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Pedestrian right-of-way violations at signalised pedestrian crossings in Edinburgh

By

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Declaration

I hereby declare that this thesis together with work contained was achieved by myself, and contains no material that have been accepted for the award of any other degree or diploma in any university. To best of my knowledge and belief, this thesis contains no material previously published or written by another person except where due acknowledgement to others has been made.

(**Khalfan Saeed Alnaqbi**)

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Date ....

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Abstract

The review of available literature related to pedestrian accidents indicates that the occurrence of pedestrian accidents is influenced by a diverse range of factors. However, few empirical studies have documented the effects of distance of pedestrian accidents from pedestrian crossing area or junction. The few studies which investigated the impact of the distance from the crossing line on pedestrian accidents, suggest that the longer the distance from road crossing facilities, the higher the likelihood of a pedestrian accident. With respect to the influence of the type of pedestrian crossing on the incidence of pedestrian accidents, a substantial body of literature has found that the types of pedestrian crossing indeed affect the frequency of pedestrian collisions. Additionally, all the available studies reviewed indicated the positive impact of signalised crossings on the reduction of pedestrian collision risk.

Data from STATS19 show that pedestrian severity rates are higher over the pedestrian crossing points or within 50 meters of pedestrian crossing facilities than those away from it. This is contrary to the expectations that accidents should be least over these crossing facilities. This study investigates in more detail the factors that affect accident occurrence at signalised pedestrian junction and pelican or similar type of crossing facilities in the Scotland area. The main objective of this current research has been to investigate those factors most commonly associated with pedestrian injury severity at a pedestrian crossing or within 50m of one. Accident data of 14 years (from 1993 until 2006) in selected sites show that 942 pedestrian accidents occurred on or within 50m of a signalised pedestrian crossing area. Grid references of accident locations as well as locations of pedestrian crossings were obtained from the STATS 19 database and the local city council. The data was used to identify the locations of accidents relative to the location of pedestrian crossing facilities.

In terms of severity of injuries models, results suggest that pedestrians from the older group received more severe injuries, compared with those from younger groups. Again, this finding underlines the importance of regulations and subsequent enforcement of traffic laws that protect and promote the safety of older pedestrians. The models also showed an association between the severity of injury and the type of pedestrian crossing. Since more KSI accidents have been associated with pelican crossings, there

may be a need to undertake raising awareness and education for pedestrians to improve pedestrian safety. In terms of ROW models; it was shown that turning manoeuvres were more likely to violate pedestrian's ROW and result in accidents than other types of manoeuvres. Moreover, the model showed that heavy-goods vehicles and cars are associated with pedestrian's ROW, as compared to other types of vehicles. The various issues related to accidents resulting from pedestrian right-of-way can be effectively resolved by rationalisation of pedestrian crossing types; and provision of education with regards to the rules and responsibilities of both pedestrians and drivers at all available crossings.

The models developed to profile pedestrian accidents in Edinburgh suggest that the highest number of pedestrian accidents occurred at pedestrian crossing lines; and that the number of pedestrian accidents decreased when moving away from pedestrian crossing lines or within 50 metres of pedestrian crossing lines. These have serious implications in terms of requiring improvements to pedestrian crossing facilities that can then ensure better pedestrian visibility and provide the public with more protection from moving vehicles. Moreover, another implication of this finding is that more regulatory instruments must be revalidated and further developed, since there are no laws to prevent pedestrians from crossing the road at certain points. The only laws being enforced in the UK are those relating to the prohibition of walking on motorways or slip roads but not regarding loitering on pedestrian crossings. Therefore, the guidelines specified in the Highway Code to deal with pedestrian behaviour while crossing the road have to be revisited and further developed.

The results show that accidents rates decrease as distance increase from the pedestrian crossing facilities. The most risky locations are those at the pedestrian crossings or within 10 meters and the distance from 10 to 30 meters before the pedestrian crossing facilities. Analysis of pedestrian accidents rates and severities for each of pelican and signalised crossings were discussed. An investigation of right-of-way violations associated with pedestrian accidents at pedestrian crossing areas or within 50 metres of the same was carried out. Modelling accidents rates and severities at these pedestrian crossings is also presented in this thesis. Multinomial logit, ordinal and probit logit and binary logit modelling are used to analyse the results.

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Chapter 1
Introduction

1.1 Introduction

In an age where environmental and economic issues are prompting people to seek alternative methods of transportation, walking remains one of the most effective ways to get from A to B. However, in many places, this option is increasingly perceived to increase a person's likelihood of being involved in some form of accident. In fact, despite improved safety mechanisms; accident and casualty rates as a reflection of pedestrian safety remain a problem worldwide. An extension of this is that pedestrian injury has become the second-greatest cause of accidental child death in the world, with critical statistical rates in countries such as the United States, France, and Northern Ireland to name a few (ERSO, 2007), making this a relevant and vital issue for researchers to address. Moreover, despite the importance of pedestrian safety and the rising number of accidents involving pedestrians around the world, many countries are not investing in pedestrian safety. For example, in the US, most traffic safety programmes focus on drivers, and many states in the country spend less than 1% of their federal funds on pedestrian safety (TRANSACT.org, 2002).

While urban areas in the UK also have more pedestrian accidents than in rural areas, similar to other countries around the world (Gunay et al., 2007), an interesting finding is that pedestrian casualty rates vary according to a large number of factors, including age, gender, vehicle type, weather conditions, road conditions and time of accidents. In the UK, a study by the Department for Transport (2008) revealed some interesting findings in relation to the factors contributing to pedestrian accidents. When looking for where to place the blame for such accidents, it was found that 55% of contributing factors were assigned to pedestrians for not looking properly before crossing, while 21% of the accident related factors were related solely to the vehicles involved, and the remaining 24% to the failure of both the pedestrian and the driver of the vehicle to look properly. Therefore, there are requirements for further investigations of crossing behaviour, impacts of road and vehicle factors on pedestrians' accident rates and severities. Despite the relatively positive records on road safety in the UK, compared to other European countries such as Austria, Finland, Ireland, Norway, Switzerland, Belgium, Denmark, Germany, the Netherlands, Sweden, France, Italy, and Spain, pedestrians form a higher proportion of fatalities in the UK than in other countries. For example, the rate of pedestrian fatality per capita of the population in the UK is almost three times the level experienced in the Netherlands, (Commission for Integrated Transport, 2007). More positively, statistics have shown a reduction in the total number of pedestrian accidents in the UK.

Statistical analysis of UK police accident records (STATS19) from 1993-2006, (which offers a rich source of pedestrian accident records, including the different variables that characterise pedestrian accidents), shows that the proportion of pedestrian accidents accounted for 13.6% of the total number of accidents. This percentage ranked third, after driver (or rider) and passenger. It is important to consider here that pedestrian accidents represent the highest percentage of deaths and serious injuries (23.7 per cent), while driver and passenger KSI accidents represent less than half of this percentage (driving 12.9%; passenger 10.4). During this period, a total of 12, 398 pedestrian accidents resulted in fatalities, 125, 220 accidents resulted in serious injury, and 443, 047 in people being slightly injured. Thus, it can be seen that, while the highest percentage of accidents resulted in slight injury, a larger proportion of pedestrians (137, 618, or 10, 586 pedestrians per annum), were seriously injured or died, as a result of pedestrian-vehicle collisions.

From the above discussion, it is evident that recent studies are starting to identify a range of explanatory variables to explain the causes of pedestrian injuries. The current research adds to this literature on pedestrian injury severity in several ways. Firstly, a multivariate modelling approach is used, which generalises the ordered response model structure used in earlier studies. This generalisation, which is referred to as the generalised ordered logit model, adds flexibility by capturing the effects of explanatory variables on the ordinal categories of injury severity, especially in the treatment of the utility thresholds; thus removing the strong restrictions imposed by the ordered response logit models used in the extant literature. Secondly, this study examines the effects of right-of-way (ROW) on injury severity levels for pedestrians; allowing for the magnitude of the effects of contributing factors between the two pedestrian groups, those who have ROW and those who do not, to be compared. Thirdly, a comprehensive set of contributing factors are included in this study in order to explain injury severity, including non-motorist, driver, vehicle, roadway, environmental, and crash characteristics. Finally, heterogeneity in the effects of injury severity determinants is integrated, due to the moderating influence of unobserved factors. For example, the consideration of ROW in the models obtained is again relevant as one of the explanatory factors.

