffic volumes.

$$GEH = \sqrt{\frac{2(M-O)^2}{(M+O)}} \qquad \textbf{Eq. (7.1)}$$

where M is the modelled traffic flows and O is the observed flows. For a GEH value less than 5 the model is considered a have a good fit, values between 5 and 10 are acceptable and values above 10 are not acceptable (Oketch and Carrick, 2005).

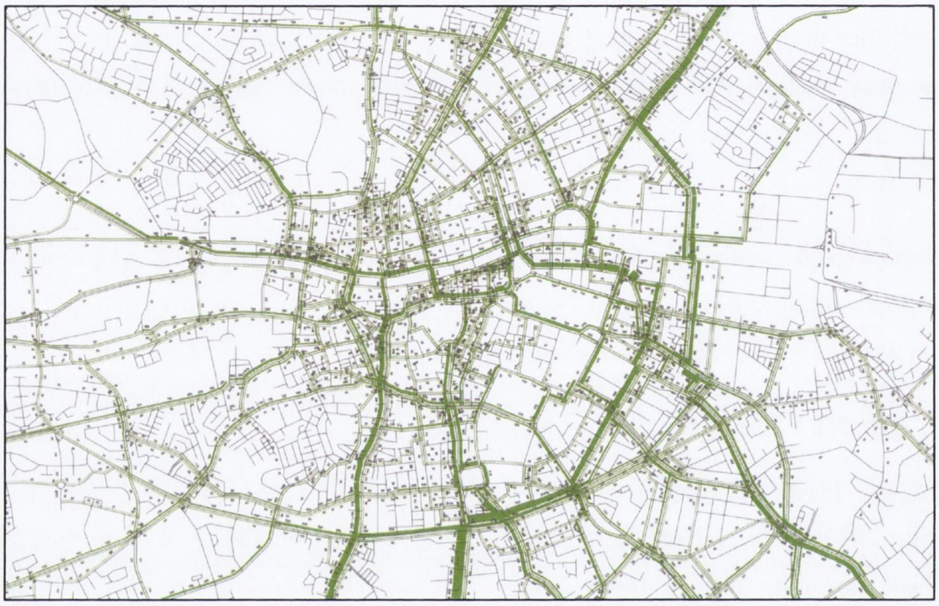


Figure 7.1 Bicycle traffic flow results from the NTA trip assignment model for Dublin city.

The NTA calculated these statistics for bicycle flow data recorded in the 2011 NTA Canal Cordon Traffic Count at each of the 33 locations where cyclists cross the canals to enter the city centre. A GEH value less than 5 was received at 23 (70%) of these locations, with the remaining 10 locations receiving a value between 5 and 10 (National Transport Authority, 2013a). These results were considered to be an acceptable fit for application of the trip assignment model in the GDA. As all cycling trips that begin outside the canal cordon and end inside it must cross one of these 33 locations it is argued that these GEH statistics provide little information as to the goodness of fit of the model; they do not provide for the movements of cyclists inside or outside of these cordons as there are many routes which can be taken on either side of the canal but still require crossing the canal at these points. For example, the 'shortest-path' method does not capture the preference of cyclists to use the segregated cycle path located along the Grand Canal immediately inside the canal cordon. The model instead assigns the shortest travel time path to Fitzwilliam Street, a highly trafficked link with no cycling facilities, which in actuality is used at a much lower rate than that suggested by this model.

7.2. A COMPARISON OF TRIP ASSIGNMENT MODELS – 'SHORTEST-PATH' AND THE PROPOSED RISK EXPOSURE METHOD

In order to understand whether adding the proposed risk equations was capable of modifying the behaviour of a travel time only model, the proposed equations were added to the 'shortest-path' algorithm. Results from both the NTA 'shortest-path' model and the model including risk considerations are presented to allow a comparison to be made. These models were implemented using Visum macroscopic transport modelling software (PTV Group, 2013).

7.2.1. Study Area

Each of the trip assignment methodologies have been demonstrated for an area of Dublin city. This study area was chosen to incorporate the city centre, a selection of each cycling facility considered by the proposed equations, and to be within an area of the city where cycling demands are sufficiently large; as such an area of the city bordered on the north by the River Liffey, on the west by the R114 arterial road and surrounded to the south and east by the Grand Canal and R111 arterial road. This area is highlighted in Figure 7.2 on the NTA cycling facility map. Figure 7.3 shows this same area but at closer proximity.

Figure 7.2 NTA map of cycling facilities in Dublin city, with trip assignment model study area highlighted.

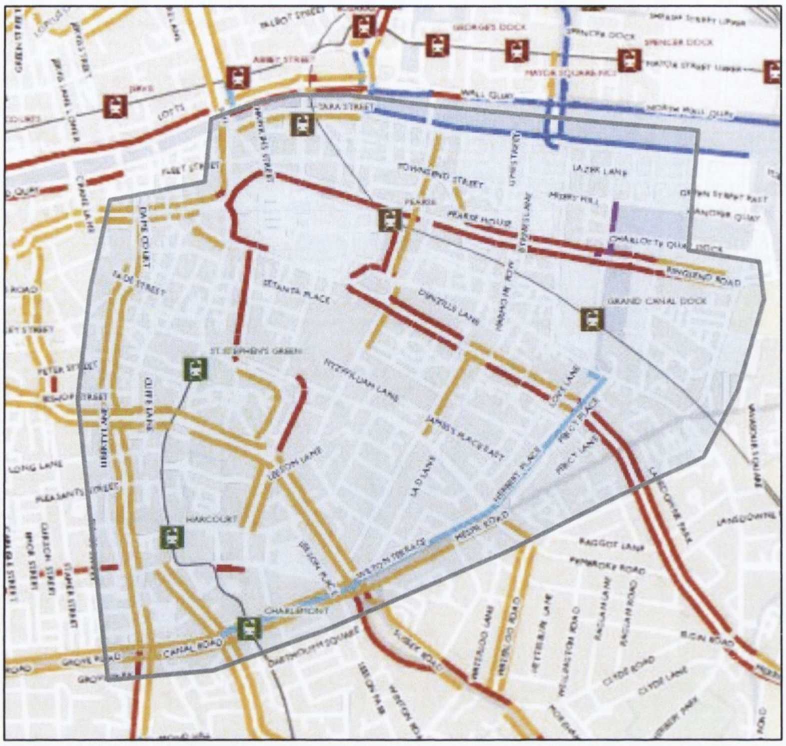


Figure 7.3 NTA map of cycling facilities for the trip assignment model study.

The simulation of this network was built in Visum (PTV Group, 2013) (Figure 7.4). Network links were programmed so that a new link is created at any intersection with another link. This results in links that tend to be short (average link length 76.4m), but is required in order for all route options available to cyclists to be captured by the assignment models. Each network link has a forward and reverse direction, referred to as directional links. While the directional links of a network link have the same length, the directional links are capable of having unique characteristics such as flows, capacity and type of cycling facility. Bicycle access can also be restricted from directional links i.e. for pedestrianised zones.

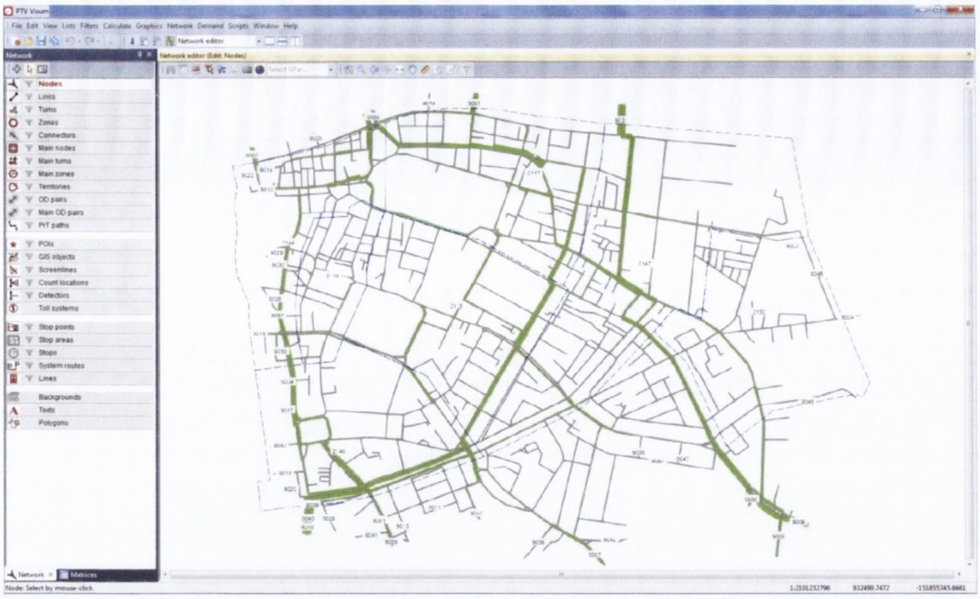


Figure 7.4 Screenshot of PTV Visum software used for modelling.

The simulation of the study zone is made up of 1,071 links or 2,142 directional links. One-way systems and pedestrian zones in operation in Dublin city reduce the number of directional links useable by bicycles to 1,890. Auto flows, bus flows and link capacities required by the proposed risk exposure methodology have been added for directional links from the NTA 2009 highway assignment model, updated to 2012 base year figures (Steer Davies Gleave, 2009). This information and link lengths for all directional links can be found in Appendix V. Table 7.1 presents a summary of these directional link characteristics. In this Table, differentiation is made between major and minor links i.e. those carrying large vehicle flows and those carrying low vehicle flows (this is done due to the different characteristics which arise on these links in the later models). From this it can be seen that the majority of the length of the network is on minor links with no cycling facilities, followed by major links with no cycling facilities; these make up 17.5% of the network length, while segregated cycle paths only cover 6.8 km (4.2%) of the network within the study area.

Table 7.1 Visum simulated network summary.

	No.	%
Links	1071	
Directional links	2142	
Cycling links	1890	
Major links with no cycling facility	326	17.2
Minor links with no cycling facility	1261	66.7
Shared-use bus lane	91	4.8
Kerbside cycle lane	166	8.8
Segregated cycle path	46	2.4
Total length	**km**	**%**
Network	163.7	
Major links with no cycling facility	28.7	17.5
Minor links with no cycling facility	104.5	63.8
Shared-use bus lane	8.1	4.9
Kerbside cycle lane	15.6	9.5
Segregated cycle path	6.8	4.2

Preforming assignment models for this smaller study area required modification of the OD matrices to create new external zones along this new cordon. Visum calculated these external OD demands once the study area cordon was specified, creating a new set of 62 OD pairs. The resulting OD matrices were also factored to a one hour, 'peak-hour' model based on the 2011 NTA Canal Cordon Traffic Count data. The resulting matrices for work, education and other trips can be found in Appendix IV.

Below is a list of assumptions made when calculating the following trip assignment models:

- All travellers will choose their routes based on what they perceive to be the minimum travel disutility i.e. by SUE;
- Where congestion effects are considered (in the proposed risk methodology), only auto and bus congestion is considered;
- Minor roads in the network (residential roads and side/access streets) are assumed to have a flow/capacity ratio of 0;
- As only cyclists are considered in the models, the baseline risk r^0 is 0.
- Demand is fixed i.e. travellers can not decide not to travel;
- Average cyclist travel speed is assumed to be 14km/hr (National Transport Authority, 2013a).

7.2.2. 'Shortest-Path' Trip Assignment Model

Using the cordoned single hour OD matrix of bicycle flows (Appendix IV), a 'shortest-path' type assignment was conducted. This model utilised the same methods as those applied by the NTA for the GDA trip assignment model as discussed in section 7.1. The 'shortest-path' model considers only bicycle travel time as part of trip disutility. The disutility is defined as (National Transport Authority, 2013a):

$$u_p = T_p, \forall p \in P_w, w \in W \quad \textbf{Eq. (7.2)}$$

$$T_p = \sum_{s \in S} t_s \delta_{sp}, \forall p \in P_w, w \in W \quad \textbf{Eq. (7.3)}$$

$$t_s = \frac{\Gamma_s}{\overline{V}} \quad \textbf{Eq. (7.4)}$$

where u_p is route disutility, T_p is route travel time, t_s is link travel time, Γ_s is link length and $\overline{V}$ is average cyclist speed. In accordance with the figure used in the NTA trip assignment model for the GDA, the average cyclist speed is taken as 14km/hr.

The individual link flow and disutility values resulting from performing a 'shortest-path' type assignment for the study are can be found in Appendix V. A summary of the minimum, maximum and average flow and disutility values in the network and on each type of cycling facility is presented in Table 7.2.

Table 7.2 Summary of NTA model flows, travel times (disutility).

	Min	Max	Average
Flow (no. of bicycles)			
Network	0	158	10.7
Major links with no cycling facility	0	128	17.3
Minor links with no cycling facility	0	135	7.3
Shared-use bus lane	0	90	12.7
Kerbside cycle lane	0	158	25.8
Segregated cycle path	0	126	23.7
Travel time (disutility) (s)			
Network	1.0	123.2	19.7
Major links with no cycling facility	1.8	86.1	20.8
Minor links with no cycling facility	1.3	123.2	18.5
Shared-use bus lane	1.8	66.9	20.5
Kerbside cycle lane	1.0	111.3	20.9
Segregated cycle path	6.7	85.1	38.2

The average link flow in the network is found to be 10.7 bicycles/hr. Only on minor links with no cycling facilities is the average flow lower than the network average, while average flow on kerbside cycle lane and segregated cycling paths was more than twice the network average, at 24 and 26 bicycles per hour, with maximum flows of 158 and 126 per hour respectively. As can be seen, there were minimums of zero for all types of links. The average link travel time or link disutility (due to the equivalency of these in the 'shortest-path' model) on any network link was found to be 19.7

seconds, calculated for an average cyclist speed of 14 km/hr. The average time spent on a segregated cycle path link was almost twice this value. This is because the segregated cycle path links were longer in length in the simulated network; the average length of a segregated cycle path link was 148m, whereas elsewhere the average link length was 78m due to a lower number of links intersecting with segregated cycle paths. Figure 7.5 displays a visual representation of the links flows resulting from the 'shortest-path' assignment of the study area, where a denser green bar represents a higher flow. As in the model for the GDA, the bicycle flow is assigned to the shortest path between the origin and destination, meaning that the resulting flows for the segregated cycle path along the canal are similarly low, while flows along Fitzwilliam Street are large. As can be seen from Figures 7.6 to 7.9, taken during morning peak traffic, the opposite is true.

Figure 7.5 Resultant bicycle flows from cordoned NTA model.

Figure 7.6 Grand Canal segregated cycle path during morning peak traffic hours.

Figure 7.7 Grand Canal segregated cycle path during morning peak traffic hours.

Figure 7.8 Fitzwilliam Street during morning peak traffic hours.

Figure 7.9 Fitzwilliam Street during morning peak traffic hours.

7.2.3. Trip Assignment with Risk Attributes

The trip assignment model was rerun, for the same study area, to include risk considerations as per the proposed risk equations presented in Chapter 6. As such, the disutility was modified as follows

$$u_p = T_p + R_p, \forall p \in P_w, w \in W \qquad \text{Eq. (7.5)}$$

where T_p is defined by Eq. (7.3) and Eq. (7.4), and R_p is the risk associated with the route and calculated as:

$$R_p = \sum_{s \in S} r_s \delta_{sp}, \forall p \in P_w, w \in W \qquad \text{Eq. (7.6)}$$

The equation used to calculate r_s depends on the type of cycling facility present on that link. These equations were first presented in Chapter 6, but are included here for clarity. As there is no mode choice element in this model the baseline risk r^0 is taken to be zero. The flow-capacity ratio for segregated cycle paths was assumed to be zero i.e. that the capacity of a segregated path was much larger than the bicycle flows on this facility. As such the resulting equations for the risk associated with cycling on a link with no cycle facility (cf_1), a shared-use bus lane (cf_2), a kerbside cycle lane (cf_3) and a segregated cycle path (cf_4) were:

$$r_{s,cf_1} = t_s \left[\rho_{cf_1} \left(\frac{v_s^a + v_s^b}{K_s} \right)^{\beta_{cf_1}} \right] \qquad \text{Eq. (7.7)}$$

$$r_{s,cf_2} = t_s \left[\rho_{cf_2} \left(\frac{v_s^b}{K_{s,cf_2}} \right)^{\beta_{cf_2}} \right] \qquad \textbf{Eq. (7.8)}$$

$$r_{s,cf_3} = t_s \left[\rho_{cf_3} \left(\frac{v_s^a + v_s^b}{K_s} \right)^{\beta_{cf_3}} \right] \qquad \textbf{Eq. (7.9)}$$

$$r_{s,cf_4} = 0 \qquad \textbf{Eq. (7.10)}$$

respectively, where r_{s,cf_i} is the risk (measured in time units) associated with cycling on cycle facility cf_i on link s, t_s is the travel time for cycling on link s, v_s^a and v_s^b are the flows of autos and buses on link s, K_s and K_{s,cf_2} are the capacity of link s and the shared-use bus lane on link s and $\rho_{cf_i}, \beta_{cf_i}$ are parameters.

The bus flow, auto flow and link capacity data used in this model were taken from the 2009 NTA highway assignment model (Steer Davies Gleave, 2009), adjusted by the NTA to 2012 base year figures. For minor, access and residential links (referred to as minor links) there is no traffic information available; as such the flow-capacity ratios on these links are zero and hence the risk values will also be zero. As no information was available on the capacities of shared-use bus lanes this capacity value was taken to be 10,000 bus/hr/km. This shared-use bus capacity figure was based on the assumption that all shared-use bus lanes in the study area operate below capacity, but that the link carrying the largest bus flow was operating close to capacity. The link in this network carrying the largest amount of flow was 0.071 km and carried 659 bus/hr. This resulted in a value of 9,282 bus/hr/km, which was rounded to 10,000 bus/hr/km to create a shared-use bus lane capacity figure for use in this model. The shared-use bus lane capacity of each link was then calculated by multiplying this figure by the link length. The parameter values used were the same arbitrary values as those used in Chapter 6: ρ_{cf_1}=1.5, ρ_{cf_2}=1, ρ_{cf_3}=0.8, β_{cf_1}=1.0, β_{cf_2}=1.0 and β_{cf_3}=2.0.

A visualisation of the flows resulting from this model, which includes risk considerations, is shown in Figure 7.10. From inspection of this Figure it would appear that this model has successfully overcome the inaccuracies of the NTA 'shortest-path' model, having moved bicycle flows from Fitzwilliam Street onto the segregated cycle path along the canal. Bicycle flow has also been removed from Macken Street (a busy street with no cycle facilities) to Grand Canal Quay, which runs parallel to Macken Street, but is made up of links with low traffic flows and segregated paths, although these links are slightly longer in length. The model also recognises Harcourt Street and Stephen's Green West as low traffic flow links, assigning more traffic to them than the 'shortest-path' model. Figures 7.11 and 7.12 present images taken during peak morning traffic of Macken Street and Grand Canal Quay. These results reflect the findings of the monitoring study as seen in Tables 5.3 to 5.5 in Chapter 5.

Figure 7.10 Resultant bicycle flows with the inclusion on risk considerations in the NTA model.

Figure 7.11 Macken Street during peak morning traffic.

Figure 7.12 Grand Canal Quay during peak morning traffic.

All of the link attribute, disutility and flow values for this model considering the proposed risk equations are presented in Appendix V. Table 7.3 includes a summary of these values. Here it can be seen that average flow of bicycles on segregated cycle paths is much higher than the network average of 12.3 bicycles/hr, with shared-use bus lanes, kerbside cycle lanes and minor links with no cycling facilities also showing average flows higher than the network average. The statistics presented relating to travel time are the same as those presented for the NTA model as travel time is calculated under the same assumption of average cyclist speed. In terms of risk values, while both major links with no cycling facilities and kerbside cycle lanes show similarly high maximum values of almost 1.4 minutes, the average value for kerbside cycle lanes lies much closer to the network average value than that of the major links with no cycling facilities. The need for the differentiation between the major and minor links with no cycling facilities becomes obvious with the discussion of risk exposure. The assumption that flows on minor links are sufficiently low to allocate them a flow-capacity ratio equal to zero deems these links to be as safe as segregated cycle paths i.e. minor links all have a risk exposure of zero seconds. In contrast, the average risk exposure on the major links (flow-capacity ratios greater than zero) is 11.7 seconds. Shared-use bus lanes and kerbside cycle lanes were seen to have average values close to either side of the network average of 2.5 seconds for a link. These risk values added an average of 2.2 and 4.4 seconds respectively to the travel disutility of cyclists. As such the average link disutility in the network was calculated at 22.2 seconds. With the exception of major links with no cycling facility and segregated cycle paths, each facility displayed a link disutility close to that of the network average. As travel time is the only attribute to the disutility of a segregated cycle path (due to the assumption that risk exposure is zero), the reasons for these high disutility values are again related to the longer link lengths used when programming the network. The final part of Table 7.3 explains the proportions of disutility attributed to risk; for minor links with no cycling facilities and segregated cycle paths these proportions are all zero. Elsewhere, this proportion reaches a maximum of 61% on major links with no cycling facilities. The average proportion (31.9%) for here is also much higher than the network average of 7.1%. Both shared-use bus lanes and kerbside cycle lanes also exhibit high maximum proportions, but with average levels much closer to that of the network average: 10.8% and 12.4% respectively.

Table 7.3 Summary of proposed risk exposure model flows, travel times, risk and disutility values

	Min	Max	Average
Flow (no. of bicycles)			
Network	0	157	12.3
Major links with no cycling facility	0	157	16.7
Minor links with no cycling facility	0	129	7.3
Shared-use bus lane	0	96	27.7
Kerbside cycle lane	0	128	26.3
Segregated cycle path	0	117	37.0
Travel time (s)			
Network	1.0	123.2	19.7
Major links with no cycling facility	1.8	86.1	20.8
Minor links with no cycling facility	1.3	123.2	18.5
Shared-use bus lane	1.8	66.9	20.5
Kerbside cycle lane	1.0	111.3	20.9
Segregated cycle path	6.7	85.1	38.2
Risk (s)			
Network	0	83.5	2.5
Major links with no cycling facility	0	83.3	11.7
Minor links with no cycling facility	0	0	0
Shared-use bus lane	0	16.9	2.2
Kerbside cycle lane	0	83.5	4.4
Segregated cycle path	0	0	0
Disutility (s)			
Network	1.0	194.9	22.2
Major links with no cycling facility	2.1	164.6	32.5
Minor links with no cycling facility	1.3	123.2	18.5
Shared-use bus lane	1.8	66.9	22.7
Kerbside cycle lane	1.0	194.9	25.2
Segregated cycle path	6.7	85.1	38.2
Risk/Distility (%)			
Network	0	61.0	7.1
Major links with no cycling facility	0.2	61.0	31.9
Minor links with no cycling facility	0	0	0
Shared-use bus lane	0	53.6	10.8
Kerbside cycle lane	0	45.7	12.4
Segregated cycle path	0	0	0

7.2.4. Model Comparison

Based on the model statistics in Tables 7.2 and 7.3 in the previous subsections it can be seen that despite the larger max flows of kerbside cycle lanes and segregated cycle paths, average flows for these facilities are much higher for the model with risk contributions than for the 'shortest-path' model. This reflects the cycling facility preference of cyclists found in Chapter 4, as well as demonstrating the behaviour anticipated by the risk exposure equations proposed in Chapter 4.

The differences between the two models are plotted in Figure 7.13; the green bars indicate increases in bicycle flow on a link with the addition of risk considerations, and the red bars indicate a decrease for the same. From this Figure it can also be seen that much simulated flow on the R815 road has been moved to the R118 road. The R118 road in Dublin city is a high traffic road with no cycling facilities; whereas although traffic volumes on the R118 are also high, there lies a shared-use bus lane along both sides of this road. As there is no observed cyclist volume data for these links it is not possible to confirm if this offers improvements over the shortest-path assignment of bicycle flow along these roads, but it would appear to be correct based on personal experience of the flows on these links.

There do still remain minor issues with the proposed risk exposure methods; for short distances with high risk values where low risk alternatives are available close by, the cyclists are assigned to these alternatives, whereas in reality a cyclist is not likely to do this. Two examples of this are seen in the model, shown in Figure 7.13, circled in blue. Reducing the likelihood of this occurring would require further calibration of the parameters in the risk equations to correlate closely with observed cyclist flows on these links.

There are also a number of items that the model can still not account for. The model assigns bicycle flow within the low traffic volume area of Temple Bar; but this area is made up largely of cobbled streets, not suitable for cycling. Also, the model assigns a large proportion of the traffic removed from Fitzwilliam Street along Lad Lane, but to access this lane would require dismounting and lifting the bicycle across a short barrier preventing vehicle access.

Despite the improvements that are visually apparent in Figure 7.13, due to insufficient bicycle flow data available it is not possible to compute GEH statistics for the links in this model. The study area contains only 8 of the 33 locations at which observed bicycle flows are available, but each of these locations lie along the south-east perimeter of the study area; therefore a GEH statistics calculation would offer no additional insight to the model performance.

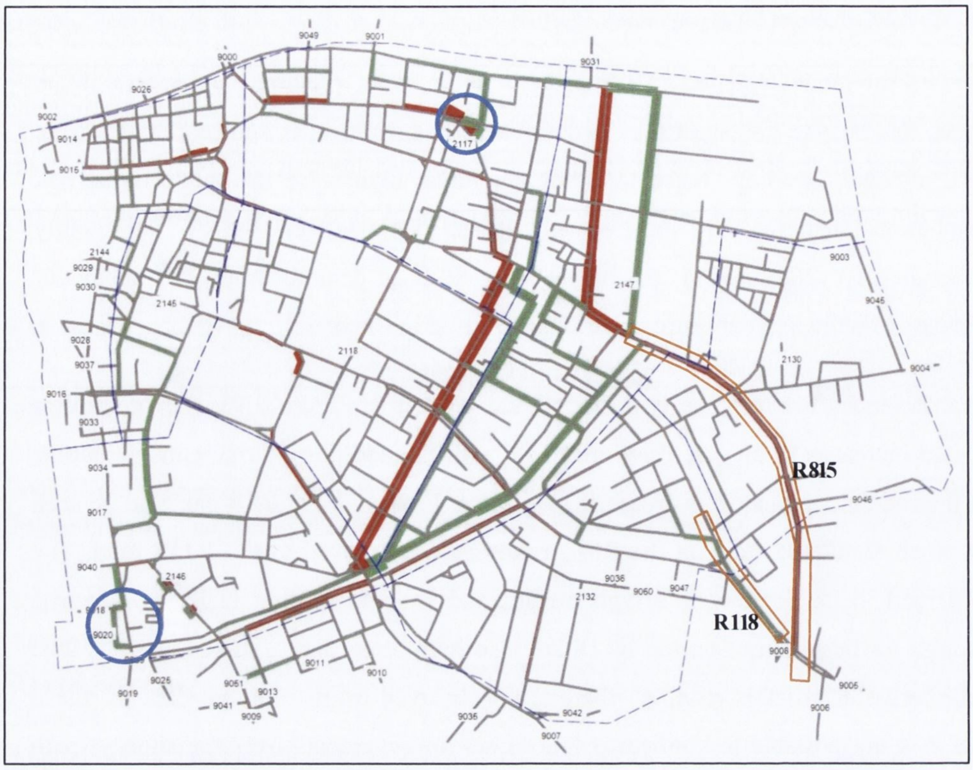


Figure 7.13 Flow differences between the NTA shortest-path model only model and the model considering risk exposure.

7.3. CONCLUSIONS

This chapter presents a study on how the perceived risk method of cyclist trip assignment, as developed in Chapter 6, might preform if applied within an actual transport network. Comparison is made between this methodology and the 'shortest-path' methodology currently in use by the NTA for bicycle trips in Dublin city. For the model presented here to include risk considerations, it would appear based on the altered route flows that it offers advantages over the 'shortest-path' assignment currently in use by the NTA.

A more extensive network of observed link flows is required in order to allow the calculation of GEH statistics and other statistical measures of fit to better understand whether the proposed methods offer improvements over the shortest-path methods, and also to facilitate the proper calibration of parameters in the risk equations. It is suggested that a turn frequency penalty added to the model may prevent the model from assigning cyclists along short detours that are not practical in actuality, and therefore solve this issue.

If this model were calibrated to produce accurate values of the parameters required by the perceived risk equations propoed in Chapter 6 (and the benefits the model offers over the 'shortest-path' method remain), transport planners would be in a position to be able to apply the methodology as long as data relating to cycling facility types and link lengths, flows and capacities were available to them. Generally this is information which is already collected for the purposes of transport planning, although additional data may be required for shared-use bus lane and segregated cycle path capacities. It was also the case for Dublin that no link capacity values were available for the more minor and residenical links in the network; if this were the case elsewhere further research may be required to better understand whether the perceived risk associated with their use in relation to other links and the various types of cycling facility. It is often the case that bicycle flow data is only calculated for the purpose of measuring modal split at access points in urban centres and as such insufficient data is available for the validation of bicycle trip assignment models; where possible additional bicycle flow data should be collected across cities to provide insight into the performance of the model.

CHAPTER 8

8. CONCLUSIONS

The main objective of this thesis was to develop a methodology for the trip assignment of bicycles in urban multi-modal transport networks. This methodology was developed to take into account the effects of safety/risk on cyclists' route choice decisions. In order to develop an efficient and effective method to do this the perceptions of safety, safety behaviours and network interactions of cyclists where investigated through survey and monitoring studies. The resulting methodology of the research has been tested and compared with the 'shortest-path' method which has been used in practise for the assignment of bicycle trips. This chapter concludes the thesis by presenting the main findings of this research, as well as its impacts, limitations and areas for further research.

8.1. CYCLIST SAFETY PERCEPTIONS AND BEHAVIOURS

In order to develop the methodology to assign bicycle trips according to the safety/risk attributes of cyclists the initial research objectives of the thesis involved an investigation of the perceptions, behaviours and network interactions of cyclists by survey questionnaire. The analysis of this data was the primary task involved in Chapter 4.

The survey revealed that respondents generally believed cycling to be unsafe compared to driving and that they will alter their routes to make use of facilities and other network attributes they find favourable, for example quiet roads and segregated cycle paths. Respondents were also found to alter their routes to avoid network elements they found undesirable, for example high traffic volumes. A clear order of preference for the types of cycling facilities usually available in urban transport networks was also revealed by the survey; cyclists found segregated cycle paths most preferable, followed by kerbside cycle lanes and shared-use bus lanes respectively, with cycling were no cycling facilities are present deemed least desirable.

Based on the analysis of the survey a number of transport policy suggestions were made. The main points from these findings are included below.

As previously mentioned, the survey revealed that the majority of respondent cyclists perceived cycling as less safe than driving in Dublin city. This is a result which is not captured by frequently cited road safety statistics which suggest that cycling is one of the safest modes of transport, due to the low number of cyclist fatalities.

Other transport modes where found to contribute to these poor perceptions of cycling safety; buses, rush hour traffic and poor driver attitudes were each associated with a reduced safety experience. On the other hand, characteristics under the control of cyclists improved this; greater compliance with the rules of the road, more regular cycling and preferring to cycle on roads with no cycling facilities each improved the safety experience of cyclists.

Despite poor perceptions of safety, cyclists who felt confident about their skills, considered themselves unlikely to be involved in accidents. These higher levels of confidence were also associated with lower levels of self-reported compliance with road traffic law. Yet, analysis revealed greater self-reported compliance to be associated with increased safety experiences. Adopting bicycle training approaches similar to that in the Netherlands, Denmark and Germany, which teach cyclists to ride defensively to avoid collision could improve cyclist and potential cyclist confidence. But as shown, a careful balance must be struck to prevent rule breaking with this confidence. Stricter enforcement of traffic law may be necessary. Law enforcement should not only focus on cyclists, but on all network users in order to increase intermodal cooperation. Requiring that both motorists and cyclists partake in training relating to cooperation may help both parties understand the others perspective.

The analysis also showed that with more regular cycling there is an increased likelihood of improved perceptions of cycling safety. This result may indicate that familiarity with the network, due to regular use, may decrease a cyclist's probability of describing cycling as less safe than driving within the network. (Møller and Hels, 2008) also found that increased regularity decreased the perceived risk, for the specific case of the use of roundabouts.

