



Title	Perception of safety of cyclists in Dublin City
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Publication date	2013-01
Publication information	Lawson, Anneka R., Vikram Pakrashi, Bidisha Ghosh, and WY Szeto. "Perception of Safety of Cyclists in Dublin City." Elsevier, January 2013. https://doi.org/10.1016/j.aap.2012.05.029 .
Publisher	Elsevier
Item record/more information	http://hdl.handle.net/10197/10427
Publisher's statement	This is the author's version of a work that was accepted for publication in Accident Analysis & Prevention. Changes resulting from the publishing process, such as peer review, editing, corrections, structural formatting, and other quality control mechanisms may not be reflected in this document. Changes may have been made to this work since it was submitted for publication. A definitive version was subsequently published in Accident Analysis & Prevention (50, (2013)) https://doi.org/10.1016/j.aap.2012.05.029
Publisher's version (DOI)	10.1016/j.aap.2012.05.029

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Perceived Safety and Travel Preferences of Cyclists in a Multi-Modal Transportation Network in Dublin City

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Abstract

In recent years, cycling has been recognized as a sustainable mode of travel to improve the transport energy efficiency of a city. The perception of cycling as an unsafe mode of travel is a significant obstacle in increasing the mode share of bicycles in a city. Hence, it is important to identify and analyze the factors which influence the safety experiences of the cyclists in an urban signalized mixed-mode transport network. A survey of existing cyclists in Dublin was conducted to gain an insight into the different aspects related to the safety experience of cyclists. Nearly 70% of the cyclists expressed that they perceive cycling to be less safe than driving. The survey responses were analyzed, using Principal Component Analysis and Ordered Logistic Regression, in three main categories: the current cycling behavior, the perception of safety and the interaction with the elements of the network. The analysis found that the attitude of car drivers, sharing of road space with buses and taxis, lack of familiarity with the network, usage of cycle lanes on footpaths, poor quality road surfaces and certain weather conditions were perceived as barriers to the safety of cyclists. Use of safety accessories and access to cycling facilities, factors typically assumed to be important to safety, were found not to be of great importance in contributing to the safety experience of existing cyclists. The policy implications of the analysis are discussed, which may provide essential information to the transport authorities not only in Dublin or Ireland but also in the countries where the bicycle mode share has been targeted to be increased.

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1. Introduction

There has been an increasing dependency of society on motorized vehicles in Dublin City over the ~~pl~~ast number of decades. This has raised significant concerns regarding growing traffic congestion, harmful vehicle emissions and public health problems. To combat these issues non-motorized modes of transport, like walking and cycling, are gaining attention from policy makers in recent years. Increased mode share of these sustainable modes of travel are expected to reduce vehicle numbers on the roads within the city thereby reducing traffic congestion, vehicle emissions and health problems associated with these vehicle emissions. In 2005, the cost of congestion to the Greater Dublin Area was €2.5 billion (Dublin Chamber of Commerce, 2005)(~~Dublin Chamber of Commerce, 2005~~). This is a huge threat to the competitiveness of Dublin as a city trying to attract investments. In 2009, the Department of Transport published Ireland's first National Cycle Policy Framework (NCPF) (Department of Transport, 2009)(~~Department of Transport, 2009~~), which is aimed at increasing the bicycle commuter mode share to 10% by 2020. At the time of publication of the NCPF, the mode share in Ireland stood at 1.9%. The cycling mode share in Dublin City stood at 3.2% in 2006 (Central Statistics Office, 2006; McMorrow and Ghosh, 2011)(~~Central Statistics Office, 2006; McMorrow and Ghosh, 2011~~). This is higher than the average rate in Ireland, but remains far below the 2020 target set out in the NCPF. In comparison with other cycling friendly countries and cities in Europe, the mode share is extremely low. Cycling mode shares in countries like the Netherlands, Denmark and Germany are on an average between 10% and 26% with some cities reaching 35%-40% (Ministerie van Verkeer en Waterstaat, 2009)(~~Ministerie van Verkeer en Waterstaat, 2009~~).

A significant obstacle to achieving this targeted mode share in Dublin City is the fact that cycling is perceived as an unsafe mode of travel. Studies have shown the risks of accident or injury due to cycling are much higher than while driving (Aultman-Hall and Kaltenecker, 1999; Zegeer, 1994)(~~Aultman-Hall and Kaltenecker, 1999; Zegeer, 1994~~). A study of the attitudes of cyclists and drivers in Dublin found that 21% of drivers do not cycle because they feel it is "too dangerous because of traffic" (Keegan and Galbraith, 2005)(~~Keegan and Galbraith, 2005~~). A report from the Irish Road Safety Authority (RSA) (Road Safety Authority, 2010)(~~Road Safety Authority, 2010~~) states that between 1998 and 2008 there were 144 cyclists (43 in County Dublin) fatally injured and 335 (115 in County Dublin) seriously injured on Irish roads. Despite the percentage of fatalities among cyclists contributing only 3.5% of all road fatalities between these years in Ireland, cycling remains a low preference mode of travel. This may be due to the larger number of minor accidents which occur unreported to authorities. The RSA report does not distinctly address minor injuries due to cycling accidents, although the RSA does recognize that cyclists are the most

vulnerable road users (Road Safety Authority, 2010)([Road Safety Authority, 2010](#)). Due to limited information it is not possible to gauge the actual number of minor cycling accidents in Dublin. Many studies have estimated the extent to which underreporting of cycling accidents and underreporting of the severity of reported accidents occur across Europe (Broughton et al., 2010)([Broughton et al., 2010](#)), Canada (Doherty et al., 2000)([Doherty et al., 2000](#)) and the USA (Stutts and Hunter, 1998)([Stutts and Hunter, 1998](#)).

It is generally assumed that the safety of cyclists can be enhanced by providing separation from vehicles in a shared multi-modal transport network (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)([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](#)). However, some studies found that cycling on-road (on pavement with no separation) is safer than on off-road paths (Aultman-Hall and Hall, 1998b; Aultman-Hall and Kaltenecker, 1999; Forester, 1993)([Aultman-Hall and Hall, 1998](#); [Aultman-Hall and Kaltenecker, 1999](#); [Forester, 1993](#)). Separation on-road, in the form of cycle lanes, often causes limited space between cars and bicycles while drivers are overtaking cyclists (Parkin and Meyers, 2010)([Parkin and Meyers, 2010](#)). Improvements of existing cycling facilities or provision of new cycling facilities on a road may result in all regular road users paying less attention to the cyclists along these routes and in turn compromising the safety of cyclists (de Lapparent, 2005)([de Lapparent, 2005](#)). It is suggested that in the U.S. and Canada cycling on the sidewalk/footpath is significantly more dangerous than on-road or on any other cycling facilities considered (Moritz, 1997)([Moritz, 1997](#)). Later, it has also been established that no single cycling facility can address the safety issues encountered by cyclists and a well-connected network of various facilities is required (Dill, 2009; Pucher et al., 2010)([Dill, 2009](#); [Pucher et al., 2010](#)).