1.2 Motivations of the study, aims and research questions

Some previous research and analysis has been conducted in terms of the locations of pedestrian accidents. For example, Ward and colleagues (1994) investigated the location of accidents relative to road-crossing facilities. They noted that while pedestrian accidents occurred mainly away from road-crossing facilities, in cases where pedestrian accidents occurred on signalised pedestrian crossings, they occurred at the pedestrian phase of traffic signals, or at pelican crossings. However, they did not investigate or model this finding to extrapolate further; indeed, there is a lack of work in this research area.

Therefore, the first aim of this research is to investigate and model pedestrian accident injury severities at signalised pedestrian crossings. The research question defined for this aim is:

What are the factors that contribute to increase/ reduce pedestrians' accident injury severities at pedestrian crossings?

Furthermore, it has formerly been anticipated that there would be a higher percentage of severity at places where there is no crossing facility. A lower percentage of severity of pedestrian accidents at pedestrian crossing facilities is predicted. Statistics show the number of pedestrian accidents where there were no crossing facilities was greater than the number of pedestrian accidents where there were crossing facilities. Table 1.1 below presents the percentage of pedestrian accidents at crossing facilities (74.6% of the total and 24.58% of the KSI), as higher than the percentage of pedestrian accidents where there were no crossing facilities KSI for (25.4% of the total and 23.34% of the KSI), which took place over the same period (from 1993 to 2006).

Table 1. 1 Pedestrian accidents at crossing and non-crossing facilities.

Pedestrian crossing physical facility	Number of casualties	KSI	Percentage of total
Non-crossing facilities	409474	95603	23.34%
Crossing facility	139193	34224	24.58%

With respect to physical pedestrian crossing facilities, Table 1.2 below presents that the highest number of pedestrian accidents to have occurred over that fourteen-year period were at pelican crossings (54,645 or 39%), followed by those that occurred at traffic signal junctions (41,123 or 30%), then those that took place at zebra crossings (28,328 or 20%), and those where there is a central refuge (13,214 or 10%). The lowest number of cases of pedestrian accidents recorded was on footbridges or subways (1,883 or 1%) (STATS19). In this research, pedestrian accidents on pelican or similar type of crossings and traffic signal junctions have been analysed.

Table 1.2: Percentage of casualties and KSI for pedestrian accidents at physical-crossing facilities

Physical pedestrian crossing facilities	Number of accidents	Number of KSI	%
Pelican	54645	13794	25.24
Pedestrian traffic signal junction	41123	9631	23.41
Zebra	28328	6107	21.55
Central refuge	13214	3922	29.68
Footbridge or subway	1883	712	37.81

The second aim of this research therefore is to investigate the impacts of location and distance from the crossing point, or within 50 meters from it, on pedestrian accident severities. The research question defined for this aim is:

Do accident severities increase or decrease as distance from the pedestrian crossing facility increases?

Lastly, in the EU, it is believed that pedestrian crossing regulations are one of many effective ways for minimising pedestrian accidents and fatalities (ERSO, 2008). One book that focused on protecting pedestrians and other vulnerable road users recommended that government institutions within the EU, and elsewhere, 'give pedestrian safety an important role in their national road safety policies', particularly in urban areas and with reference to pedestrian crossings (OECD, 2000). Previous work modelling pedestrian accidents has included factors such as traffic flow, width of road, type of crossing facility, time spent crossing, and socio-economic data. There is no definition of the right-of-way for pedestrians in the UK; therefore minimal work has been done regarding pedestrians' right-of-way (ROW) and its impact on accidents rates and severities.

The final aim of this research therefore, is an investigation of the right-of-way (ROW) and right-of-way violations of pedestrians at pedestrian crossings. Further, modelling pedestrian right-of-way taking into account the different factors affecting pedestrian accidents is presented. The research questions defined for this aim are:

1. ***Is there a clear definition and appropriate regulations regarding the pedestrian right-of-way ROW in the UK?***
2. ***What factors contribute to the pedestrian right-of-way at pedestrian crossings?***

1.3 Specific objectives of study

A number of research projects and investigations have examined pedestrian accidents at pedestrian crossings in a general manner. The aim of this work is to investigate pedestrians' accident severities with specific regard directed towards signalised pedestrian crossings, as well as the ROW of pedestrians at pedestrian crossings. In order to achieve this aim, the following specific objectives have been set:

1. Carry out a literature review on pedestrian accident analysis and pedestrian exposure at signalised pedestrian crossing facilities.
2. Investigate exposure factors for the analysis of pedestrian accidents at pedestrian crossings.

3. Gather data on pedestrian accidents and distances from the selected signalised pedestrian crossing locations in Edinburgh.
4. Identify a number of sites in Edinburgh in order to assess and analyse the frequency and severity of pedestrian accidents.
5. Investigate right-of-way (ROW) violations associated with pedestrian accidents at pedestrian crossings.
6. Calibrating and comparing pedestrian accidents with ROW violations using a number of modelling approaches, including relevant factors which have been identified to affect pedestrians' accidents at pedestrian crossings.
7. Draw conclusions and offer recommendations for further future work.

1.4 Outline of the thesis

This thesis is organised into seven chapters. Chapter 1 provides the background to the study; offering a brief overview of previous studies, relevant national statistics, research objectives, and the outline of the thesis. It also covers the motivation for this investigation into pedestrian accidents and right of way violations at signalised pedestrian crossing facilities, the aim of the thesis, and the set of objectives necessary to achieve the aim.

Chapter 2 reviews pertinent former studies that have developed our understanding of pedestrian accidents, involving a variety of road users, as well as those relating to pedestrian accidents at crossing facilities, in order to further consider how pedestrian accidents have progressed in extant literature. Also, these have provided an evaluation of limited work on, and definitions of, right-of-way (ROW), and the violations of this in different contexts and countries. A review of these studies is expected to provide guidance as to an appropriate definition and an investigative approach for the present study.

Chapter 3 presents the research methodology. As the primary aim of this research is to investigate pedestrian accidents and the severity at pedestrian crossing facilities or within 50 metres of such facilities, the relevant data and information will be gathered. Basically most information in this research will be taken from accident injury database STATS19 data that include all needed information about pedestrian accidents. The contributing factors from STATS19 that led to pedestrian accidents on pedestrian crossing line or with 50 metres of pedestrian crossing facility will be identified and analysed. A number of sites in Edinburgh, where a high number of accidents have been observed, will be selected for further more detailed analysis. Modelling of accident severity as a function of the factors identified, and analysis of these models' results will be presented in this chapter. Finally, an investigation of right-of-way violations associated with pedestrian accidents at pedestrian crossing areas or within 50 metres of the same will be carried out.

Chapter 4 presents the general statistics and preliminary analysis of pedestrian accident data over the last 14 years on the five selected sites in Edinburgh. These factors include Socio-economic factors, vehicle related factors, environmental factors and road related factors are discussed. The rates and severities associated with pedestrian accidents, at these pedestrian crossings, at those routes have been investigated. Finally, an investigation of ROW will be presented, and the variables representing the ROW for pedestrians and for motorists will be included in the analysis.

Chapter 5 presents a multivariate examination of the determinants of the severity of pedestrians' injury (i.e. controlling for all factors that influence pedestrian injury severity) involving pedestrians hit by car accidents. The chapter starts with an investigation of a correlation between the factors defined and discussions of the appropriateness of inclusion of these factors in the models. Models calibrated for the severity of injuries using the four approaches Multinomial Logit (MNL), Ordinal Logit (OL), Ordinal Probit (OP) and Binary Logit (BL) models are presented and discussed.

Chapter 6 presents the investigation of a multivariate examination of the determinants of pedestrians' injury severity (i.e. controlling for all factors that influence pedestrians' injury severity), taking account of right-of-way (ROW). The chapter presents the estimation results for the MNL, OL, OP and BL models for pedestrians hit by car accidents. The aggregate model is useful for obtaining a general understanding of the factors (i.e. human, vehicle, environmental, weather, or geometric factors) that significantly affect pedestrians' injury severity at signalised pedestrian crossings.