The equipment used by cyclists was considered in this analysis; cyclists who used lights and reflective bicycle accessories (mandatory by law) were even more likely to use hi-visibility clothing and helmets. But light use was not associated with safety perceptions and the use of hi-visibility clothing and helmets were found to be associated with decreased safety experiences. Therefore, requiring their use will not benefit the perception of safety and may only serve to highlight to cyclists the lack of confidence road safety agencies have in cycling safety. This could potentially be detrimental to cycling mode shares.

It was also seen in this analysis that the probability of describing cycling as safer than or as safe as driving grew with age. Consequently, older people were more likely to deem the cycling network as safer than the relatively younger population. This observation may be a cause for concern, since it is the younger population who is, and will, constitute the largest proportion of beginner cyclists to contribute to the growing bicycle mode share in Dublin. Additionally, it is the younger population who will play a major role in influencing the growth and evolution of cycling as a preferred choice of travel mode.

Male respondents with access to a vehicle (and therefore assumed to have had driving experience) were seen to be much less likely to rate cycling highly in terms of safety. The differences between driver behaviours by gender has been widely researched and has shown male drivers to be more aggressive than their female counterparts; a report from the Social Issues Research Centre (Marsh, 2004) outlines a large number of these studies. It may be as a result of male drivers being aware of their aggressive attitudes to driving that the model has produced this result.

Despite the recommendations of literature relating to cycling policy to the need to change attitudes and perceptions relating to cycling, among all road users, the focus of policy has remaining largely on cycling facility provision. None of the cycling facilities considered in analysis were found to contribute to improving safety perceptions of cycling. This is in spite of a clear order of preference for these facilities among the respondent cyclists and their use in the monitoring study. Only those comfortable with cycling on roads with no facilities were likely to have a better perception of safety. With many cities unable to provide space for these facilities instruction for cyclists on where to position themselves safely on these roads with no facilities may help them to feel more comfortable in such situations.

8.2. A TRIP ASSIGNMENT METHODOLOGY TO CONSIDER CYCLIST RISK EXPOSURE

The final research objectives of the thesis involved the development of a methodology for the assignment of cyclists in network modelling. A monitoring study of cyclists' route choices was preformed to determine whether the 'shortest-path' could efficiently describe cyclist behaviour and whether cyclists alter their routes as suggested by the respondents to the survey in Chapter 4. The study found cyclists were unlikely to follow the 'shortest-path' route, instead following less trafficked routes and making use of cycling facility facilities where possible. Assignment of cyclists in multi-modal transport networks by this method is therefore inappropriate. Based on these results and the order of preference for cycling facilities revealed by the cycling safety survey, an alternative bicycle trip assignment methodology was developed.

This methodology consisted of four 'risk exposure' equations; one for each type of cycling facility, this includes one equation for the presence of no cycling facility. The equation takes a similar to that of the BPR function, unlike previous attempts to consider safety in bicycle trip assignment which used regressions equations which tended to require large amounts of data. The equation measures risk exposure in time units to reflect how cyclists will act to minimise their exposure to undesirable network conditions. A system of equations is created which can recognise, for example, that travel on a low trafficked route with no cycling facilities can be preferable to a longer route on a kerbside cycle lane with high traffic volumes.

These equations are considered together with travel time, and not in place of it i.e. as an additional attribute in the 'shortest-path' method. This prevents bicycles from being assigned to the highest quality cycle facilities available, at unrealistic expense to travel time.

The methodology was initially tested in arbitrary networks with promising results. Following on from this, the method was applied to a real transport network to determine whether it was capable of achieving more accurate flows than the 'shortest-path' method.

Although detailed bicycle flow data was not available to accurately verify the flows resulting from the trip assignment with risk exposure attributes, the model did present improvement over the 'shortest-path' method, correctly assigning bicycles along the largely popular segregated cycle facilities which run adjacent to a heavily trafficked links with no cycling facilities.

8.3. DISCUSSION IN THE CONTEXT OF RESEARCH IN THE FIELD

The research in this thesis has identified that cycling is perceived poorly in terms of cycling safety. This has deterred the use of cycling as a mode of travel (Keegan and Galbraith, 2005, Noland, 1995), but also presents difficulties for those who do cycle (Harkey et al., 1998, Hughes and Harkey, 1999, Landis, 1994, Landis et al., 1997, Landis et al., 2003, Møller and Hels, 2008, Parkin et al., 2007, Winters et al., 2012). Participants in this research stated their preferences to network elements such as quieter roads and quality cycling facilities. Observations of cyclists routes suggested similar use of quieter roads and cycling facilities, where available. These deviations from more direct routes to improve safety perceptions have been seen in other studies of cyclists revealed preferences (Broach et al., 2011, Hood et al., 2011, Landis et al., 1997, Menghini et al., 2010) and stated preferences (Hunt and Abraham, 2007, Ortúzar et al., 2000, Sener et al., 2009, Stinson and Bhat, 2003).

By traditional trip assignment methods, travellers are assumed to traverse along the route which minimises their travel time (Sheffi, 1985); the 'shortest-path'. This is generally how vehicular traffic is assigned in a network, with an additional consideration of delay due to the volume of traffic (U.S. Department of Commerce and Bureau of Public Roads, 1964). Previously not considered in transport modelling of this nature, cyclists are being assigned within transport networks using these simplistic methods (Hill and Stefan, 2014, National Transport Authority, 2013a, Ridgway, 1997, U.S. Department of Transportation, 1999); not taking account of the additional factors which have been shown to be considered by cyclists in making route choice decisions.

Previous research which has attempted to improve upon 'shortest-path' methods has considered congestion, emissions and energy usage, but each have used a system optimal approach (Si et al., 2008a, Si et al., 2011, Si et al., 2008b), not representative of the behaviour of cyclists in making their own route choice decisions, but rather display the characteristics that transport authorities might want from a cycling network. (Li et al., 2014) have considered a rider fatigue attribute (among other costs associated with public bicycle rental schemes), but this attribute can only act to encourage the use of the 'shortest-path'.

Previous studies by (Ehrgott et al., 2012, Klobucar and Fricker, 2007) and (Smith and Haghani, 2012) which have taken safety aspects into consideration in bicycle trip assignment have done so using regression based indices developed as a measure of the level of service (or similar) of links (Palmer et al., 1998, Harkey et al., 1998 and Landis et al., 1997, respectively). The difficulty with each of these methods is that they are complex and data intensive; often requiring data not available to transport authorities without expensive data collection procedures.

The method proposed by this research aims to provide a simpler method to effectively model cyclists route choice decisions based on perceived risk/safety, using data which is generally already collected by transport authorities for other purposes. This method considers the presence and preference for different types of cycling facilities and the congestion effects felt while travelling in the network, while still considering time travel. In testing, this method appears to perform better than the 'shortest-path' method in use by the NTA for the test site in Dublin city (National Transport Authority, 2013a).

8.4. CONTRIBUTION OF THE RESEARCH

As individuals begin to use the bicycle as a mode of transport as part of their daily routine for commuting etc., relevant state agencies must commit to placing the same value on this mode as is placed on PT and private motorised modes. This requires both policy and planning changes. This thesis presents a methodology for the assignment of bicycles in multi-modal transport networks that considers how cyclists act to minimise their risk exposure in their route choices. The methodology requires less data than previously proposed methods, and uses data readily available to transport planners. In testing the methodology presented improvements over the 'shortest-path' method, currently applied in practice. Safety is often cited as a reason behind stifled efforts to increase bicycle mode shares, yet cycling is also cited as one of the safest modes of transport due to the small numbers of fatalities. Cycling needs to be considered using alternative approaches to safety. The research presents a comprehensive survey relating to the safety perceptions of cyclists. This survey included variables that, to the best of the authors knowledge, have not been considered by research in this area. The findings from the analysis of this survey demonstrate that an increased understanding of cyclist safety perceptions and the attributes contributing to these perceptions would assist better informed and more effective cycling policy provision. As shown in this thesis, the provision of cycling infrastructure should not be the sole focus of policy; perceptions and behaviours of cyclists and other road users are also required.

8.5. CRITICAL ASSESSMENT

Although the work of this thesis adds to previous research in the areas of cycling safety and trip assignment modelling, there are limitations associated with the research which are discussed in this section.

Almost all respondents (98%) to the survey presented in Chapter 4 described themselves as being competent or experienced cyclists. It is not possible to know from the survey data whether inexperienced cyclists have been under represented in the survey responses or whether cyclists generally do not consider themselves to be inexperienced. If the former is the case, this may introduce a bias in the analyses of survey data.

This survey also collected responses only from those having cycled in Dublin in any of the five years prior to the survey. Therefore the work presented does not consider the cycling safety perceptions of non-cyclists. It is recognised that to increase cycling mode shares the safety perceptions of non-cyclists must improve, but without first improving the safety perceptions of cycling among those already cycling, non-cyclists cannot be expected to consider to take up cycling to exposure themselves to these situations perceived as unsafe.

All efforts were made to ensure the anonymity of participants in the monitoring study and to reassure them that the sole purpose of the data collection was research. But due to the nature of the data being collected sensitive information relating to the home, work and other locations visited by participants on these trips are collected by the data. This may have played a role in the low number of participants in the study despite being advertised on the Trinity College Dublin campus and in the local cycling campaign newsletter. Although, the study did find similarly to other studies on cyclists' route choices, the number of trips studied may be too low to state conclusive findings.

The focus of this thesis has been on the safety perceptions of cyclists, rather than observed safety. This is, in part, due to the unreliability of reported data for incidents involving cyclists. Research suggests a considerable amount of underreporting (Hendrie and Ryan, 1994, Veisten et al., 2007, Doherty et al., 2000, Broughton et al., 2010, Short and Caulfield, 2014) – increasing as injury severities decrease (Veisten et al., 2007, Hendrie and Ryan, 1994). Research projects are underway to try to fill this gap in the knowledge of the causes and locations that contribute to both cycling incidents and 'near misses' which may otherwise go unreported (Aldred, 2014, mySociety, 2014). But it remains that cyclists will make their route choice decisions based on their perceptions of safety, and not based on reported safety statistics, and therefore the study of these perceptions and their impact on route choice decisions is necessary to the development of more accurate trip assignment methods for cyclists.

8.6. AREAS FOR FURTHER RESEARCH

Possible areas for further research could focus on a similar study of cycling safety perceptions among non-cyclists. This would provide insight into the attributes preventing them from beginning to cycle. This would allow comparison to be made the safety perceptions of cyclists and non-cyclists. Considering the safety perceptions of both cyclists and potential cyclists would provide the most rounded cycling policy for improving cycling safety perceptions and cycling mode shares.

The proposed method for trip assignment contains parameters which could not be calibrated due to insufficient bicycle flow data availability. In order for the proposed method to be able to be used as a tool by transport planners calibration would be necessary. Collecting the required data to accurately calibrate these equations may prove expensive. A less costly method of calibration would be to use a stated preference technique; by asking cyclists questions about their preference to different situations arising from these equations it may be possible to estimate these parameter values. This stated preference technique has limitations, in that there often arise differences between stated and revealed preferences of individuals.

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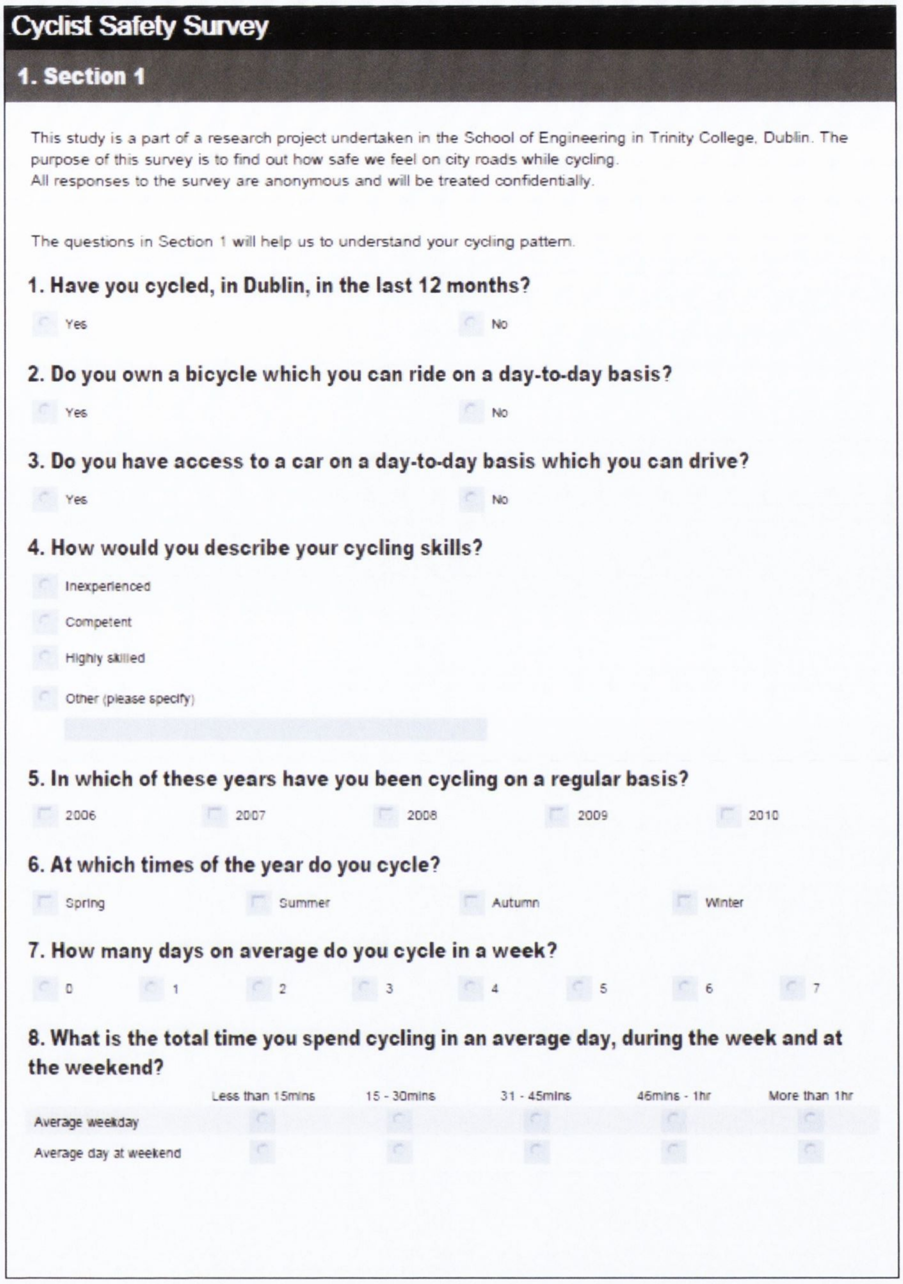
APPENDIX I: CYCLING SAFETY SURVEY



Cyclist Safety Survey

1. Section 1

This study is a part of a research project undertaken in the School of Engineering in Trinity College, Dublin. The purpose of this survey is to find out how safe we feel on city roads while cycling.
All responses to the survey are anonymous and will be treated confidentially.

The questions in Section 1 will help us to understand your cycling pattern.

1. Have you cycled, in Dublin, in the last 12 months?

○ Yes ○ No

2. Do you own a bicycle which you can ride on a day-to-day basis?

○ Yes ○ No

3. Do you have access to a car on a day-to-day basis which you can drive?

○ Yes ○ No

4. How would you describe your cycling skills?

○ Inexperienced
○ Competent
○ Highly skilled
○ Other (please specify)

5. In which of these years have you been cycling on a regular basis?

☐ 2006 ☐ 2007 ☐ 2008 ☐ 2009 ☐ 2010

6. At which times of the year do you cycle?

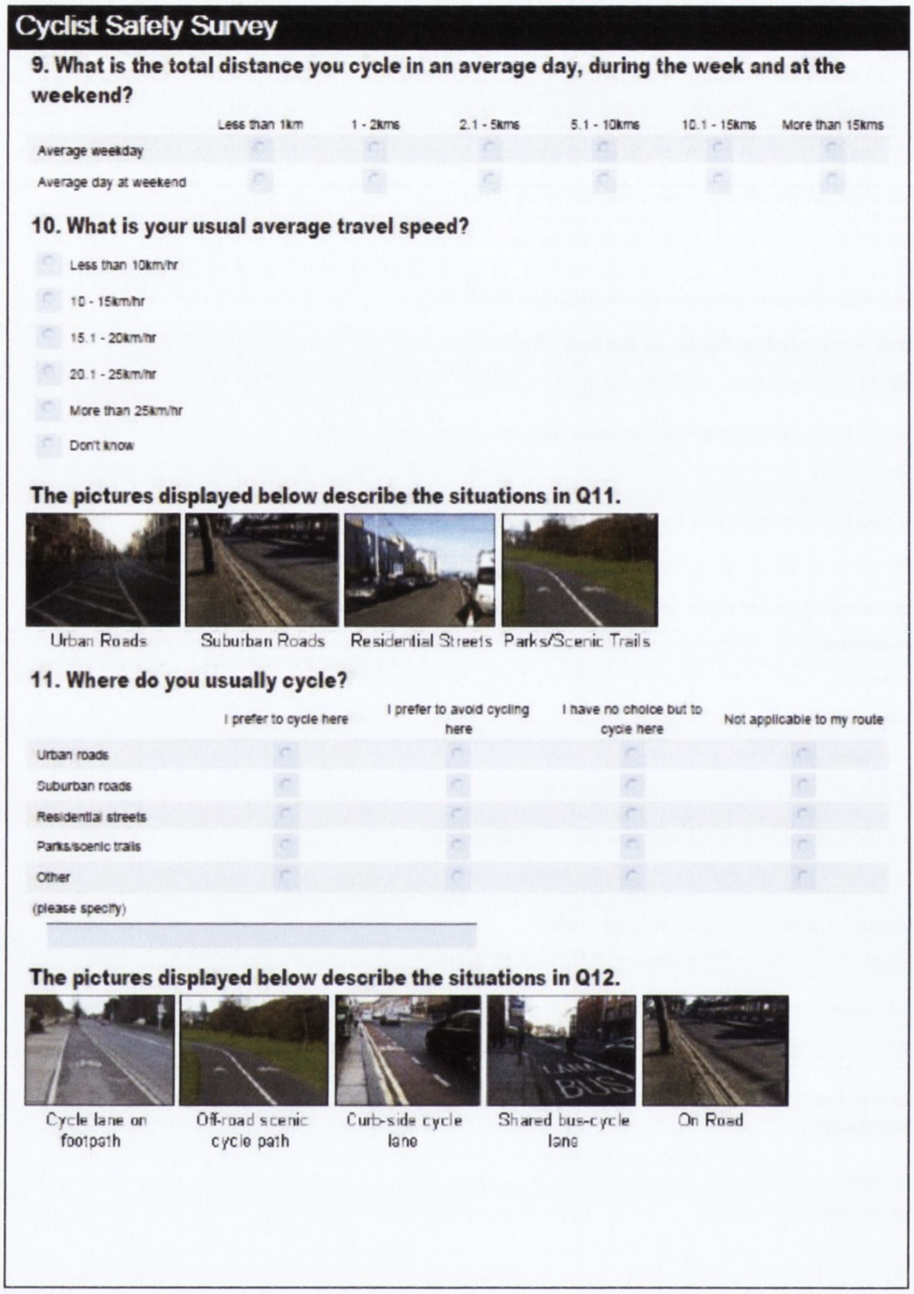
☐ Spring ☐ Summer ☐ Autumn ☐ Winter

7. How many days on average do you cycle in a week?

○ 0 ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7

8. What is the total time you spend cycling in an average day, during the week and at the weekend?

	Less than 15mins	15 - 30mins	31 - 45mins	46mins - 1hr	More than 1hr
Average weekday	○	○	○	○	○
Average day at weekend	○	○	○	○	○



Cyclist Safety Survey

9. What is the total distance you cycle in an average day, during the week and at the weekend?

	Less than 1km	1 - 2kms	2.1 - 5kms	5.1 - 10kms	10.1 - 15kms	More than 15kms
Average weekday	○	○	○	○	○	○
Average day at weekend	○	○	○	○	○	○

10. What is your usual average travel speed?

○ Less than 10km/hr
○ 10 - 15km/hr
○ 15.1 - 20km/hr
○ 20.1 - 25km/hr
○ More than 25km/hr
○ Don't know

The pictures displayed below describe the situations in Q11.

Urban Roads
Suburban Roads
Residential Streets
Parks/Scenic Trails

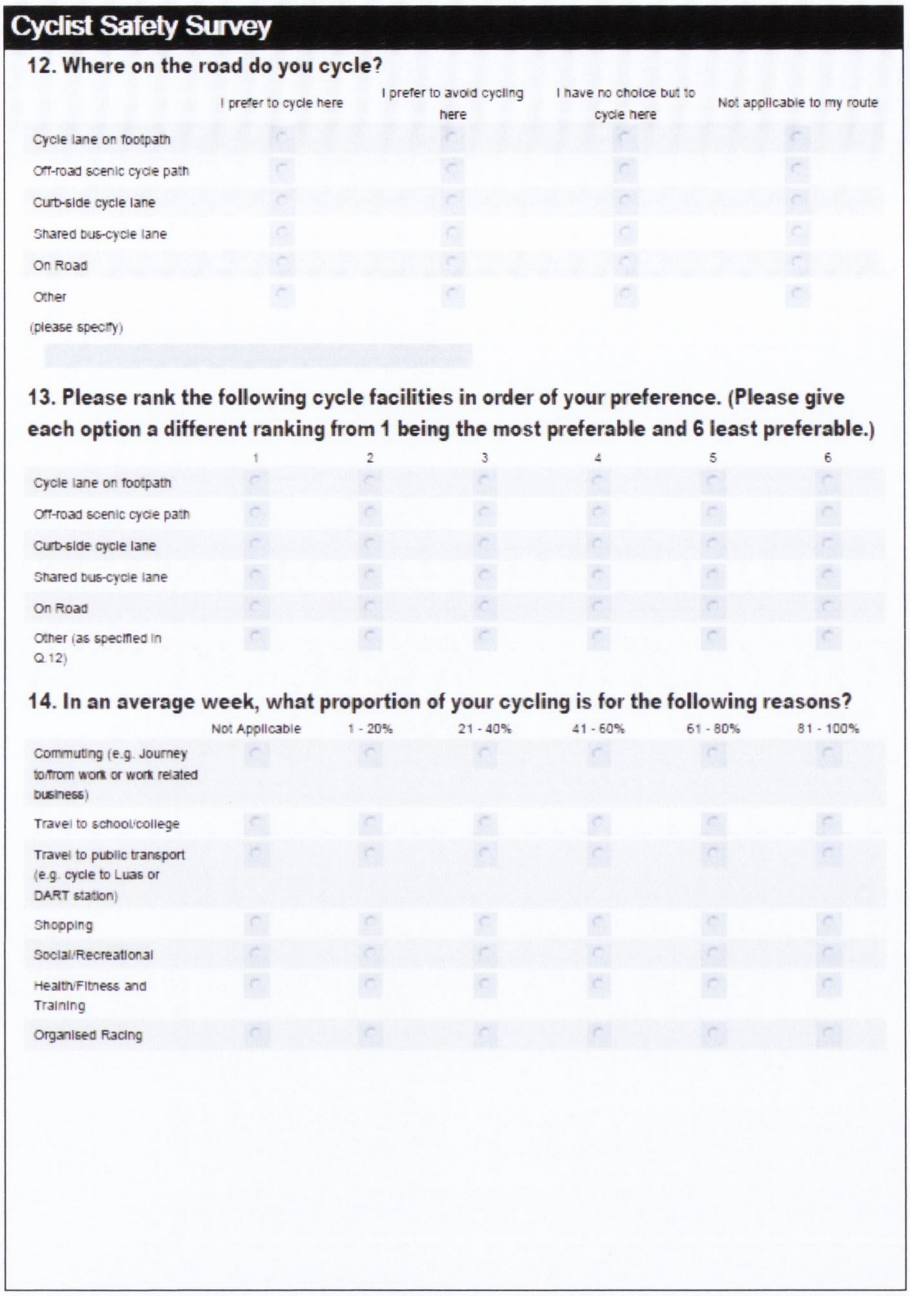
11. Where do you usually cycle?

	I prefer to cycle here	I prefer to avoid cycling here	I have no choice but to cycle here	Not applicable to my route
Urban roads	○	○	○	○
Suburban roads	○	○	○	○
Residential streets	○	○	○	○
Parks/scenic trails	○	○	○	○
Other	○	○	○	○

(please specify)

The pictures displayed below describe the situations in Q12.

Cycle lane on footpath
Off-road scenic cycle path
Curb-side cycle lane
Shared bus-cycle lane
On Road



Cyclist Safety Survey

12. Where on the road do you cycle?

	I prefer to cycle here	I prefer to avoid cycling here	I have no choice but to cycle here	Not applicable to my route
Cycle lane on footpath	○	○	○	○
Off-road scenic cycle path	○	○	○	○
Curb-side cycle lane	○	○	○	○
Shared bus-cycle lane	○	○	○	○
On Road	○	○	○	○
Other	○	○	○	○

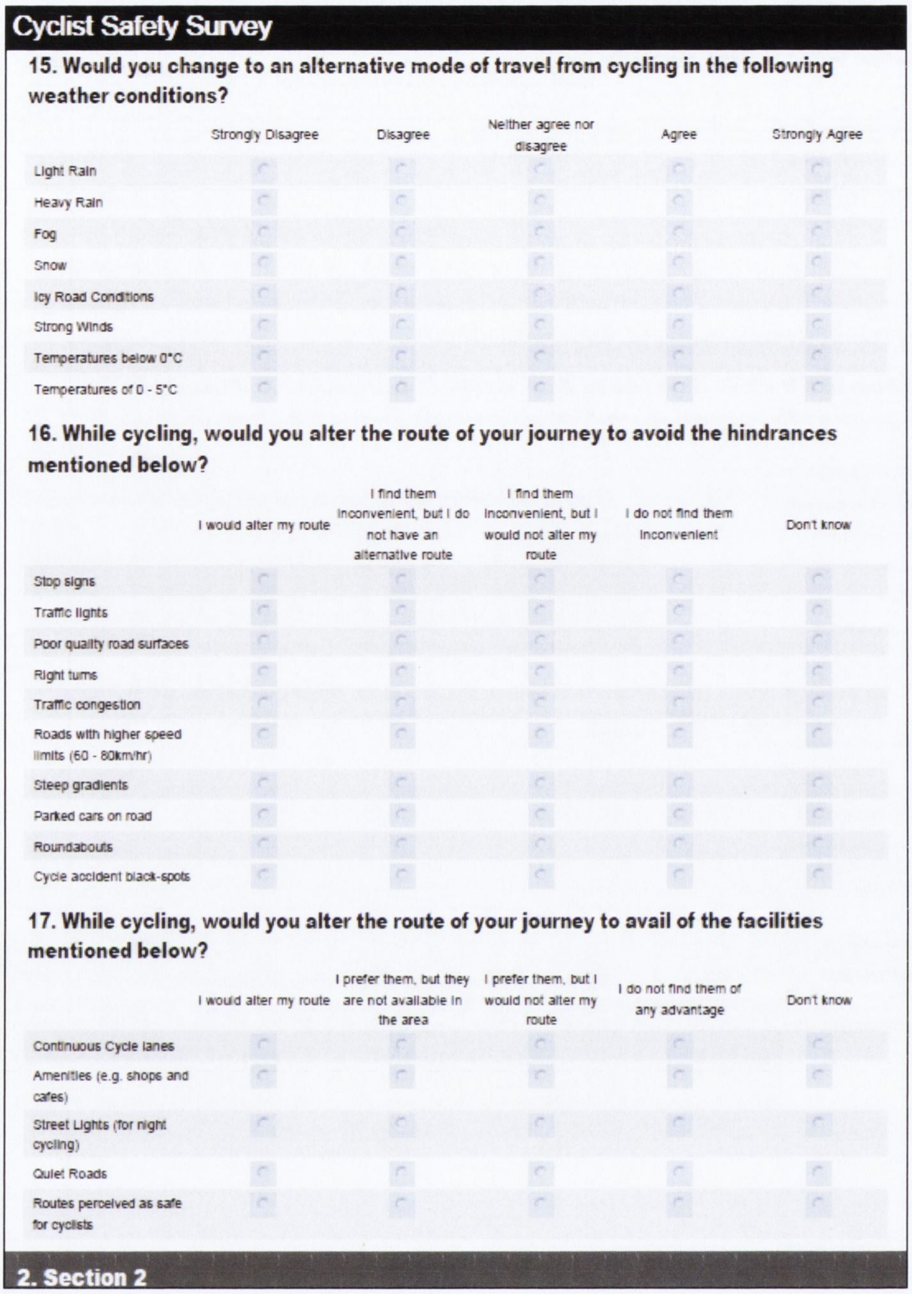
(please specify)

13. Please rank the following cycle facilities in order of your preference. (Please give each option a different ranking from 1 being the most preferable and 6 least preferable.)

	1	2	3	4	5	6
Cycle lane on footpath	○	○	○	○	○	○
Off-road scenic cycle path	○	○	○	○	○	○
Curb-side cycle lane	○	○	○	○	○	○
Shared bus-cycle lane	○	○	○	○	○	○
On Road	○	○	○	○	○	○
Other (as specified in Q.12)	○	○	○	○	○	○

14. In an average week, what proportion of your cycling is for the following reasons?

	Not Applicable	1 - 20%	21 - 40%	41 - 60%	61 - 80%	81 - 100%
Commuting (e.g. Journey to/from work or work related business)	○	○	○	○	○	○
Travel to school/college	○	○	○	○	○	○
Travel to public transport (e.g. cycle to Luas or DART station)	○	○	○	○	○	○
Shopping	○	○	○	○	○	○
Social/Recreational	○	○	○	○	○	○
Health/Fitness and Training	○	○	○	○	○	○
Organised Racing	○	○	○	○	○	○



Cyclist Safety Survey

15. Would you change to an alternative mode of travel from cycling in the following weather conditions?

	Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree
Light Rain	○	○	○	○	○
Heavy Rain	○	○	○	○	○
Fog	○	○	○	○	○
Snow	○	○	○	○	○
Icy Road Conditions	○	○	○	○	○
Strong Winds	○	○	○	○	○
Temperatures below 0°C	○	○	○	○	○
Temperatures of 0 - 5°C	○	○	○	○	○

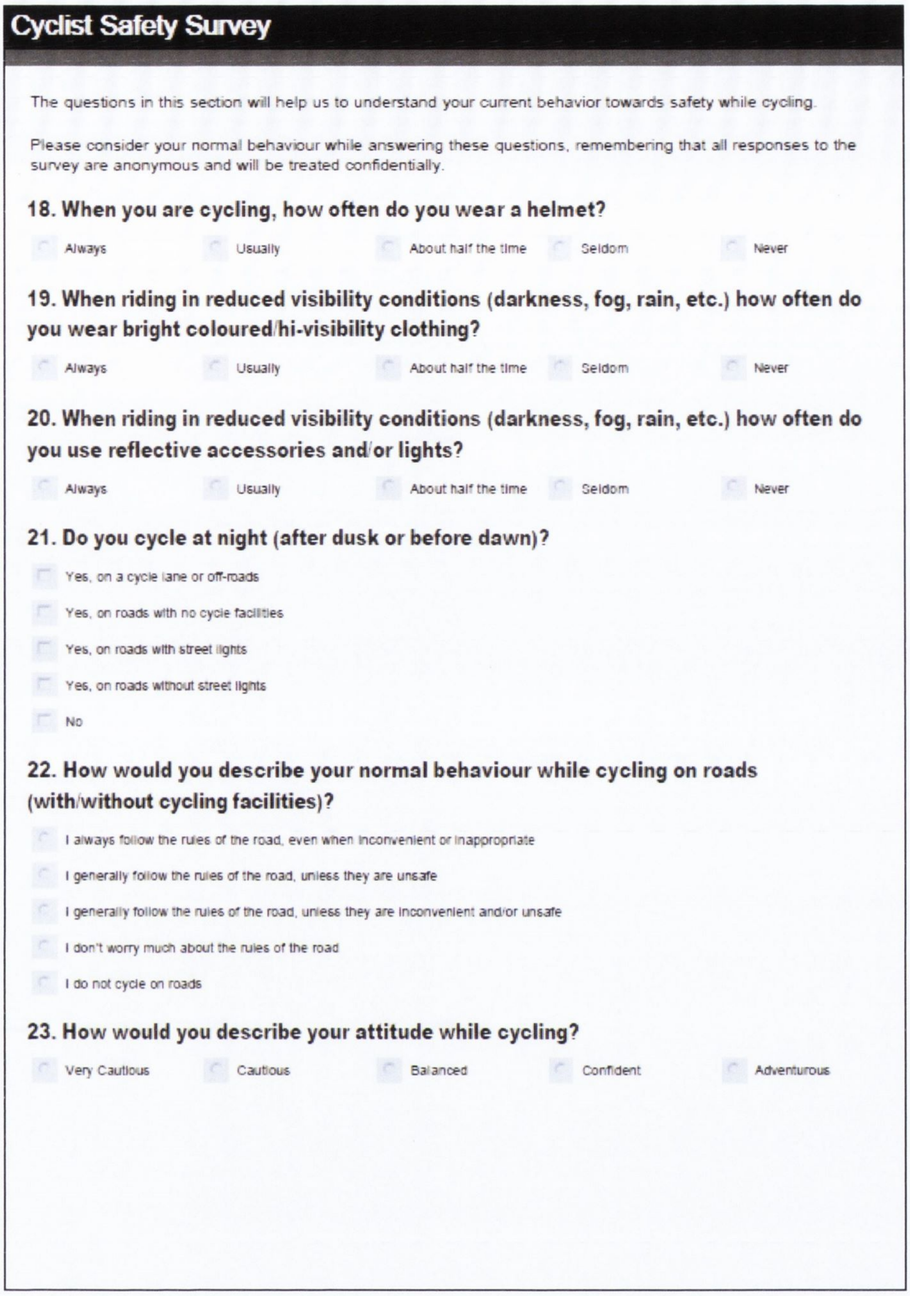
16. While cycling, would you alter the route of your journey to avoid the hindrances mentioned below?