Apart from cycling facilities, another major factor that can influence the safety of cyclists is the use of safety accessories such as, reflective lights, hi-visibility clothing and helmets. Such usage is not mandatory in Dublin or Ireland and to date no studies are available to investigate the effect of such usage on the safety of cyclists in Dublin. Studies have shown ([Scuffham et al., 2000](#); [Scuffham and Langley, 1997](#); [Welander et al., 1999](#)) that recommending or making mandatory the use of such equipment did not result in full compliance by cyclists (Ferguson and Blampied, 1991; Hagel et al., 2007; Osberg et al., 1998)([Ferguson and Blampied, 1991](#); [Hagel et al., 2007](#); [Osberg et al., 1998](#)). Much debate exists regarding the mandatory use of helmets for cyclists (Cameron et al., 1994; Depreitere et al., 2004; Ekman et al., 1997; McIntosh et al., 1998; Povey et al., 1999; Robinson, 2001;

Scuffham et al., 2000; Scuffham and Langley, 1997; Welander et al., 1999)(~~Cameron et al., 1994; Depreitere et al., 2004; Ekman et al., 1997; McIntosh et al., 1998; Povey et al., 1999; Robinson, 2001; Scuffham et al., 2000; Scuffham and Langley, 1997; Welander et al., 1999~~); although it has been successful in reducing the severity of head injuries, it has discouraged cycling as a mode of travel and therefore the benefits of introducing such a law may not outweigh the health benefits of cycling (Robinson, 1996)(~~Robinson, 1996~~).

Previous research investigating the perception of risk among cyclists and non-cyclists, is presented in Table X, including variables collected as part of each study (not all variables were considered in the analysis of each study; not all variables were found significant). These studies have mainly been conducted in order to aid engineers and planners in the design, improvement and prioritization of road and intersection works to cater for cyclists. These analysis' have tended to consider only a small number of variables and are usually specific to a certain location within the network; link segments (Harkey et al., 1998; Hughes and Harkey, 1997; Hughes and Harkey, 1999; Klobucar and Fricker, 2007; Landis et al., 1997; Landis, 1994, 1996; Sorton and Walsh, 1994)(~~Harkey et al., 1998~~); intersections (Landis et al., 2003); roundabouts (Møller and Hels, 2008); and bicycle crossings (Leden et al., 2000). Parkin et al. (2007) asked cyclists to give an overall rating of their trip, including movements through intersections. The majority of these studies asked cyclists to rate their overall risk perception of a route described by survey, video-clips or simulation or by completion of a test track. Geometric and operational variables were then applied as independent variables in regression analysis to investigate if and how they affect the perceived risk (Harkey et al., 1998; Klobucar and Fricker, 2007; Landis et al., 1997; Landis et al., 2003). Parkin et al. (2007) asked participants to rate the perceived risk of their own home-work trip, then added or removed elements of this trip and the route was rating again. This allowed calculation of the perceived risk associated with each element considered. Møller and Hels (2008) conducted interviews with cyclists to investigate the perceived risk associated with a number of cyclist's individual characteristics and design characteristics, but this was done only in relation to roundabout sites. Leden et al. (2000) asked cycling experts to plot curves of relative risk for changing levels of bicycle and motor vehicle volumes etc. at bicycle crossings. The range of answers presented vary quite widely, which may suggest that these experts have answered according to the focuses of their own researches, and therefore these relationships may not be an accurate representation of the perceived risk of typical cyclists. Hughes and Harkey (1997; 1999) use video simulations to monitor perceived risk among cyclists, controlling for traffic speeds, volumes and a number of kerb-side lane characterizes, as shown in Table X.(Møller and Hels, 2008)

~~Existing research also looks into the impression of the risk of cycling within a transport network. Crash risk has been studied in relation to actual accident data (Moritz, 1997) and in relation to socio-demographics and land use patterns (Cho et al., 2009). Other studies used virtual environments rated by participants to develop a risk index, for a route choice scenario (Klobucar and Fricker, 2007) and a facility choice scenario (Parkin et al., 2007). Expert judgments of cyclist safety in various situations have also been applied to developing a risk index (Leden et al., 2000). The perception of cyclists on how safe they feel within a network has not been explored. This paper aims to investigate the overall perceptions of cyclists in a mixed-mode signalized transport network, rather than for a location specific approach. This paper looks into how existing cyclists perceive the effect of different network agents in influencing their personal safety while using the network.~~ The network agents explored include existing users, other transport modes, facilities and network infrastructure applicable to cycling as well as other modes. The perceptions studied are based on the personal experiences of cyclists in the transport network of Dublin city. It is important to understand the safety behavior and the perceived safety of cyclists in relation to the existing transportation network in the city. This investigation is complex, yet interesting since the transportation infrastructure; along with the conditions for cycling vary widely throughout the city. The key factors influencing the safety and its perception from a cyclist's perspective have been identified from a relatively large pool of variables, and the identified factors, both motivators and deterrents, represent the actual experience of the user. These key factors have been established through Ordered Logistic Regression (OLR) and Principal Component Analysis (PCA) based models.

In this study, a questionnaire based survey on the different aspects of the safety of cyclists in an urban transport network has been conducted on a large number of existing cyclists in Dublin City, Ireland. The survey responses have been analyzed to explore the aspects of safety of cyclists in three main categories; the current safety behavior of the cyclists, the perception of safety of the cyclists and the interaction of the cyclists with the elements of the network within a multi-modal transportation system. Three models, namely safety behavior model, perceived safety model, and cyclist-network interaction model, have been fitted to that effect.

The next two sections of this paper depict the ~~data and methods~~ methods and data respectively, followed by the analysis section employing the three aforementioned models. The discussion on the policy implications is provided next. Finally, a conclusion is given.