Chapter 7 discusses the findings shown in the results, concludes the research and provides recommendations for future work.

Chapter 2

Literature review

2.1 Introduction

The statistical data describing the various factors relating to pedestrian accidents, as presented above, highlight the importance of pedestrian safety. This chapter aims to evaluate the literature available in relation to accident risk exposure for pedestrians, pedestrian-vehicle collisions, pedestrian severity of injuries, pedestrian rights-of-way (ROW), and modelling approaches. Published literature that explores the concepts, definitions, and measures associated with pedestrian exposure will be examined in the first section; focusing on the general concept of exposure, from the earliest to the most recent, thereby demonstrating, to some extent, the evolution of the concepts of exposure. Literature that takes into account the context of epidemiology will then be reviewed, followed by that which explores the difference between exposure and risk. An analysis of literature that addresses the more specific concepts of pedestrian exposure will be presented, before a final evaluation of literature encompassing proxy or indicator measures of pedestrian exposure.

Studies related to factors contributing to pedestrian-vehicle accidents will be examined in the third section. It will consider literature related to the frequency of accidents, with regard to the distance between the site of the pedestrian accident and the pedestrian crossing area or junction. The influence of pedestrian crossing types associated with pedestrian accidents will be inquired into and followed by an analysis of the literature relating to the legal instruments being enforced on pedestrians in pedestrian crossing areas.

In the fourth section, the factors that may impact on the severity of an injury in the case of pedestrian accidents will be presented and those are divided into three categories: factors associated with pedestrian characteristics and behaviour, those associated with driver characteristics and behaviour, and those relating to the environment. This literature review therefore presents the evidence available from studies covering these variants.

Studies related to pedestrian behaviour will be considered in section five. Two types of adverse pedestrian behaviour can be identified. The first arises when pedestrians cross the road against the lights; that is, crossing when they have not been signalled to do so. The second is when pedestrians cross the road close to, but not within, a designated crossing area.

In the sixth section, right of way violations; 'jaywalking' commonly refers to the crossing of a pedestrian from one side of the road to another in an unauthorised area, or in violation of pedestrian laws is discussed. The section will present a general definition of right of way violations, and then carry out a comparison of pedestrian right of way regulations and rules in the UK and other countries.

The seventh section illustrates the different types of pedestrian crossing facilities in the UK, while the eighth section presents the modelling approaches available regarding incidences of pedestrian accidents.

2.2 Accident risk exposure for pedestrian

2.2.1 General concepts of exposure

One of the most comprehensive reviews of exposure literature was authored by Chapman (1973); who defined exposure as 'a measure of the opportunities or possibilities of having an accident'. However, many of the concepts relating to exposure that he examined focused on 'driving exposure', failing to consider the concept of 'pedestrian exposure' in any depth. In the same way, an earlier review of exposure literature by Carroll (1971) emphasised driving exposure and excluded pedestrian exposure. He defined driving exposure as 'the frequency of traffic events which create a risk of accident'. Both literature reviews included a discussion of the different methods for measuring exposure in accident research. Chapman (1973) evaluated exposure literature that essentially centres on accident rates, particularly with regards to accidents at intersections, while Carroll (1971) suggested accident measurements in terms of units of driving distance and driving time, which he further categorised into various risk variables, such as those associated with the vehicle, the driver, the road, and the environment. In a more recent study, the Organisation for Economic Cooperation and Development (OECD, 2004), defined exposure as 'the level of an individual or group's activity that is exposed to traffic as a pedestrian, cyclist, or car passenger', which can be measured in terms of 'distance, time, or number of trips'.

2.2.1.1 Exposure within the context of epidemiology

There are several empirical studies and an agency-commissioned report that further explore the concept of exposure within the context of epidemiology. Greene-Roesel et al. (2007) claimed that 'exposure refers to a person's contact with a potentially hazardous situation or substance'. In this case, exposure can be construed 'as a 'trial event' during which a harmful outcome might occur'. Lassarrea et al. (2007) associated exposure science with environmental epidemiology, whereby they asserted that 'it is a common practice to collect detailed and precise data about the quality of the micro-environments in which an individual stays or moves', which is subsequently utilised in the formulation of a methodology for evaluating 'the risk exposure of pedestrians in urban areas'. In particular, the authors stressed that, within the context of environmental epidemiology, exposure is defined as 'an event that occurs when there is a contact at the boundary between a human and the environment with a contaminant of a specific concentration for an interval of time'. Conversely, the authors also explained that, when applied to exposure science, this direct contact would specifically pertain 'to a collision between a road user and a vehicle that generates mechanical energy, which is the cause of the damage, during a certain amount of time'. However, Briggs (2000) claimed that, when health is perceived as a more positive construct, 'a looser definition of exposure may often need to be applied'. Thus, Lassarrea et al. (2007) stated that 'the quality of the atmosphere', which 'depends on the presence of contaminants', corresponds 'to the traffic, to the moving vehicles and are described by a traffic volume and a speed'.

2.2.1.2 Exposure and risk

Only a small amount of previous literature has demonstrated the distinction between exposure and risk. Chapman (1973), evaluating research from 1967 to '72, discussed the difference between exposure and propensity. His comprehensive review resulted in the following definitions of exposure and propensity: (1) exposure 'is the number of opportunities for accidents of a certain type in a given time in a given area' (i.e. it is the possible number of accidents of that type that could occur at that time in that area), and (2) propensity 'is the conditional probability that an accident occurs given the opportunity for one'. He asserted that a simple mathematical equation links the two definitions; such that 'the number of accidents is equal to the exposure multiplied by the propensity. This equation in reality defines a conditional probability, the propensity. When measures of exposure are given, the propensity becomes the accident rate, in one of its many forms. Moreover, Greene-Roesel et al. (2007) distinguished the concept of exposure from the concept of risk, applying both in the format of a mathematical equation. The authors claimed that a 'risk is an abstract concept that refers to the probability that a harmful event will occur given a certain number of trials'. They explained that 'in pedestrian safety, each "trial" is a unit of exposure such as a minute spent walking or on a road crossing'. Mathematically, the authors defined risk (i.e. the probability of collision/injury/fatality (c) per unit of exposure) as 'P (c/ x)', where 'P' is the probability, 'c' is the collision/ injury/fatality, and 'x' represents the exposure. This is supported by the work of Forgensen (1996), which defined risk as the quotient of an accidental event and exposure (i.e. risk = accidental event/exposure). Similarly, Lay (1990) expanded on the difference between risk and exposure. He explained that exposure is 'the frequency of encountering events which might cause an accident, i.e. accident opportunities'; while risk, on the other hand, is the 'accident potential, propensity or conditional probability' of an exposure.

2.2.1.3 Concepts of pedestrian exposure

The above-mentioned concepts associated with exposure were defined in such a way that they were restricted to driving exposure (Carroll, 1971; Chapman, 1973). These were expanded on by Wolfe (1982) to include both passive and active elements of the traffic system, and, subsequently, also the concept of pedestrian exposure. Wolfe's definition was broader and more generalised. According to him, exposure can be defined simply as 'being in a situation which has some risk of involvement in a road traffic accident'. However, there are still some perceived difficulties associated with generating concrete definitions for pedestrian exposure. The National Highway Traffic Safety Administration (NHTSA, 2008) asserts that it is critical to capture the concept of pedestrian exposure, due to its numerous and diverse definitions.

For example, exposure can be defined as the number of roads crossed, time spent walking near roads, or distance travelled near roads. There is also controversy as to what type of trip should be counted. Exposure can include walking to a post box, walking in a car park, or a walking trip that begins and ends at the same location, etc. In addition, walking may not provide exposure to traffic and consequently risk of a crash.

In order to understand pedestrian crash risk, exposure will be defined as any situation in which a pedestrian is at risk of being hit by a vehicle on public roads (fatalities included in NHTSA's Fatality Analysis Report System only include crashes that occur on public roads).