	I would alter my route	I find them inconvenient, but I do not have an alternative route	I find them inconvenient, but I would not alter my route	I do not find them inconvenient	Don't know
Stop signs	○	○	○	○	○
Traffic lights	○	○	○	○	○
Poor quality road surfaces	○	○	○	○	○
Right turns	○	○	○	○	○
Traffic congestion	○	○	○	○	○
Roads with higher speed limits (60 - 80km/hr)	○	○	○	○	○
Steep gradients	○	○	○	○	○
Parked cars on road	○	○	○	○	○
Roundabouts	○	○	○	○	○
Cycle accident black-spots	○	○	○	○	○

17. While cycling, would you alter the route of your journey to avail of the facilities mentioned below?

	I would alter my route	I prefer them, but they are not available in the area	I prefer them, but I would not alter my route	I do not find them of any advantage	Don't know
Continuous Cycle lanes	○	○	○	○	○
Amenities (e.g. shops and cafes)	○	○	○	○	○
Street Lights (for night cycling)	○	○	○	○	○
Quiet Roads	○	○	○	○	○
Routes perceived as safe for cyclists	○	○	○	○	○

2. Section 2



Cyclist Safety Survey

The questions in this section will help us to understand your current behavior towards safety while cycling.

Please consider your normal behaviour while answering these questions, remembering that all responses to the survey are anonymous and will be treated confidentially.

18. When you are cycling, how often do you wear a helmet?

○ Always ○ Usually ○ About half the time ○ Seldom ○ Never

19. When riding in reduced visibility conditions (darkness, fog, rain, etc.) how often do you wear bright coloured/hi-visibility clothing?

○ Always ○ Usually ○ About half the time ○ Seldom ○ Never

20. When riding in reduced visibility conditions (darkness, fog, rain, etc.) how often do you use reflective accessories and/or lights?

○ Always ○ Usually ○ About half the time ○ Seldom ○ Never

21. Do you cycle at night (after dusk or before dawn)?

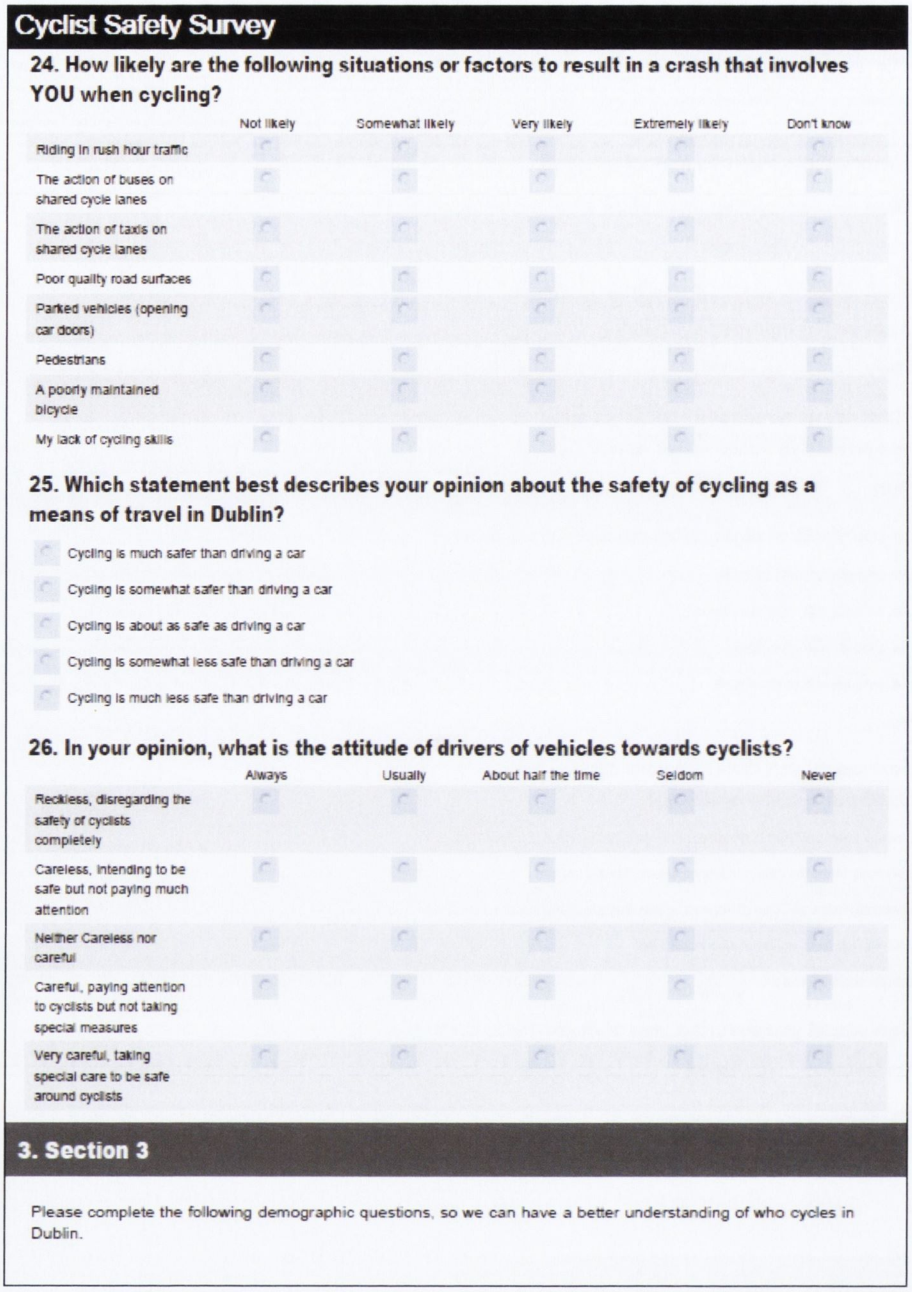
- ☐ Yes, on a cycle lane or off-roads
- ☐ Yes, on roads with no cycle facilities
- ☐ Yes, on roads with street lights
- ☐ Yes, on roads without street lights
- ☐ No

22. How would you describe your normal behaviour while cycling on roads (with/without cycling facilities)?

- ○ I always follow the rules of the road, even when inconvenient or inappropriate
- ○ I generally follow the rules of the road, unless they are unsafe
- ○ I generally follow the rules of the road, unless they are inconvenient and/or unsafe
- ○ I don't worry much about the rules of the road
- ○ I do not cycle on roads

23. How would you describe your attitude while cycling?

○ Very Cautious ○ Cautious ○ Balanced ○ Confident ○ Adventurous



Cyclist Safety Survey

24. How likely are the following situations or factors to result in a crash that involves YOU when cycling?

	Not likely	Somewhat likely	Very likely	Extremely likely	Don't know
Riding in rush hour traffic	○	○	○	○	○
The action of buses on shared cycle lanes	○	○	○	○	○
The action of taxis on shared cycle lanes	○	○	○	○	○
Poor quality road surfaces	○	○	○	○	○
Parked vehicles (opening car doors)	○	○	○	○	○
Pedestrians	○	○	○	○	○
A poorly maintained bicycle	○	○	○	○	○
My lack of cycling skills	○	○	○	○	○

25. Which statement best describes your opinion about the safety of cycling as a means of travel in Dublin?

○ Cycling is much safer than driving a car

○ Cycling is somewhat safer than driving a car

○ Cycling is about as safe as driving a car

○ Cycling is somewhat less safe than driving a car

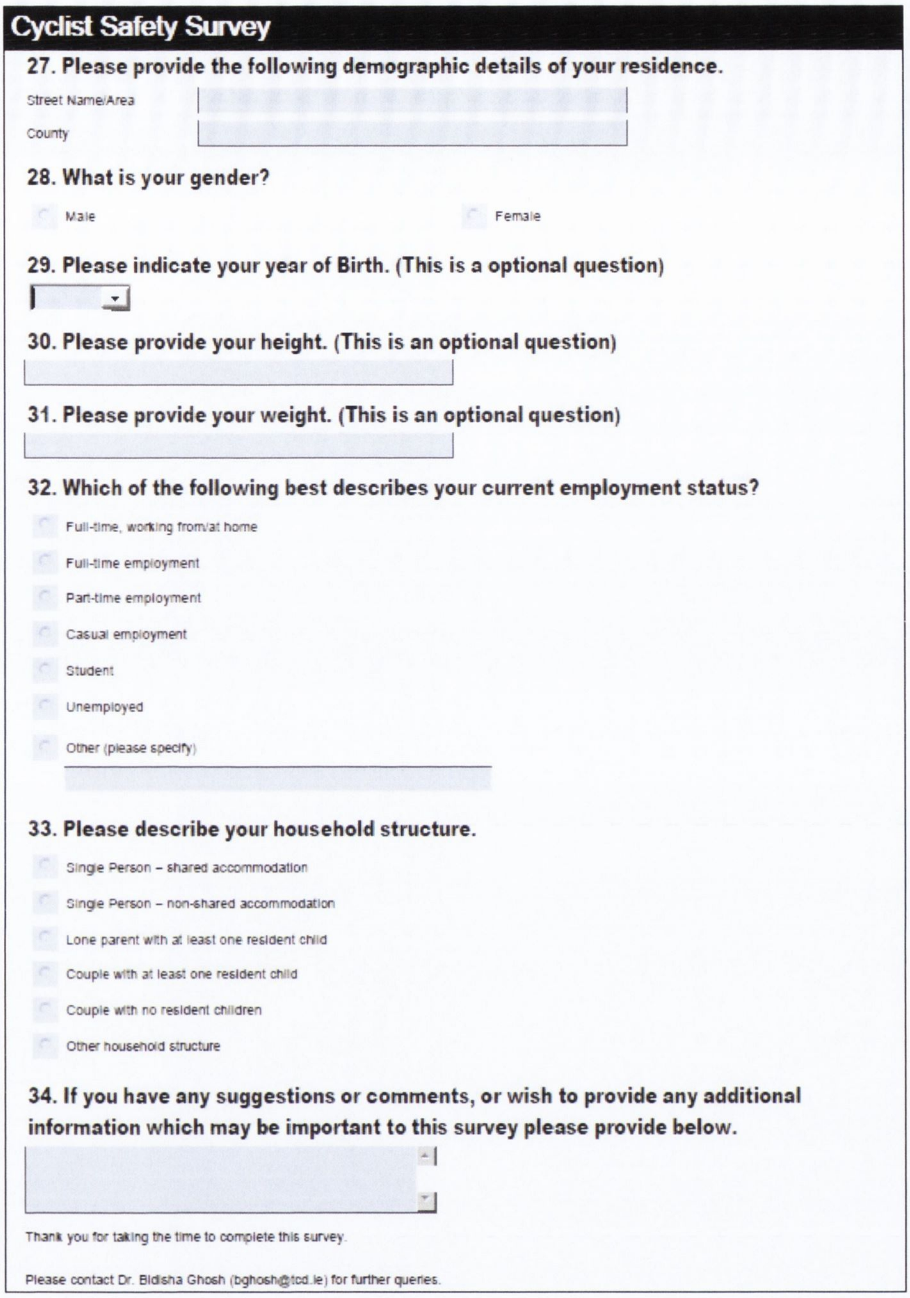
○ Cycling is much less safe than driving a car

26. In your opinion, what is the attitude of drivers of vehicles towards cyclists?

	Always	Usually	About half the time	Seldom	Never
Reckless, disregarding the safety of cyclists completely	○	○	○	○	○
Careless, intending to be safe but not paying much attention	○	○	○	○	○
Neither Careless nor careful	○	○	○	○	○
Careful, paying attention to cyclists but not taking special measures	○	○	○	○	○
Very careful, taking special care to be safe around cyclists	○	○	○	○	○

3. Section 3

Please complete the following demographic questions, so we can have a better understanding of who cycles in Dublin.



Cyclist Safety Survey

27. Please provide the following demographic details of your residence.

Street Name/Area

County

28. What is your gender?

○ Male ○ Female

29. Please indicate your year of Birth. (This is a optional question)

30. Please provide your height. (This is an optional question)

31. Please provide your weight. (This is an optional question)

32. Which of the following best describes your current employment status?

○ Full-time, working from/at home

○ Full-time employment

○ Part-time employment

○ Casual employment

○ Student

○ Unemployed

○ Other (please specify)

33. Please describe your household structure.

○ Single Person – shared accommodation

○ Single Person – non-shared accommodation

○ Lone parent with at least one resident child

○ Couple with at least one resident child

○ Couple with no resident children

○ Other household structure

34. If you have any suggestions or comments, or wish to provide any additional information which may be important to this survey please provide below.

Thank you for taking the time to complete this survey.

Please contact Dr. Bidisha Ghosh (bghosh@tcd.ie) for further queries.

APPENDIX II: 'SHORTEST-PATH' AND OBSERVED ROUTE CHOICE MAPS

Chapter 5 'Shortest-path' and observed route comparison: Trip ID 1

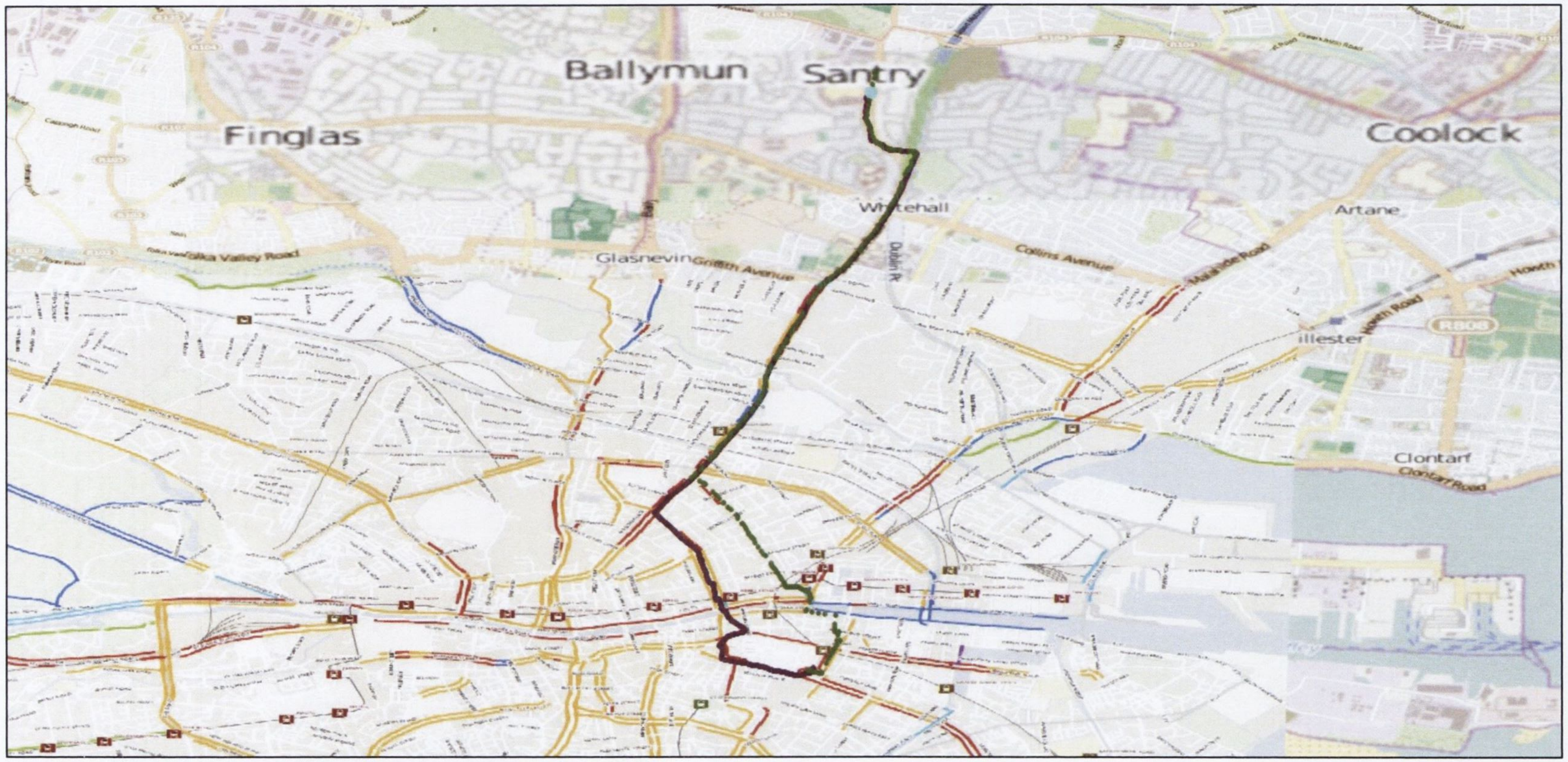
Chapter 5 'Shortest-path' and observed route comparison: Trip ID 2

Chapter 5 'Shortest-path' and observed route comparison: Trip ID 3

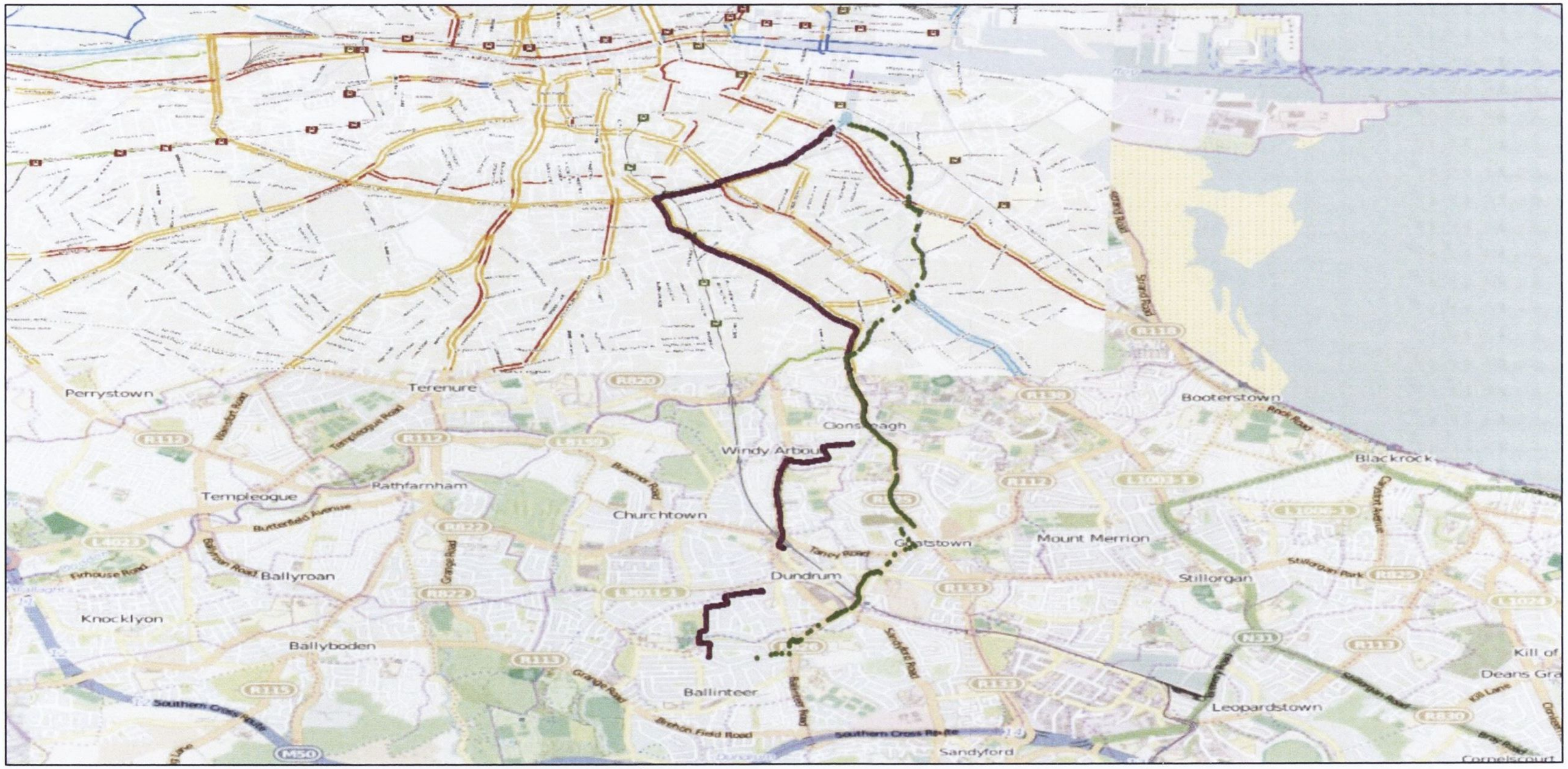
Chapter 5 'Shortest-path' and observed route comparison: Trip ID 4

Chapter 5 'Shortest-path' and observed route comparison: Trip ID 5

Chapter 5 'Shortest-path' and observed route comparison: Trip ID 6



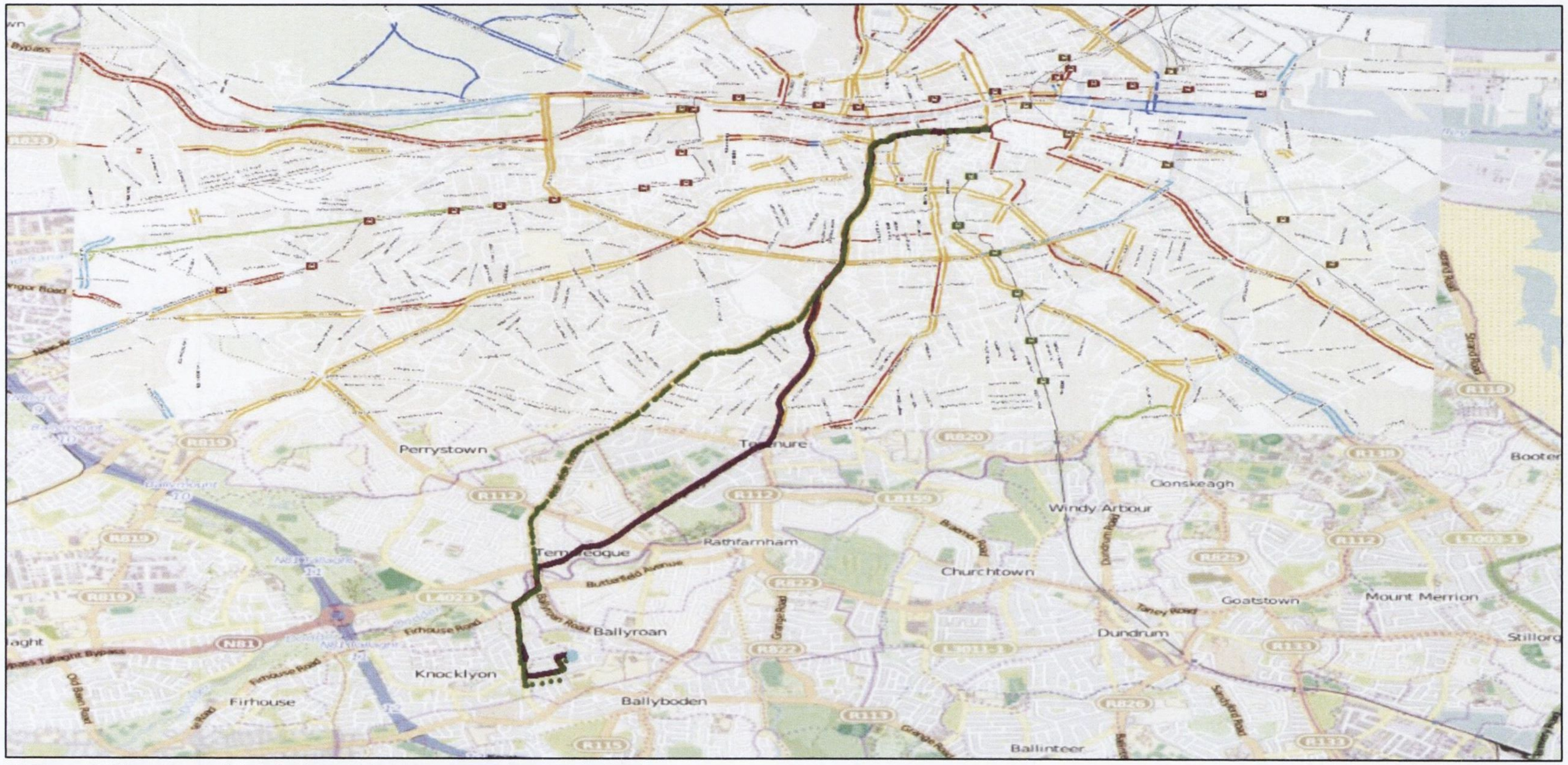
Chapter 5 'Shortest-path' and observed route comparison: Trip ID 7



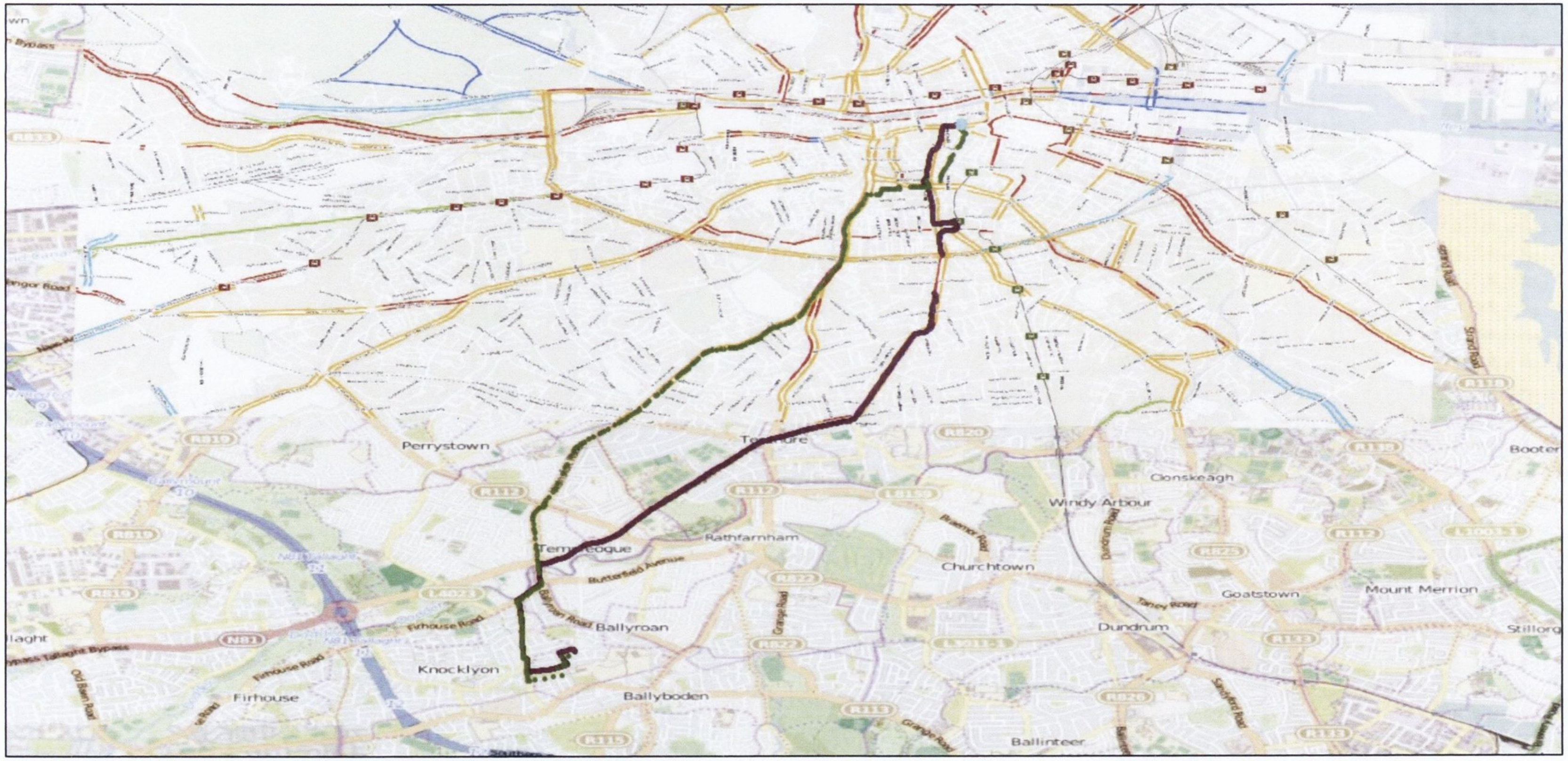
Chapter 5 'Shortest-path' and observed route comparison: Trip ID 8

Chapter 5 'Shortest-path' and observed route comparison: Trip ID 9 and 10

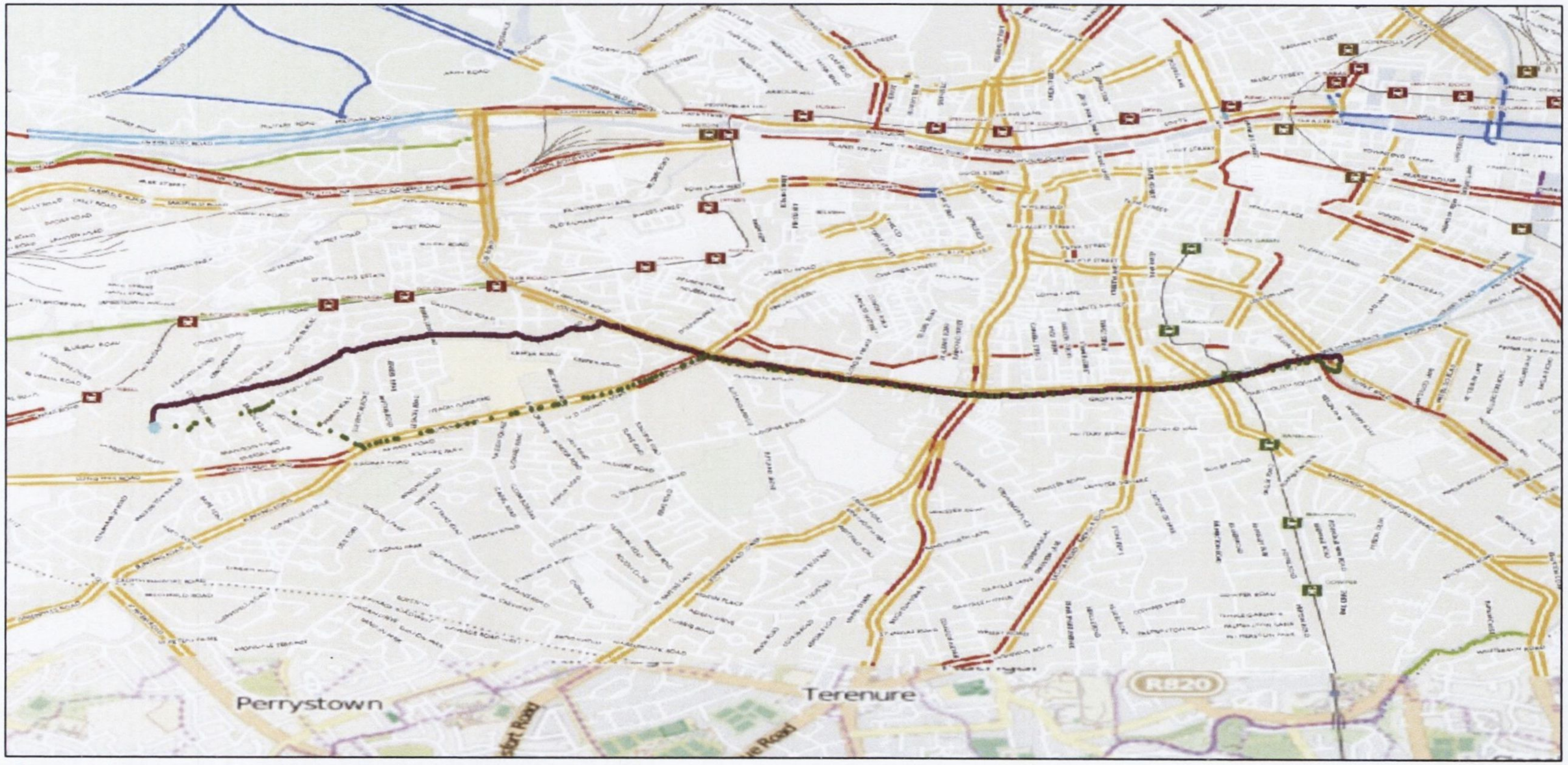
Chapter 5 'Shortest-path' and observed route comparison: Trip ID 11