2. Methods

A fixed-response questionnaire based survey was conducted in order to gather information, previously unavailable in Dublin, on the perceived safety and safety behaviors of cyclists, with regards to the available cycling infrastructure, the use of safety accessories, the effect of prevalent road and weather conditions, as well as various other aspects of travelling by bicycle in Dublin's mixed-mode network. The survey, conducted over a 3 month period between March 7th and June 1st 2011 receiving 1,954 responses, collected information from existing cyclists, who have regularly cycled in Dublin within the previous 12 months. The questionnaire was distributed among major Irish and multi-national companies, major universities in Dublin, governmental departments and through word of mouth. The questionnaire was also 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 obtainable from local cycle repair shops and from the authors, upon request.

The survey questionnaire was divided into 3 sections, each corresponding to the focus of the separate models used in the analysis, collecting information on socio-demographics, trip purposes, trip distance and time, cycling infrastructure preferences and safety equipment preferences, as well as information on the effects of adverse road & weather conditions and 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. For the PCA models (Safety Behavior model and Cyclist-Network Interaction model) the questions were asked according to what extensive literature review and discussion with cycling experts from the city council, National Transport Authority and cycling forums indicated as 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).

Principal component analysis (PCA) and ordered logistic regression (OLR) are the chosen methods for analyzing the survey responses. PCA is a multivariate data analysis methodology similar to Factor Analysis (FA). Logistic regression is a powerful tool in establishing probabilities related typically to binary choices. However, there can be ordinal dependent variables for which an extension of the binary model, an ordered logistic regression model, should be used. For detailed discussions on PCA and OLR the reader is advised to refer to Hair (2010), Semmlow (2009), Hosmer and Lemeshow (2000), Jolliffe (2002) Jambu (1991)(2002). Both of these methods have been widely used in the areas of cycling and other transportation studies. (Ben-Elia and Ettema, 2011; Borgnat et al., 2010; Brown et al., 2009; Dupont et al., 2010; Heinen et al., 2011; Kiryu et al., 1997; Kiss et al.,

2010; Ma et al., 2009; Morrongiello et al., 2010; Popuri et al., 2011; Winters et al., 2010a; Yannis et al., 2005; Yau, 2004).

Three models, namely this Safety Behavior Model, the Perceived Safety Model and the Cyclist-Network Interaction Model, are used to analyze the survey responses using the abovementioned methods. The Safety Behavior Model investigates the behavior of cyclists in an urban multi-modal network, while considering aspects of their personal safety. PCA is used in the model to analysis survey responses related to their attitudes and behaviors towards safety while cycling. The Perceived Safety Model investigates the determinants which influence a cyclist's perception of safety as compared to driving in the shared multi-modal transport network of Dublin City. The model utilizes an Ordered Logistic Regression (OLR) analysis to identify these determinants. The final model, the Cyclist-Network Interaction Model investigates the interaction between the cyclist and the elements of the shared multi-modal transport network of Dublin through PCA to understand the perception of safety of the cyclists in relation to the existing infrastructure. The results from each of these models are discussed in the Analysis section of this article, Data.

2.1 Cycling in Dublin

Dublin City is the capital of Ireland and the largest city in terms of area, residing and working population of the country (Central Statistics Office, 2006). The transport network in Dublin City is primarily designed for the use of private vehicles. Other main modes of motorized transport in Dublin City are Dublin Bus, Luas (tram), Dublin Area Rapid Transport (light rail) and Commuter trains (suburban railway networks). In 2006, nearly 16.4% of the commuter trips were made using non-motorized modes of transport (McMorrow and Ghosh, 2011). However, the percentage of employees walking to their workplaces was much higher than that using bicycle as their preferred mode of commuter travel. The transport network in Dublin City contains cycling facilities mainly in the form of cycle lanes; approximately 120 km of on-road cycle tracks, 50 km of shared bus cycle lanes and 25 km of off road cycle tracks exist in the network. Figure 1 presents a map of these available cycling facilities published by the Dublin Transportation Office in 2008 (Dublin Transportation Office, 2008).

Despite the presence of these facilities, there exist many threats to the cyclists in Dublin. A few of these threats are unforeseen ending of cycle lanes which expose cyclists to suddenly share their commuting space with other modes of high speed differential; cars and taxis frequently making unforeseen stops and turns, forcing cyclists joining oncoming traffic from behind. Also, poorly maintained cycling surfaces often result in falls causing injury and damage to property. Abrupt barriers in the form of signposts, on street parking and the

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presence of bus-stops tend to encroach on the cycle lanes; entries to the cycle lanes are often not ramped and are unsafely kerbed. Also, new designs like speed breakers on cycle lanes near bus stops have been reported to be uncomfortable, unsafe and unnecessary by many cyclists. These conditions and/or threats naturally lead to actual and perceived discomfort and a lack of safety for cyclists. There exist many more such factors or conditions which influence a cyclist's perception of safety in Dublin City. To understand which aspects of the transport network prove most hostile to cyclists, a detailed analysis is required to track the factors that most strongly affect the actual and perceived safety of the cyclists in this network.

3. Data

Dublin City is the capital of Ireland and the largest city in terms of area, residing and working population of the country (Central Statistics Office, 2006). The transport network in Dublin City is primarily designed for the use of private vehicles. Other main modes of motorized transport in Dublin City are Dublin Bus, Luas (tram), Dublin Area Rapid Transport (light rail) and Commuter trains (suburban railway networks). In 2006, nearly 16.4% of the commuter trips were made using non-motorized modes of transport (McMorrow and Ghosh, 2011). However, the percentage of employees walking to their workplaces was much higher than that using bicycle as their preferred mode of commuter travel. The transport network in Dublin City contains cycling facilities mainly in the form of cycle lanes: approximately 120 km of on-road cycle tracks, 50 km of shared bus-cycle lanes and 25 km of off-road cycle tracks exist in the network. Figure 1 presents a map of these available cycling facilities published by the Dublin Transportation Office in 2008 (Dublin Transportation Office, 2008).

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the factors that most strongly affect the actual and perceived safety of the cyclists in this network.

2.2 Summary Statistics

A fixed response questionnaire based survey was conducted in order to gather information, previously unavailable in Dublin, on the perceived safety and safety behaviors of cyclists, with regards to the available cycling infrastructure, the use of safety accessories, the effect of prevalent road and weather conditions, as well as various other aspects of travelling by cycle in Dublin's mixed mode network. The survey, conducted over a 3 month period between March 7th and June 1st 2011 receiving 1,954 responses, collected information from existing cyclists, who have regularly cycled in Dublin within the previous 12 months. The questionnaire was distributed among major Irish and multi national companies, major universities in Dublin's, governmental departments and through word of mouth. The questionnaire was also available on-line; the link to which was circulated via e-mail, posts on cycle clubs and group websites, cycling forums, and posts on social networking web sites. Hardcopies of the questionnaire were obtainable from local cycle repair shops and from the authors, upon request.