The protocol report by the University of California Traffic Safety Centre, which was authored by Greene-Roesel et al. (2007), maintains that the concept of pedestrian exposure pertains 'to the amount that people are exposed to the risk of being involved in a traffic collision', and that this risk occurs whenever pedestrians 'are walking in the vicinity of automobiles'. Thus, in this instance, pedestrian volume becomes one of the key metrics used in the measurement of pedestrian exposure. The protocol report is a comprehensive work that discusses in detail the various fundamental aspects of pedestrian exposure, such as the concepts and definitions of pedestrian exposure, area-wide and site-specific methods of measuring pedestrian exposure, data collection and planning at intersections, and estimation of annual pedestrian volumes. However, it lacks a single concrete and prescriptive definition of pedestrian exposure, as the authors acknowledge the abstract nature of this concept and the necessity for utilising proxy measures in order to arrive at an approximation of pedestrian exposure.

2.2.2 Proxy measures or exposure indicators of pedestrian exposure

There is a substantial amount of information available in published literature in terms of the use of proxy measures or exposure indicators. One of the earliest pedestrian exposure measures was that proposed by Smeed (1955), who utilised the rate of personal injury accidents per million motor vehicle miles and found that exposure was greater in built-up areas than in rural ones. Battey (1959) divided accidents into various groups, including pedestrian-vehicle accidents, and employed the square of vehicle mileage as an exposure measure. Chapman (1973) suggested four measures of pedestrian to motor vehicle accidents (i.e. pedestrian exposure), namely: '(a) the total traffic using an intersection (i.e. sum of all entering flows); (b) the product of cross flows at conflict points; (c) the square root of the product of the cross flows; (d) the observed number of conflicts at a location'.

Wolfe (1982) identified two general types of exposure measures for both vehicles and pedestrians. The first type of exposure pertains to vehicle or pedestrian movement along the system; the second type refers to the 'exposure and accident rates for particular sites or fixed objects as the road users go past'. He suggested that, for the first type of exposure, 'distance travelled seems generally the most appropriate exposure measure', and, for the second type, 'a direct count of road user movements seems the most appropriate'. Additionally, for the first type of exposure, other measures may 'include duration of travel, number of discrete trips, and number of road crossings'.

Conversely, for the second exposure type, interactive measures, such as those proposed by Chapman (1973), may be used. Routledge et al. (1974 and 1976) suggested a pedestrian exposure indicator that measures accident risk in relation to the proportion of space that is unavailable to the pedestrian for crossing the road safely, taking into consideration the length of the vehicle occupying a particular road-way crossing. Accordingly, this measures the 'accessibility to the other side of the road. If there are long vehicles, travelling quickly and in large numbers, one cannot access the other side of the road because one faces a kind of "moving wall" and if one chooses to cross, one has an increased accident risk' (Lassarrea et al., 2007). This measure uses the equation: $Pc = \zeta + vtc/d$, where 'Pc' is the accident risk of the crossing, 'ζ' is the average length of the vehicle, 'v' is the average speed of the flow, 'tc' is the average pedestrian crossing time, and 'd' is the average traffic gap. This exposure measurement tool became the foundation for more recent work by Lassarrea et al. (2007), which focused on the creation of a pedestrian exposure indicator based on the concentration of vehicles according to lane, as well as on the time spent on the crossing and the speed of the traffic flow. The authors recommended the use of this indicator in 'two specific micro-environments: junctions and mid-block locations. A model of pedestrians' crossing behaviour during a trip is then developed, based on a hierarchical choice between junctions and mid-block locations and taking account of origin and destination, traffic characteristics and pedestrian facilities' (Lassarrea et al, 2007).

Greene-Roesel et al. (2007) discussed the various pedestrian exposure measures based on the following: (1) population data, (2) pedestrian volumes, (3) trips made, (4) distance, and (5) time. The authors extensively discussed pedestrian exposure measures, which included the appropriate use of each measure, data gathering procedures, and the pros and cons of each measure. According to Greene-Roesel et al. (2007), pedestrian exposure based on population data provides an estimate of the number of residents in a given area, or the number of people in a specific demographic group. Population estimates are cost effective and simple to carry-out, and are therefore commonly used as proxy measures. The authors assert that these can be most appropriately used (1) as an alternative to data exposure when cost constraints make collecting exposure data impractical, and (2) to compare jurisdictions over time because population data is available for many geographies and time periods. Population data can be obtained annually in the US from the American Community Survey (ACS), which is administered by the US Census Bureau, and can also be accessed online (US Census Bureau, 2006, cited in Greene-Roesel et al., 2007). Furthermore, the authors maintain that the advantages of using population estimates as proxy measures include: (1) they are easy and low-cost to obtain; available for most geographies and time periods; (2) they can be adjusted for differences in the underlying resident population of an area – for example, sparsely populated suburbs versus densely populated inner-city areas; (3) they provide crude adjustment for amount of vehicle traffic on the streets, since areas where more people live also tend to be areas where more people drive; and (4) they may be the only way to represent exposure if direct measurements cannot be taken.

However, some disadvantages associated with the use of population data estimates have also been observed: (1) their failure to ‘accurately represent pedestrian exposure’; (2) their inability to ‘account for the number of people who travel as pedestrians in the area’; and (3) their lack of information about ‘amount of time or distance that members of the population were exposed to traffic’. With respect to the common measures provided by population data, the authors maintain that these include: (1) the ‘number of people in a given area’, i.e. ‘neighbourhood, city, county, state or country’; and (2) the ‘number of people in a particular demographic group’, i.e. ‘age, sex, race, immigrant status or socioeconomic status’. They also give examples of population data estimates of pedestrian exposure, as follows:

(1) In 2001, pedestrian collisions killed 20 people per million in California, but only 7 people per million in Nebraska (FARS and US Census data, 2001).

(2) In 2004, the male pedestrian fatality rate per 100,000 populations in the US was 2.22, while the female pedestrian fatality rate was 0.95 per 100,000 populations (NHTSA, 2004) (Greene-Roesel et al., 2007).

Additionally, another metric used to describe pedestrian exposure is pedestrian volume, which is used specifically for (1) 'estimating pedestrian volume and risk in a specific location', and (2) 'assessing changes in pedestrian volume or characteristics due to countermeasure implementation at that site' (Greene-Roesel et al., 2007). Since data is gathered through 'manual or automated counts of pedestrians', counts are 'simpler to collect than other measures such as time or distance walked', which is advantageous as 'automated methods for counting number of pedestrians are improving' (Greene-Roesel et al., 2007). On the other hand, the disadvantages when using pedestrian volume as a proxy measure include the following: (1) it 'does not differentiate pedestrians by walking speed, age, or other factors that may influence individual risk', (2) it 'does not account for the amount of time spent walking or the distance walked', and (3) it is 'not easily adapted to assess exposure over wide areas (for example, a city)' (Greene-Roesel et al., 2007). Common measures for measuring pedestrian volume include: (1) averaging the number of pedestrians per day, sometimes called 'Average Annual Number of Pedestrians' (Zeeger et al., 2005; Cameron, 1976; Hocherman et al., 1988; cited in Greene-Roesel et al, 2007); and (2) measuring number of pedestrians per time period, e.g. by the hour (Davis et al., 1988; Cove and Clark, 1993; cited in Greene-Roesel et al., 2007). Examples of a pedestrian volume estimation could be presented as: (1) 'the average daily pedestrian traffic at marked crossings was 312 pedestrians per site (Zeeger et al., 2005; cited in Greene-Roesel et al., 2007) or (2) 'between 7:00 am and 10:00 am, 203 pedestrians crossed Rose Street at the intersection of Shattuck Avenue' (Greene-Roesel et al., 2007).

Greene-Roesel et al. (2007) caution that, although the most commonly used term for this metric is 'number of pedestrians', such 'terminology is not, strictly speaking, accurate'. The authors suggest that 'a more precise term is 'number of pedestrian crossings', since a single pedestrian can contribute to the count more than once if that person passes through the measurement point more than one time during the observation period (such as during an outbound journey, and then again on the return). Moreover, they explain that when using pedestrian volume estimates, it is important to distinguish crossing exposure from roadside or pavement exposure, and to establish 'a good operative definition of what constitutes an entry into the area, and what constitutes a pedestrian'. They also suggest using a fixed point, such as an intersection crossing where activity is considered high-risk, and subscribing to the assumption that 'each crossing represents a fixed unit of risk, independent of crossing distance or location within the crossing'.