Chapter 5 'Shortest-path' and observed route comparison: Trip ID 12



Chapter 5 'Shortest-path' and observed route comparison: Trip ID 13



Chapter 5 'Shortest-path' and observed route comparison: Trip ID 14

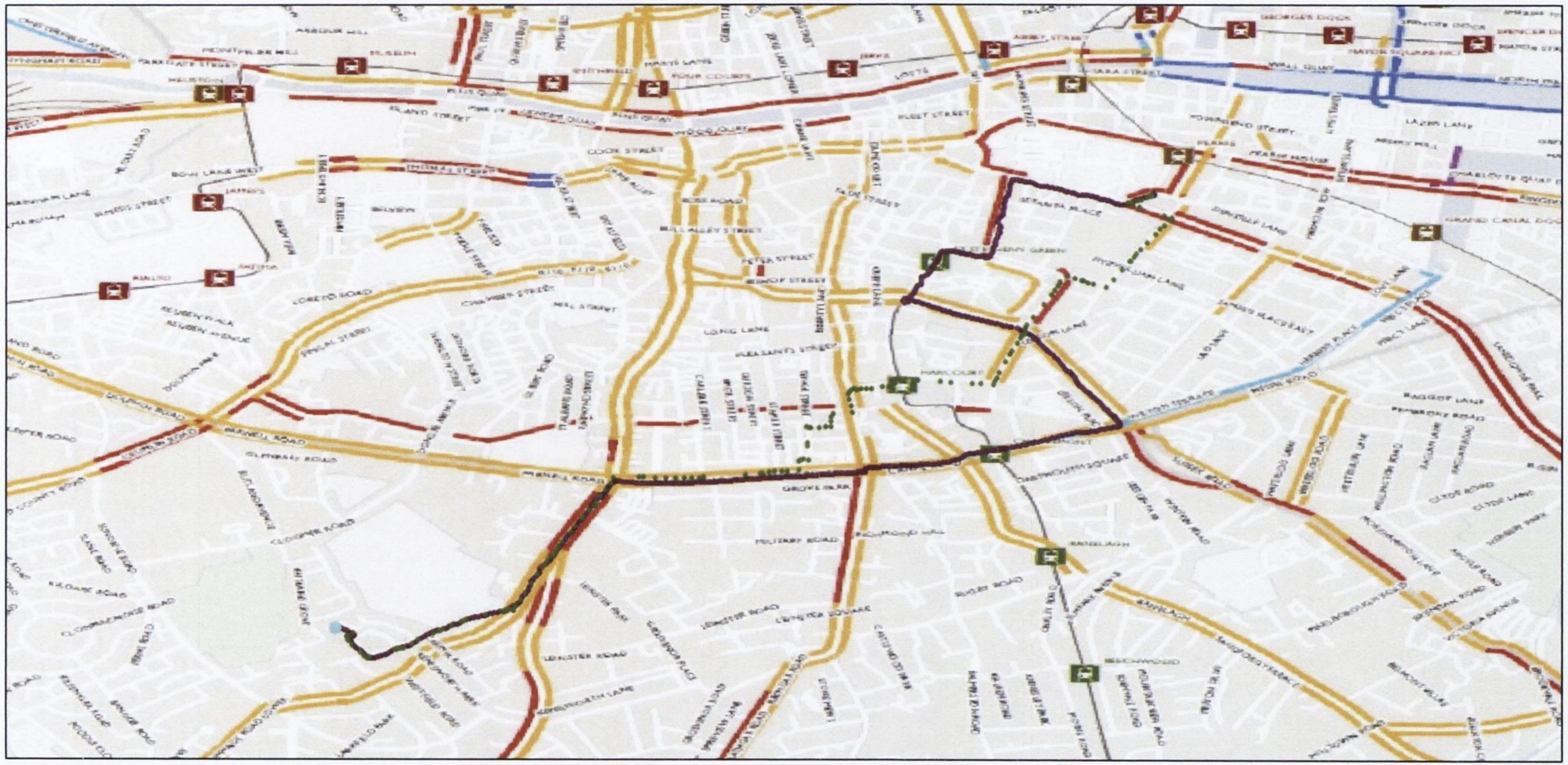
Chapter 5 'Shortest-path' and observed route comparison: Trip ID 15

Chapter 5 'Shortest-path' and observed route comparison: Trip ID 16

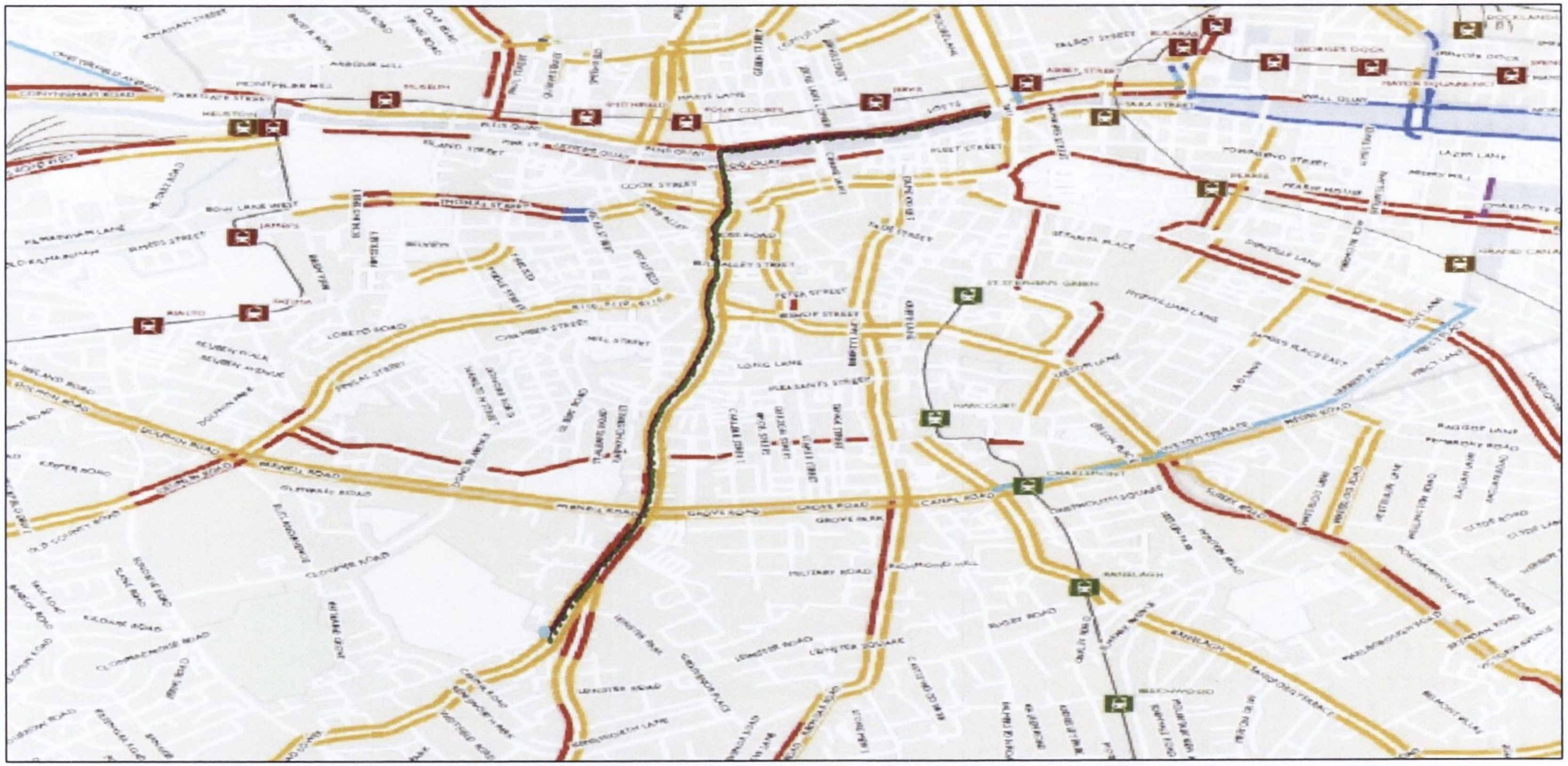
Chapter 5 'Shortest-path' and observed route comparison: Trip ID 17

Chapter 5 'Shortest-path' and observed route comparison: Trip ID 18

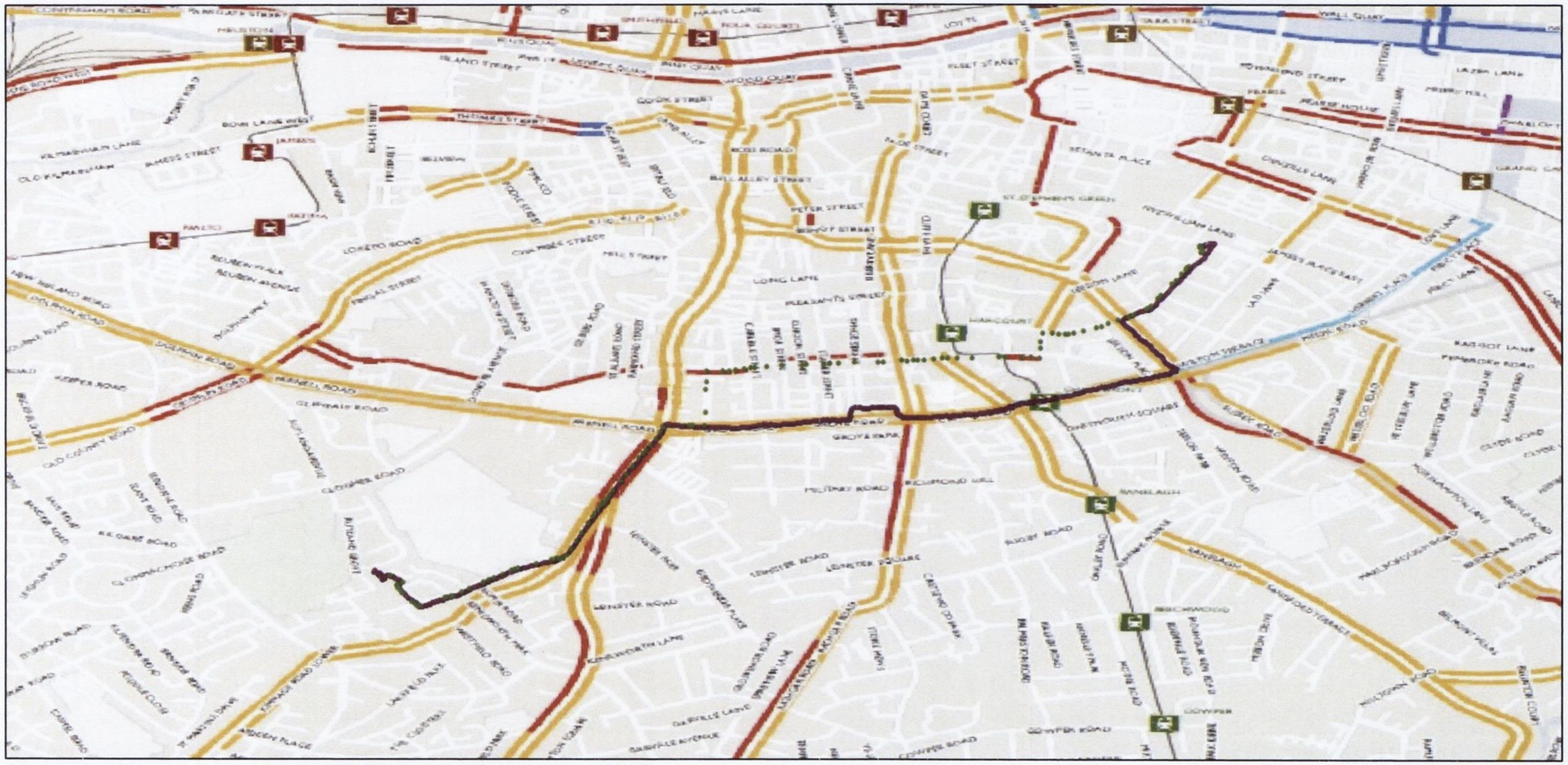
Chapter 5 'Shortest-path' and observed route comparison: Trip ID 19



Chapter 5 'Shortest-path' and observed route comparison: Trip ID 20

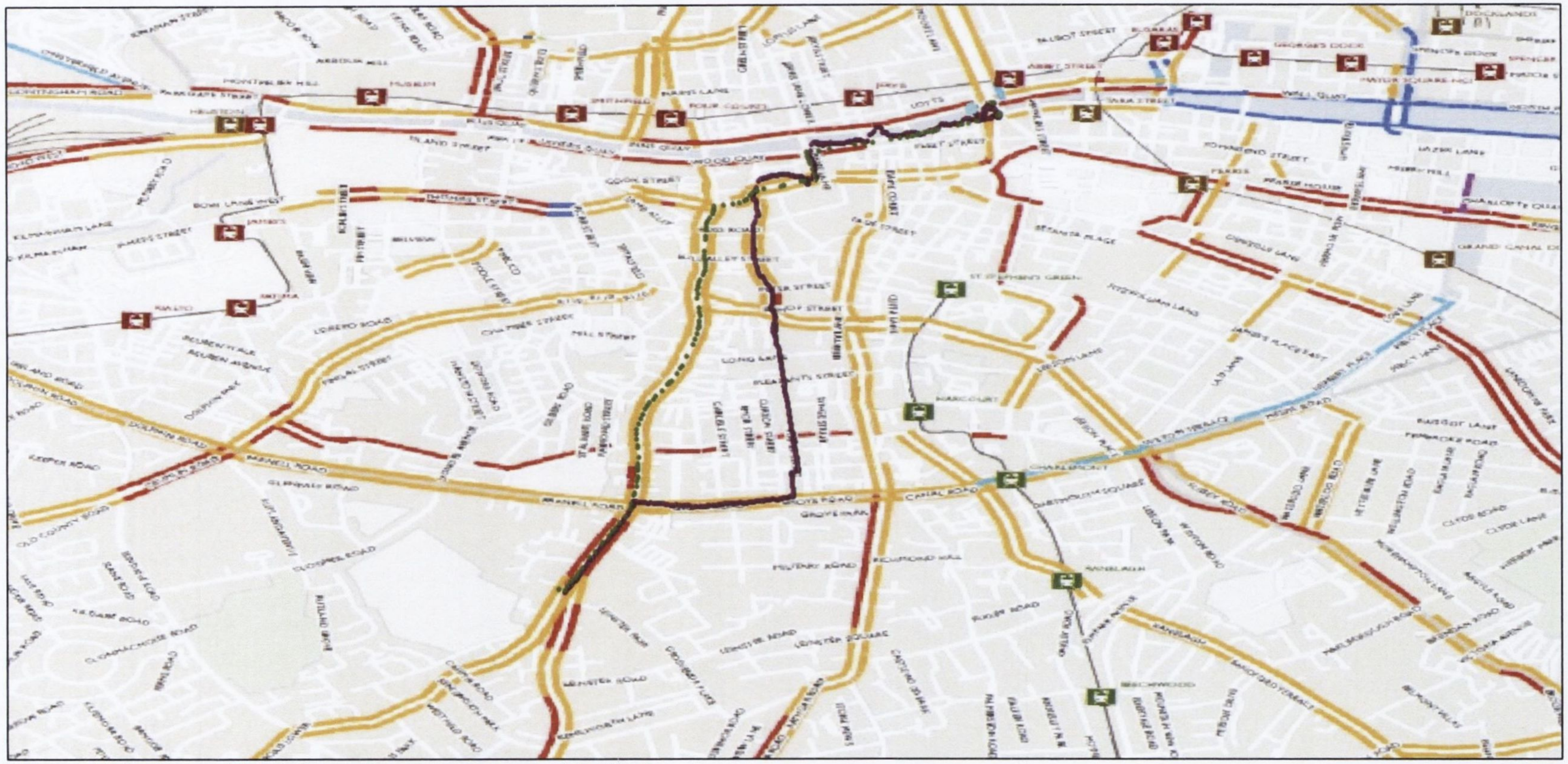


Chapter 5 'Shortest-path' and observed route comparison: Trip ID 21



Chapter 5 'Shortest-path' and observed route comparison: Trip ID 22

Chapter 5 'Shortest-path' and observed route comparison: Trip ID 23



Chapter 5 ‘Shortest-path’ and observed route comparison: Trip ID 24

Chapter 5 'Shortest-path' and observed route comparison: Trip ID 25

Chapter 5 'Shortest-path' and observed route comparison: Trip ID 26

APPENDIX III: MULTI-MODAL NETWORK EXAMPLE – AUTO AND BUS MODE RESULTS

Chapter 6 Link flows and travel times for auto mode in the multi-modal network example.

Link No.	Flow v_s^c persons/hr	In-vehicle time t_s^c hr
1	1711	0.067
2	603	0.133
3	1591	0.089
4	1108	0.134
5	603	0.067
6	1014	0.156
7	2381	0.118
8	577	0.133
9	2477	0.121
10	2984	0.114
11	577	0.089
12	3054	0.091

Chapter 6 Route flows, in-vehicle travel times, walking times, monetary costs and disutilities for auto mode in the multi-modal network example.

Route No.	Flow h_p^a persons/hr	In-vehicle time T_p^a hr	Walking time Z_p^a hr	Monetary cost Λ^a €	Disutility u_p^a €
1	603	0.380	0.1	10	15.80
2	543	0.433	0.1	10	16.33
3	565	0.413	0.1	10	16.13
4	497	0.477	0.1	10	16.77
5	517	0.457	0.1	10	16.57
6	577	0.402	0.1	10	16.02
7	1341	0.232	0.1	6	10.32
8	1395	0.212	0.1	6	10.12

Chapter 6 Link bus flows, passenger flows and travel times for bus mode in the multi-modal network example.

Link No.	Bus frequency F_s^b Bus/hr	Bus flow (in auto equivalents) v_s^b auto-vehicles/hr	Passenger flow x_s^b persons/hr	In-vehicle time t_p^b hr
1	15	60	800	0.150
2	15	60	800	0.300
3	20	80	1650	0.200
4	0	0	0	~
5	15	60	800	0.150
6	20	80	1650	0.351
7	15	60	1766	0.266
8	0	0	0	~
9	40	160	3958	0.272
10	30	120	2566	0.256
11	0	0	0	~
12	40	160	3958	0.205

Chapter 6 Link passenger flows and in-vehicle crowding discomforts on each line for bus mode in the multi-modal network example.

	Passenger flow				In-vehicle crowding discomfort			
	L1 $x_{1,s}^b$	L2 $x_{2,s}^b$	L3 $x_{3,s}^b$	L4 $x_{4,s}^b$	L1 $g_{1,s}^b$	L2 $g_{2,s}^b$	L3 $g_{3,s}^b$	L4 $g_{4,s}^b$
Link No.	persons/hr				hr			
1	800	0	0	0	0.024	~	~	~
2	800	0	0	0	0.003	~	~	~
3	0	1650	0	0	~	0.005	~	~
4	~	~	~	~	~	~	~	~
5	800	0	0	0	0.001	~	~	~
6	0	1650	0	0	~	0.008	~	~
7	0	0	1766	0	~	~	0.013	~
8	~	~	~	~	~	~	~	~
9	0	1988	0	1971	~	0.009	~	0.009
10	1268	0	1298	0	0.006	~	0.007	~
11	~	~	~	~	~	~	~	~
12	0	1981	0	1978	~	0.007	~	0.007

Chapter 6 Route passenger flows, in-vehicle travel times, walking times, in-vehicle crowding discomforts, waiting times, monetary costs and disutilities for bus mode in the multi-modal network example.

Route No.	Flow h_p^b persons/hr	In-vehicle time T_p^b hr	Walking time Z_p^b hr	In-vehicle Crowding discomfort g_p^b hr	Waiting time W_p^b hr	Monetary cost Λ^b €	Disutility u_p^b €
1	414	0.856	0.250	0.035	0.021	3	17.69
2	299	1.029	0.250	0.029	0.021	3	19.30
3	387	0.856	0.250	0.035	0.038	3	18.03
4	282	1.029	0.250	0.032	0.034	3	19.60
5	261	1.073	0.250	0.033	0.031	3	19.99
6	289	1.029	0.250	0.029	0.031	3	19.48
7	244	1.073	0.250	0.032	0.047	3	20.32
8	275	1.029	0.250	0.029	0.043	3	19.73
9	651	0.522	0.250	0.019	0.016	3	13.93
10	721	0.478	0.250	0.016	0.016	3	13.43
11	721	0.478	0.250	0.016	0.016	3	13.42
12	610	0.522	0.250	0.019	0.033	3	14.26
13	685	0.4775	0.250	0.016	0.029	3	13.68
14	686	0.4775	0.250	0.016	0.029	3	13.67

APPENDIX IV: CORDONED, SINGLE HOUR DEMAND MATRIX

Chapter 7 NTA Bicycle demands- cordoned, single hour work trip matrix.

OD Code	2117	2118	2130	2132	2144	2145	2146	2147	9000	9001	9002	9003	9004	9005	9006	9007	9008	9009	9010	9011	9012
2117	0.18	0.18	0.45	0.36	0.00	0.00	0.54	0.18	0.00	0.00	0.00	0.13	0.01	0.31	0.19	0.19	0.00	0.00	0.00	0.00	0.00
2118	0.09	0.00	0.09	0.00	0.00	0.00	0.18	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.00	0.00	0.00	0.00	0.00
2130	0.72	1.08	0.36	0.54	0.54	0.18	2.16	1.98	0.00	0.00	0.00	0.44	0.00	0.08	1.29	0.04	0.41	0.00	0.00	0.00	0.00
2132	0.99	0.27	0.45	0.54	0.99	0.27	1.08	1.08	0.00	0.00	0.00	0.06	0.00	0.72	0.00	0.75	0.20	0.00	0.00	0.00	0.00
2144	0.18	0.99	0.45	0.00	0.27	0.18	0.27	0.63	0.00	0.00	0.00	0.00	0.09	0.09	0.00	0.40	0.00	0.35	0.03	0.01	0.00
2145	0.00	0.09	0.00	0.09	0.00	0.00	0.09	0.09	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.09	0.09	0.00	0.00	0.00
2146	0.72	0.72	0.54	0.36	0.63	0.27	0.45	1.62	0.00	0.00	0.00	0.06	0.00	0.12	0.00	0.36	0.00	0.84	0.00	0.00	0.00
2147	1.80	0.90	0.90	0.36	0.45	0.36	2.25	0.81	0.00	0.00	0.00	0.18	0.00	0.93	1.91	0.10	0.13	0.09	0.00	0.00	0.00
9000	15.01	3.31	2.15	0.83	2.85	3.18	4.33	6.17	0.00	0.00	0.00	0.61	0.00	1.04	0.69	0.43	0.41	0.13	0.00	0.00	0.00
9001	20.74	19.48	0.96	1.86	6.59	1.93	8.35	7.19	0.00	0.00	0.00	0.23	0.03	2.24	2.35	1.02	0.68	0.11	0.00	0.00	0.00
9002	0.00	6.46	0.00	0.90	8.10	1.52	4.33	6.68	0.00	0.00	0.00	0.00	0.15	2.08	1.00	0.25	0.53	0.78	0.05	0.04	0.00
9003	2.00	0.81	3.10	0.45	0.94	0.45	0.90	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00
9004	0.31	0.77	0.36	0.00	0.23	0.50	0.30	2.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9005	5.93	8.01	1.23	4.18	1.03	1.80	1.70	10.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.62	0.00	0.00	0.00	0.00
9006	4.20	0.00	1.91	0.54	0.00	0.00	0.00	9.50	0.00	0.00	0.00	0.14	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9007	1.78	4.75	0.00	1.81	1.77	0.58	3.82	4.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9008	0.63	0.54	2.13	0.36	0.00	0.07	0.00	3.84	0.00	0.00	0.00	0.09	0.00	2.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9009	0.60	1.38	0.23	0.19	5.11	1.29	11.78	1.12	0.00	0.00	0.00	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9010	4.77	6.87	0.00	0.00	0.63	2.28	0.37	1.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.58
9011	0.45	0.38	0.08	0.07	0.00	0.00	0.11	0.94	0.00	0.00	0.00	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9012	0.40	0.40	0.31	0.08	0.00	0.00	0.00	1.02	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	1.23	0.00	0.00
9013	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9014	0.73	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9015	0.00	3.86	0.00	0.50	4.33	0.72	2.23	3.31	0.00	0.00	0.00	0.00	0.08	1.14	0.05	0.15	0.37	0.42	0.03	0.00	0.00

Chapter 7 NTA Bicycle demands- cordoned, single hour work trip matrix.

OD Code	2117	2118	2130	2132	2144	2145	2146	2147	9000	9001	9002	9003	9004	9005	9006	9007	9008	9009	9010	9011	9012
9016	0.00	6.96	0.14	1.69	0.00	1.94	9.41	1.45	0.00	0.00	0.00	0.00	0.07	1.34	0.00	3.57	0.10	3.32	0.23	0.17	0.00
9017	0.05	0.10	0.00	0.00	0.10	0.06	3.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.83	0.00	0.81	0.04	0.03	0.00
9018	0.00	0.00	0.62	0.97	0.00	0.00	0.00	1.29	0.00	0.00	0.00	0.00	0.02	0.29	0.00	0.72	0.00	1.10	0.04	0.03	0.00
9019	13.58	15.39	1.99	1.73	7.23	5.52	15.27	18.37	0.00	0.00	0.00	0.27	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9020	0.00	0.00	0.21	0.27	0.00	0.00	0.00	0.42	0.00	0.00	0.00	0.00	0.01	0.11	0.00	0.56	0.00	0.36	0.02	0.01	0.00
9021	1.54	0.18	0.30	0.00	0.00	0.00	0.00	1.92	0.00	0.00	0.00	0.04	0.02	0.07	0.00	0.00	0.01	0.00	0.00	0.00	0.00
9022	7.30	0.00	0.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9023	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9024	4.75	0.59	0.51	0.00	0.00	0.00	0.00	5.56	0.00	0.00	0.00	0.19	0.07	0.55	0.00	0.00	0.03	0.00	0.00	0.00	0.00
9025	0.00	0.03	0.00	0.00	0.14	0.04	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9026	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9027	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9028	0.00	0.00	0.00	0.04	0.98	0.00	0.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.22	0.02	0.27	0.00	0.00	0.00
9029	0.20	0.57	0.20	0.47	10.76	0.00	0.00	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9030	0.08	0.00	0.17	0.04	0.70	5.03	0.00	0.82	0.00	0.00	0.00	0.02	0.01	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00
9031	2.73	1.89	4.42	5.12	0.30	0.28	2.93	26.72	0.00	0.00	0.00	1.04	0.00	6.28	9.53	0.70	2.22	0.07	0.00	0.00	0.00
9032	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9033	1.95	8.03	0.10	0.00	5.84	4.73	0.05	1.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00
9034	0.28	0.30	0.00	0.00	0.26	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9035	0.00	0.00	1.60	5.42	0.00	0.00	0.00	3.98	0.00	0.00	0.00	0.35	0.00	0.00	0.00	0.62	0.00	0.00	0.00	0.00	0.00
9036	0.00	0.66	0.00	1.99	0.00	0.00	0.32	1.62	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9037	0.05	0.00	0.16	0.02	3.38	1.33	0.01	1.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
9038	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9039	2.33	1.97	1.80	4.56	0.00	0.55	11.65	12.13	0.00	0.00	0.00	0.49	0.06	1.41	0.00	2.79	0.00	2.47	0.23	0.20	0.00
9040	0.12	0.39	0.24	0.33	0.00	0.14	5.89	1.28	0.00	0.00	0.00	0.00	0.01	0.10	0.00	0.24	0.00	0.00	0.00	0.00	0.00
9041	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.07	0.00	0.00	0.00

Chapter 7 NTA Bicycle demands- cordoned, single hour work trip matrix.

OD Code	2117	2118	2130	2132	2144	2145	2146	2147	9000	9001	9002	9003	9004	9005	9006	9007	9008	9009	9010	9011	9012
9042	0.00	0.00	0.00	0.00	0.67	0.07	1.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9043	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9044	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.81	0.00	0.00	0.16	0.00	0.00	0.00	0.00
9045	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9046	0.00	0.22	0.00	0.63	0.00	0.13	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.00	0.00	0.00
9047	0.00	0.00	0.00	0.00	0.14	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9048	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9049	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9050	0.00	0.00	0.00	0.00	0.00	0.00	0.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9051	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9052	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9053	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Chapter 7 NTA Bicycle demands- cordoned, single hour work trip matrix.

OD Code	9013	9014	9015	9016	9017	9018	9019	9020	9021	9022	9023	9024	9025	9026	9027	9028	9029	9030	9031	9032	9033
2117	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.06	0.00	0.00	0.18	0.00	0.00	0.00	0.00	0.07	0.00	0.49	0.11	0.00
2118	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.28	0.00	0.00
2130	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.25	0.00	0.06	0.45	0.00	0.00	0.00	0.00	0.37	0.00	2.15	0.26	0.00
2132	0.00	0.00	0.02	1.19	0.00	0.00	0.09	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.10	0.00	0.00	1.86	0.00	0.00
2144	0.02	0.00	0.14	0.00	0.02	0.00	0.04	0.00	0.00	0.00	0.15	0.00	0.00	0.00	0.00	0.00	1.02	0.13	0.00	0.00	0.00
2145	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00
2146	0.00	0.00	0.00	0.89	0.26	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.36	0.00	0.00	1.17	0.00	0.00
2147	0.00	0.00	0.00	0.05	0.00	0.00	0.40	0.00	0.08	0.00	0.07	0.39	0.00	0.00	0.00	0.00	0.03	0.04	2.52	0.32	0.00
9000	0.00	0.00	0.00	0.00	0.04	0.00	0.21	0.00	0.00	0.26	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.06
9001	0.00	0.00	0.00	0.00	0.00	0.00	0.69	0.00	0.33	1.44	0.00	1.74	0.00	0.00	0.00	0.00	0.67	0.00	0.00	0.98	0.05
9002	0.07	17.21	0.00	0.00	0.00	0.00	0.23	0.00	0.31	4.25	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.30	0.00
9003	0.00	0.00	0.00	0.00	0.00	0.00	0.31	0.00	0.10	0.00	0.02	0.26	0.00	0.00	0.00	0.00	0.19	0.00	2.84	0.22	0.00
9004	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.03	0.56	0.04	0.00
9005	0.00	0.00	0.00	1.49	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.05	0.00	0.00	0.00	0.09	0.00	0.01	8.06	0.24	0.00
9006	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.29	0.00	0.00
9007	0.00	0.00	0.00	3.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.35	0.00	0.03	2.00	0.00	0.00
9008	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.55	0.00	0.00
9009	5.26	0.00	0.00	3.60	1.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.34	0.00	0.00	0.67	0.00	0.00
9010	0.00	0.00	0.00	0.75	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.00	0.04	3.69	0.00	0.00
9011	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.45	0.00	0.00
9012	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.58	0.00	0.00
9013	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9014	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9015	0.02	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Chapter 7 NTA Bicycle demands- cordoned, single hour work trip matrix.