The survey questionnaire was divided into 3 sections, each corresponding to the focus of the separate models used in the analysis, collecting information on socio demographics, trip purposes, trip distance and time, cycling infrastructure preferences and safety equipment preferences, as well as information on the effects of adverse road & weather conditions and 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. For the PCA models (Safety Behavior model and Cyclist Network Interaction model) the questions were asked according to what extensive literature review and discussion with cycling experts from the city council, National Transport Authority and cycling forums indicated as 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).

The profile of the cyclists of Dublin who responded to the survey has been presented in Table 1. The table has been summarized according to the self-reported experience of the cyclists ('Inexperienced', 'Competent', or 'Highly Skilled'). The majority of the respondents were male (63.7%), aged less than 45 years. According to the available statistics, the majority of the cycling population in Dublin City are population in Dublin City is male and less than 40 years of age (Central Statistics Office, 2006)(Central Statistics Office, 2006). Consequently, the respondent demographic of the survey is an unbiased representation of

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the cycling population of 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%), a couple with resident child(ren) (24.1%) or a couple 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 available to them which they can use of a day-to-day basis. Although the survey collected anonymous responses, no information on household income was collected as it was felt such a question may hinder the survey response rate.

On average, the respondents cycle 9.54 km on a weekday and 6.85 km at the weekend. Other studies of cyclists observed average distances for utilitarian trips of between 3.5 km and 7km (Broach et al., 2011; Howard and Burns, 2001; Nankervis, 1999; Winters et al., 2010a; Winters et al., 2010b)([Broach et al., 2011](#); [Howard and Burns, 2001](#); [Nankervis, 1999](#); [Winters et al., 2010a](#); [Winters et al., 2010b](#)). These figures may be lower compared with our study as they 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 at the weekend on average. Table 1 also shows that generally cyclists travel at speeds of 10-20 km/hr, although a great number of those describing themselves as highly skilled travel at higher speeds. It can be seen that, almost 98% of the respondents in Dublin describe themselves as being either a competent or highly skilled cyclist. Moreover, over 85% are regular cyclists and cycle at least 3 days per week. Consequently, it is of significant concern if confident and regular cyclists perceive the network to be potentially unsafe from a number of perspectives. The survey reveals that bicycles are used for social and recreational trips by the greatest number of respondents (65.4%), and such trips consume an average of 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 a respondent's 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 respondent's cycle from spring through to autumn and 74.1% continue to cycle during the winter months. 93.7% of respondents own a bicycle; it is thought that the remaining respondents make use of the bicycle sharing scheme available in the city. [The survey suggests high rates of safety accessory use; nearly 54% of cyclists claim to wear a helmet and 88% use lights or reflective accessories while cycling at night. Similar studies suggest lower use of safety accessories; 2.2% of 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 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 differences may be due to legal, cultural and social differences between the various cities and countries.

3. Methods

Principal component analysis (PCA) and ordered logistic regression (OLR) are the chosen methods for analyzing the survey responses. PCA is a multivariate data analysis methodology similar to Factor Analysis (FA). FA, a popular tool for parsimoniously representing high-dimensional data along with appropriate recognition of the contribution of the key variables in a multivariate dataset, has been used in a wide range of applications (Hair et al., 2010; Jambu, 1991; Semmlow, 2009). The method has recently become popular in investigating the travel behavior of cyclists. It has been used to determine the factors contributing to a person's decision to ride a bicycle (Heinen et al., 2011; Winters et al., 2010a). FA has also been used to identify the key factors which affect the injuries received among children in cycling accidents (Kiss et al., 2010; Morrongiello et al., 2010). Analysis using PCA, a method very closely related to FA, has been used in sports cycling research to explain muscle fatigue (Kiryu et al., 1997) and the motion of a cyclist while maneuvering on a bicycle (Moore et al., 2009). It has also been used to determine what factors are important to the members of an American competitive cycling body in choosing cycling as a 'serious leisure sport' (Brown et al., 2009). In Lyon, the public bicycle-sharing scheme was analyzed using PCA to uncover the factors which have been significant to its use (Borgnat et al., 2010). A significant amount of work in identifying the determinants of traffic accidents (Dupont et al., 2010; Ma et al., 2009; Yannis et al., 2005; Yau, 2004) and the determinants of route choice options (Ben-Elia and Ettema, 2011; Popuri et al., 2011) employing Logistic Regression (LR) models are present in the field of transportation engineering. Logistic regression is a powerful tool in establishing probabilities related typically to binary choices. However, there can be ordinal dependent variables for which an extension of the binary model, an ordered logistic regression model, should be used.

PCA reduces the dimensionality of a data set containing a large number (p) of possibly correlated random variables (X_1, X_2, \dots, X_p) by transforming the variables to a new set of variables called principal components (F_1, F_2, \dots, 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, \dots, F_p as follows,

$$X_i = \left(\sum_{k=1}^p a_{ik} F_k \right) + R_i \quad i = 1, 2, \dots, p \quad (1)$$

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 paper are heterogeneous with regard to their means and dispersions (measured in different units, across different ranges) they must be standardized. The

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elements of the matrix \mathbf{X} are denoted by X_{ij} (j = the number of units in X_i) which are replaced by,

$$\Pi_{ij} = \frac{X_{ij} - \bar{X}_i}{\sigma_i} \quad (2)$$

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 and corresponding eigenvectors (or principal components) are found. In this paper, 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 1 are considered as insignificant and are disregarded. Λ is the matrix formed by ordered principal components with their eigenvalues greater than 1.

Having found this initial solution, other solutions may be found by rotating Λ . Rotation criteria are designed to make the structure of Λ as simple as possible, with most of the elements of Λ either 'close to zero' or 'far from zero' (Jolliffe, 2002). In this paper an orthogonal varimax rotation is applied such that $B = \Lambda T$, where B is the resulting matrix with elements b_{il} , $i = 1, 2, \dots, p$; $l = 1, 2, \dots, m$; $m (\leq p)$ is the number of principal components in Λ and T is the rotation matrix used to create B in order to maximize the raw varimax criterion

$$Q = \sum_{l=1}^m \left[\sum_{i=1}^p b_{il}^4 - \frac{1}{p} \left(\sum_{i=1}^p b_{il}^2 \right)^2 \right] \quad (3)$$

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. 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.