‘Exposure based on trips’ is another proxy measure of pedestrian exposure, which is calculated according to the number of trips estimated, or the number of walking trips taken by an individual, regardless of the distance or the time the journey takes (Greene-Roesel et al., 2007). To obtain this estimate, a representative subset of a population is surveyed, for example, the ‘National Household Travel Survey’. According to Greene-Roesel et al. (2007), this metric can be used for: (1) assessing pedestrian behaviour in large areas, such as cities, states, or countries; (2) ‘examining changes in pedestrian behaviour over time’, (3) ‘making comparisons between jurisdictions’; (4) ‘assessing common characteristics of walking trips, such as purpose, route, etc’. The authors enumerate the benefits of utilising such estimates as follows: (1) it is ‘appropriate for use in large areas’; (2) it is the ‘best metric to assess relationship of walking with trip purpose’; and (3) ‘Trips can be assessed as a function of person, household and location attributes’. On the other hand, the disadvantages include: (1) the need to survey a sufficiently large number of respondents in order to ‘adequately represent the underlying population’; (2) an inability to ‘provide information at the level of detail needed to assess risk’; and (3) the high tendency for pedestrian trips to be under-reported in surveys (Schwartz and Porter, 2000; cited in Greene-Roesel et al., 2007). The authors further describe the common measures for exposure based on trips as : (1) ‘average number of walking trips made by members of a population per day, week or year’ and (2) ‘proportion of walking trips taken for particular purposes, such as commuting or shopping’. They also provided the following examples of exposure measure, as based on this metric:

(1) In the US, the percentage of all work trips made by walking fell from 10.3% in 1960 to only 2.9% in 2000 (Pucher and Dijkstra, 2003; cited in Greene-Roesel et al., 2007).
(2) In the Mid - Atlantic States 15.8% of all trips are made walking, in the east-south-central and west-south-central states it is around 6% (Pucher and Renne, 2003).
(3) In the US, 38% of all pedestrian trips are made for social and recreational purposes; 32% for going to school and church, while 10% represent work trips (Pucher and Renne, 2003; Greene-Roesel et al., 2007).

In addition to this, exposure measures based on distance is another important measurement of pedestrian exposure, which can be used to (1) estimate ‘exposure at the micro or macro level', (2) to ascertain 'whether risk increases in a linear manner with distance travelled', and (3) to evaluate 'how crossing distance affects risk' (Greene-Roesel et al., 2007). According to Greene-Roesel et al. (2007), data can be obtained (1) 'through surveys such as the National Household Travel Survey (2001)', if an individual's level exposure is required, and (2) through the 'measurement of the length of the area of interest, combined with a manual or automatic count of the number of pedestrians', if the aggregate level of exposure is desired. The use of this metric has many benefits, including: (1) 'measuring exposure at the micro and macro levels'; (2) its more intricate nature compared to either pedestrian volumes or population data; (3) its utility in comparing 'risk between different travel modes'; and (4) its consideration as a common measure of vehicle exposure. However, it also has three disadvantages: (1) the failure to 'take into account the speed of travel and thus cannot be reliably used to compare risk between different modes (e.g. walking and driving); (2) it 'assumes risk is equal over the distance walked'; and (3) it 'must typically assume that each pedestrian walks the same distance in a crossing or along a sidewalk' (Greene-Roesel et al., 2007). Moreover, some common measures of this metric include 'average miles walked, per person, per day' and 'total aggregate distance of pedestrian travel across an intersection' (Greene-Roesel et al., 2007). Examples of such metric are as follows:

(1) The 2001 fatality rate per 100 million miles travelled in the US was 1.3 for drivers and their passengers and 20.1 for pedestrians (STPP, 2004).
(2) Between 1990 and 2000, the share of Americans walking to work fell from 3.9% to 2.9% (US Census, 2000, Summary File 3; Census, 1990, Summary Tape File 3) (Greene-Roesel et al., 2007).

Lastly, exposure based on time is appropriately used for (1) 'estimating total pedestrian time exposure for specific locations'; (2) 'comparing risks between different modes of travel (e.g. walking vs. riding in a car)'; (3) estimating whether risk increases in a linear manner with time spent walking; and (4) 'comparing risk between intersections with different crossing distances and between individuals with different walking speeds' (Greene-Roesel et al., 2007). As a means of obtaining data for the purpose of estimating exposure based on time, 'the number of persons passing through an area' is 'multiplied by the time travelled' (Greene-Roesel et al., 2007).

Additionally, 'time spent on walking activities', such as those reported in surveys, can be used when gathering data (Greene-Roesel et al., 2007). Greene-Roesel et al. (2007) maintain that the use of this metric is advantageous because it (1) 'accounts for different walking speeds', (2) 'allows for accurate comparison between different modes of travel', (3) 'can be used to measure exposure at the micro and macro levels', and (4) is 'more detailed than pedestrian volumes or population data'. Many disadvantages are associated with this, however, such as:

1. Time-based measures assume equal risk over the entire distance of a crossing. Only a small portion of the time spent walking on road-ways represents genuine exposure to vehicle traffic. This portion would include time spent crossing roads, walking on the surface of the roads, or possibly walking along a roadside where there is no pavement (Chu, 2003).
2. Time spent walking can be over-estimated in surveys, as people perceive themselves as spending more time walking than they do (Chu, 2003).
3. Walking may also be under-reported in surveys, because people may forget particular trips or may purposely choose not to report them. Both of these reasons are related to the fact that walking trips are relatively short. Such short trips may not register in the memory of respondents, or the respondents may think that these trips are unimportant (Chu, 2003; Greene-Roesel et al., 2007).

According to Greene-Roesel et al. (2007), common measures for this metric include: (1) the 'average time walked, per person, per day or year' and (2) the 'total aggregate travel time of pedestrian travel across an intersection'. For example, 'in 2001, the U.S. annual per capita minutes travelled was 2,139 minutes' (Chu, 2003; cited in Greene-Roesel, et al, 2007).

2.3 Factors contributing to pedestrian accidents

Pedestrian-vehicle accidents occur most frequently at intersections and at other areas where there is a large volume of foot and vehicular traffic. However, factors that contribute to pedestrian-vehicle accidents are not limited to congestion. The characteristics associated with the vehicle and the driver, as well as those of the pedestrian, can increase the statistical likelihood that accidents may occur; the characteristics of the roads themselves and the type of traffic also impacts on the number of such accidents (Campbell et al., 2004). In particular, the physical features and land-use qualities, including the presence of crossings, and roundabout design, in different areas can contribute to higher rates of pedestrian-vehicle accidents (Campbell et al., 2004). These findings have been supported by Sideris (2006), who claimed that pedestrian-vehicle clashes are influenced by: (1) the social and behavioural characteristics of drivers and victims; (2) road design characteristics; (3) vehicular and pedestrian traffic characteristics; and (4) area socio-demographic and physical characteristics. Both authors provided extensive discussion regarding each factor, and the manner in which each influences the prevalence of pedestrian-vehicle collisions.

In terms of the distance of pedestrian accidents from pedestrian crossing areas or junctions, Ward et al. (1994) claimed that a large number of cases of pedestrian accidents occurred away from road crossing facilities; with only a few taking place at these facilities, and with the largest number of pedestrian accidents occurring at traffic signals that have a pedestrian phase, or at pelican crossings. Such findings indicate that pedestrians are most at risk when they decide to cross in places with traffic signals with a pedestrian phase, at pelican crossings, or away from road crossing facilities. The findings in this case are similar to those of the Department for Transport (2004), which indicated that 40% of pedestrian collisions in 2003 occurred when pedestrians crossed the road away from a pedestrian crossing. In contrast, only 9% of collisions occurred on pedestrian crossings, and only 8% of those within 50m of a particular crossing.

With respect to the types of pedestrian crossing, Greenshields et al. (2006) organised the various advantages and disadvantages of different types of crossing: zebra, pelican, toucan, and parallel. The study was not empirical, however, and took a descriptive and narrative angle, providing guidance on (1) the legal instruments covering the different crossing types and (2) the various design standards of pedestrian crossing facilities. A more comprehensive study of mid-block pedestrian crossings in Great Britain was conducted by Hunt (1998), who documented that '80% of pedestrian casualties occurred while pedestrians were crossing the carriageway and, that more than 12% of these pedestrian casualties were at or within 50m of a Pelican or Zebra crossing'. Hunt also outlined the following findings:

- From 1975 to 1985, there had been an increase in the number of pelican crossings and a corresponding increase in the number of pedestrian casualties at, or close to, pelican crossings.