OD Code	9013	9014	9015	9016	9017	9018	9019	9020	9021	9022	9023	9024	9025	9026	9027	9028	9029	9030	9031	9032	9033
9016	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9017	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9018	0.04	0.00	0.00	0.00	0.00	0.00	3.87	0.00	0.00	0.00	0.00	0.00	0.55	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9019	0.00	0.00	0.00	2.28	0.49	0.68	0.00	0.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.01	0.00	0.00	11.02	0.00	0.00
9020	0.01	0.00	0.00	0.00	0.00	0.00	1.35	0.00	0.00	0.00	0.00	0.00	0.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9021	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9022	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9023	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	1.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9024	0.00	0.00	0.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.93	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9025	0.00	0.00	0.00	0.11	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00
9026	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	22.96	0.00	0.00	0.00	0.00	0.00	0.00
9027	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9028	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9029	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9030	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9031	0.00	0.00	0.00	0.00	0.00	0.00	0.83	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.22	0.00
9032	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9033	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9034	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9035	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.00	0.00
9036	0.00	0.00	0.00	0.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00
9037	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9038	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9039	0.19	0.00	0.00	0.00	0.00	0.00	0.42	0.00	0.00	0.00	0.00	0.00	3.41	0.00	0.00	0.00	0.00	0.00	2.30	0.00	0.00
9040	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9041	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Chapter 7 NTA Bicycle demands- cordoned, single hour work trip matrix.

OD Code	9013	9014	9015	9016	9017	9018	9019	9020	9021	9022	9023	9024	9025	9026	9027	9028	9029	9030	9031	9032	9033
9042	0.00	0.00	0.00	0.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00
9043	0.00	0.00	0.00	0.00	0.00	0.00	0.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9044	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9045	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9046	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
9047	0.00	0.00	0.00	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00
9048	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9049	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9050	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9051	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9052	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9053	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Chapter 7 NTA Bicycle demands- cordoned, single hour work trip matrix.

OD Code	9034	9035	9036	9037	9038	9039	9040	9041	9042	9043	9044	9045	9046	9047	9048	9049	9050	9051	9052	9053
2117	0.00	0.07	0.00	0.00	0.24	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.14	0.00	0.00	0.00	0.00
2118	0.00	0.03	0.00	0.09	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00
2130	0.00	0.36	0.00	0.00	0.92	0.16	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.08	0.00	0.00	0.00	0.00
2132	0.00	0.09	0.79	0.00	0.76	0.18	0.13	0.00	0.00	0.00	0.00	0.03	0.00	0.16	0.00	0.27	0.00	0.00	0.00	0.00
2144	0.11	0.00	0.00	0.00	1.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2145	0.00	0.00	0.00	0.14	0.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2146	0.00	0.00	0.03	0.00	1.64	0.00	1.20	0.00	0.15	0.00	0.00	0.03	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.51
2147	0.00	0.45	0.03	0.00	1.17	0.33	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.21	0.37	0.00	0.00	0.00	0.00
9000	0.31	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9001	0.28	0.67	0.00	0.00	0.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9002	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9003	0.00	0.12	0.00	0.00	1.69	0.13	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.15	0.00	0.00	0.00	0.00
9004	0.00	0.00	0.00	0.00	0.40	0.05	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00
9005	0.00	0.00	0.00	0.00	3.59	0.32	0.41	0.00	0.00	0.00	3.63	0.00	0.00	0.00	0.05	1.49	0.00	0.00	0.00	0.00
9006	0.00	0.00	0.00	0.00	0.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.70	0.00	0.00	0.00	0.00
9007	0.00	0.45	0.00	0.00	0.88	0.88	0.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.31	0.00	0.02	0.00	0.00
9008	0.00	0.00	0.00	0.00	0.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.04	0.00	0.00	0.00	0.00
9009	0.00	0.00	0.00	0.00	4.35	1.29	2.21	1.66	0.00	0.00	0.00	0.01	0.02	0.00	0.00	0.00	0.00	0.39	0.00	2.00
9010	0.00	0.00	0.00	0.00	5.35	0.23	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.00
9011	0.00	0.00	0.00	0.00	0.00	0.09	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9012	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9013	0.00	0.00	0.00	0.00	0.00	0.09	0.02	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9014	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.00	0.00
9015	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Chapter 7 NTA Bicycle demands- cordoned, single hour work trip matrix.

OD Code	9034	9035	9036	9037	9038	9039	9040	9041	9042	9043	9044	9045	9046	9047	9048	9049	9050	9051	9052	9053
9016	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9017	0.00	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9018	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.03	0.04	0.00	0.00	0.00	0.00	0.00	0.00
9019	0.00	0.00	0.00	0.00	8.84	0.31	0.52	0.00	0.00	0.99	0.00	0.08	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.94
9020	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9021	0.00	0.00	0.00	0.00	1.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9022	0.00	0.00	0.00	0.00	6.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.46	0.00	0.00	0.00	0.00	0.00
9023	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9024	0.00	0.00	0.00	0.00	5.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9025	0.00	0.00	0.00	0.00	0.17	2.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05
9026	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9027	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9028	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9029	0.00	0.00	0.00	0.00	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9030	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9031	0.00	0.91	0.15	0.00	0.40	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9032	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9033	0.00	0.00	0.00	0.00	1.50	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9034	0.00	0.00	0.00	0.00	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9035	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.77	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9036	0.00	0.00	0.00	0.00	0.00	0.03	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9037	0.00	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9038	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9039	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00	2.36	0.00	0.00	0.11	0.12	0.28	0.00	0.00	0.00	0.00	0.00	0.00
9040	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9041	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Chapter 7 NTA Bicycle demands- cordoned, single hour work trip matrix.

OD Code	9034	9035	9036	9037	9038	9039	9040	9041	9042	9043	9044	9045	9046	9047	9048	9049	9050	9051	9052	9053
9042	0.00	0.50	0.00	0.00	0.00	0.29	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00
9043	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9044	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9045	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9046	0.00	0.10	0.00	0.00	0.00	0.05	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00
9047	0.00	0.00	0.00	0.00	0.00	0.03	0.06	0.00	0.00	0.00	0.00	0.00	0.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9048	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9049	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9050	0.00	0.00	0.00	0.00	0.00	0.03	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9051	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9052	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9053	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Chapter 7 NTA Bicycle demands- cordoned, single hour education trip matrix.

OD Code	2117	2118	2130	2132	2144	2145	2146	2147	9000	9001	9002	9003	9004	9005	9006	9007	9008	9009	9010	9011	9012
2117	0.98	0.00	0.00	0.00	0.08	0.16	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.12	0.04	0.16	0.00	0.00	0.00	0.00
2118	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00
2130	0.66	0.08	0.00	0.33	0.25	0.08	0.00	0.00	0.00	0.00	0.00	1.15	0.00	0.00	0.47	0.02	0.25	0.00	0.00	0.00	0.00
2132	0.74	0.16	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.88	0.05	0.00	0.00	0.00	0.00
2144	0.41	0.16	0.00	0.00	0.08	0.16	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.00	0.09	0.00	0.00	0.00
2145	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00
2146	0.49	0.08	0.00	0.08	0.41	0.16	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.72	0.00	0.70	0.00	0.00	0.00
2147	0.74	0.33	0.00	0.16	0.41	0.49	0.08	0.16	0.00	0.00	0.00	0.00	0.70	0.12	0.41	0.00	0.00	0.00	0.00	0.00	0.00
9000	6.62	0.11	0.00	0.00	1.07	0.48	0.19	0.04	0.00	0.00	0.00	0.02	0.00	0.08	0.35	0.26	0.00	0.00	0.00	0.00	0.00
9001	6.74	0.46	0.00	0.00	1.13	0.35	0.14	0.08	0.00	0.00	0.00	0.03	0.02	0.00	1.07	0.19	0.00	0.00	0.00	0.00	0.00
9002	0.00	0.10	0.00	0.00	1.94	0.14	0.08	0.03	0.00	0.00	0.00	0.00	0.00	0.08	0.42	0.12	0.00	0.00	0.00	0.00	0.00
9003	1.40	0.08	0.00	0.16	0.33	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9004	0.24	0.00	0.00	0.00	0.00	0.19	0.00	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9005	3.43	0.00	0.00	0.19	0.50	0.25	0.03	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.65	0.00	0.00	0.00	0.00
9006	2.65	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9007	1.22	0.15	0.00	0.12	0.81	0.49	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9008	0.49	0.00	0.00	0.16	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9009	0.19	0.05	0.00	0.00	1.04	0.17	0.53	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9010	3.74	0.62	0.00	0.00	0.16	0.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10
9011	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9012	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9013	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9014	0.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9015	0.00	0.06	0.00	0.00	1.09	0.09	0.05	0.01	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.06	0.00	0.00	0.00	0.00	0.00

Chapter 7 NTA Bicycle demands- cordoned, single hour education trip matrix.

OD Code	2117	2118	2130	2132	2144	2145	2146	2147	9000	9001	9002	9003	9004	9005	9006	9007	9008	9009	9010	9011	9012
9016	0.00	0.31	0.00	0.00	0.00	0.20	0.22	0.00	0.00	0.00	0.00	0.00	0.05	0.02	0.00	1.55	0.00	0.48	0.00	0.00	0.00
9017	0.04	0.01	0.00	0.00	0.01	0.02	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.11	0.00	0.00	0.00
9018	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.05	0.04	0.00	0.25	0.00	0.62	0.00	0.00	0.00
9019	10.40	0.44	0.00	0.11	2.61	0.99	0.56	0.17	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9020	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.02	0.03	0.00	0.22	0.00	0.17	0.00	0.00	0.00
9021	0.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9022	4.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9023	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9024	2.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.05	0.00	0.00	0.05	0.00	0.00	0.00	0.00
9025	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9026	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9027	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9028	0.00	0.00	0.00	0.00	0.31	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.01	0.00	0.00	0.00
9029	0.09	0.00	0.00	0.00	2.83	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9030	0.04	0.00	0.00	0.00	0.15	0.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9031	1.52	0.16	0.00	0.00	0.03	0.16	0.08	0.16	0.00	0.00	0.00	0.32	0.00	0.20	3.20	0.00	0.08	0.00	0.00	0.00	0.00
9032	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9033	1.50	0.40	0.00	0.00	2.11	0.98	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9034	0.21	0.02	0.00	0.00	0.02	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9035	0.00	0.00	0.00	0.38	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.59	0.00	0.00	0.00	0.00	0.00
9036	0.00	0.00	0.00	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9037	0.04	0.00	0.00	0.00	1.30	0.19	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9038	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9039	1.23	0.09	0.00	0.00	0.00	0.06	0.41	0.19	0.00	0.00	0.00	0.00	0.03	0.08	0.00	1.55	0.00	0.85	0.00	0.00	0.00
9040	0.09	0.03	0.00	0.02	0.00	0.04	0.66	0.02	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.08	0.00	0.00	0.00	0.00	0.00
9041	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.94	0.00	0.00	0.00

Chapter 7 NTA Bicycle demands- cordoned, single hour education trip matrix.

OD Code	2117	2118	2130	2132	2144	2145	2146	2147	9000	9001	9002	9003	9004	9005	9006	9007	9008	9009	9010	9011	9012
9042	0.00	0.00	0.00	0.00	0.18	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9043	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9044	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.55	0.00	0.00	0.04	0.00	0.00	0.00	0.00
9045	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9046	0.00	0.00	0.00	0.25	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9047	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9048	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9049	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9050	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9051	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9052	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9053	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Chapter 7 NTA Bicycle demands- cordoned, single hour education trip matrix.

OD Code	9013	9014	9015	9016	9017	9018	9019	9020	9021	9022	9023	9024	9025	9026	9027	9028	9029	9030	9031	9032	9033
2117	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.04	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.12	0.00	0.00	0.01	0.00
2118	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2130	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00
2132	0.00	0.00	0.00	0.19	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00
2144	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2145	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2146	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2147	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.01	0.06	0.00	0.00	0.00	0.00	0.05	0.07	0.20	0.03	0.00
9000	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.03	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00
9001	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.05	0.13	0.00	0.12	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.36	0.01
9002	0.00	1.41	0.00	0.00	0.00	0.00	0.02	0.00	0.03	0.34	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.22	0.00
9003	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.00	0.00
9004	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
9005	0.00	0.00	0.00	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.06	0.00	0.00	0.00	0.03	0.00	0.00	0.63	0.03	0.00
9006	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.32	0.00	0.00
9007	0.00	0.00	0.00	0.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.05	0.00	0.00
9008	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.00	0.00
9009	0.45	0.00	0.00	0.32	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.00	0.00	0.00	0.00	0.00
9010	0.00	0.00	0.00	0.20	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.01	0.11	0.00	0.00
9011	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9012	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9013	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9014	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9015	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Chapter 7 NTA Bicycle demands- cordoned, single hour education trip matrix.

OD Code	9013	9014	9015	9016	9017	9018	9019	9020	9021	9022	9023	9024	9025	9026	9027	9028	9029	9030	9031	9032	9033
9016	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9017	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9018	0.00	0.00	0.00	0.00	0.00	0.00	0.74	0.00	0.00	0.00	0.00	0.00	0.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9019	0.00	0.00	0.00	0.34	0.08	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.41	0.00	0.00	0.08	0.00	0.00
9020	0.00	0.00	0.00	0.00	0.00	0.00	0.21	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9021	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9022	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9023	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9024	0.00	0.00	0.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9025	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9026	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.79	0.00	0.00	0.00	0.00	0.00	0.00
9027	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9028	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9029	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9030	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9031	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00
9032	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9033	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9034	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9035	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00
9036	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
9037	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9038	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9039	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00	1.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9040	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9041	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Chapter 7 NTA Bicycle demands- cordoned, single hour education trip matrix.

OD Code	9013	9014	9015	9016	9017	9018	9019	9020	9021	9022	9023	9024	9025	9026	9027	9028	9029	9030	9031	9032	9033
9042	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
9043	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9044	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9045	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9046	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9047	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9048	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9049	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9050	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9051	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9052	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9053	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Chapter 7 NTA Bicycle demands- cordoned, single hour education trip matrix.

OD Code	9034	9035	9036	9037	9038	9039	9040	9041	9042	9043	9044	9045	9046	9047	9048	9049	9050	9051	9052	9053
2117	0.00	0.00	0.00	0.00	0.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00
2118	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00
2130	0.00	0.00	0.00	0.00	0.10	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
2132	0.00	0.16	1.00	0.00	0.08	0.05	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00
2144	0.05	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2145	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2146	0.00	0.00	0.01	0.00	0.25	0.00	0.41	0.00	0.26	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
2147	0.00	0.00	0.00	0.00	0.33	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.13	0.00	0.00	0.00	0.00
9000	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9001	0.05	0.00	0.00	0.00	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9002	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9003	0.00	0.00	0.00	0.00	0.08	0.05	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9004	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9005	0.00	0.00	0.00	0.00	0.94	0.00	0.03	0.00	0.00	0.00	0.42	0.00	0.00	0.00	0.01	0.15	0.00	0.00	0.00	0.00
9006	0.00	0.00	0.00	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00
9007	0.00	0.00	0.00	0.00	0.29	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00
9008	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9009	0.00	0.00	0.00	0.00	0.65	0.12	0.13	0.15	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.05	0.00	0.15
9010	0.00	0.00	0.00	0.00	0.84	0.07	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00
9011	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9012	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9013	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9014	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9015	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Chapter 7 NTA Bicycle demands- cordoned, single hour education trip matrix.

OD Code	9034	9035	9036	9037	9038	9039	9040	9041	9042	9043	9044	9045	9046	9047	9048	9049	9050	9051	9052	9053
9016	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9017	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9018	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.09	0.01	0.00	0.00	0.00	0.00	0.00	0.00
9019	0.00	0.00	0.00	0.00	1.56	0.06	0.07	0.00	0.00	0.08	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.17
9020	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9021	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9022	0.00	0.00	0.00	0.00	0.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
9023	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9024	0.00	0.00	0.00	0.00	0.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9025	0.00	0.00	0.00	0.00	0.03	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
9026	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9027	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9028	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9029	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9030	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9031	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9032	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9033	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9034	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9035	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9036	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9037	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9038	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9039	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.21	0.00	0.00	0.00	0.05	0.01	0.00	0.00	0.00	0.00	0.00	0.00
9040	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9041	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Chapter 7 NTA Bicycle demands- cordoned, single hour education trip matrix.

OD Code	9034	9035	9036	9037	9038	9039	9040	9041	9042	9043	9044	9045	9046	9047	9048	9049	9050	9051	9052	9053
9042	0.00	0.25	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9043	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9044	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9045	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9046	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00
9047	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9048	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9049	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9050	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9051	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9052	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9053	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Chapter 7 NTA Bicycle demands- cordoned, single hour other trip matrix.

OD Code	2117	2118	2130	2132	2144	2145	2146	2147	9000	9001	9002	9003	9004	9005	9006	9007	9008	9009	9010	9011	9012
2117	0.13	0.05	0.01	0.02	0.10	0.07	0.05	0.07	0.00	0.00	0.00	0.01	0.00	0.04	0.03	0.03	0.06	0.01	0.00	0.00	0.00
2118	0.02	0.02	0.00	0.00	0.02	0.02	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.03	0.01	0.00	0.00	0.00	0.00
2130	0.13	0.02	0.01	0.02	0.03	0.02	0.09	0.09	0.00	0.00	0.00	0.05	0.00	0.01	0.03	0.00	0.02	0.01	0.00	0.00	0.00
2132	0.03	0.02	0.02	0.01	0.03	0.03	0.13	0.03	0.00	0.00	0.00	0.01	0.00	0.04	0.00	0.03	0.01	0.01	0.00	0.00	0.00
2144	0.04	0.02	0.01	0.00	0.13	0.11	0.04	0.02	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.03	0.01	0.05	0.00	0.00	0.00
2145	0.02	0.03	0.01	0.00	0.07	0.12	0.03	0.02	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.01	0.01	0.04	0.00	0.00	0.00
2146	0.05	0.06	0.01	0.02	0.13	0.12	0.15	0.05	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.03	0.00	0.13	0.00	0.00	0.00
2147	0.10	0.06	0.01	0.03	0.09	0.06	0.06	0.09	0.00	0.00	0.00	0.01	0.01	0.05	0.05	0.01	0.05	0.01	0.00	0.00	0.00
9000	0.57	0.09	0.03	0.01	0.37	0.51	0.13	0.12	0.00	0.00	0.00	0.03	0.00	0.03	0.02	0.01	0.02	0.05	0.00	0.00	0.00
9001	0.82	0.33	0.01	0.02	0.38	0.22	0.14	0.16	0.00	0.00	0.00	0.01	0.00	0.03	0.03	0.03	0.04	0.01	0.00	0.00	0.00
9002	0.00	0.13	0.00	0.01	0.79	0.25	0.12	0.09	0.00	0.00	0.00	0.00	0.00	0.03	0.01	0.00	0.05	0.08	0.00	0.00	0.00
9003	0.28	0.02	0.07	0.02	0.06	0.01	0.09	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00
9004	0.05	0.01	0.01	0.00	0.01	0.02	0.03	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9005	0.57	0.13	0.02	0.06	0.09	0.09	0.14	0.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
9006	0.29	0.00	0.03	0.01	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9007	0.09	0.08	0.00	0.04	0.13	0.06	0.25	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9008	0.07	0.02	0.02	0.01	0.00	0.01	0.00	0.08	0.00	0.00	0.00	0.01	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9009	0.01	0.03	0.00	0.00	0.31	0.17	0.96	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9010	0.17	0.17	0.00	0.00	0.11	0.33	0.05	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05
9011	0.01	0.01	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9012	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00
9013	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9014	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9015	0.00	0.08	0.00	0.01	0.42	0.13	0.07	0.05	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.03	0.04	0.00	0.00	0.00

Chapter 7 NTA Bicycle demands- cordoned, single hour other trip matrix.

OD Code	2117	2118	2130	2132	2144	2145	2146	2147	9000	9001	9002	9003	9004	9005	9006	9007	9008	9009	9010	9011	9012
9016	0.00	0.23	0.00	0.02	0.00	0.28	0.23	0.02	0.00	0.00	0.00	0.00	0.01	0.05	0.00	0.04	0.01	0.15	0.02	0.01	0.00
9017	0.00	0.00	0.00	0.00	0.01	0.01	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.05	0.00	0.00	0.00
9018	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.03	0.00	0.00	0.00
9019	0.22	0.27	0.02	0.02	0.40	0.57	0.68	0.16	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9020	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.00	0.00
9021	0.06	0.00	0.01	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9022	0.19	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9023	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9024	0.17	0.02	0.02	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.01	0.01	0.02	0.00	0.00	0.01	0.00	0.00	0.00	0.00
9025	0.00	0.00	0.00	0.00	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9026	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9027	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9028	0.00	0.00	0.00	0.00	0.10	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
9029	0.01	0.02	0.00	0.01	1.38	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9030	0.00	0.00	0.00	0.00	0.13	0.70	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9031	0.13	0.03	0.02	0.02	0.04	0.09	0.03	0.19	0.00	0.00	0.00	0.02	0.00	0.03	0.07	0.02	0.03	0.01	0.00	0.00	0.00
9032	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9033	0.04	0.16	0.00	0.00	0.41	0.50	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9034	0.01	0.01	0.00	0.00	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9035	0.00	0.00	0.02	0.08	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
9036	0.00	0.02	0.00	0.05	0.00	0.00	0.03	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9037	0.00	0.00	0.01	0.00	0.34	0.21	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9038	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9039	0.03	0.02	0.04	0.08	0.00	0.03	0.39	0.12	0.00	0.00	0.00	0.03	0.01	0.03	0.00	0.06	0.00	0.13	0.01	0.01	0.00
9040	0.00	0.01	0.00	0.01	0.00	0.01	0.33	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9041	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.00	0.00	0.00

Chapter 7 NTA Bicycle demands- cordoned, single hour other trip matrix.

OD Code	2117	2118	2130	2132	2144	2145	2146	2147	9000	9001	9002	9003	9004	9005	9006	9007	9008	9009	9010	9011	9012
9042	0.00	0.00	0.00	0.00	0.03	0.01	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9043	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9044	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.01	0.00	0.00	0.00	0.00
9045	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9046	0.00	0.00	0.00	0.01	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9047	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9048	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9049	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9050	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9051	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9052	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9053	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Chapter 7 NTA Bicycle demands- cordoned, single hour other trip matrix.

OD Code	9013	9014	9015	9016	9017	9018	9019	9020	9021	9022	9023	9024	9025	9026	9027	9028	9029	9030	9031	9032	9033
2117	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.01	0.00	0.00
2118	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.03	0.01	0.00
2130	0.00	0.00	0.00	0.05	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00
2132	0.00	0.00	0.02	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.38	0.07	0.00	0.00	0.02
2144	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.00	0.02
2145	0.00	0.00	0.00	0.10	0.04	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.03	0.00	0.00
2146	0.00	0.00	0.00	0.02	0.00	0.00	0.04	0.00	0.01	0.00	0.01	0.04	0.00	0.00	0.00	0.00	0.01	0.01	0.11	0.03	0.00
2147	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.02	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.01
9000	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.03	0.14	0.00	0.13	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.10	0.02
9001	0.00	0.85	0.00	0.00	0.00	0.00	0.02	0.00	0.05	0.71	0.00	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00
9002	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.01	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.01	0.00	0.06	0.01	0.00
9003	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
9004	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.10	0.01	0.00
9005	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.00
9006	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.03	0.00	0.00
9007	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00
9008	0.07	0.00	0.00	0.14	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.01	0.00	0.00
9009	0.00	0.00	0.00	0.07	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.07	0.00	0.00
9010	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
9011	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
9012	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9013	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9014	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9015	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.01	0.00	0.00

Chapter 7 NTA Bicycle demands- cordoned, single hour other trip matrix.

OD Code	9013	9014	9015	9016	9017	9018	9019	9020	9021	9022	9023	9024	9025	9026	9027	9028	9029	9030	9031	9032	9033
9016	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9017	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9018	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9019	0.00	0.00	0.00	0.09	0.03	0.06	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.04	0.00	0.00
9020	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9021	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9022	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9023	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9024	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9025	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9026	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.08	0.00	0.00	0.00	0.00	0.00	0.00
9027	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9028	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9029	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9030	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9031	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
9032	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9033	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9034	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9035	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
9036	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9037	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9038	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9039	0.01	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00
9040	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
9041	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Chapter 7 NTA Bicycle demands- cordoned, single hour other trip matrix.

OD Code	9013	9014	9015	9016	9017	9018	9019	9020	9021	9022	9023	9024	9025	9026	9027	9028	9029	9030	9031	9032	9033
9042	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9043	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9044	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9045	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9046	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9047	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9048	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9049	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9050	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9051	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9052	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9053	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Chapter 7 NTA Bicycle demands- cordoned, single hour other trip matrix.

OD Code	**9034**	**9035**	**9036**	**9037**	**9038**	**9039**	**9040**	**9041**	**9042**	**9043**	**9044**	**9045**	**9046**	**9047**	**9048**	**9049**	**9050**	**9051**	**9052**	**9053**
2117	0.00	0.02	0.00	0.00	0.24	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.20	0.00	0.00	0.00	0.00
2118	0.00	0.01	0.00	0.02	0.03	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00
2130	0.00	0.02	0.00	0.00	0.08	0.02	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
2132	0.00	0.08	0.04	0.00	0.04	0.04	0.06	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.02	0.00	0.00	0.00	0.00
2144	0.02	0.00	0.00	0.03	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2145	0.02	0.00	0.00	0.11	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2146	0.00	0.00	0.00	0.00	0.27	0.02	0.23	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06
2147	0.00	0.02	0.00	0.01	0.19	0.03	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.09	0.00	0.00	0.00	0.00
9000	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9001	0.02	0.03	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9002	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9003	0.00	0.02	0.00	0.00	0.11	0.02	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.00	0.00	0.00	0.00
9004	0.00	0.00	0.00	0.00	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9005	0.00	0.00	0.00	0.00	0.19	0.02	0.08	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00
9006	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00
9007	0.00	0.02	0.00	0.00	0.05	0.05	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
9008	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.02	0.00	0.00	0.00	0.00
9009	0.00	0.00	0.00	0.00	0.29	0.06	0.20	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.08
9010	0.00	0.00	0.00	0.00	0.38	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00
9011	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9012	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9013	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9014	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00
9015	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Chapter 7 NTA Bicycle demands- cordoned, single hour other trip matrix.

OD Code	**9034**	**9035**	**9036**	**9037**	**9038**	**9039**	**9040**	**9041**	**9042**	**9043**	**9044**	**9045**	**9046**	**9047**	**9048**	**9049**	**9050**	**9051**	**9052**	**9053**
9016	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9017	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9018	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9019	0.00	0.00	0.00	0.00	0.59	0.01	0.03	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
9020	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9021	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9022	0.00	0.00	0.00	0.00	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00
9023	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9024	0.00	0.00	0.00	0.00	0.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9025	0.00	0.00	0.00	0.00	0.01	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9026	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9027	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9028	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9029	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9030	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9031	0.00	0.02	0.00	0.00	0.07	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9032	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9033	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9034	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9035	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9036	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9037	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9038	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9039	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.01	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00
9040	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9041	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Chapter 7 NTA Bicycle demands- cordoned, single hour other trip matrix.