The second method chosen for analysis, 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 ($1, 2, \dots, N$), ordered from low to high. In OLR, the conditional probability of an outcome can be expressed as,

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(4)

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

$$g(\mathbf{x}) = \ln \frac{\pi(y=q|\mathbf{x})}{1 - \pi(y=q|\mathbf{x})} = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \dots + \beta_N x_N + \varepsilon \quad (5)$$

where $\beta_1, \beta_2, \dots, \beta_N$ denote the relative importance of the independent variables x_1, x_2, \dots, 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 $\beta_1, \beta_2, \dots, \beta_N$. For the OLR model to be valid the proportional odds assumption must hold. This is tested using the Brant test. If this test does not hold, full-scale 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 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,

$$OR = \frac{\pi(y=a|\mathbf{x})}{\pi(y=b|\mathbf{x}) + \pi(y=c|\mathbf{x})} = \frac{\pi(y=c|\mathbf{x})}{\pi(y=a|\mathbf{x}) + \pi(y=b|\mathbf{x})} = \frac{\pi(y=b|\mathbf{x})}{\pi(y=a|\mathbf{x}) + \pi(y=c|\mathbf{x})} \quad (6)$$

For further details of the ordered logistic regression method and related diagnostic tests please refer to (Hosmer and Lemeshow, 2000).

Three models are used to analyse the survey responses and these models are discussed in the subsequent section.

4. Analysis

In examining this data, it must be taken into consideration that the data collected from the survey is self-reported and may vary from the actual behavior of the respondent cyclists. Initial analysis of the survey looked at the travel behavior of the respondents while cycling. 57.8% of respondents have said that they would alter their routes to make use of continuous cycle lanes, while 50.4% and 50.6% of respondents would alter their routes to use quiet

roads and routes perceived as safe by cyclists, respectively. Information provided in the questionnaire on route alternatives was qualitative; a Likert scale, with 5 options, was used to measure the likelihood of the cyclist altering their route. There are a number of elements in a transport network which are generally considered as hindrances to cyclists and would often compel them to change their routes. The strongest aversion felt by respondents was roads with higher speed limits and roads with poor quality surfaces, with 32.9% and 31.7% of respondents respectively, stating they would alter their routes in order to avoid these roads. Infrastructure to allow easier movement of cyclists through right turns, across opposing traffic lanes has recently been introduced to Dublin, but this survey suggests that only 10.9% of cyclists find right turns of such an inconvenience to cause them to alter their routes. Respondents were also asked if they would consider changing to another mode of transport 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 of students in the universities of Melbourne, Australia found that 40% would change mode in rain and 66% in ice and snow (Nankervis, 1999)(Nankervis, 1999). In Dublin, more survey respondents are likely to change their mode of travel due to greater access to alternative modes than a student only population.

4. Analysis

4.1 Safety Behavior Model

Initially 31 variables were included in the analysis of the Safety Behavior Model; of these, 5 were found to be insignificant (the use of a bicycle for travel to school/college, the use of a bicycle for organized racing, the distance and time cycled on an average weekday/weekend and average cyclist speed) and were therefore removed from the analysis, as these variables are not related to any of the safety variables studied for this case of an urban mixed-mode network. Table 2 presents the results of the final analysis but it is noted that the model revealed a number of other results during analysis which are not displayed in this table; the respondent cyclists are significantly confident regarding their skills; people who wear safety accessories (helmets, high-visibility clothing, reflectors and lights) tend to claim that they are more compliant with the rules of the road; the majority of these cyclists tend to be commuters; and only the more experienced cyclists were comfortable cycling during night-time. Table 2 presents the significant eigenvalues, percentage of variance explained, factor loadings, mean and standard error values grouped according to factors which are related to each other. From this table a number of interesting results can be inferred.

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The likelihood of an accident due to pedestrians, rush hours traffic, road surface quality, parked vehicles along road sides, buses and taxis in shared lanes move similarly to each other in the perceived risk they present to the cyclist. This means that if a cyclist feels the threat of an accident due to one of these factors, they will feel similarly about the other factors from this group. This result may be a cause of concern as these elements are encountered on a day to day basis within the transport network. These abovementioned factors move independently of the likelihood of accident due to poor bicycle maintenance and a lack of cycling skills. Table 2 shows that safety accessory use moves independently of all other variables and therefore, interestingly, is not associated with attitude (confidence) or level of experience, although interim results of analysis did reveal that cyclists who use safety accessories are more compliant to the rules of the road. A lack of compliance with the rules of the road is shown in Table 2 to be associated with cyclists who describe themselves as being more experienced and more confident cyclists, these cyclists are also shown to cycle more regularly within the network. Another interesting point revealed by the PCA is how the purposes of bicycle use are not related to any of the safety aspect considered in the model. Finally, Table 2 indicates that cyclists feel motorists to be both reckless and careless with regard to the presence of cyclists in Dublin's transport network, a major cause for concern, as it is vital the each mode cooperates with the other to ensure a safe environment. The ranked scores for the variables of the Safety Behavior Model are presented in Figure 2. The bar graph shows the degree of significance of the variables. The scores signify that the variables of similar signs are interpreted to be of similar influence in a binary sense. The behavior of cyclists in a shared urban multi-modal network, while considering the aspects of personal safety is investigated through the Safety Behavior Model. This model analyses the survey responses related to their attitude and behavior towards safety while cycling. PCA has been used to reveal the guiding factors. Initially 31 variables were included in the analysis; of these, 6 were found to be insignificant (the use of a bicycle for travel to school/college, the use of a bicycle for organised racing, the distance and time cycled on an average weekday/weekend and average cyclist speed) and were therefore removed from the analysis. Performing the PCA with the remaining variables, 8 eigenvectors remained significant having taken the latent root criterion into account.

Some observations from the initial results, before rotation of the matrix indicated that the respondent cyclists are significantly confident regarding their skills. People who wear safety accessories (helmets, high-visibility clothing, reflectors and lights) tend to claim that they are more compliant with the rules of the road. It was also observed that the majority of these cyclists tend to be commuters. Only the more experienced cyclists were comfortable cycling during nighttime.