- From 1975 to 1985, there had been a decrease in pedestrian casualties at, or close to, zebra crossings, and there was a decrease in the number of this type of crossing.
- From 1985 to 1995, there was a decrease in pedestrian casualties at both zebra and pelican crossings.
- In terms of zebra crossings, there were fewer accidents within 50 metres of the crossings, although not on the crossings themselves; this was not the case with pelican crossings.
- Between 1990 and 1995, pedestrian casualties at pelican crossings 'decreased at a similar rate to the decrease in pedestrian casualties in built up areas; over the same period the number of pedestrian casualties at Zebra crossings continued to fall more rapidly than those for built up areas – this is unlikely to be explained by a reduced number of Zebra crossings'.

Similarly, the Department of Transport (2004) claimed that, in 2003, more pedestrian collisions were recorded at mid-block signalised crossings in comparison to other types of pedestrian crossing. The study conducted by the AA Foundation (1994) on pedestrian risk indicated that signalised crossings reduce pedestrian accident risk by 50%, compared to crossings that are lacking in such facilities. Moreover, the study conducted by Ghee et al. (1998) found that lack of crossing facilities affected 'older women more than anyone else as they were found to have difficulty understanding and monitoring the sequence of traffic movements and a tendency to monitor nearside and far side traffic independently as they crossed the road'.

Elliot and Broughton (2005) conducted an extensive review that centred on the impact of the methods and levels of policing on road casualty rates and driving violations, such as speeding, ignoring a red light, and being over the limit for alcohol. The authors concluded that the presence of legal enforcement reduced the number of collisions, driving violations, and casualties successfully. Moreover, the authors claimed that the most effective policing methods appeared to be stationary and highly visible in design. In terms of pedestrian enforcement, Martin (2006) claimed that there are no laws preventing pedestrians from crossing the road, and that the only laws being enforced in the UK are those relating to the prohibition of walking on motorways or slip roads and to not loitering on pedestrian crossings. He noted that the guidelines in the Highway Code only specify how to deal with pedestrian behaviour when crossing a road. In an earlier publication, Smeed (1968, cited in Heraty, 1986) concluded that increased police presence had a positive impact on pedestrian and driver behaviour in areas of London that have automatic traffic signals.

Traffic engineering is essentially concerned with examining the characteristics and features attributed to an increase in accidents involving pedestrians and vehicles. Researchers have found that urban areas, specifically arterial roads, tend to be the focus of more pedestrian-vehicle accidents (Mile-Doan and Thompson, 1999). Arterial roads may be responsible for slightly less than half of the occurrences of accidents between pedestrians and vehicles, with other land-use locations being responsible for the majority (Campbell et al., 2004). Land-use characteristics, including mid-block intersecting connections, car parks, garages, and pavements, contribute to the larger portion of pedestrian-motor vehicle accidents (Campbell et al., 2004). In particular, pavements and crossings that lack traffic control lights have higher levels of pedestrian-vehicle accidents than marked crossing areas (Campbell et al., 2004). Zeeger et al. (2002) asserted that areas with high traffic and multi-lane roads have higher rates of pedestrian to vehicle accidents, even with marked crossings. It can therefore be established that there is a strong link between the number of incidents and the volume of traffic flowing through high incident areas (Zeeger et al., 2002). There was also an especially significant increase in higher speed areas with more than two lanes of traffic reported (Zeeger et al., 2002).

2.4 Factors contributing to the severity of the pedestrian injury

The factors that may impact on the severity of injury in cases of pedestrian accidents can be divided into three categories: pedestrian characteristics, driver characteristics and behaviour, and environmental factors. This literature review presents the evidence available from studies describing and evaluating these different factors.

Their inherent characteristics may also hold some importance in determining the likely severity of any accident in which they are involved. There is evidence that the age of a pedestrian may have a significant effect on the severity of injury suffered. In particular, modelling by Lee and Abdel-Aty (2005) indicated that those aged 65 years and over were at highest risk of serious injury, with those aged 15–24 years at least risk. This is supported by findings from Zajac and Ivan (2003) and Sze and Wong (2007), who also found strong evidence to this effect. Kim et al. (2008) suggested that the risk of severe injury also increased significantly as age moved beyond this threshold. Sze and Wong (2007) further confirmed that those aged 15 and under were at reduced risk from severe accident.

Lee and Abdel-Aty (2005) suggested that this may reflect lower levels of health in the older population, which would appear to be supported by other studies that have shown the elderly suffer increased frequency of serious injury in road accidents, as compared to younger people (Yee et al., 2006). This is most likely due to changes in the composition of the bone, which takes place with aging and leads to greater risk of serious fracture (Chan and Duque, 2002). It may also reflect changes in arterial and organ tissue structures, which could place various physical structures in positions of greater fragility during accidents, as well as reducing the likelihood of full recovery (Najjar et al., 2005; Colloca et al., 2010). Lee and Abdel-Aty (2005) suggest that this may reflect the fact that people of different ages cross the road at different speeds, which results in different severities of impact, although there is little evidence in the literature to support the significance of this.

The model constructed by Lee and Abdel-Aty (2005) predicted that pedestrians under the influence of drugs or alcohol were at a greatest risk of severe injury. The authors suggested that this was due to altered behaviour causing impact to be inevitable. This could, however, be suggested as an appropriate explanation for the increased probability of collision, but not severity. This was supported by other authors who found strong evidence of an association between the presence or absence of alcohol in the victim's system and the severity of injury attained (Zajac and Ivan, 2003).

In addition to the behaviour of the pedestrian, the behaviour of the driver and the manner in which the car is travelling is also likely to be significant for determining the severity of impact affecting the pedestrian, and therefore the injuries sustained. Particularly important factors are likely to be the speed at which the vehicle is travelling, the type of vehicle involved in the crash, the behaviour of the driver, and whether the driver was under the influence of alcohol. The heteroscedastic model applied by Kim et al. (2008) indicated that male drivers were associated with the more severe pedestrian injuries. This may be due to males being less likely to observe speed limits than female drivers (Elliott et al., 2003).

The speed at which the car is travelling may be one of the most critical factors in determining the severity of injury to pedestrians. This has been confirmed by a number of different models, including that tested by Lee and Abdel-Aty (2005) and Garder (2004). Zajac and Ivan (2003) found pedestrian speed to be insignificant in their ordered probit model. They only examined accidents on stretches of a two-lane motorway, on which a set range of urbanisation was present, and where pedestrians crossed without the use of a designated crossing area. Therefore, it was possible that vehicles were travelling at relatively uniform speeds, which may make it less obvious if there was an effect relating to vehicle speed.

The type of vehicle involved in the crash is suggested by Lee and Abdel-Aty (2005) to be an important factor in determining the severity of the injuries suffered by pedestrians. This is based on analysis of data taken from the Florida Traffic Crash Records Database, which used an ordered probit model. This is an approach that has been taken by several other authors investigating crash impact factors and the impact of different factors on injury severity. It has been suggested as particularly suitable for this type of analysis, based on the capacity of the model to account for numerous factors simultaneously, without the need to assume equal variances between categories for the ordinal variables (Kockelman and Kweon, 2002; Zajac and Ivan, 2003). Other studies have further supported the importance of this factor in their final models for pedestrian injury severity (Zajac and Ivan, 2003). Therefore, based on the cumulative sample sizes of the various studies and the different geographical locations of study, this would be anticipated to be a factor of global significance.

Ballesteros et al. (2004) initially found that pedestrians hit by sports utility vehicles or pick-up trucks in the US were most likely to die. However, when controlling for weight and speed of the vehicle, they found there to be no significant difference between vehicle types in the risk of fatal injury. This would thus appear to indicate that the weight of the vehicle is more significant than the type of vehicle. It also indicates that risk of severe injury may be largely linked to commonalities in the behaviour of the drivers of certain types of car. Yet, other studies have indeed found that larger vehicles pose a higher risk of severe injury to pedestrians than passenger vehicles when controlling speed (Roudsari et al., 2004).