OD Code	9034	9035	9036	9037	9038	9039	9040	9041	9042	9043	9044	9045	9046	9047	9048	9049	9050	9051	9052	9053
9042	0.00	0.08	0.00	0.00	0.00	0.02	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9043	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9044	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9045	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9046	0.00	0.01	0.00	0.00	0.00	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
9047	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9048	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9049	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9050	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9051	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9052	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9053	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix V: Dublin City Trip Assignment Models Link Results

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	Direction	Type of cycling facility	Length km	Auto & bus flow auto-vehicles/hr	Bus flow buses/hr	Capacity auto-vehicles/hr	Travel time hr	Risk exposure hr	Disutility hr	Link flow 'shortest-path' bicycles/hr	Link flow with risk exposure bicycle/hr
0	Forward	1	0.081	19	0	348	0.006	0	0.006	3	21
0	Reverse	1	0.081	21	0	740	0.006	0	0.006	8	17
1	Forward	1	0.033	508	0	740	0.002	0.002	0.005	16	6
1	Reverse	1	0.033	632	0	695	0.002	0.003	0.006	30	4
2	Forward	1	0.01	0	0	0	0.001	0	0.001	0	13
2	Reverse	1	0.01	19	0	348	0.001	0	0.001	2	5
3	Forward	3	0.148	531	0	740	0.011	0.004	0.015	42	50
3	Reverse	3	0.148	250	0	743	0.011	0.001	0.012	53	47
4	Forward	3	0.054	489	0	14800	0.004	0	0.004	1	67
4	Reverse	1	0.054	0	0	740	0.004	0	0.004	36	1
5	Forward	3	0.031	362	0	740	0.002	0	0.003	0	25
5	Reverse	3	0.031	379	0	740	0.002	0	0.003	34	0
6	Forward	1	0.06	0	0	0	0.004	0	0	38	0
6	Reverse	1	0.06	710	0	1480	0.004	0.003	0.007	0	41
7	Forward	1	0.023	1179	0	2276	0	0	0.002	0	48
7	Reverse	1	0.023	0	0	0	0	0	0	46	0

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	Direction	Type of cycling facility	Length km	Auto & bus flow auto-vehicles/hr	Bus flow buses/hr	Capacity auto-vehicles/hr	Travel time hr	Risk exposure hr	Disutility hr	Link flow 'shortest-path' bicycles/hr	Link flow with risk exposure bicycle/hr
8	Forward	1	0.049	0	0	0	0.004	0	0.004	2	54
8	Reverse	1	0.049	43	0	330	0.004	0	0.004	43	7
9	Forward	4	0.105	418	0	913	0.008	0	0.008	3	22
9	Reverse	1	0.105	16	0	740	0.008	0	0.008	0	11
10	Forward	1	0.115	0	0	0	0.008	0	0.008	36	12
10	Reverse	1	0.115	1440	0	1480	0.008	0.012	0.02	3	23
11	Forward	3	0.09	1409	0	1480	0	0.005	0.011	0	20
11	Reverse	1	0.09	0	0	0	0	0	0	27	0
12	Forward	1	0.065	0	0	0	0.005	0	0	27	0
12	Reverse	3	0.065	1409	0	1480	0.005	0.003	0.008	0	18
13	Forward	1	0.059	644	0	1480	0	0.003	0.007	0	61
13	Reverse	1	0.059	0	0	0	0	0	0	75	0
14	Forward	1	0.056	0	0	0	0.004	0	0	85	0
14	Reverse	1	0.056	644	0	1480	0.004	0.003	0.007	0	74
15	Forward	1	0.071	0	0	0	0.005	0	0	62	0
15	Reverse	1	0.071	543	0	1480	0.005	0.003	0.008	0	38
16	Forward	1	0.121	902	0	1008	0	0.012	0.02	0	21
16	Reverse	1	0.121	0	0	0	0	0	0	62	0

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	**Direction**	**Type of cycling facility**	**Length** km	**Auto & bus flow** auto-vehicles/hr	**Bus flow** buses/hr	**Capacity** auto-vehicles/hr	**Travel time** hr	**Risk exposure** hr	**Disutility** hr	**Link flow 'shortest-path'** bicycles/hr	**Link flow with risk exposure** bicycle/hr
17	Forward	1	0.017	762	0	1008	0	0.001	0.003	0	38
17	Reverse	1	0.017	0	0	0	0	0	0	62	0
18	Forward	1	0.071	1518	0	2960	0	0.004	0.009	0	2
18	Reverse	1	0.071	0	0	0	0	0	0	6	0
19	Forward	1	0.105	1734	0	2220	0	0.009	0.016	0	2
19	Reverse	1	0.105	0	0	0	0	0	0	10	0
20	Forward	1	0.067	0	0	0	0.005	0	0	10	0
20	Reverse	1	0.067	1734	0	2220	0.005	0.006	0.01	0	19
21	Forward	2	0.056	1421	173	2960	0	0.001	0.005	0	18
21	Reverse	1	0.056	0	0	0	0	0	0	25	0
22	Forward	1	0.044	0	0	0	0.003	0	0	24	0
22	Reverse	2	0.044	831	62	2303	0.003	0	0.004	0	18
23	Forward	1	0.045	831	62	2303	0	0.002	0.005	0	58
23	Reverse	1	0.045	0	0	0	0	0	0	56	0
24	Forward	1	0.054	0	0	0	0.004	0	0.004	0	7
24	Reverse	1	0.054	0	0	414	0.004	0	0	4	0
25	Forward	1	0.06	0	0	0	0.004	0	0.004	4	17
25	Reverse	1	0.06	217	0	740	0.004	0.002	0.006	0	9

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	Direction	Type of cycling facility	Length km	Auto & bus flow auto-vehicles/hr	Bus flow buses/hr	Capacity auto-vehicles/hr	Travel time hr	Risk exposure hr	Disutility hr	Link flow 'shortest-path' bicycles/hr	Link flow with risk exposure bicycle/hr
26	Forward	1	0.036	146	0	740	0	0.001	0.003	0	17
26	Reverse	1	0.036	0	0	0	0	0	0	3	0
27	Forward	1	0.049	34	0	735	0.004	0	0.004	6	62
27	Reverse	1	0.049	418	0	781	0.004	0.003	0.006	56	13
28	Forward	1	0.126	0	0	0	0.009	0	0.009	2	4
28	Reverse	1	0.126	0	0	0	0.009	0	0.009	1	51
29	Forward	1	0.079	0	0	0	0.006	0	0.006	2	31
29	Reverse	1	0.079	0	0	0	0.006	0	0.006	2	6
30	Forward	3	0.14	800	0	1599	0	0.002	0.012	0	31
30	Reverse	1	0.14	0	0	0	0	0	0	26	0
31	Forward	4	0.331	11	0	740	0.024	0	0	0	0
31	Reverse	1	0.331	3	0	740	0.024	0	0.024	0	0
32	Forward	4	0.162	31	0	740	0.012	0	0.012	3	37
32	Reverse	1	0.162	3	0	740	0.012	0	0.012	9	30
33	Forward	1	0.087	16	0	740	0.006	0	0.006	1	26
33	Reverse	4	0.087	418	0	913	0.006	0	0.006	6	5
34	Forward	1	0.093	540	0	980	0.007	0.005	0.012	47	2
34	Reverse	1	0.093	651	0	723	0.007	0.009	0.016	23	4

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	**Direction**	**Type of cycling facility**	**Length** km	**Auto & bus flow** auto-vehicles/hr	**Bus flow** buses/hr	**Capacity** auto-vehicles/hr	**Travel time** hr	**Risk exposure** hr	**Disutility** hr	**Link flow 'shortest-path'** bicycles/hr	**Link flow with risk exposure** bicycle/hr
35	Forward	1	0.02	540	0	980	0.001	0.001	0.003	47	5
35	Reverse	1	0.02	651	0	723	0.001	0.002	0.003	23	5
36	Forward	1	0.085	572	0	723	0.006	0.007	0.013	47	8
36	Reverse	1	0.085	740	0	980	0.006	0.007	0.013	23	10
37	Forward	1	0.157	749	0	980	0.011	0.013	0.024	54	9
37	Reverse	1	0.157	695	0	980	0.011	0.012	0.023	37	14
38	Forward	1	0.222	638	0	980	0.016	0.015	0.031	28	8
38	Reverse	1	0.222	628	0	980	0.016	0.015	0.031	52	6
39	Forward	2	0.157	627	51	644	0.011	0	0.012	15	29
39	Reverse	2	0.157	728	23	1041	0.011	0	0.011	31	24
40	Forward	2	0.046	522	62	2220	0.003	0	0.004	6	19
40	Reverse	2	0.046	846	23	131	0.003	0	0.003	15	10
41	Forward	2	0.059	846	23	1310	0.004	0	0.004	15	10
41	Reverse	2	0.059	522	62	2220	0.004	0	0.005	6	18
42	Forward	2	0.047	846	23	131	0.003	0	0.004	15	10
42	Reverse	2	0.047	522	62	2220	0.003	0	0.004	6	19
43	Forward	2	0.052	522	62	2220	0.004	0	0.004	5	33
43	Reverse	2	0.052	846	23	131	0.004	0	0.004	19	21

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	Direction	Type of cycling facility	Length km	Auto & bus flow auto-vehicles/hr	Bus flow buses/hr	Capacity auto-vehicles/hr	Travel time hr	Risk exposure hr	Disutility hr	Link flow 'shortest-path' bicycles/hr	Link flow with risk exposure bicycle/hr
44	Forward	1	0.093	107	0	371	0.007	0.003	0.01	16	4
44	Reverse	1	0.093	55	0	480	0.007	0.001	0.008	11	6
45	Forward	1	0.036	107	0	371	0.003	0.001	0.004	16	7
45	Reverse	1	0.036	55	0	480	0.003	0	0.003	11	8
46	Forward	1	0.039	55	0	480	0.003	0	0.003	11	9
46	Reverse	1	0.039	107	0	371	0.003	0.001	0.004	16	10
47	Forward	1	0.066	55	0	480	0.005	0.001	0.006	11	15
47	Reverse	1	0.066	107	0	371	0.005	0.002	0.007	16	18
48	Forward	1	0.043	55	0	480	0.003	0.001	0.004	11	15
48	Reverse	1	0.043	107	0	371	0.003	0.001	0.004	16	18
49	Forward	1	0.044	135	0	740	0.003	0.001	0.004	3	7
49	Reverse	1	0.044	62	0	740	0.003	0	0.004	0	5
50	Forward	1	0.115	592	0	7400	0.008	0.001	0.009	27	9
50	Reverse	1	0.115	541	0	1480	0.008	0.005	0.013	16	9
51	Forward	4	0.045	592	0	740	0.003	0	0.003	58	26
51	Reverse	4	0.045	541	0	740	0.003	0	0.003	27	48
52	Forward	1	0.039	160	0	740	0.003	0.001	0.004	59	20
52	Reverse	1	0.039	196	0	740	0.003	0.001	0.004	19	94

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	Direction	Type of cycling facility	Length km	Auto & bus flow auto-vehicles/hr	Bus flow buses/hr	Capacity auto-vehicles/hr	Travel time hr	Risk exposure hr	Disutility hr	Link flow 'shortest-path' bicycles/hr	Link flow with risk exposure bicycle/hr
53	Reverse	1	0.079	195	0	740	0.006	0.002	0.008	19	94
54	Forward	1	0.064	183	0	740	0.005	0.002	0.006	22	56
54	Reverse	1	0.064	119	0	1312	0.005	0.001	0.005	42	35
55	Forward	4	0.204	0	0	0	0.015	0	0.015	10	101
55	Reverse	4	0.204	0	0	0	0.015	0	0.015	89	20
56	Forward	3	0.046	379	0	740	0.003	0.001	0.004	93	24
56	Reverse	3	0.046	362	0	740	0.003	0.001	0.004	22	76
57	Forward	1	0.068	0	0	0	0.005	0	0	38	0
57	Reverse	1	0.068	629	0	1480	0.005	0.003	0.008	0	26
58	Forward	1	0.036	0	0	0	0.003	0	0	4	0
58	Reverse	1	0.036	646	0	1480	0.003	0.002	0.004	0	1
59	Forward	1	0.057	32	0	1480	0	0	0.004	0	37
59	Reverse	1	0.057	0	0	0	0	0	0	6	0
60	Forward	1	0.071	4	0	580	0.005	0	0.005	9	0
60	Reverse	1	0.071	182	0	740	0.005	0.002	0.007	0	2
61	Forward	1	0.091	89	0	1480	0.007	0.001	0.007	42	9
61	Reverse	3	0.091	100	0	740	0.007	0	0.007	8	55
62	Forward	3	0.099	75	0	740	0.007	0	0.007	50	14

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	Direction	Type of cycling facility	Length km	Auto & bus flow auto-vehicles/hr	Bus flow buses/hr	Capacity auto-vehicles/hr	Travel time hr	Risk exposure hr	Disutility hr	Link flow 'shortest-path' bicycles/hr	Link flow with risk exposure bicycle/hr
63	Forward	3	0.089	75	0	740	0.006	0	0.006	50	15
63	Reverse	3	0.089	97	0	740	0.006	0	0.006	11	52
64	Forward	3	0.087	136	0	740	0.006	0	0.006	18	43
64	Reverse	3	0.087	112	0	740	0.006	0	0.006	49	24
65	Forward	3	0.027	136	0	740	0.002	0	0.002	22	40
65	Reverse	3	0.027	112	0	1480	0.002	0	0.002	50	24
66	Forward	3	0.098	129	0	1480	0.007	0	0.007	19	43
66	Reverse	3	0.098	156	0	740	0.007	0	0.007	52	20
67	Forward	1	0.009	276	0	0	0.001	0	0.001	48	44
67	Reverse	1	0.009	164	0	0	0.001	0	0.001	37	39
68	Forward	3	0.061	164	0	481	0.004	0	0.005	37	42
68	Reverse	3	0.061	276	0	740	0.004	0	0.005	50	44
69	Forward	3	0.107	701	0	740	0.008	0.005	0.013	55	47
69	Reverse	3	0.107	161	0	740	0.008	0	0.008	43	52
70	Forward	3	0.056	531	0	740	0.004	0.002	0.006	48	52
70	Reverse	3	0.056	250	0	743	0.004	0	0.004	55	53
71	Forward	1	0.026	392	0	690	0.002	0.002	0.003	15	6
71	Reverse	1	0.026	0	0	720	0.002	0	0.002	8	13

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	Direction	Type of cycling facility	Length	Auto & bus flow	Bus flow	Capacity	Travel time	Risk exposure	Disutility	Link flow 'shortest-path'	Link flow with risk exposure
			km	auto-vehicles/hr	buses/hr	auto-vehicles/hr	hr	hr	hr	bicycles/hr	bicycle/hr
72	Forward	1	0.052	392	0	690	0.004	0.003	0.007	4	3
72	Reverse	1	0.052	0	0	720	0.004	0	0.004	8	4
73	Forward	3	0.039	114	0	33	0.003	0	0	46	0
73	Reverse	3	0.039	1091	0	1480	0.003	0.001	0.004	0	29
74	Forward	1	0.081	67	0	740	0.006	0.001	0.007	0	17
74	Reverse	1	0.081	287	0	740	0.006	0.003	0.009	2	5
75	Forward	1	0.079	450	0	1480	0	0.003	0.008	0	50
75	Reverse	1	0.079	0	0	0	0	0	0	42	0
76	Forward	1	0.088	0	0	0	0.006	0	0	26	0
76	Reverse	1	0.088	377	0	1480	0.006	0.002	0.009	0	9
77	Forward	1	0.077	441	0	1480	0	0.002	0.008	0	40
77	Reverse	1	0.077	0	0	0	0	0	0	16	0
78	Forward	1	0.032	119	0	1312	0.002	0	0.003	36	19
78	Reverse	1	0.032	183	0	740	0.002	0.001	0.003	16	38
79	Forward	1	0.042	183	0	740	0.003	0.001	0.004	18	24
79	Reverse	1	0.042	119	0	1312	0.003	0	0.003	37	40
80	Forward	1	0.053	135	0	740	0.004	0.001	0.005	32	19
80	Reverse	1	0.053	434	0	740	0.004	0.003	0.007	35	7

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	Direction	Type of cycling facility	Length km	Auto & bus flow auto-vehicles/hr	Bus flow buses/hr	Capacity auto-vehicles/hr	Travel time hr	Risk exposure hr	Disutility hr	Link flow 'shortest-path' bicycles/hr	Link flow with risk exposure bicycle/hr
81	Forward	1	0.079	26	0	296	0.006	0.001	0.006	22	6
81	Reverse	1	0.079	83	0	740	0.006	0.001	0.007	4	13
82	Forward	1	0.088	26	0	296	0.006	0.001	0.007	22	3
82	Reverse	1	0.088	83	0	740	0.006	0.001	0.007	4	10
83	Forward	1	0.058	83	0	740	0.004	0.001	0.005	13	24
83	Reverse	1	0.058	26	0	296	0.004	0.001	0.005	22	12
84	Forward	1	0.021	0	0	0	0.002	0	0	43	0
84	Reverse	1	0.021	1029	0	2280	0.002	0.001	0.003	0	34
85	Forward	2	0.007	613	0	740	0.001	0	0.001	32	77
85	Reverse	2	0.007	0	524	740	0.001	0	0.001	60	31
86	Forward	3	0.074	345	0	740	0.005	0.001	0.006	53	22
86	Reverse	3	0.074	444	0	740	0.005	0.002	0.007	26	84
87	Forward	3	0.057	345	0	740	0.004	0.001	0.005	14	15
87	Reverse	2	0.057	444	59	740	0.004	0	0.004	13	53
88	Forward	3	0.08	617	0	740	0.006	0.003	0.009	15	11
88	Reverse	2	0.08	467	59	740	0.006	0	0.006	13	51
89	Forward	3	0.081	617	0	740	0.006	0.003	0.009	10	9
89	Reverse	2	0.081	467	59	740	0.006	0	0.006	12	26

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	**Direction**	**Type of cycling facility**	**Length** km	**Auto & bus flow** auto-vehicles/hr	**Bus flow** buses/hr	**Capacity** auto-vehicles/hr	**Travel time** hr	**Risk exposure** hr	**Disutility** hr	**Link flow 'shortest-path'** bicycles/hr	**Link flow with risk exposure** bicycle/hr
90	Forward	3	0.086	617	0	740	0.006	0.003	0.01	5	7
90	Reverse	3	0.086	467	0	740	0.006	0.002	0.008	18	7
91	Forward	1	0.03	400	0	740	0.002	0.002	0.004	71	15
91	Reverse	1	0.03	461	0	740	0.002	0.002	0.004	19	5
92	Forward	1	0.076	447	0	614	0.005	0.006	0.011	10	10
92	Reverse	1	0.076	366	0	740	0.005	0.004	0.009	65	4
93	Forward	1	0.079	318	0	1480	0.006	0.002	0.007	5	23
93	Reverse	1	0.079	198	0	740	0.006	0.002	0.008	76	3
94	Forward	1	0.104	198	0	740	0.007	0.003	0.01	75	5
94	Reverse	1	0.104	318	0	1480	0.007	0.002	0.01	6	19
95	Forward	1	0.178	267	0	584	0.013	0.009	0.021	6	19
95	Reverse	1	0.178	212	0	740	0.013	0.005	0.018	75	5
96	Forward	1	0.014	267	0	0	0.001	0	0.001	7	69
96	Reverse	1	0.014	212	0	0	0.001	0	0.001	116	5
97	Forward	1	0.181	375	0	740	0.013	0.01	0.023	10	2
97	Reverse	3	0.181	176	0	740	0.013	0.001	0.014	76	13
98	Forward	1	0.079	48	0	0	0.006	0	0.006	3	17
98	Reverse	1	0.079	43	0	0	0.006	0	0.006	5	8

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	Direction	Type of cycling facility	Length km	Auto & bus flow auto-vehicles/hr	Bus flow buses/hr	Capacity auto-vehicles/hr	Travel time hr	Risk exposure hr	Disutility hr	Link flow 'shortest-path' bicycles/hr	Link flow with risk exposure bicycle/hr
99	Forward	1	0.105	524	0	740	0	0.008	0.015	0	1
99	Reverse	1	0.105	0	0	0	0	0	0	7	0
100	Forward	1	0.072	0	0	0	0.005	0	0.005	0	42
100	Reverse	1	0.072	0	0	0	0.005	0	0.005	16	4
101	Forward	1	0.095	0	0	0	0.007	0	0.007	3	34
101	Reverse	1	0.095	0	0	0	0.007	0	0.007	6	5
102	Forward	1	0.031	390	0	777	0.002	0.002	0.004	14	1
102	Reverse	1	0.031	156	0	740	0.002	0.001	0.003	29	7
103	Forward	1	0.046	390	0	777	0.003	0.002	0.006	25	8
103	Reverse	1	0.046	156	0	740	0.003	0.001	0.004	23	24
104	Forward	1	0.04	8	0	626	0.003	0	0.003	9	42
104	Reverse	1	0.04	292	0	740	0.003	0.002	0.005	50	6
105	Forward	1	0.068	0	0	0	0.005	0	0.005	1	6
105	Reverse	1	0.068	0	0	0	0.005	0	0.005	11	4
106	Forward	1	0.076	0	0	0	0.005	0	0.005	4	13
106	Reverse	1	0.076	0	0	0	0.005	0	0.005	5	5
107	Forward	1	0.104	76	0	1480	0.007	0.001	0.008	50	11
107	Reverse	1	0.104	617	0	772	0.007	0.009	0.016	3	30

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	**Direction**	**Type of cycling facility**	**Length** km	**Auto & bus flow** auto-vehicles/hr	**Bus flow** buses/hr	**Capacity** auto-vehicles/hr	**Travel time** hr	**Risk exposure** hr	**Disutility** hr	**Link flow 'shortest-path'** bicycles/hr	**Link flow with risk exposure** bicycle/hr
108	Forward	1	0.181	110	0	740	0.013	0.003	0.016	50	9
108	Reverse	1	0.181	670	0	1480	0.013	0.009	0.022	2	27
109	Forward	1	0.077	0	536	0	0.006	0	0	3	0
109	Reverse	1	0.077	536	0	821	0.006	0.005	0.011	0	0
110	Forward	1	0.083	352	0	1480	0	0.002	0.008	0	0
110	Reverse	1	0.083	0	0	0	0	0	0	1	0
111	Forward	1	0.079	352	0	1480	0	0.002	0.008	0	0
111	Reverse	1	0.079	0	0	0	0	0	0	0	0
112	Forward	1	0.058	0	0	0	0.004	0	0	8	0
112	Reverse	2	0.058	726	253	740	0.004	0.002	0.006	0	1
113	Forward	2	0.036	1088	268	1128	0	0.002	0.004	0	22
113	Reverse	1	0.036	0	0	0	0	0	0	16	0
114	Forward	2	0.187	192	192	136	0.013	0	0	51	0
114	Reverse	1	0.187	1208	192	1471	0.013	0.016	0.03	0	48
115	Forward	2	0.093	186	186	1518	0.007	0	0	33	0
115	Reverse	1	0.093	1306	276	1480	0.007	0.009	0.015	0	4
116	Forward	1	0.075	838	0	1480	0.005	0	0	19	0
116	Reverse	3	0.075	482	0	1480	0.005	0	0.006	0	18

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	Direction	Type of cycling facility	Length km	Auto & bus flow auto-vehicles/hr	Bus flow buses/hr	Capacity auto-vehicles/hr	Travel time hr	Risk exposure hr	Disutility hr	Link flow 'shortest-path' bicycles/hr	Link flow with risk exposure bicycle/hr
117	Forward	1	0.074	86	0	216	0.005	0.003	0.008	27	3
117	Reverse	1	0.074	0	0	0	0.005	0	0.005	9	48
118	Forward	1	0.01	0	0	58	0.001	0	0.001	7	1
118	Reverse	1	0.01	188	0	338	0.001	0.001	0.001	0	13
119	Forward	1	0.072	188	0	338	0.005	0.004	0.009	0	22
119	Reverse	1	0.072	2	0	58	0.005	0	0.005	8	0
120	Forward	1	0.104	0	0	0	0.007	0	0.007	6	30
120	Reverse	1	0.104	0	0	0	0.007	0	0.007	6	28
121	Forward	1	0.117	0	0	0	0.008	0	0.008	3	13
121	Reverse	1	0.117	0	0	0	0.008	0	0.008	13	9
122	Forward	1	0.239	0	0	0	0.017	0	0.017	5	33
122	Reverse	1	0.239	0	0	0	0.017	0	0.017	17	15
123	Forward	4	0.159	0	0	0	0.011	0	0.011	6	55
123	Reverse	4	0.159	0	0	0	0.011	0	0.011	16	12
124	Forward	4	0.174	67	0	740	0.012	0	0.012	16	15
124	Reverse	4	0.174	287	0	418	0.012	0	0.012	8	48
125	Forward	4	0.128	287	0	418	0.009	0	0.009	8	64
125	Reverse	4	0.128	67	0	740	0.009	0	0.009	16	18

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	Direction	Type of cycling facility	Length km	Auto & bus flow auto-vehicles/hr	Bus flow buses/hr	Capacity auto-vehicles/hr	Travel time hr	Risk exposure hr	Disutility hr	Link flow 'shortest-path' bicycles/hr	Link flow with risk exposure bicycle/hr
126	Forward	4	0.303	111	0	460	0.022	0	0.022	22	13
126	Reverse	4	0.303	304	0	1480	0.022	0	0.022	3	55
127	Forward	4	0.107	323	0	740	0.008	0	0.008	6	54
127	Reverse	4	0.107	132	0	740	0.008	0	0.008	25	15
128	Forward	4	0.154	265	0	0	0.011	0	0.011	32	26
128	Reverse	4	0.154	276	0	0	0.011	0	0.011	12	48
129	Forward	1	0.057	0	0	0	0.004	0	0.004	0	4
129	Reverse	1	0.057	21	0	740	0.004	0	0.004	0	15
130	Forward	1	0.016	21	0	740	0.001	0	0.001	0	15
130	Reverse	1	0.016	0	0	0	0.001	0	0.001	0	4
131	Forward	1	0.071	0	0	0	0.005	0	0.005	0	13
131	Reverse	1	0.071	19	0	348	0.005	0	0.005	1	5
132	Forward	1	0.046	1300	0	1480	0.003	0.004	0.008	4	4
132	Reverse	1	0.046	771	0	740	0.003	0.005	0.008	19	10
133	Forward	1	0.076	1	0	783	0.005	0	0.005	0	19
133	Reverse	1	0.076	0	0	0	0.005	0	0.005	15	10
134	Forward	1	0.066	31	0	740	0.005	0	0.005	21	14
134	Reverse	1	0.066	460	0	740	0.005	0.004	0.009	4	18

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	Direction	Type of cycling facility	Length km	Auto & bus flow auto-vehicles/hr	Bus flow buses/hr	Capacity auto-vehicles/hr	Travel time hr	Risk exposure hr	Disutility hr	Link flow 'shortest-path' bicycles/hr	Link flow with risk exposure bicycle/hr
135	Forward	1	0.108	75	0	104	0.008	0.008	0.016	1	5
135	Reverse	1	0.108	0	0	0	0.008	0	0.008	1	8
136	Forward	1	0.049	118	0	343	0.004	0.002	0.005	3	36
136	Reverse	1	0.049	148	0	740	0.004	0.001	0.005	13	14
137	Forward	1	0.085	0	0	0	0.006	0	0.006	0	26
137	Reverse	1	0.085	172	0	740	0.006	0.002	0.008	6	2
138	Forward	1	0.124	261	0	740	0	0.005	0.014	0	1
138	Reverse	1	0.124	0	0	0	0	0	0	8	0
139	Forward	1	0.105	951	0	1480	0	0.007	0.015	0	33
139	Reverse	1	0.105	0	0	0	0	0	0	43	0
140	Forward	1	0.126	0	0	0	0.009	0	0	47	0
140	Reverse	1	0.126	951	0	1480	0.009	0.009	0.018	0	45
141	Forward	1	0.061	0	0	0	0.004	0	0.004	6	16
141	Reverse	1	0.061	428	0	740	0.004	0.004	0.008	12	2
142	Forward	1	0.066	0	0	0	0.005	0	0.005	12	1
142	Reverse	1	0.066	28	0	575	0.005	0	0.005	0	10
143	Forward	1	0.097	261	0	740	0.007	0.004	0.011	0	1
143	Reverse	1	0.097	0	0	0	0.007	0	0.007	0	2

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	Direction	Type of cycling facility	Length km	Auto & bus flow auto-vehicles/hr	Bus flow buses/hr	Capacity auto-vehicles/hr	Travel time hr	Risk exposure hr	Disutility hr	Link flow 'shortest-path' bicycles/hr	Link flow with risk exposure bicycle/hr
144	Forward	1	0.055	2	0	740	0.004	0	0.004	2	17
144	Reverse	1	0.055	0	0	0	0.004	0	0.004	0	2
145	Forward	1	0.047	0	0	0	0.003	0	0.003	3	18
145	Reverse	1	0.047	2	0	740	0.003	0	0.003	8	12
146	Forward	1	0.071	36	0	608	0.005	0	0.006	8	7
146	Reverse	1	0.071	0	0	0	0.005	0	0.005	9	18
147	Forward	1	0.079	162	0	740	0.006	0.002	0.007	8	6
147	Reverse	1	0.079	0	0	0	0.006	0	0.006	9	33
148	Forward	1	0.083	386	0	740	0.006	0.005	0.011	10	7
148	Reverse	1	0.083	422	0	740	0.006	0.005	0.011	7	3
149	Forward	1	0.069	254	0	1381	0.005	0.001	0.006	11	18
149	Reverse	1	0.069	315	0	416	0.005	0.006	0.011	8	10
150	Forward	1	0.109	0	0	0	0.008	0	0.008	34	4
150	Reverse	1	0.109	0	0	0	0.008	0	0.008	6	41
151	Forward	1	0.06	0	0	0	0.004	0	0	135	0
151	Reverse	1	0.06	820	0	1480	0.004	0.004	0.008	0	74
152	Forward	1	0.058	784	0	1480	0	0.003	0.007	0	34
152	Reverse	1	0.058	0	0	0	0	0	0	103	0

Chapter 7 Variables and flows from the ‘shortest-path’ model and the model considering risk exposure.

Link ID	Direction	Type of cycling facility	Length km	Auto & bus flow auto-vehicles/hr	Bus flow buses/hr	Capacity auto-vehicles/hr	Travel time hr	Risk exposure hr	Disutility hr	Link flow 'shortest-path' bicycles/hr	Link flow with risk exposure bicycle/hr
153	Forward	1	0.065	0	0	0	0.005	0	0.005	15	10
153	Reverse	1	0.065	1	0	783	0.005	0	0.005	0	19
154	Forward	1	0.077	0	0	0	0.006	0	0	30	0
154	Reverse	3	0.077	857	0	1480	0.006	0.001	0.007	0	22
155	Forward	3	0.073	1000	0	1323	0	0.002	0.008	0	19
155	Reverse	1	0.073	0	0	0	0	0	0	21	0
156	Forward	1	0.112	0	0	0	0.008	0	0.008	2	1
156	Reverse	1	0.112	0	0	0	0.008	0	0.008	1	4
157	Forward	1	0.083	0	0	0	0.006	0	0.006	5	5
157	Reverse	1	0.083	0	0	0	0.006	0	0.006	0	1
158	Forward	1	0.012	506	0	740	0.001	0.001	0.002	34	7
158	Reverse	1	0.012	376	0	740	0.001	0.001	0.002	19	14
159	Forward	1	0.088	340	0	740	0.006	0.004	0.011	23	10
159	Reverse	1	0.088	376	0	740	0.006	0.005	0.011	14	19
160	Forward	1	0.061	86	0	660	0.004	0.001	0.005	4	0
160	Reverse	1	0.061	0	0	0	0.004	0	0.004	1	16
161	Forward	1	0.079	0	0	0	0.006	0	0.006	2	4
161	Reverse	1	0.079	0	0	0	0.006	0	0.006	2	20

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	**Direction**	**Type of cycling facility**	**Length** km	**Auto & bus flow** auto-vehicles/hr	**Bus flow** buses/hr	**Capacity** auto-vehicles/hr	**Travel time** hr	**Risk exposure** hr	**Disutility** hr	**Link flow 'shortest-path'** bicycles/hr	**Link flow with risk exposure** bicycle/hr
162	Forward	1	0.07	0	0	0	0.005	0	0.005	9	18
162	Reverse	1	0.07	36	0	608	0.005	0	0.005	8	7
163	Forward	1	0.12	226	0	740	0.009	0.004	0.012	3	17
163	Reverse	1	0.12	0	0	0	0.009	0	0.009	17	3
164	Forward	1	0.047	0	0	0	0.003	0	0	20	0
164	Reverse	1	0.047	338	0	1031	0.003	0.002	0.005	0	10
165	Forward	1	0.103	0	0	0	0.007	0	0.007	4	9
165	Reverse	1	0.103	0	0	0	0.007	0	0.007	5	7
166	Forward	1	0.008	1	0	783	0.001	0	0.001	0	19
166	Reverse	1	0.008	0	0	0	0.001	0	0.001	15	10
167	Forward	1	0.167	0	0	0	0.012	0	0	19	0
167	Reverse	1	0.167	554	0	1132	0.012	0.009	0.021	0	10
168	Forward	1	0.06	432	0	1480	0	0.002	0.006	0	15
168	Reverse	1	0.06	0	0	0	0	0	0	19	0
169	Forward	1	0.057	21	0	740	0.004	0	0.004	0	28
169	Reverse	1	0.057	19	0	348	0.004	0	0.004	2	10
170	Forward	1	0.011	21	0	740	0.001	0	0.001	0	15
170	Reverse	1	0.011	0	0	0	0.001	0	0.001	0	4

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	Direction	Type of cycling facility	Length km	Auto & bus flow auto-vehicles/hr	Bus flow buses/hr	Capacity auto-vehicles/hr	Travel time hr	Risk exposure hr	Disutility hr	Link flow 'shortest-path' bicycles/hr	Link flow with risk exposure bicycle/hr
171	Forward	1	0.077	0	0	0	0.006	0	0.006	13	14
171	Reverse	1	0.077	0	0	0	0.006	0	0.006	4	23
172	Forward	1	0.066	0	0	0	0.005	0	0.005	6	14
172	Reverse	1	0.066	0	0	0	0.005	0	0.005	2	20
173	Forward	1	0.124	188	0	338	0.009	0.007	0.016	0	0
173	Reverse	1	0.124	2	0	58	0.009	0	0.009	2	0
174	Forward	1	0.334	263	0	740	0.024	0.013	0.037	1	3
174	Reverse	1	0.334	263	0	740	0.024	0.013	0.037	1	5
175	Forward	1	0.125	86	0	216	0.009	0.005	0.014	27	3
175	Reverse	1	0.125	0	0	0	0.009	0	0.009	9	48
176	Forward	3	0.07	0	0	0	0	0	0.005	0	38
176	Reverse	1	0.07	0	0	0	0	0	0	25	0
177	Forward	2	0.128	726	253	740	0	0.002	0.011	0	6
177	Reverse	1	0.128	0	0	0	0	0	0	9	0
178	Forward	1	0.153	536	0	821	0	0.011	0.022	0	10
178	Reverse	1	0.153	0	0	0	0	0	0	4	0
179	Forward	1	0.089	0	0	0	0.006	0	0.006	0	4
179	Reverse	1	0.089	0	0	0	0.006	0	0.006	0	3

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	**Direction**	**Type of cycling facility**	**Length** km	**Auto & bus flow** auto-vehicles/hr	**Bus flow** buses/hr	**Capacity** auto-vehicles/hr	**Travel time** hr	**Risk exposure** hr	**Disutility** hr	**Link flow 'shortest-path'** bicycles/hr	**Link flow with risk exposure** bicycle/hr
180	Forward	1	0.215	0	0	0	0.015	0	0.015	0	9
180	Reverse	1	0.215	0	0	0	0.015	0	0.015	9	14
181	Forward	1	0.102	90	0	1480	0.007	0.001	0.008	10	50
181	Reverse	1	0.102	364	0	772	0.007	0.005	0.012	37	3
182	Forward	1	0.084	8	0	626	0.006	0	0.006	14	42
182	Reverse	1	0.084	292	0	740	0.006	0.004	0.01	53	8
183	Forward	1	0.047	390	0	777	0.003	0.003	0.006	14	1
183	Reverse	1	0.047	156	0	740	0.003	0.001	0.004	29	7
184	Forward	2	0.127	633	23	1480	0.009	0	0.009	11	12
184	Reverse	2	0.127	440	62	1480	0.009	0	0.01	6	10
185	Forward	1	0.095	0	0	0	0.007	0	0.007	6	5
185	Reverse	1	0.095	0	0	0	0.007	0	0.007	3	34
186	Forward	1	0.06	0	0	0	0.004	0	0.004	16	4
186	Reverse	1	0.06	0	0	0	0.004	0	0.004	0	42
187	Forward	1	0.169	49	0	489	0.012	0.002	0.014	0	0
187	Reverse	1	0.169	56	0	740	0.012	0.001	0.013	0	0
188	Forward	1	0.168	0	0	0	0.012	0	0	3	0
188	Reverse	1	0.168	0	0	0	0.012	0	0.012	0	5