Table 2 presents the significant eigenvalues, percentage of variance explained, factor loadings, mean and standard error values grouped according to principal component, for the Safety Behavior Model following the application of a varimax rotation technique. The PCA model groups related variables together within each principal component. From this table a number of inferences can be drawn. Cyclists who believe that it is unlikely that they may be involved in an accident due to one of the following situations will also believe that it is unlikely of them to be involved in an accident due to any of the other situations: the action of taxis or buses in a cycle lane, vehicles parked along road-side causing an obstruction, poor quality road surfaces, rush hour traffic and pedestrian obstruction. A poorly maintained bicycle, along with lack of cycling skills is observed to be related to the likelihood of an accident. However, the likelihood of these factors influencing an accident is independent from the bunched factors stated above. The attitude of drivers on the streets of Dublin is generally perceived as both careless and reckless towards cyclists. The regular cyclists in Dublin, who consider themselves as experienced and competent claim to be less compliant of the rules of the road. Cyclists who wear bright coloured/high-visibility clothing are also likely to wear other safety accessories. It is to be noted that no strong relationship was observed between the experience of a cyclist and the use of safety accessories. The model suggests that these existing cyclists tend not to alter their safety behavior based on the variables distance travelled, travel time, or travel speed. These variables should be studied in the context of other types of transport networks, especially in inter-urban and rural scenarios to determine if they are influential in these situations. The ranked scores for the variables of the Safety Behavior Model are presented in Figure 2. The bar graph shows the degree of significance of the variables. The scores signify that the variables of similar signs are interpreted to be of similar influence in a binary sense.

4.2 Perceived Safety Model

The Perceived Safety Model investigates the determinants which influence a cyclist's perception of safety as compared to driving in the shared multi-modal transport network of Dublin City. The model utilizes an Ordered Logistic Regression (OLR) analysis to identify these determinants. Initially 23 variables were included as explanatory variables in the Perceived Safety Model (Table 3). In Table 3, the coefficients, odds-ratio, standard errors of the coefficients, indicative significance according to p-values and 95% confidence interval of the coefficients of the explanatory variables are presented. Age, regularity of cycling (number of days per week), use of urban roads, use of roads with no cycle facilities, use of bright colored/high-visibility clothing, compliance with the rules of the road and the attitude of vehicle drivers were identified as the significant determinants to influence the probability of

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the perception of safety of a cyclist when compared to driving. ~~The coefficients for each significant explanatory variable indicate that for unit increase of the predictor, the level of perception of safety will change by its respective log-odds coefficient while the other variables in the model are held constant. It is simpler to interpret the effect of an explanatory variable on the OLR outcome through the odds ratio; this is obtained by exponentiation of the log-odds coefficient. The compliance with the rules of the road has the largest OR, and can be interpreted as by deciding to always comply with the rules of the road, the probability of a person perceiving cycling to be 'safer than' driving are 2.2 times greater than the probability of combined 'less safe' and 'as safe as' category, given all other predictor variables are held constant. The influence of all other predictors can be interpreted similarly.~~

The probabilities of describing cycling as safer than, as safe as or less safe than driving, ~~were calculated for each explanatory variable~~ while the other explanatory variables were assumed constant and are displayed in Figures 3 and 4. The probability of an "event", as mentioned in Figures 3 and 4, is the probability of describing cycling as less safe, about as safe as or safer than driving in Dublin. Figure 3 indicates that cyclists perceive cycling to be less safe than driving in Dublin for all cases, except with regard to compliance with the rules of the road. In this exceptional case, it is quite interesting to see that people 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. The use of safety accessories do not have a large influence on the probability of describing cycling as less safe than driving. Cyclists who prefer to cycle on urban roads and on-road with no cycling facilities are 10% less likely to consider cycling as less safe than driving than cyclists who do not prefer to do so. This result suggests that those who are comfortable with cycling along roads with higher volumes of traffic feel safer while cycling in urban areas. As the number of days people cycle per week increases, the probability of describing cycling as safer than driving in Dublin also increases, and the probability of describing it as less safe decreases. This result may indicate that a familiarity with the network, due to regular use, may decrease a cyclist's probability of describing cycling as less safe than driving. [Møller & Hels \(2008\) also found that increased regularity decreased the perceived risk, for the specific case of the use of roundabouts.](#) The model also indicates reckless and careless driver behavior is one of the major factors in cycling being perceived as less safe than drivers. Figure 4 presents the probability of cycling being perceived as a safe mode when compared with driving in Dublin according to the age of the cyclists. It is interesting to observe that the probability of describing cycling as safer than or as safe as driving grows with age. Consequently, older people are more likely to deem the cycling network as safer than the relatively younger population. This observation is a cause for concern, since it is the younger population who are 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.

In addition to this model of all participants, [further analysis was conducted to analyze and compare responses according to similar gender specific and age categorized \(under 25 years of age and 25 years of age and older\) modeling was also carried out. This analysis was also carried out using OLR methods.](#) Table 4 shows the odds ratios for each of these models. From the results in Table 4 for the gender specific models it can be seen that the age of the cyclist is significant only to females in increasing how safe they feel while cycling compared to driving in Dublin. This is also clear from the OLR model of cyclists who are 25 years old and above. The regularity of cycling is significant to both male and female groups in increasing their safety experience. The preference for cycling on urban roads reveals an increasing feeling of safety while cycling in Dublin for males, while a preference for kerb-side cycle lanes has a similar effect for females. A preference for using roads with no cycling facilities is significant to increasing how safe both males and females feel while cycling in Dublin when compared to driving. However, for female cyclists this effect is more considerable. For male cyclists, wearing bright colored/hi-visibility clothing while cycling is associated with a reduced safety experience. For female cyclists, the use of a helmet and lights/reflective accessories shows a similar response. This result may appear to be counterintuitive; however it suggests that the use of safety accessories will not increase how cyclists perceive their safety. Finally the model indicates that, for both males and females, their feeling of safety while cycling in Dublin is reduced by the reckless attitude they feel drivers have towards cyclists.

The results of modeling cyclists within two age categories show that an increased feeling of safety is associated with a greater number of days cycled among the older age group. Cyclists under the age of 25 describing themselves as more experienced feel nearly 1.8 times safer cycling in Dublin, than less experienced cyclists. This is the only case where the experience of the respondents has been shown to be significant by the OLR models to how safe they feel while cycling in Dublin. Similar to male cyclists, those under 25 who prefer to use urban roads while cycling feel safer than those who prefer to avoid this type of road. For cyclists 25 years old and above, a preference for cycling on roads with no cycling facilities is associated with an increased safety experience. As seen in the previous OLR models, safety accessories are associated with a reduced safety experience. It is again believed that these cyclists wear safety accessories because they feel unsafe while cycling, but their use does not enable them to feel safer. For those under 25 years of age, wearing bright/hi-visibility

clothing is significant to this case, whereas for cyclists 25 years and older both the use of helmets and bright/hi-visibility clothing are significant. Full compliance with the rules of the road among the older age group increases their safety experience 2.7 times compared to those who stated that they break the rules of the road, while a general compliance with the rules among the younger cyclists has been shown by the model to increase their safety experience much more significantly (4.2 times). Again, modeling has revealed a reckless driver attitude to be associated with a reduced safety experience, among both age groups, while cycling in Dublin.