The initial results reported by Zajac and Ivan (2003) indicated that there may be some evidence of an association between the vehicle operator being under the influence of alcohol and the severity of pedestrian injury. In the final model this was significant only to the 90% confidence level, however, this is weak evidence (Cohen et al., 2003). The heteroscedastic model applied by Kim et al. (2008) is suggested to fit better than logistic models, due to the heteroscedacity introduced by the variable of the pedestrian's age. This model indicates that drink driving is one of the most crucial factors indicating the severity of pedestrian injury, with up to 2.7 times a greater risk of fatality when the driver involved is intoxicated.

Finally, the conditions in which the accident occurs may also be important in determining the severity of any injuries sustained, including characteristics associated with the road, the weather, the level of light, and whether the accident occurs in a rural or urban setting. The width of the road needing to be crossed was suggested by Zajac and Ivan (2003) to be a significant factor in determining accident severity in cases where pedestrians crossed the road without the aid of a designated crossing area. On the basis of their refined model, this was only a significant factor at the 90% confidence level, and not the 95% level; this appeared to be less significant for the model than the type of vehicle, the pedestrian's age, and whether the pedestrian was under the influence of alcohol. This was confirmed by Garder (2004), who found road width to be highly significant, and also potentially associated with the number of lanes in the road, which was demonstrated by Kim et al.'s (2008) heteroscedastic model to be a significant factor.

There is little evidence available thus far that road surface type has a significant impact on the severity of pedestrian injury (Zajac and Ivan, 2003). Environmental conditions, such as the presence of rain, have been shown in some studies to impact on the severity of any accidents suffered by pedestrians (Lee and Abdel-Aty, 2005). Conversely, Zajac and Ivan (2003) did not find weather to be a significant factor in injury severity in incidents where the pedestrian was injured during the crossing of a road in an unmarked area.

Many of the studies of other factors that may impact the severity of accidents have been conducted, predominantly in daylight hours (e.g. King et al., 2009). This may be for a number of reasons, including constraints on the availability of human resources outside of these hours, or the fact that the majority of pedestrian accidents occur during this time (King et al., 2009). This may influence the severity of any accidents that occur, however, as levels of light have been indicated as important factors in determining the severity of injuries suffered by pedestrians in road accidents (Lee and Abdel-Aty, 2005; Kim et al., 2008). This is most likely to be due to the reduced line of sight that drivers may have of a pedestrian in the road in darker conditions, which may then significantly impair their ability to stop in time (Johansson et al., 1963).

It is possible that the location of the accident may have an impact on the severity of injuries suffered by pedestrians. This assumption is based on the results presented by Lee and Abdel-Aty (2005), which show that fewer accidents occur around intersections in rural areas. They suggest that this may be due to drivers approaching these intersections with caution, which can be taken to mean that they drive more slowly and are more vigilant in their approach. This would also suggest that, in the event of an accident occurring, pedestrians would suffer less severe injuries due to the reduced speed of impact.

The results of the Lee and Abdel-Aty's (2005) study, however, demonstrated that injuries could be more severe in rural areas when compared to urban areas. The authors suggest that this may be due to less medical assistance being immediately available. Other papers featuring simpler regression analyses appear to be split, however, with regards to whether survival after road accidents is associated with the length of time taken to receive medical care, or the length of time taken to reach a hospital (Jones and Bentham, 1995; Nicholl et al., 2007). This would indicate an impact on survival, as opposed to influencing the actual severity of the injuries initially sustained during the accident. Another possible explanation for this, as given by the authors, is that road speeds are generally higher in rural areas, which would therefore also indicate that when accidents do occur they may be associated with the greater damage on impact (Lee and Abdel-Aty, 2005). This would appear to be supported by the findings of Sze and Wong (2007), which indicate that areas of congestion, such as those found in urban areas, were reduced with a decreased risk of severe injury. Conversely, areas of the road with higher speed limits and less traffic were found to present greater risk to pedestrians in terms of severe injury. What is more, traffic signage may also contribute to problems(Kim et al., 2008), with the possibly of a greater presence in urban areas.

2.5 Pedestrian behaviour

The behaviour of pedestrians themselves is an important factor in determining their risk of sustaining serious or fatal injury. Two types of adverse pedestrian behaviour can be identified. The first arises when pedestrians cross the road against the lights; that is, crossing when they have not been signaled to do so. The second is when pedestrians cross the road close to, but not within, a designated crossing area. Research by King et al. (2009) in Brisbane, Australia, indicated that there may be up to an eight-times greater exposure to risk of accident when pedestrians cross the road on a red signal, or cross outside of, but near to, a crossing zone. This information was based on measures of relative risk, which are based upon both accident rate and rates of exposure. These results were obtained in spite of the fact that a higher proportion of pedestrian accidents occurred when the pedestrians crossed legally than at any other time. The results of this study did not provide any measure of the effects of these behaviour on the severity of the accident, however.

Other studies have also shown that the act of crossing a road may place the pedestrian at greater risk of severe injury in the first place, than when they are merely walking along the road-way. Kim et al. (2008) also indicated that pedestrians were at increased risk in off-road-way areas. It is not only pedestrian behaviour that can be important, however. Their inherent characteristics may also hold some importance in determining the likely severity of any accident in which they are involved.

Hunt and Griffiths (1991) describe the results of surveys of pedestrian behaviour and delays when crossing the road at random points within a 100m section of road at 45 locations in England and Wales. The primary objective of their study was to develop simple relationships in which pedestrian delay can be evaluated from variables such as pedestrian flow, vehicle flow and speed and road width. The objective of the site surveys was to facilitate the development of a simulation model of pedestrian road crossing behaviour and to define and evaluate pedestrian delay and the range of associated parameters which could provide the input to a simulation model. Their surveys included both two way roads, with and without a central refuge, and one way roads.

Ideally, according to Hunt and Griffiths (1991), surveys of pedestrian behaviour should be carried out at locations which have a range of pedestrian and vehicle activity but are fairly busy sites typical of sites on which pedestrian crossing facilities might be installed. For their study, the initial specification required that the sites should be fairly clear of major junctions, with good sight lines and represent a range of road widths and land use types. However the over-riding requirement was that sites should provide an acceptable level of pedestrian/vehicle interaction. That was compatible with the time and financial resources available for their study.

Pilot studies and discussions with their Local Highway Authorities had indicated that the identification of ideal sites was extremely difficult, probably because few such sites exist. A high pedestrian flow across the carriageway will usually be associated with areas where vehicle flow is low or restricted by traffic control; high vehicle flow will usually be associated with few pedestrian crossing movements at random locations along the carriageway, or alternatively with queues of stationary vehicles. These situations provide very little pedestrian/vehicle interaction data and it was necessary to compromise in the choice of sites. In particular it proved necessary to include more sites located along roads with frequent Pelican crossings and/or junction signals than was originally intended.

During Hunt and Griffiths's study (1991), at each site, data were captured on video, using two cameras with each camera recording activity along part of the section of road being observed. The cameras were, subject to the availability of vantage points, positioned to provide optimum clarity of the observation section. This method of data capture is very expensive and time consuming. However, it can be preferred to direct on site recording as it allows verification of data and avoiding the need for a large number of enumerators to be simultaneously available at each of a number of sites covering a wide geographical spread. Activities, at each of the chosen locations, were recorded for a period of 4 to 5 hours depending on the conditions. For the less busy sites a period of 5 hours data recording was used to ensure that there was an adequate sample of pedestrian/vehicle interaction available. Most of the data were recorded during the period from 9 a.m. to 4 p.m. Peak periods were usually not included because of presence of queuing stationary vehicles and general turbulence in activities which precluded the possibility of recording useful data defining pedestrian/vehicle interaction. Vehicle and pedestrian flow were also recorded manually at each survey site.

Hunt and Griffiths (1991) developed a simulation model, representing pedestrian behaviour using decision matrices and vehicle inter arrival time distributions using a double displaced negative exponential distribution. They used data from the survey and applied the results to analyse and assess pedestrian delay. The simulation model has been calibrated to show good agreement with site recorded data. The simulation model has been applied to generate a database of pedestrian delay corresponding to specified levels of pedestrian and vehicle flow. For each of a range of layouts a simple model of 24 hour pedestrian delay based on five hour counts of pedestrian and vehicle flow has been derived from the database using generalised linear modelling techniques.