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	Direction	Type of cycling facility	Length	Auto & bus flow	Bus flow	Capacity	Travel time	Risk exposure	Disutility	Link flow 'shortest-path'	Link flow with risk exposure
			km	auto-vehicles/hr	buses/hr	auto-vehicles/hr	hr	hr	hr	bicycles/hr	bicycle/hr
189	Forward	1	0.179	279	0	740	0.013	0.007	0.02	75	2
189	Reverse	1	0.179	674	0	511	0.013	0.017	0.03	5	9
190	Forward	2	0.194	613	59	740	0.014	0	0.014	28	59
190	Reverse	2	0.194	524	81	740	0.014	0.001	0.014	47	23
191	Forward	1	0.041	119	0	1312	0.003	0	0.003	42	35
191	Reverse	1	0.041	183	0	740	0.003	0.001	0.004	22	56
192	Forward	1	0.209	0	0	0	0.015	0	0.015	0	42
192	Reverse	1	0.209	0	0	0	0.015	0	0.015	16	4
193	Forward	1	0.087	0	0	0	0.006	0	0	13	0
193	Reverse	1	0.087	419	0	1480	0.006	0.003	0.009	0	7
194	Forward	1	0.039	0	0	0	0.003	0	0	51	0
194	Reverse	1	0.039	0	0	0	0.003	0	0.003	0	60
195	Forward	1	0.09	187	0	740	0	0.002	0.009	0	1
195	Reverse	1	0.09	0	0	0	0	0	0	1	0
196	Forward	1	0.033	0	0	0	0.002	0	0	37	0
196	Reverse	1	0.033	629	0	1480	0.002	0.002	0.004	0	25
197	Forward	1	0.091	67	0	740	0.007	0.001	0.007	0	14
197	Reverse	1	0.091	287	0	740	0.007	0.004	0.01	2	17

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	**Direction**	**Type of cycling facility**	**Length** km	**Auto & bus flow** auto-vehicles/hr	**Bus flow** buses/hr	**Capacity** auto-vehicles/hr	**Travel time** hr	**Risk exposure** hr	**Disutility** hr	**Link flow 'shortest-path'** bicycles/hr	**Link flow with risk exposure** bicycle/hr
198	Forward	1	0.123	685	0	1480	0	0.006	0.015	0	6
198	Reverse	1	0.123	0	0	0	0	0	0	8	0
199	Forward	1	0.171	0	0	0	0.012	0	0.012	12	7
199	Reverse	1	0.171	0	0	0	0.012	0	0.012	0	12
200	Forward	1	0.031	567	0	720	0.002	0.003	0.005	6	2
200	Reverse	1	0.031	274	0	690	0.002	0.001	0.004	6	5
201	Forward	1	0.136	432	0	1480	0	0.004	0.014	0	57
201	Reverse	1	0.136	0	0	0	0	0	0	51	0
202	Forward	1	0.066	0	0	0	0.005	0	0.005	7	2
202	Reverse	1	0.066	0	0	0	0.005	0	0.005	2	7
203	Forward	1	0.037	100	0	1480	0.003	0	0.003	1	40
203	Reverse	1	0.037	89	0	740	0.003	0	0.003	24	7
204	Forward	1	0.036	380	0	0	0.003	0	0.003	0	38
204	Reverse	1	0.036	307	0	0	0.003	0	0.003	6	1
205	Forward	1	0.121	4	0	580	0.009	0	0.009	9	0
205	Reverse	1	0.121	182	0	740	0.009	0.003	0.012	0	2
206	Forward	1	0.013	32	0	0	0	0	0.001	0	53
206	Reverse	1	0.013	0	0	0	0	0	0	29	0

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	Direction	Type of cycling facility	Length km	Auto & bus flow auto-vehicles/hr	Bus flow buses/hr	Capacity auto-vehicles/hr	Travel time hr	Risk exposure hr	Disutility hr	Link flow 'shortest-path' bicycles/hr	Link flow with risk exposure bicycle/hr
207	Forward	1	0.033	0	0	0	0.002	0	0	13	0
207	Reverse	1	0.033	1132	0	2220	0.002	0.002	0.004	0	33
208	Forward	4	0.164	0	0	0	0.012	0	0.012	10	96
208	Reverse	4	0.164	0	0	0	0.012	0	0.012	77	21
209	Forward	1	0.144	508	0	740	0.01	0.011	0.021	16	6
209	Reverse	1	0.144	632	0	695	0.01	0.014	0.024	30	4
210	Forward	1	0.108	62	0	740	0.008	0.001	0.009	0	13
210	Reverse	1	0.108	135	0	740	0.008	0.002	0.01	3	10
211	Forward	1	0.178	418	0	781	0.013	0.01	0.023	22	16
211	Reverse	1	0.178	34	0	735	0.013	0.001	0.014	8	25
212	Forward	1	0.218	0	0	0	0.016	0	0.016	9	8
212	Reverse	1	0.218	0	0	0	0.016	0	0.016	2	6
213	Forward	1	0.049	651	0	723	0.004	0.005	0.008	23	4
213	Reverse	1	0.049	540	0	980	0.004	0.003	0.006	47	2
214	Forward	4	0.206	0	0	0	0.015	0	0.015	9	30
214	Reverse	4	0.206	0	0	0	0.015	0	0.015	3	37
215	Forward	1	0.189	0	0	740	0.014	0	0.014	9	30
215	Reverse	1	0.189	0	0	740	0.014	0	0.014	3	37

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	Direction	Type of cycling facility	Length km	Auto & bus flow auto-vehicles/hr	Bus flow buses/hr	Capacity auto-vehicles/hr	Travel time hr	Risk exposure hr	Disutility hr	Link flow 'shortest-path' bicycles/hr	Link flow with risk exposure bicycle/hr
216	Forward	1	0.335	0	0	740	0.024	0	0	0	0
216	Reverse	1	0.335	12	0	740	0.024	0.001	0.025	0	0
217	Forward	1	0.087	16	0	1403	0	0	0.006	0	54
217	Reverse	1	0.087	0	0	0	0	0	0	36	0
218	Forward	1	0.083	0	0	0	0.006	0	0.006	4	8
218	Reverse	1	0.083	0	0	0	0.006	0	0.006	2	40
219	Forward	1	0.051	0	0	0	0.004	0	0.004	47	4
219	Reverse	1	0.051	0	0	0	0.004	0	0.004	3	120
220	Forward	1	0.182	0	0	0	0.013	0	0.013	2	46
220	Reverse	1	0.182	0	0	0	0.013	0	0.013	44	9
221	Forward	1	0.136	418	0	781	0.01	0.008	0.018	56	13
221	Reverse	1	0.136	34	0	735	0.01	0.001	0.01	6	62
222	Forward	1	0.077	0	0	0	0.006	0	0	21	0
222	Reverse	3	0.077	857	0	1480	0.006	0.001	0.007	0	10
223	Forward	1	0.072	0	0	0	0.005	0	0.005	0	3
223	Reverse	1	0.072	0	0	0	0.005	0	0.005	0	2
224	Forward	1	0.078	217	0	740	0.006	0.002	0.008	0	7
224	Reverse	1	0.078	0	0	0	0.006	0	0.006	4	17

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	Direction	Type of cycling facility	Length km	Auto & bus flow auto-vehicles/hr	Bus flow buses/hr	Capacity auto-vehicles/hr	Travel time hr	Risk exposure hr	Disutility hr	Link flow 'shortest-path' bicycles/hr	Link flow with risk exposure bicycle/hr
225	Forward	1	0.107	0	0	414	0.008	0	0	0	0
225	Reverse	1	0.107	0	0	0	0.008	0	0.008	0	17
226	Forward	1	0.133	0	0	0	0.01	0	0	104	0
226	Reverse	1	0.133	644	0	1480	0.01	0.006	0.016	0	72
227	Forward	4	0.097	418	0	913	0.007	0	0.007	4	6
227	Reverse	1	0.097	16	0	740	0.007	0	0.007	0	20
228	Forward	1	0.039	545	0	740	0.003	0.003	0.006	10	11
228	Reverse	1	0.039	0	0	0	0.003	0	0.003	18	21
229	Forward	1	0.086	0	0	0	0.006	0	0	36	0
229	Reverse	3	0.086	489	0	1480	0.006	0.001	0.007	0	67
230	Forward	3	0.033	748	0	1480	0.002	0	0.003	11	23
230	Reverse	3	0.033	350	0	1480	0.002	0	0.002	43	12
231	Forward	3	0.029	748	0	1480	0.002	0	0.002	7	22
231	Reverse	3	0.029	350	0	1480	0.002	0	0.002	41	4
232	Forward	3	0.063	748	0	1480	0.005	0.001	0.005	6	15
232	Reverse	3	0.063	350	0	1480	0.005	0	0.005	41	7
233	Forward	3	0.023	273	0	740	0.002	0	0.002	53	3
233	Reverse	3	0.023	681	0	1480	0.002	0	0.002	3	45

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	Direction	Type of cycling facility	Length km	Auto & bus flow auto-vehicles/hr	Bus flow buses/hr	Capacity auto-vehicles/hr	Travel time hr	Risk exposure hr	Disutility hr	Link flow 'shortest-path' bicycles/hr	Link flow with risk exposure bicycle/hr
234	Forward	1	0.015	350	0	1480	0.001	0	0.001	38	12
234	Reverse	1	0.015	748	0	1480	0.001	0.001	0.002	11	22
235	Forward	1	0.071	0	0	0	0.005	0	0	18	0
235	Reverse	2	0.071	1055	659	1463	0.005	0.005	0.01	0	21
236	Forward	1	0.057	0	0	0	0.004	0	0	10	0
236	Reverse	2	0.057	1055	659	1463	0.004	0.005	0.009	0	7
237	Forward	3	0.037	914	0	1480	0	0.001	0.003	0	15
237	Reverse	1	0.037	0	0	0	0	0	0	32	0
238	Forward	1	0.055	0	0	0	0.004	0	0	40	0
238	Reverse	3	0.055	914	0	1480	0.004	0.001	0.005	0	29
239	Forward	1	0.051	0	0	0	0	0	0.004	0	14
239	Reverse	1	0.051	0	0	0	0	0	0	9	0
240	Forward	1	0.061	292	0	1480	0	0.001	0.006	0	6
240	Reverse	1	0.061	0	0	0	0	0	0	7	0
241	Forward	3	0.036	292	0	1480	0.003	0	0.003	51	16
241	Reverse	3	0.036	274	0	1480	0.003	0	0.003	24	35
242	Forward	3	0.004	274	0	1480	0	0	0	7	31
242	Reverse	3	0.004	292	0	1480	0	0	0	50	6

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	Direction	Type of cycling facility	Length km	Auto & bus flow auto-vehicles/hr	Bus flow buses/hr	Capacity auto-vehicles/hr	Travel time hr	Risk exposure hr	Disutility hr	Link flow 'shortest-path' bicycles/hr	Link flow with risk exposure bicycle/hr
243	Forward	1	0.132	0	0	0	0.009	0	0	66	0
243	Reverse	1	0.132	1570	0	2220	0.009	0.01	0.019	0	55
244	Forward	1	0.04	0	0	0	0	0	0.003	0	22
244	Reverse	1	0.04	0	0	0	0	0	0	27	0
245	Forward	1	0.016	338	0	0	0.001	0	0.001	0	9
245	Reverse	1	0.016	0	0	0	0.001	0	0	20	0
246	Forward	1	0.104	0	0	0	0.007	0	0.007	6	7
246	Reverse	1	0.104	0	0	0	0.007	0	0.007	10	7
247	Forward	1	0.01	38	0	740	0.001	0	0.001	10	11
247	Reverse	1	0.01	0	0	0	0.001	0	0.001	10	7
248	Forward	1	0.045	0	0	0	0.003	0	0.003	4	3
248	Reverse	1	0.045	38	0	740	0.003	0	0.003	0	6
249	Forward	1	0.035	0	0	0	0.003	0	0	10	0
249	Reverse	2	0.035	739	0	0	0.003	0	0.003	0	9
250	Forward	2	0.049	739	627	1480	0.004	0.001	0.005	32	6
250	Reverse	2	0.049	562	476	1480	0.004	0.001	0.005	10	14
251	Forward	1	0.056	262	0	1480	0	0.001	0.005	0	5
251	Reverse	1	0.056	0	0	0	0	0	0	7	0

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	Direction	Type of cycling facility	Length km	Auto & bus flow auto-vehicles/hr	Bus flow buses/hr	Capacity auto-vehicles/hr	Travel time hr	Risk exposure hr	Disutility hr	Link flow 'shortest-path' bicycles/hr	Link flow with risk exposure bicycle/hr
252	Forward	1	0.022	0	0	0	0.002	0	0.002	7	23
252	Reverse	1	0.022	262	0	1480	0.002	0	0.002	38	5
253	Forward	3	0.061	562	0	1480	0	0.001	0.005	0	40
253	Reverse	1	0.061	0	0	0	0	0	0	70	0
254	Forward	1	0.02	0	0	0	0.001	0	0	38	0
254	Reverse	1	0.02	0	0	0	0.001	0	0.001	0	23
255	Forward	3	0.061	0	0	0	0.004	0	0	50	0
255	Reverse	3	0.061	274	0	1480	0.004	0	0.004	0	31
256	Forward	1	0.067	543	0	1480	0	0.003	0.007	0	55
256	Reverse	1	0.067	0	0	0	0	0	0	62	0
257	Forward	2	0.07	1421	173	2960	0	0.001	0.006	0	22
257	Reverse	1	0.07	0	0	0	0	0	0	25	0
258	Forward	1	0.057	16	0	1403	0	0	0.004	0	24
258	Reverse	1	0.057	0	0	0	0	0	0	23	0
259	Forward	1	0.032	0	0	0	0.002	0	0	23	0
259	Reverse	1	0.032	16	0	1403	0.002	0	0.002	0	24
260	Forward	1	0.076	0	0	0	0.005	0	0	25	0
260	Reverse	2	0.076	1557	173	2960	0.005	0.001	0.007	0	23

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	Direction	Type of cycling facility	Length km	Auto & bus flow auto-vehicles/hr	Bus flow buses/hr	Capacity auto-vehicles/hr	Travel time hr	Risk exposure hr	Disutility hr	Link flow 'shortest-path' bicycles/hr	Link flow with risk exposure bicycle/hr
261	Forward	2	0.057	1557	173	2960	0	0.001	0.005	0	23
261	Reverse	1	0.057	0	0	0	0	0	0	25	0
262	Forward	4	0.141	1440	0	1480	0.01	0	0.01	3	40
262	Reverse	1	0.141	0	0	0	0.01	0	0.01	21	10
263	Forward	1	0.018	0	0	0	0.001	0	0.001	0	10
263	Reverse	1	0.018	1440	0	1480	0.001	0.002	0.003	3	22
264	Forward	1	0.062	0	0	0	0.004	0	0	21	0
264	Reverse	3	0.062	1000	0	1323	0.004	0.002	0.006	0	19
265	Forward	1	0.018	1000	0	1323	0	0.001	0.003	0	1
265	Reverse	1	0.018	0	0	0	0	0	0	1	0
266	Forward	1	0.01	0	0	0	0.001	0	0.001	16	14
266	Reverse	1	0.01	545	0	740	0.001	0.001	0.002	6	9
267	Forward	1	0.006	0	0	0	0	0	0	7	12
267	Reverse	1	0.006	0	0	0	0	0	0	3	15
268	Forward	1	0.073	0	0	0	0.005	0	0.005	1	9
268	Reverse	1	0.073	177	0	407	0.005	0.003	0.009	6	3
269	Forward	1	0.077	0	0	0	0.006	0	0.006	8	17
269	Reverse	1	0.077	23	0	740	0.006	0	0.006	5	11

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	Direction	Type of cycling facility	Length km	Auto & bus flow auto-vehicles/hr	Bus flow buses/hr	Capacity auto-vehicles/hr	Travel time hr	Risk exposure hr	Disutility hr	Link flow 'shortest-path' bicycles/hr	Link flow with risk exposure bicycle/hr
270	Forward	1	0.04	23	0	0	0.003	0	0.003	4	15
270	Reverse	1	0.04	0	0	0	0.003	0	0.003	5	12
271	Forward	1	0.088	0	0	0	0.006	0	0.006	7	12
271	Reverse	1	0.088	0	0	0	0.006	0	0.006	3	15
272	Forward	1	0.054	0	0	0	0.004	0	0.004	4	15
272	Reverse	1	0.054	0	0	0	0.004	0	0.004	9	9
273	Forward	1	0.018	283	0	740	0.001	0.001	0.002	17	2
273	Reverse	1	0.018	0	0	0	0.001	0	0.001	7	40
274	Forward	1	0.024	0	0	0	0.002	0	0.002	7	26
274	Reverse	1	0.024	283	0	740	0.002	0.001	0.003	12	1
275	Forward	1	0.036	0	0	0	0.003	0	0.003	9	31
275	Reverse	1	0.036	283	0	740	0.003	0.001	0.004	13	4
276	Forward	1	0.063	181	0	740	0.005	0.002	0.006	3	6
276	Reverse	1	0.063	0	0	0	0.005	0	0.005	7	17
277	Forward	1	0.03	0	0	0	0.002	0	0.002	7	17
277	Reverse	1	0.03	181	0	740	0.002	0.001	0.003	3	6
278	Forward	1	0.107	261	0	740	0.008	0.004	0.012	42	0
278	Reverse	1	0.107	477	0	740	0.008	0.007	0.015	8	26

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	Direction	Type of cycling facility	Length km	Auto & bus flow auto-vehicles/hr	Bus flow buses/hr	Capacity auto-vehicles/hr	Travel time hr	Risk exposure hr	Disutility hr	Link flow 'shortest-path' bicycles/hr	Link flow with risk exposure bicycle/hr
279	Forward	2	0.083	1058	267	1128	0	0.002	0.008	0	1
279	Reverse	1	0.083	0	0	0	0	0	0	9	0
280	Forward	1	0.087	0	0	0	0.006	0	0	9	0
280	Reverse	2	0.087	1088	268	1128	0.006	0.002	0.008	0	1
281	Forward	2	0.01	652	108	740	0.001	0.001	0.001	22	9
281	Reverse	1	0.01	285	0	0	0.001	0	0.001	1	9
282	Forward	3	0.027	989	0	1480	0	0.001	0.003	0	20
282	Reverse	2	0.027	0	0	0	0	0	0	31	0
283	Forward	1	0.034	0	0	0	0.002	0	0	6	0
283	Reverse	1	0.034	0	0	0	0.002	0	0.002	0	5
284	Forward	2	0.108	652	108	987	0.008	0.001	0.008	22	9
284	Reverse	1	0.108	285	0	740	0.008	0.004	0.012	1	9
285	Forward	1	0.02	285	0	987	0.001	0.001	0.002	1	14
285	Reverse	2	0.02	652	108	740	0.001	0.001	0.002	28	9
286	Forward	1	0.104	0	0	0	0.007	0	0.007	3	37
286	Reverse	1	0.104	0	0	0	0.007	0	0.007	12	6
287	Forward	1	0.013	0	0	0	0.001	0	0.001	12	6
287	Reverse	1	0.013	0	0	0	0.001	0	0.001	3	37

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	Direction	Type of cycling facility	Length km	Auto & bus flow auto-vehicles/hr	Bus flow buses/hr	Capacity auto-vehicles/hr	Travel time hr	Risk exposure hr	Disutility hr	Link flow 'shortest-path' bicycles/hr	Link flow with risk exposure bicycle/hr
288	Forward	1	0.016	156	0	740	0.001	0	0.002	22	21
288	Reverse	1	0.016	390	0	777	0.001	0.001	0.002	23	7
289	Forward	1	0.028	292	0	740	0.002	0.001	0.003	51	8
289	Reverse	1	0.028	8	0	626	0.002	0	0.002	11	41
290	Forward	1	0.11	0	0	0	0.008	0	0.008	2	6
290	Reverse	1	0.11	0	0	0	0.008	0	0.008	5	7
291	Forward	1	0.063	447	0	614	0.005	0.005	0.009	9	4
291	Reverse	1	0.063	336	0	740	0.005	0.003	0.008	71	6
292	Forward	1	0.044	447	0	614	0.003	0.003	0.007	9	4
292	Reverse	1	0.044	336	0	740	0.003	0.002	0.005	71	6
293	Forward	2	0.052	467	59	740	0.004	0	0.004	31	19
293	Reverse	3	0.052	617	0	740	0.004	0.002	0.006	11	30
294	Forward	3	0.009	467	0	0	0.001	0	0.001	30	19
294	Reverse	3	0.009	617	0	0	0.001	0	0.001	7	68
295	Forward	1	0.084	43	0	0	0.006	0	0.006	7	7
295	Reverse	1	0.084	48	0	0	0.006	0	0.006	12	8
296	Forward	1	0.035	0	0	0	0.003	0	0.003	0	43
296	Reverse	1	0.035	0	0	0	0.003	0	0.003	31	3

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	**Direction**	**Type of cycling facility**	**Length** km	**Auto & bus flow** auto-vehicles/hr	**Bus flow** buses/hr	**Capacity** auto-vehicles/hr	**Travel time** hr	**Risk exposure** hr	**Disutility** hr	**Link flow 'shortest-path'** bicycles/hr	**Link flow with risk exposure** bicycle/hr
297	Forward	1	0.023	0	0	0	0	0	0.002	0	5
297	Reverse	1	0.023	0	0	0	0	0	0	6	0
298	Forward	1	0.032	0	0	0	0.002	0	0	6	0
298	Reverse	1	0.032	0	0	0	0.002	0	0.002	0	13
299	Forward	1	0.024	567	0	720	0	0.002	0.004	0	2
299	Reverse	1	0.024	274	0	690	0	0	0	6	0
300	Forward	1	0.027	567	0	720	0	0.002	0.004	0	9
300	Reverse	1	0.027	274	0	690	0	0	0	6	0
301	Forward	1	0.018	0	0	0	0.001	0	0.001	0	8
301	Reverse	1	0.018	0	0	0	0.001	0	0	0	0
302	Forward	3	0.044	1228	0	2125	0.003	0.001	0.004	10	23
302	Reverse	3	0.044	515	0	1480	0.003	0	0.003	106	3
303	Forward	3	0.088	746	0	739	0.006	0.005	0.011	32	0
303	Reverse	3	0.088	192	0	1480	0.006	0	0.006	0	21
304	Forward	1	0.014	1091	0	1480	0	0.001	0.002	0	24
304	Reverse	1	0.014	114	0	133	0	0	0	44	0
305	Forward	1	0.019	524	0	740	0	0.001	0.003	0	1
305	Reverse	1	0.019	0	0	0	0	0	0	8	0

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	**Direction**	**Type of cycling facility**	**Length** km	**Auto & bus flow** auto-vehicles/hr	**Bus flow** buses/hr	**Capacity** auto-vehicles/hr	**Travel time** hr	**Risk exposure** hr	**Disutility** hr	**Link flow 'shortest-path'** bicycles/hr	**Link flow with risk exposure** bicycle/hr
306	Forward	3	0.138	746	0	1480	0.01	0.002	0.012	0	21
306	Reverse	3	0.138	192	0	739	0.01	0.001	0.01	32	0
307	Forward	3	0.015	746	0	1480	0	0	0.001	0	22
307	Reverse	3	0.015	192	0	739	0	0	0	40	0
308	Forward	1	0.115	0	0	0	0.008	0	0	32	0
308	Reverse	3	0.115	820	0	1480	0.008	0.002	0.01	0	42
309	Forward	3	0.03	820	0	1480	0	0.001	0.003	0	36
309	Reverse	1	0.03	0	0	0	0	0	0	30	0
310	Forward	2	0.027	831	62	2303	0	0	0.002	0	17
310	Reverse	1	0.027	0	0	0	0	0	0	34	0
311	Forward	2	0.088	831	62	2303	0	0	0.007	0	23
311	Reverse	1	0.088	0	0	0	0	0	0	36	0
312	Forward	1	0.024	0	0	0	0	0	0.002	0	6
312	Reverse	1	0.024	0	0	0	0	0	0	1	0
313	Forward	3	0.038	286	0	740	0.003	0	0.003	22	74
313	Reverse	3	0.038	311	0	740	0.003	0	0.003	83	24
314	Forward	1	0.031	0	0	0	0.002	0	0.002	0	4
314	Reverse	1	0.031	0	0	0	0.002	0	0.002	0	27

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	Direction	Type of cycling facility	Length km	Auto & bus flow auto-vehicles/hr	Bus flow buses/hr	Capacity auto-vehicles/hr	Travel time hr	Risk exposure hr	Disutility hr	Link flow 'shortest-path' bicycles/hr	Link flow with risk exposure bicycle/hr
315	Forward	1	0.033	0	0	0	0.002	0	0.002	0	27
315	Reverse	1	0.033	0	0	0	0.002	0	0.002	0	4
316	Forward	3	0.026	286	0	740	0.002	0	0.002	22	48
316	Reverse	3	0.026	311	0	740	0.002	0	0.002	83	20
317	Forward	3	0.044	379	0	740	0.003	0.001	0.004	34	37
317	Reverse	3	0.044	362	0	740	0.003	0.001	0.004	51	12
318	Forward	3	0.041	362	0	740	0.003	0.001	0.003	51	24
318	Reverse	3	0.041	379	0	740	0.003	0.001	0.004	34	60
319	Forward	1	0.054	0	0	0	0.004	0	0.004	0	23
319	Reverse	1	0.054	0	0	0	0.004	0	0.004	0	12
320	Forward	1	0.016	0	0	0	0.001	0	0.001	0	23
320	Reverse	1	0.016	0	0	0	0.001	0	0.001	0	12
321	Forward	3	0.057	411	0	740	0.004	0.001	0.005	8	35
321	Reverse	3	0.057	650	0	1051	0.004	0.001	0.005	37	6
322	Forward	3	0.073	650	0	740	0.005	0.003	0.008	8	35
322	Reverse	3	0.073	411	0	1051	0.005	0.001	0.006	37	6
323	Forward	1	0.04	675	0	740	0.003	0.004	0.007	52	5
323	Reverse	1	0.04	634	0	740	0.003	0.004	0.007	17	31

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	**Direction**	**Type of cycling facility**	**Length** km	**Auto & bus flow** auto-vehicles/hr	**Bus flow** buses/hr	**Capacity** auto-vehicles/hr	**Travel time** hr	**Risk exposure** hr	**Disutility** hr	**Link flow 'shortest-path'** bicycles/hr	**Link flow with risk exposure** bicycle/hr
324	Forward	4	0.06	323	0	740	0.004	0	0.004	6	54
324	Reverse	4	0.06	132	0	740	0.004	0	0.004	25	15
325	Forward	4	0.026	323	0	740	0.002	0	0.002	6	54
325	Reverse	4	0.026	132	0	740	0.002	0	0.002	25	15
326	Forward	3	0.032	505	0	2220	0	0	0.002	0	55
326	Reverse	1	0.032	0	0	0	0	0	0	55	0
327	Forward	3	0.088	505	0	2220	0	0	0.007	0	77
327	Reverse	1	0.088	0	0	0	0	0	0	81	0
328	Forward	1	0.096	1179	0	2267	0	0.005	0.012	0	27
328	Reverse	3	0.096	0	0	0	0	0	0	31	0
329	Forward	1	0.011	0	0	0	0.001	0	0	31	0
329	Reverse	1	0.011	1179	0	2267	0.001	0	0.001	0	27
330	Forward	1	0.017	1570	585	2220	0	0.001	0.003	0	33
330	Reverse	1	0.017	0	0	0	0	0	0	39	0
331	Forward	1	0.013	0	0	0	0.001	0	0	39	0
331	Reverse	1	0.013	1570	585	2220	0.001	0.001	0.002	0	33
332	Forward	1	0.105	377	0	1480	0	0.003	0.01	0	12
332	Reverse	1	0.105	0	0	0	0	0	0	26	0

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	**Direction**	**Type of cycling facility**	**Length** km	**Auto & bus flow** auto-vehicles/hr	**Bus flow** buses/hr	**Capacity** auto-vehicles/hr	**Travel time** hr	**Risk exposure** hr	**Disutility** hr	**Link flow 'shortest-path'** bicycles/hr	**Link flow with risk exposure** bicycle/hr
333	Forward	1	0.082	377	0	1480	0	0.002	0.008	0	9
333	Reverse	1	0.082	0	0	0	0	0	0	26	0
334	Forward	1	0.083	0	0	0	0.006	0	0	13	0
334	Reverse	1	0.083	419	0	1480	0.006	0.003	0.008	0	7
335	Forward	1	0.113	0	0	0	0.008	0	0	13	0
335	Reverse	1	0.113	419	0	1480	0.008	0.003	0.011	0	10
336	Forward	1	0.012	0	0	0	0.001	0	0	0	0
336	Reverse	1	0.012	0	0	0	0.001	0	0.001	0	3
337	Forward	2	0.02	522	62	2220	0.001	0	0.002	6	19
337	Reverse	2	0.02	846	23	131	0.001	0	0.002	15	10
338	Forward	2	0.007	846	23	131	0.001	0	0.001	15	10
338	Reverse	2	0.007	522	62	2220	0.001	0	0.001	6	19
339	Forward	1	0.073	0	0	0	0.005	0	0	8	0
339	Reverse	1	0.073	243	0	1480	0.005	0.001	0.006	0	3
340	Forward	1	0.119	0	0	0	0.009	0	0	8	0
340	Reverse	1	0.119	243	0	1480	0.009	0.002	0.011	0	4
341	Forward	1	0.103	110	0	740	0	0.002	0.009	0	0
341	Reverse	1	0.103	0	0	0	0	0	0	1	0

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	Direction	Type of cycling facility	Length km	Auto & bus flow auto-vehicles/hr	Bus flow buses/hr	Capacity auto-vehicles/hr	Travel time hr	Risk exposure hr	Disutility hr	Link flow 'shortest-path' bicycles/hr	Link flow with risk exposure bicycle/hr
342	Forward	1	0.073	110	0	740	0	0.001	0.006	0	1
342	Reverse	1	0.073	0	0	0	0	0	0	1	0
343	Forward	1	0.09	0	0	0	0.006	0	0	6	0
343	Reverse	1	0.09	543	0	1480	0.006	0.004	0.01	0	0
344	Forward	1	0.029	0	0	0	0.002	0	0	14	0
344	Reverse	1	0.029	685	0	1480	0.002	0.001	0.004	0	4
345	Forward	1	0.087	32	0	1480	0	0	0.006	0	37
345	Reverse	1	0.087	0	0	0	0	0	0	6	0
346	Forward	1	0.131	0	0	0	0.009	0	0	6	0
346	Reverse	1	0.131	32	0	1480	0.009	0	0.01	0	37
347	Forward	1	0.071	582	0	740	0.005	0.006	0.011	10	36
347	Reverse	3	0.071	385	0	736	0.005	0.001	0.006	112	8
348	Forward	1	0.101	582	0	740	0.007	0.009	0.016	11	17
348	Reverse	3	0.101	385	0	736	0.007	0.002	0.009	81	22
349	Forward	1	0.164	0	0	0	0.012	0	0.012	2	38
349	Reverse	1	0.164	0	0	0	0.012	0	0.012	34	4
350	Forward	1	0.06	0	0	0	0.004	0	0.004	2	38
350	Reverse	1	0.06	0	0	0	0.004	0	0.004	34	4