4.3 Cyclist-Network Interaction Model

~~The interaction between the cyclist and the elements of the shared multi-modal transport network of Dublin was investigated through PCA to understand the perception of safety of the cyclists in relation to the existing infrastructure.~~ There exist many different views on the position of cyclists within a shared multi-modal network; integration or separation, on-road or off-road cycling facility based, mixed facility or single facility systems. Initially the PCA for the Cyclist-Network Interaction Model included 28 variables, of which 3 were found to be insignificant (the use of off-road paths and trails, light rain and strong winds) and therefore were removed as they are not related to the interaction of a cyclist with the elements of the transport network. ~~Performing PCA on the remaining variables 8 eigenvectors remain significant considering the latent root criterion.~~

Table 5 presents the significant eigenvalues, percentage of variance explained, factor loadings, mean and standard error values for the Cyclist-Network Interaction Model, ~~after a varimax rotation has been applied.~~ Respondents were asked if they would alter their route to avoid or make use of various factors encountered within the network that are often described as hindrances or beneficial to cyclists. The PCA reveals that cyclists altering their route to make use of routes perceived as safe, quiet roads, well lit streets, continuous cycle lanes and amenities move together. This means that a cyclists who will (or will not) alter their route for one of these factors will do similar for all other factors in the group. Interestingly, all factors studied, and viewed as beneficial to cyclists are contained within this group, explaining the largest amount of variance within the data modelled. Factors considered as hindrances move in 2 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. In terms of road types studied, urban, residential and suburban roads move together (off-road paths and trails were found to be insignificant in this analysis). Cyclists preferring to use kerb-side cycle lanes also

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prefer to use shared bus-cycle lanes, while those who prefer roads without cycling facilities prefer not to cycle on footpaths. These cyclists will also alter their routes to avoid roads with poor quality surfaces. The final point displayed by this model shows that more regular cyclists will tend not to change mode in adverse weather conditions. All observations before rotation are found to be present in the rotated matrix. The analysis indicates that cyclists generally alter their routes to make use of facilities such as continuous cycle lanes, amenities such as shops and cafes, streets with lighting (when cycling at night), quiet roads, and routes perceived as safe by cyclists. Cyclists, who would alter their routes to avoid traffic lights, would also alter their routes to avoid stop signs. Additionally, cyclists show a preference for cycling on urban roads, suburban roads and residential streets as compared to off road parks and trails. This observation is trivial, but it proceeds to confirm the credibility of the model. It is also found that people who cycle a greater number of days in a week are less likely to change to an alternative mode of transport under inclement weather conditions. This includes heavy rain, icy road conditions or in temperatures below freezing. Cyclists with a preference for cycling on roads with no cycling facilities have strong aversion towards cycling on footpaths with cycle lanes. However, these cyclists will alter their routes to avoid poor quality road surfaces. The model has shown that there are a number of cyclists who would not tend to alter their routes to avoid elements encountered within the transport network, which are usually viewed as hindrances. These include steep gradients, traffic congestion, right turns, cars parked along road-side, roads with higher speed limits, and roundabouts. Cyclists who prefer to use kerb-side cycle lanes also prefer shared bus-cycle lanes. Figure 5 represents the ranked scores for the Cyclist-Network Interaction Model. The figure shows the degree of significance of each variable within the model and the scores signify that the variables of similar signs are interpreted to be of similar influence in a binary sense.

5. Discussion on Policy Implications

Analysis of the survey responses of cyclists in Dublin has revealed several areas, in which improvement could increase the perceived safety of cyclists in Dublin. The effects of such improvements are discussed in detail in this section.

The analysis has shown that the use of safety accessories is not associated with an improvement in cyclist's safety experience, but instead is shown to be associated with a decreased safety experience compared to driving in Dublin. The presence of situations perceived by cyclists as potentially unsafe has led to the cyclist making use of such safety accessories, but has not helped them overcome the fear of such situations. Therefore,

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[making their use mandatory among cyclists may be of little or no benefit to the improvement of the perceived safety of cyclists required to make cycling a viable mode of transport in Dublin. Such a measure may even prove counteractive to cycle mode share, as presented by a study of Australian cyclists \(Robinson, 1996\).](#)

[An interesting result uncovered by analysis has shown that 74% of cyclists who claim to be fully compliant with the rules of the road feel cycling is as safe as or safer than driving in Dublin. Road safety initiatives encouraging improved compliance among cyclists could therefore be beneficial to improving the perceived safety of cycling. Increased compliance of the rules of the road has been achieved among motorists through penalty systems which impose fines and 'points' on offenders. This system is easily implemented among vehicle users as each vehicle must be registered to the user and displays a unique identification code. Such a system may not be successful among cyclists due to difficulties with displaying a viewable identification code on a bicycle. Enforcing penalties on cyclists may also prove detrimental to cycling mode share, as increased costs may decrease the attractiveness of cycling as a viable mode. Analysis also revealed that cyclists, who use the network regularly and who describe themselves as confident and experienced cyclists, are less compliant with the rules of the road. It is also this group of cyclists who prefer to cycle on-road and not on segregated facilities. Therefore, similar to motorized network design, design for cyclists with a mixed mode network should consider that not all cyclists use the network in the same way. Policies and network design must consider that there are cyclists who will break the rules of the road, and design for these cases. As similarly found by Parkin et al. \(2007\), the provision of infrastructure does not necessarily correspond to an increased attractiveness of a route. Segregated facilities provide a more comfortable environment for beginner/learning cyclists, but for more conversant cyclists improvement of driver attitudes may be more beneficial to their perceived safety. Campaigns which encourage cyclist-driver cooperation within the network may help combat Dublin's 'road rage' problems.](#)

[The models identified many elements of the transport network were recognized by the respondents as positively or negatively influencing the perception of safety among cyclists. The respondent cyclists \(79%\) envisage that the presence of pedestrians and cycle lanes on footpaths as likely causes of an accident. This result confirms the findings of studies investigating the relative safety of various types of cycling infrastructure that shared use \(pedestrian-cycle\) paths to be one of the least safe options for cyclists \(Aultman-Hall and Hall, 1998a; Aultman-Hall and Kaltenecker, 1999; Kaplan, 1975; Moritz, 1997, 1998; Wachtel and Lewiston, 1994\). This could suggest that the introduction of new cycle lanes on footpaths and busy shopping districts may not be beneficial. Similar to studies elsewhere \(Doherty et al., 2000\), poor road condition was identified as another major factor negatively](#)

influencing the perception of safety by 81% of the respondents. It is therefore recommended that the National Roads Authority and town/city councils should focus on maintaining the kerb-side surfaces on the on-road cycle lanes and roads with no cycling facilities. In relation to other elements viewed by cyclists as a potential accident risk, including a lack of cycling skills and bicycle maintenance skills, cycling workshops and community initiatives, for young, new and improving cyclists may prove beneficial for providing education and information about the rules of the road, bicycle care and safe cyclist practices for cycling in a mixed mode situation. With this increased knowledge cyclists can feel more confident and conversant within network.

The analysis demonstrates that cyclists prefer less busy and quiet roads, roads with street lights, routes perceived as safe and routes with continuous cycling facilities. Cycling policy, based on user feedback, should emphasize on improving safety along routes which have been identified by cyclists as unsafe. Provision of street lights, alternative routes to those along busy roads, continuous cycling facilities on priority routes should all be considered by policy to attract more non-cyclists into cycling. The provision of more information through websites and social networks on alternative routes within the road network which are viewed as safer and more comfortable by cyclists may be advantageous to cyclists.

Young cyclists were identified as more likely to perceive cycling to be less safe than driving than older cyclists. The economic boom in the nineties saw a drastic drop in bicycle mode share throughout Ireland and therefore the younger generations have not been exposed to the culture of cycling; feeling less comfortable and less safe than older generations when using a bicycle in a multimodal network. To make cycling an intrinsic part of Irish mobility, it may be beneficial to introduce the knowledge and culture in school. Introducing cycling education at the primary school level could encourage cycling among a younger population, would inform them on the safe and responsible use of the shared multi-modal transport network and would also educate the future drivers to appreciate the safety requirements of cyclists within the network.

Modeling has revealed that the perception of safety of a cyclist does not alter with the experience of the cyclist, although 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 transport policies which encourage regular cycling activities such as the 'Bike to Work' scheme should be expanded and further encouraged.

The growth of cycling as a viable mode of transport is largely dependent on the perceived safety of the mode among non-cyclists. The opinions of these non-cyclists are based on the

Finally, the study presents contrasts and confirmations to the results of existing research, as described above and contributes new information on the impacts that infrastructure, network users, safety accessories, and road & weather conditions have on the impression of safety among cyclists. It adds to existing research in that it has approached the topic from the safety point of view of the network users. This is important as improving the perceived safety experience of cyclists is vital to improving the overall image of cycling as a safe and viable mode of travel. The study also looks into the self-reported perceived safety experience. In doing this, aspects which prevent the portrayal of cycling as a safe and viable mode of travel can be identified, and targeted by policy makers to improve the safety image of cycling.

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6. Conclusion

This paper presents the most comprehensive study of safety perceptions of cyclists. A questionnaire survey of cyclists in Dublin collected the perceptions of current cyclists with regard to their safety experiences, to gain an overall view of how the network, its users and their attitudes impact on the safety perceptions of cyclists. The survey instrument provided a platform to allow collection of data for a network wide view from cyclists, and not just specific to a particular type of link, intersection or facility. It also allowed the collection of information on variables which are not operationally or geometrically related to the network, and not previously studied in the domain of cyclist's safety perceptions. These include important policy variables such as cyclist compliance with the rules of the road, as well as other variables of indirect influence; safety accessory use, bus, taxi and vehicle driver behavior, cyclist experience and confidence, trip purpose, local amenities, weather conditions and good will of the road.

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This paper also presents the first study to make comparison between the perceived safety of cycling and another mode. In this case, participants compared cycling to the dominant mode of transport in use in Dublin. Cyclists were asked to compare cycling with driving in terms of safety. Overall, 70% of cyclists stated that they perceive cycling as less safe than driving in Dublin. This clearly highlights a deficiency in cycling safety and a strong requirement of the improvement of cycling safety conditions, including safety perceptions to be at least on a par with driving. Analysis revealed that, for all cases considered, participants felt cycling was less safe than driving, with the exception of participants claiming to be fully compliant with the rules of the road. This presents a strong case for policy to place focus on the education of cyclists to the rules of the road and compliance with these rules. The implementation of such policy, together with other policy suggestions based on the results of analysis; improvement of inter-modal cooperation, design of a mixed-mode network to consider cyclists and the possible counteractive effects of mandatory safety accessory use, may prove beneficial to the advancement of how cycling is perceived among both cyclists and

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non-cyclists in terms of safety and in turn as a viable mode of travel. This paper presents the first case study of its kind in Dublin. It is one of the first studies on the influence of the elements of the transport network with which the cyclists interact on a regular basis and how these elements affect their perceived safety. This paper also presents the first study of the influence of other modes within a mixed mode environment on the perceptions of safety from the viewpoint of cyclists. The responses from a questionnaire based survey of 1,954 cyclists in the city of Dublin, Ireland have been analyzed using PCA and OLR to gain an understanding of their safety behavior and their perception of safety while cycling. Upon review of the results of analysis, it is suggested that educating all network users to the presence of cyclists within a multi-modal transport network may be necessary in order to improve the safety of cyclists. This education could be provided at a school going age, so as the safe and responsible use of a bicycle within the transport network may become a part of everyday life and be understood by all road users from an early age. This may also prove important in changing the trend of younger cyclists feeling less safe within the network identified through the perceived safety model.

The large response to this survey and the comments received from respondents about the survey revealed the concern of cyclists about the safety issues related to this mode in Dublin. Overall, nearly 70% of the cyclists expressed that they perceive cycling to be less safe than driving in Dublin. The analysis of the responses showed that there are several elements of the existing shared multi-modal transport network of Dublin which could be altered or improved to enhance the perception of safety among cyclists. These elements are often independent of cycling facilities and require policy changes more than investment in the network. The policy implications of the analysis as discussed in the paper may provide essential information to the transport authorities not only in Dublin or Ireland but also in countries where the bicycle mode share has been targeted to be increased.

Further analysis of the survey questionnaire, requires the use of alternative methodologies to quantify the likelihood of the willingness of the cyclists to alter their route with an increase in distance or time.

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