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	Direction	Type of cycling facility	Length km	Auto & bus flow auto-vehicles/hr	Bus flow buses/hr	Capacity auto-vehicles/hr	Travel time hr	Risk exposure hr	Disutility hr	Link flow 'shortest-path' bicycles/hr	Link flow with risk exposure bicycle/hr
351	Forward	3	0.07	519	0	1480	0	0	0.005	0	8
351	Reverse	1	0.07	0	0	0	0	0	0	12	0
352	Forward	1	0.076	876	0	1480	0	0.005	0.01	0	12
352	Reverse	1	0.076	0	0	0	0	0	0	21	0
353	Forward	3	0.059	876	0	1480	0	0.001	0.005	0	13
353	Reverse	1	0.059	0	0	0	0	0	0	21	0
354	Forward	1	0.009	0	0	0	0.001	0	0.001	0	1
354	Reverse	1	0.009	0	0	0	0.001	0	0	0	0
355	Forward	1	0.059	0	0	0	0.004	0	0.004	1	2
355	Reverse	1	0.059	34	0	0	0.004	0	0.004	2	1
356	Forward	1	0.184	19	0	348	0.013	0.001	0.014	1	10
356	Reverse	1	0.184	21	0	740	0.013	0.001	0.014	0	28
357	Forward	1	0.01	21	0	740	0.001	0	0.001	12	21
357	Reverse	1	0.01	19	0	348	0.001	0	0.001	4	54
358	Forward	1	0.031	0	0	0	0.002	0	0	9	0
358	Reverse	1	0.031	685	0	1480	0.002	0.002	0.004	0	7
359	Forward	1	0.033	685	0	1480	0	0.002	0.004	0	7
359	Reverse	1	0.033	0	0	0	0	0	0	9	0

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	**Direction**	**Type of cycling facility**	**Length** km	**Auto & bus flow** auto-vehicles/hr	**Bus flow** buses/hr	**Capacity** auto-vehicles/hr	**Travel time** hr	**Risk exposure** hr	**Disutility** hr	**Link flow 'shortest-path'** bicycles/hr	**Link flow with risk exposure** bicycle/hr
360	Forward	1	0.05	685	0	1480	0	0.002	0.006	0	7
360	Reverse	1	0.05	0	0	0	0	0	0	9	0
361	Forward	1	0.058	524	0	740	0	0.004	0.009	0	7
361	Reverse	1	0.058	0	0	0	0	0	0	9	0
362	Forward	1	0.007	0	0	740	0.001	0	0	8	0
362	Reverse	1	0.007	524	0	740	0.001	0.001	0.001	0	2
363	Forward	1	0.045	0	0	0	0.003	0	0	8	0
363	Reverse	1	0.045	524	0	740	0.003	0.003	0.007	0	2
364	Forward	1	0.043	0	0	740	0.003	0	0	8	0
364	Reverse	1	0.043	524	0	740	0.003	0.003	0.006	0	2
365	Forward	1	0.106	0	0	2220	0	0	0.008	0	91
365	Reverse	1	0.106	1132	0	0	0	0	0	64	0
366	Forward	1	0.023	0	0	0	0.002	0	0	55	0
366	Reverse	1	0.023	0	0	0	0.002	0	0.002	0	66
367	Forward	3	0.091	1409	0	2960	0	0.001	0.008	0	90
367	Reverse	3	0.091	0	0	743	0	0	0	71	0
368	Forward	3	0.027	532	0	740	0	0.001	0.003	0	65
368	Reverse	3	0.027	0	0	743	0	0	0	61	0

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	Direction	Type of cycling facility	Length km	Auto & bus flow auto-vehicles/hr	Bus flow buses/hr	Capacity auto-vehicles/hr	Travel time hr	Risk exposure hr	Disutility hr	Link flow 'shortest-path' bicycles/hr	Link flow with risk exposure bicycle/hr
369	Forward	1	0.033	1132	0	2220	0	0.002	0.004	0	24
369	Reverse	1	0.033	0	0	0	0	0	0	9	0
370	Forward	1	0.055	43	0	0	0.004	0	0.004	7	10
370	Reverse	1	0.055	48	0	0	0.004	0	0.004	12	8
371	Forward	1	0.021	43	0	0	0.002	0	0.002	7	10
371	Reverse	1	0.021	48	0	0	0.002	0	0.002	12	8
372	Forward	1	0.14	0	0	0	0.01	0	0	42	0
372	Reverse	2	0.14	477	417	740	0.01	0.003	0.013	0	27
373	Forward	3	0.073	482	0	980	0.005	0.001	0.006	25	13
373	Reverse	3	0.073	825	0	825	0.005	0.004	0.009	12	7
374	Forward	1	0.036	151	0	740	0.003	0.001	0.003	0	8
374	Reverse	1	0.036	195	0	1480	0.003	0.001	0.003	2	5
375	Forward	1	0.064	0	0	0	0.005	0	0.005	1	9
375	Reverse	1	0.064	125	0	740	0.005	0.001	0.006	9	1
376	Forward	2	0.174	429	81	740	0.012	0.001	0.013	48	20
376	Reverse	2	0.174	542	60	1480	0.012	0	0.013	29	52
377	Forward	1	0.163	281	0	1480	0.012	0.003	0.015	25	23
377	Reverse	3	0.163	421	0	740	0.012	0.003	0.015	37	19

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	**Direction**	**Type of cycling facility**	**Length** km	**Auto & bus flow** auto-vehicles/hr	**Bus flow** buses/hr	**Capacity** auto-vehicles/hr	**Travel time** hr	**Risk exposure** hr	**Disutility** hr	**Link flow 'shortest-path'** bicycles/hr	**Link flow with risk exposure** bicycle/hr
378	Forward	1	0.009	0	0	0	0.001	0	0.001	6	2
378	Reverse	1	0.009	0	0	0	0.001	0	0.001	2	9
379	Forward	3	0.318	749	0	825	0.023	0.015	0.038	12	6
379	Reverse	3	0.318	449	0	980	0.023	0.004	0.027	27	9
380	Forward	3	0.067	749	0	825	0.005	0.003	0.008	13	7
380	Reverse	3	0.067	449	0	980	0.005	0.001	0.006	29	7
381	Forward	3	0.092	449	0	980	0.007	0.001	0.008	31	8
381	Reverse	3	0.092	749	0	825	0.007	0.004	0.011	12	12
382	Forward	1	0.011	315	0	416	0.001	0.001	0.002	8	11
382	Reverse	1	0.011	254	0	1381	0.001	0	0.001	11	16
383	Forward	1	0.277	376	0	740	0.02	0.015	0.035	6	2
383	Reverse	1	0.277	340	0	740	0.02	0.014	0.033	9	1
384	Forward	1	0.075	422	0	740	0.005	0.005	0.01	8	9
384	Reverse	1	0.075	386	0	740	0.005	0.004	0.01	10	7
385	Forward	3	0.09	949	0	980	0.006	0.005	0.011	9	14
385	Reverse	3	0.09	453	0	729	0.006	0.002	0.008	44	22
386	Forward	1	0.021	315	0	416	0.002	0.002	0.003	9	8
386	Reverse	1	0.021	254	0	1381	0.002	0	0.002	12	16

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	Direction	Type of cycling facility	Length km	Auto & bus flow auto-vehicles/hr	Bus flow buses/hr	Capacity auto-vehicles/hr	Travel time hr	Risk exposure hr	Disutility hr	Link flow 'shortest-path' bicycles/hr	Link flow with risk exposure bicycle/hr
387	Forward	1	0.079	315	0	416	0.006	0.006	0.012	9	8
387	Reverse	1	0.079	254	0	1381	0.006	0.002	0.007	12	16
388	Forward	2	0.087	273	0	1480	0.006	0	0.006	128	12
388	Reverse	3	0.087	525	0	1051	0.006	0.001	0.007	12	128
389	Forward	1	0.022	402	0	0	0.002	0	0.002	6	3
389	Reverse	1	0.022	193	0	0	0.002	0	0.002	3	6
390	Forward	3	0.057	916	0	1200	0.004	0.002	0.006	9	38
390	Reverse	3	0.057	447	0	981	0.004	0.001	0.005	35	11
391	Forward	3	0.231	735	0	717	0.017	0.014	0.03	6	31
391	Reverse	3	0.231	476	0	1200	0.017	0.002	0.019	28	7
392	Forward	3	0.05	79	0	740	0.004	0	0.004	44	29
392	Reverse	3	0.05	290	0	740	0.004	0	0.004	16	38
393	Forward	1	0.01	566	0	0	0.001	0	0	29	0
393	Reverse	3	0.01	0	0	0	0.001	0	0.001	0	34
394	Forward	3	0.075	404	0	740	0.005	0.001	0.007	24	41
394	Reverse	3	0.075	153	0	1020	0.005	0	0.005	52	26
395	Forward	3	0.01	404	0	740	0.001	0	0.001	34	28
395	Reverse	3	0.01	153	0	1020	0.001	0	0.001	47	36

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	**Direction**	**Type of cycling facility**	**Length** km	**Auto & bus flow** auto-vehicles/hr	**Bus flow** buses/hr	**Capacity** auto-vehicles/hr	**Travel time** hr	**Risk exposure** hr	**Disutility** hr	**Link flow 'shortest-path'** bicycles/hr	**Link flow with risk exposure** bicycle/hr
396	Forward	1	0.014	0	0	0	0.001	0	0	15	0
396	Reverse	1	0.014	0	0	0	0.001	0	0.001	0	23
397	Forward	3	0.057	276	0	740	0.004	0	0.005	50	44
397	Reverse	3	0.057	164	0	481	0.004	0	0.004	37	42
398	Forward	3	0.01	276	0	481	0.001	0	0.001	37	43
398	Reverse	3	0.01	164	0	740	0.001	0	0.001	50	43
399	Forward	1	0.011	0	0	0	0.001	0	0	12	0
399	Reverse	3	0.011	519	0	1480	0.001	0	0.001	0	8
400	Forward	1	0.013	0	0	0	0.001	0	0	0	0
400	Reverse	1	0.013	0	0	0	0.001	0	0.001	0	1
401	Forward	1	0.018	0	0	0	0.001	0	0	14	0
401	Reverse	1	0.018	645	107	1480	0.001	0.001	0.002	0	10
402	Forward	3	0.043	0	0	0	0.003	0	0	37	0
402	Reverse	1	0.043	989	0	1480	0.003	0.003	0.006	0	25
403	Forward	1	0.033	83	0	296	0.002	0.001	0.003	26	6
403	Reverse	1	0.033	26	0	740	0.002	0	0.002	7	49
404	Forward	1	0.024	0	0	0	0	0	0.002	0	15
404	Reverse	1	0.024	0	0	0	0	0	0	7	0

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	Direction	Type of cycling facility	Length km	Auto & bus flow auto-vehicles/hr	Bus flow buses/hr	Capacity auto-vehicles/hr	Travel time hr	Risk exposure hr	Disutility hr	Link flow 'shortest-path' bicycles/hr	Link flow with risk exposure bicycle/hr
405	Forward	1	0.022	0	0	0	0.002	0	0	0	0
405	Reverse	1	0.022	0	0	0	0.002	0	0.002	0	1
406	Forward	1	0.027	0	0	0	0.002	0	0	12	0
406	Reverse	1	0.027	0	0	0	0.002	0	0.002	0	34
407	Forward	1	0.016	0	0	0	0.001	0	0	30	0
407	Reverse	1	0.016	1029	0	2280	0.001	0.001	0.002	0	9
408	Forward	1	0.009	0	0	0	0.001	0	0	36	0
408	Reverse	1	0.009	1029	0	2280	0.001	0	0.001	0	17
409	Forward	1	0.013	0	0	0	0	0	0.001	0	33
409	Reverse	1	0.013	0	0	0	0	0	0	12	0
410	Forward	1	0.012	83	0	296	0.001	0	0	18	0
410	Reverse	1	0.012	26	0	740	0.001	0	0.001	0	41
411	Forward	1	0.008	83	0	296	0.001	0	0	26	0
411	Reverse	1	0.008	26	0	740	0.001	0	0.001	0	58
412	Forward	1	0.018	0	0	0	0.001	0	0	8	0
412	Reverse	1	0.018	0	0	0	0.001	0	0.001	0	17
413	Forward	1	0.062	0	0	0	0.004	0	0	7	0
413	Reverse	1	0.062	543	0	1480	0.004	0.002	0.007	0	1

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	**Direction**	**Type of cycling facility**	**Length** km	**Auto & bus flow** auto-vehicles/hr	**Bus flow** buses/hr	**Capacity** auto-vehicles/hr	**Travel time** hr	**Risk exposure** hr	**Disutility** hr	**Link flow 'shortest-path'** bicycles/hr	**Link flow with risk exposure** bicycle/hr
414	Forward	1	0.015	543	0	1480	0	0.001	0.002	0	1
414	Reverse	1	0.015	0	0	0	0	0	0	7	0
415	Forward	1	0.06	241	0	740	0.004	0.002	0.006	14	17
415	Reverse	1	0.06	0	0	343	0.004	0	0.004	13	29
416	Forward	1	0.024	325	0	740	0.002	0.001	0.003	13	4
416	Reverse	1	0.024	0	0	0	0.002	0	0.002	9	31
417	Forward	1	0.022	0	0	0	0.002	0	0.002	7	21
417	Reverse	1	0.022	325	0	740	0.002	0.001	0.003	10	1
418	Forward	1	0.017	0	0	740	0.001	0	0.001	5	8
418	Reverse	1	0.017	200	0	0	0.001	0	0.001	4	15
419	Forward	1	0.015	0	0	0	0.001	0	0.001	3	4
419	Reverse	1	0.015	0	0	0	0.001	0	0.001	1	11
420	Forward	1	0.056	0	0	740	0.004	0	0.004	5	4
420	Reverse	1	0.056	200	0	0	0.004	0	0.004	2	19
421	Forward	1	0.015	0	0	0	0.001	0	0.001	7	4
421	Reverse	1	0.015	0	0	0	0.001	0	0.001	3	7
422	Forward	1	0.022	0	0	0	0.002	0	0.002	5	2
422	Reverse	1	0.022	0	0	0	0.002	0	0.002	1	7

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	Direction	Type of cycling facility	Length	Auto & bus flow	Bus flow	Capacity	Travel time	Risk exposure	Disutility	Link flow 'shortest-path'	Link flow with risk exposure
			km	auto-vehicles/hr	buses/hr	auto-vehicles/hr	hr	hr	hr	bicycles/hr	bicycle/hr
423	Forward	1	0.012	204	0	740	0.001	0	0.001	20	36
423	Reverse	1	0.012	156	0	1020	0.001	0	0.001	50	20
424	Forward	1	0.012	203	0	740	0.001	0	0.001	3	3
424	Reverse	1	0.012	0	0	0	0.001	0	0.001	2	6
425	Forward	3	0.124	838	0	1480	0.009	0.002	0.011	19	35
425	Reverse	3	0.124	482	0	1480	0.009	0.001	0.01	25	15
426	Forward	1	0.143	0	0	0	0.01	0	0	19	0
426	Reverse	3	0.143	432	0	1480	0.01	0.001	0.011	0	15
427	Forward	4	0.054	0	0	0	0.004	0	0.004	24	5
427	Reverse	4	0.054	0	0	0	0.004	0	0.004	1	35
428	Forward	1	0.132	83	0	740	0	0.002	0.011	0	3
428	Reverse	1	0.132	0	0	0	0	0	0	10	0
429	Forward	1	0.045	1208	192	1471	0	0.004	0.007	0	11
429	Reverse	2	0.045	192	192	136	0	0	0	27	0
430	Forward	4	0.071	0	0	0	0.005	0	0.005	10	29
430	Reverse	4	0.071	0	0	0	0.005	0	0.005	7	33
431	Forward	1	0.013	0	0	0	0.001	0	0.001	0	62
431	Reverse	1	0.013	0	0	0	0.001	0	0.001	16	8

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	**Direction**	**Type of cycling facility**	**Length** km	**Auto & bus flow** auto-vehicles/hr	**Bus flow** buses/hr	**Capacity** auto-vehicles/hr	**Travel time** hr	**Risk exposure** hr	**Disutility** hr	**Link flow 'shortest-path'** bicycles/hr	**Link flow with risk exposure** bicycle/hr
432	Forward	1	0.12	0	0	0	0.009	0	0.009	0	62
432	Reverse	1	0.12	0	0	0	0.009	0	0.009	16	8
433	Forward	1	0.141	0	0	0	0.01	0	0.01	2	40
433	Reverse	1	0.141	0	0	0	0.01	0	0.01	22	6
434	Forward	1	0.079	292	0	740	0.006	0.003	0.009	54	12
434	Reverse	1	0.079	8	0	626	0.006	0	0.006	17	47
435	Forward	1	0.033	156	0	740	0.002	0.001	0.003	20	16
435	Reverse	1	0.033	390	0	777	0.002	0.002	0.004	17	1
436	Forward	1	0.095	740	0	34	0.007	0.008	0.014	23	10
436	Reverse	1	0.095	572	0	980	0.007	0	0.007	47	8
437	Forward	1	0.073	0	0	0	0.005	0	0	26	0
437	Reverse	3	0.073	800	0	1599	0.005	0.001	0.006	0	22
438	Forward	1	0.102	274	0	690	0.007	0.004	0.012	6	5
438	Reverse	1	0.102	567	0	720	0.007	0.009	0.016	6	2
439	Forward	1	0.051	0	0	0	0.004	0	0.004	0	1
439	Reverse	1	0.051	0	0	0	0.004	0	0.004	0	2
440	Forward	1	0.056	567	0	720	0.004	0.005	0.009	6	1
440	Reverse	1	0.056	274	0	690	0.004	0.002	0.006	6	3

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	Direction	Type of cycling facility	Length km	Auto & bus flow auto-vehicles/hr	Bus flow buses/hr	Capacity auto-vehicles/hr	Travel time hr	Risk exposure hr	Disutility hr	Link flow 'shortest-path' bicycles/hr	Link flow with risk exposure bicycle/hr
441	Forward	1	0.032	0	0	0	0.002	0	0.002	0	1
441	Reverse	1	0.032	0	0	0	0.002	0	0.002	0	2
442	Forward	1	0.084	86	0	454	0.006	0.002	0.008	18	8
442	Reverse	1	0.084	0	0	0	0.006	0	0.006	4	21
443	Forward	1	0.106	141	0	343	0.008	0.005	0.012	18	8
443	Reverse	1	0.106	0	0	0	0.008	0	0.008	4	21
444	Forward	1	0.103	2933	0	3800	0	0.009	0.016	0	96
444	Reverse	1	0.103	0	0	0	0	0	0	96	0
445	Forward	1	0.154	214	0	1220	0	0.003	0.014	0	4
445	Reverse	1	0.154	0	0	0	0	0	0	3	0
446	Forward	3	0.146	1091	0	1480	0	0.005	0.015	0	24
446	Reverse	3	0.146	114	0	133	0	0	0	44	0
447	Forward	3	0.028	114	0	133	0.002	0	0	44	0
447	Reverse	3	0.028	1091	0	1480	0.002	0.001	0.003	0	24
448	Forward	2	0.032	1421	173	2960	0	0.001	0.004	0	12
448	Reverse	1	0.032	0	0	0	0	0	0	24	0
449	Forward	1	0.123	0	0	0	0.009	0	0	25	0
449	Reverse	2	0.123	1421	173	2960	0.009	0.001	0.01	0	17

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	Direction	Type of cycling facility	Length km	Auto & bus flow auto-vehicles/hr	Bus flow buses/hr	Capacity auto-vehicles/hr	Travel time hr	Risk exposure hr	Disutility hr	Link flow 'shortest-path' bicycles/hr	Link flow with risk exposure bicycle/hr
450	Forward	3	0.217	832	0	1480	0.016	0.004	0.019	0	25
450	Reverse	2	0.217	565	108	1480	0.016	0.001	0.016	30	1
451	Forward	3	0.026	832	0	1480	0.002	0	0.002	0	28
451	Reverse	2	0.026	565	108	1480	0.002	0.001	0.003	30	0
452	Forward	1	0.043	0	0	0	0	0	0.003	0	4
452	Reverse	1	0.043	0	0	0	0	0	0	0	0
453	Forward	3	0.06	648	12	1480	0.004	0.001	0.005	25	17
453	Reverse	2	0.06	591	0	740	0.004	0	0.004	14	17
454	Forward	2	0.012	12	0	740	0.001	0	0.001	14	17
454	Reverse	3	0.012	0	0	1480	0.001	0	0.001	25	17
455	Forward	3	0.203	648	0	1480	0.015	0.002	0.017	25	17
455	Reverse	3	0.203	591	0	740	0.015	0.007	0.022	14	17
456	Forward	2	0.044	591	30	740	0.003	0	0.003	14	17
456	Reverse	3	0.044	648	0	1480	0.003	0	0.004	25	17
457	Forward	4	0.271	0	0	0	0.019	0	0.019	2	108
457	Reverse	4	0.271	0	0	0	0.019	0	0.019	126	16
458	Forward	1	0.076	567	0	720	0.005	0.006	0.012	6	2
458	Reverse	1	0.076	274	0	690	0.005	0.003	0.009	6	5

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	Direction	Type of cycling facility	Length km	Auto & bus flow auto-vehicles/hr	Bus flow buses/hr	Capacity auto-vehicles/hr	Travel time hr	Risk exposure hr	Disutility hr	Link flow 'shortest-path' bicycles/hr	Link flow with risk exposure bicycle/hr
459	Forward	2	0.118	392	90	1480	0	0.001	0.009	0	5
459	Reverse	1	0.118	0	0	0	0	0	0	13	0
460	Forward	1	0.1	39	0	739	0.007	0.001	0.008	2	10
460	Reverse	1	0.1	385	0	0	0.007	0	0.007	6	4
461	Forward	3	0.084	286	0	740	0.006	0.001	0.007	22	74
461	Reverse	3	0.084	311	0	0	0.006	0	0.006	83	24
462	Forward	1	0.221	197	0	740	0.016	0.006	0.022	8	4
462	Reverse	1	0.221	0	0	0	0.016	0	0.016	6	13
463	Forward	1	0.15	0	0	0	0.011	0	0.011	5	16
463	Reverse	1	0.15	0	0	0	0.011	0	0.011	1	20
464	Forward	1	0.042	545	0	740	0.003	0.003	0.006	0	2
464	Reverse	1	0.042	0	0	0	0.003	0	0.003	6	7
465	Forward	1	0.083	315	0	416	0.006	0.007	0.013	9	6
465	Reverse	1	0.083	254	0	1381	0.006	0.002	0.008	12	12
466	Forward	1	0.119	0	0	0	0.009	0	0.009	11	6
466	Reverse	1	0.119	0	0	0	0.009	0	0.009	1	9
467	Forward	1	0.301	135	0	740	0.022	0.006	0.027	3	5
467	Reverse	1	0.301	62	0	740	0.022	0.003	0.024	0	7

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	**Direction**	**Type of cycling facility**	**Length** km	**Auto & bus flow** auto-vehicles/hr	**Bus flow** buses/hr	**Capacity** auto-vehicles/hr	**Travel time** hr	**Risk exposure** hr	**Disutility** hr	**Link flow 'shortest-path'** bicycles/hr	**Link flow with risk exposure** bicycle/hr
468	Forward	1	0.122	37	0	740	0.009	0.001	0.009	1	40
468	Reverse	1	0.122	0	0	0	0.009	0	0.009	26	10
469	Forward	1	0.186	0	0	0	0.013	0	0.013	4	14
469	Reverse	1	0.186	83	0	208	0.013	0.008	0.021	1	14
470	Forward	1	0.083	537	0	0	0.006	0	0	27	0
470	Reverse	3	0.083	0	0	1480	0.006	0	0.006	0	37
471	Forward	1	0.039	0	0	0	0.003	0	0	32	0
471	Reverse	3	0.039	562	0	1480	0.003	0	0.003	0	17
472	Forward	1	0.06	42	0	740	0.004	0	0.005	2	19
472	Reverse	1	0.06	0	0	0	0.004	0	0.004	8	8
473	Forward	1	0.098	172	0	740	0.007	0.002	0.009	11	6
473	Reverse	1	0.098	0	0	0	0.007	0	0.007	4	32
474	Forward	3	0.123	156	0	740	0.009	0	0.009	50	17
474	Reverse	3	0.123	204	0	740	0.009	0.001	0.009	19	37
475	Forward	1	0.109	83	0	740	0.008	0.001	0.009	39	2
475	Reverse	1	0.109	0	0	0	0.008	0	0.008	3	45
476	Forward	1	0.065	0	0	0	0.005	0	0	62	0
476	Reverse	1	0.065	543	0	1480	0.005	0.003	0.007	0	54

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	Direction	Type of cycling facility	Length km	Auto & bus flow auto-vehicles/hr	Bus flow buses/hr	Capacity auto-vehicles/hr	Travel time hr	Risk exposure hr	Disutility hr	Link flow 'shortest-path' bicycles/hr	Link flow with risk exposure bicycle/hr
477	Forward	1	0.044	541	0	1480	0.003	0.002	0.005	16	9
477	Reverse	1	0.044	592	0	740	0.003	0.004	0.007	27	9
478	Forward	1	0.05	496	0	1480	0.004	0.002	0.005	43	31
478	Reverse	1	0.05	464	0	1480	0.004	0.002	0.005	21	29
479	Forward	1	0.067	1441	0	2960	0	0.003	0.008	0	54
479	Reverse	1	0.067	0	0	0	0	0	0	54	0
480	Forward	1	0.071	390	0	777	0.005	0.004	0.009	17	1
480	Reverse	1	0.071	156	0	740	0.005	0.002	0.007	20	16
481	Forward	1	0.12	55	0	480	0.009	0.001	0.01	11	7
481	Reverse	1	0.12	107	0	371	0.009	0.004	0.012	16	10
482	Forward	3	0.268	75	0	186	0.019	0	0	0	0
482	Reverse	1	0.268	93	0	1062	0.019	0.003	0.022	0	1
483	Forward	1	0.127	634	0	740	0.009	0.012	0.021	30	57
483	Reverse	1	0.127	675	0	740	0.009	0.012	0.021	90	8
484	Forward	1	0.137	0	0	0	0.01	0	0.01	0	2
484	Reverse	1	0.137	0	0	740	0.01	0	0.01	0	1
485	Forward	4	0.331	0	0	0	0.024	0	0.024	7	33
485	Reverse	4	0.331	0	0	0	0.024	0	0.024	10	29

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	Direction	Type of cycling facility	Length km	Auto & bus flow auto-vehicles/hr	Bus flow buses/hr	Capacity auto-vehicles/hr	Travel time hr	Risk exposure hr	Disutility hr	Link flow 'shortest-path' bicycles/hr	Link flow with risk exposure bicycle/hr
486	Forward	1	0.04	495	0	1480	0.003	0.001	0.004	77	15
486	Reverse	1	0.04	1056	0	2125	0.003	0.002	0.005	17	68
487	Forward	3	0.027	273	0	1480	0.002	0	0.002	158	15
487	Reverse	1	0.027	525	0	1051	0.002	0.001	0.003	15	157
488	Forward	1	0.201	838	0	0	0.014	0	0	25	0
488	Reverse	3	0.201	0	0	1480	0.014	0	0.014	0	35
489	Forward	2	0.064	1056	90	1480	0.005	0.001	0.005	20	50
489	Reverse	2	0.064	495	119	1480	0.005	0.001	0.005	56	8
490	Forward	2	0.157	103	103	1234	0.011	0.001	0.012	0	21
490	Reverse	1	0.157	0	0	0	0.011	0	0.011	15	16
491	Forward	3	0.433	949	0	980	0.031	0.023	0.054	7	11
491	Reverse	3	0.433	453	0	729	0.031	0.01	0.04	45	6
492	Forward	1	0.093	0	0	0	0.007	0	0	5	0
492	Reverse	1	0.093	949	0	2220	0.007	0.004	0.011	0	5
493	Forward	1	0.142	107	0	371	0.01	0.004	0.015	16	11
493	Reverse	1	0.142	55	0	480	0.01	0.002	0.012	11	11
494	Forward	1	0.043	0	0	0	0.003	0	0.003	5	16
494	Reverse	1	0.043	0	0	0	0.003	0	0.003	2	31

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	Direction	Type of cycling facility	Length	Auto & bus flow	Bus flow	Capacity	Travel time	Risk exposure	Disutility	Link flow 'shortest-path'	Link flow with risk exposure
			km	auto-vehicles/hr	buses/hr	auto-vehicles/hr	hr	hr	hr	bicycles/hr	bicycle/hr
495	Forward	2	0.19	717	11	740	0.014	0	0.014	28	26
495	Reverse	2	0.19	606	30	1376	0.014	0	0.014	14	29
496	Forward	1	0.035	613	0	740	0.003	0.003	0.006	32	77
496	Reverse	1	0.035	524	0	740	0.003	0.003	0.005	60	31
497	Forward	3	0.032	79	0	740	0.002	0	0.002	58	32
497	Reverse	3	0.032	290	0	740	0.002	0	0.003	42	72
498	Forward	4	0.08	0	0	0	0.006	0	0.006	33	21
498	Reverse	4	0.08	0	0	0	0.006	0	0.006	6	117
499	Forward	1	0.12	32	0	380	0	0.001	0.01	0	46
499	Reverse	1	0.12	0	0	0	0	0	0	22	0
500	Forward	2	0.132	645	107	1480	0	0.001	0.01	0	44
500	Reverse	1	0.132	0	0	0	0	0	0	26	0
501	Forward	1	0.291	78	0	0	0.021	0	0.021	7	16
501	Reverse	1	0.291	700	0	0	0.021	0	0.021	0	12
502	Forward	1	0.129	0	0	0	0.009	0	0	12	0
502	Reverse	3	0.129	519	0	1480	0.009	0.001	0.01	0	10
503	Forward	1	0.066	0	0	0	0.005	0	0	62	0
503	Reverse	1	0.066	829	0	1480	0.005	0.004	0.009	0	62

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	**Direction**	**Type of cycling facility**	**Length** km	**Auto & bus flow** auto-vehicles/hr	**Bus flow** buses/hr	**Capacity** auto-vehicles/hr	**Travel time** hr	**Risk exposure** hr	**Disutility** hr	**Link flow 'shortest-path'** bicycles/hr	**Link flow with risk exposure** bicycle/hr
504	Forward	1	0.102	0	0	740	0.007	0	0.007	0	1
504	Reverse	1	0.102	0	0	0	0.007	0	0.007	0	2
505	Forward	1	0.11	0	0	0	0.008	0	0.008	31	3
505	Reverse	1	0.11	0	0	0	0.008	0	0.008	0	43
506	Forward	1	0.115	0	0	0	0.008	0	0	0	0
506	Reverse	1	0.115	136	0	470	0.008	0.004	0.012	0	4
507	Forward	1	0.075	1300	0	2146	0	0.005	0.01	0	4
508	Reverse	1	0.082	0	0	0	0.006	0	0	19	0
509	Forward	2	0.177	461	91	740	0.013	0.001	0.013	0	10
510	Reverse	2	0.135	400	94	740	0.01	0.001	0.01	10	2
507	Forward	1	0.075	0	0	0	0	0	0	19	0
508	Reverse	1	0.082	1300	0	2146	0.006	0.005	0.011	0	4
509	Forward	2	0.177	400	94	740	0.013	0.001	0.013	10	2
510	Reverse	2	0.135	461	91	740	0.01	0.001	0.01	0	10
511	Forward	1	0.074	0	0	0	0.005	0	0	46	0
512	Reverse	1	0.066	599	0	1480	0	0.003	0.008	0	45
511	Forward	1	0.074	599	0	1480	0.005	0.003	0.008	0	45
512	Reverse	1	0.066	0	0	0	0	0	0	46	0

Chapter 7 Variables and flows from the 'shortest-path' model and the model considering risk exposure.

Link ID	**Direction**	**Type of cycling facility**	**Length** km	**Auto & bus flow** auto-vehicles/hr	**Bus flow** buses/hr	**Capacity** auto-vehicles/hr	**Travel time** hr	**Risk exposure** hr	**Disutility** hr	**Link flow 'shortest-path'** bicycles/hr	**Link flow with risk exposure** bicycle/hr
513	Forward	4	0.152	0	0	0	0.011	0	0.011	13	27
514	Reverse	1	0.055	672	0	1960	0.004	0.002	0.006	61	35
515	Forward	4	0.157	778	0	740	0.011	0	0.011	53	74
516	Reverse	4	0.159	0	0	0	0.011	0	0.011	77	21

APPENDIX VII: PUBLISHED WORK

GAVIN, M., GHOSH, B., PAKRASHI, V., BARTON, J., O'FLYNN, B. & LAWSON, A. R. 2011. A Cycle Route Planner mobile App for Dublin City. Irish Transport Research Network Annual Conference. Cork.

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LAWSON, A. R., PAKRASHI, V., GHOSH, B. & SZETO, W. Y. 2013. Perception of safety of cyclists in Dublin City. Accident Analysis & Prevention, 50, 499-511.

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