There is another group of models and research work employing theories of psychology, which investigate pedestrian behaviour at pedestrian crossings. The model developed by Ajsen (1988 and 1991) illustrated the theory of planned behaviour, a social-psychological model of health and safety behaviour. The predictive utility of the theory of planned behaviour in understanding pedestrians' road crossing decisions was evaluated by Evans and Norman (1998), who found that perceived behavioural control is the strongest predictor of road-crossing intentions, and recommended the influencing of perceptions of control in potentially dangerous road situations. For further reading on the issues of pedestrian behaviour using such models

2.6 Pedestrian Right-Of-Way (ROW)

Knowing and applying a right-of-way for any road user should lead to a better and safer transport system. Giving right of way to pedestrians and motorised drivers or riders can definitely help to prevent injuries and fatalities. To increase the safety on public roads, pedestrians should use marked crossing points to cross the roads, and the drivers of motorised vehicle should yield to the right-of-way of pedestrians and vice versa.

Pedestrian right-of-way violations, or jaywalking, commonly refer to the crossing of a pedestrian from one side of the road to another, in unauthorised areas or in violation of pedestrian laws. For some US jurisdictions that have imposed jaywalking laws, authorised pedestrian crossing can only be made in those parts of the road specially marked as being safe pedestrian walkways. Different jurisdictions treat jaywalking in different ways. North American countries such as the US and Canada have laws that make jaywalking illegal, as does Australia. The UK, however, does not have anti-jaywalking laws, leaving pedestrians to exercise prudence in crossing roads and to take responsibility for their own safety.

Jaywalking laws were first instigated in the early 1900s in the United States, accompanying the rise of the automobile industry. The term 'jaywalking' itself began as a description of pedestrians by automobile drivers in the early twentieth century, as a defensive gesture deriving from the ill-treatment generally received by them from members of the public who considered them a road nuisance; later on, this term evolved to refer to pedestrians who disobeyed road traffic rules. The early 1900s saw the rise of the automobile industry, as automobile ownership shifted from a mere hobby (pursued only by enthusiasts) to widespread personal ownership, as a result of advancing automobile technology. The rapid rise of the industry was accompanied by a parallel rise in pedestrian fatalities, with children constituting most of the statistical fatalities. Public anger towards cars and their drivers characterised the early reception of the industry. In response, local governments had to compose stricter traffic laws, which were at first geared only towards the slowing down of vehicles' drivers. This was underpinned by an initial belief that pedestrians had more rights to the roads than vehicle drivers, because automobiles were not necessities but luxuries. At the urging of particularly pragmatic people, and the automotive industry itself, which stood to lose out if public perception did not change, people were eventually swayed from their belief that they took precedence on the road and that vehicles could not enjoy the same rights as they did.

Pedestrian laws expanded throughout the states, as well as into other countries, such as Australia. Yet, despite progress in the laws and advances in both the automobile industry and road technology, pedestrian deaths persist to this day, albeit in lesser numbers. To streamline traffic laws and reduce traffic-related fatalities, several states in the US have changed their pedestrian laws from giving right of way to pedestrians at crossings, to obligating drivers to stop. In Australia, the authorities have waged a campaign to reduce pedestrian deaths through the launching of programmes designed to solve road deaths, invigorating safety measures at all levels and perspectives.

2.6.1 Defining pedestrian crossing regulations

Traffic rules for the EU were laid out by the Vienna Convention of 1968, with further regulations being added in the interim that more specifically cover the ways in which pedestrians can be protected (ERSO, 2008). While there are some differences, as based on defined national legislation for countries in the EU, pedestrians are generally subject to the rules listed in table 2.1 below (ERSO, 2008a).

Table 2. 1: Pedestrian regulations in the EU

- If, at the side of the carriageway, there are pavements (sidewalks) or suitable verges for pedestrians, pedestrians shall use them. Other precautions include:
    - (a) Pedestrians pushing or carrying bulky objects may use the carriageway if they would severely inconvenience other pedestrians by walking on the pavement (sidewalk) or verge;
    - (b) Groups of pedestrians led by a person in charge or forming a procession may walk on the carriageway.
- If it is not possible to use pavements (sidewalks) or verges, or if none is provided, pedestrians may walk on the carriageway; where there is a cycle track and the density of traffic so permits, they may walk on the cycle track, but shall not obstruct cycle and moped traffic in doing so.
- Pedestrians walking on the carriageway shall keep as close as possible to the edge of the carriageway.
- It is recommended that domestic legislation should provide as follows: pedestrians walking on the carriageway shall keep to the side opposite to that appropriate to the direction of traffic except where to do so places them in danger. However, persons pushing a cycle, a moped or a motorcycle, and groups of pedestrians led by a person in charge or forming a procession shall in all cases keep to the side of the carriageway appropriate to the direction of traffic. Unless they form a procession, pedestrians walking on the carriageway shall, by night or when visibility is poor and, by day, if the density of vehicular traffic so requires, walk in single file wherever possible.
- Pedestrians wishing to cross a carriageway:
    - (a) Shall not step on to it without exercising care; they shall use a pedestrian crossing whenever there is one nearby.
    - (b) In order to cross the carriageway at a pedestrian crossing signposted as such or indicated by markings on the carriageway:
        - (i) If the crossing is equipped with light signals for pedestrians, the latter shall obey the instructions given by such lights;
        - (ii) If the crossing is not equipped with such lights, but vehicular traffic is regulated by traffic light signals or by an authorized official, pedestrians shall not step onto the carriageway while the traffic light signal or the signal given by the authorized official indicates that vehicles may proceed along it;
        - (iii) At other pedestrian crossings, pedestrians shall not step on to the carriageway without taking the distance and speed of approaching vehicles into account.

(c) In order to cross the carriageway elsewhere than at a pedestrian crossing signposted as such or indicated by markings on the carriageway, pedestrians shall not step on to the carriageway without first making sure that they can do so without impeding vehicular traffic.
(d) Once they have started to cross a carriageway, pedestrians shall not take an unnecessarily long route, and shall not linger or stop on the carriageway unnecessarily.

Source: UNECE 1993.

According to the above definition of responsibilities, pedestrians must use pedestrian crossing facilities when they cross roads and obey the instructions at each facility. Furthermore, pedestrians may cross the carriageway elsewhere, but should then exercise care and take the distance and speed of any approaching vehicle into account. In the UK, pedestrian regulations and rules are explained in the Highway Code. In general, the definition of a pedestrian crossing regulation is the same as that established in the Vienna Convention of 1968. Therefore, pedestrians are advised to cross the road wherever there are pedestrian crossing facilities, and if there are no facilities they should only cross with great care.

2.6.2 Jaywalking laws in the US

The majority of states in the US have adopted the Uniform Vehicle Code, which is a set of rules and regulations concerning traffic. The code was prepared by a private non-profit organisation called the National Committee on Uniform Traffic Laws and Ordinance, and includes rules regarding pedestrian conduct while crossing roadways and crosswalks, among others. In California, jaywalking laws began to take shape in the 1920s, as a means of responding to the chaos brought about by the gradual congestion of cities and the rise of the automobile industry. Government efforts were widely supported by the automobile industry in particular the popularisation of the term 'jaywalker', through campaigns aimed at shaming heedless pedestrians who were endangering their lives and causing traffic jams (Ladd, 2008, 74).

Jaywalking laws also brought in revenue for California, in the form of several million dollars in jaywalking fines imposed upon violators (Silverstein, 1996, 105). California's anti-jaywalking law can be found in the California Vehicle Code (CVC). The CVC jaywalking law states that pedestrians must lawfully cross at intersections controlled by traffic signals or by police officers, and on crossings marked by lines or other forms of markings on the road's surface. CVC §21456 governs a 'walk, wait, or don't walk' policy to control intersections or roads, whilst CVC §21955 relates to the prohibition of crossing road-ways between intersections that are not considered to be crossings. There are three elements to the latter provision: the area must be between two intersections, the area must not be marked as a crossing, and the intersections flanking the road-way where the pedestrian is crossing must be controlled by traffic signals or police officers (Brown, 2009, 90).

In the state of New York, jaywalking was declared unlawful in 1958, and as many as 5,000 tickets were handed out to violators in the six weeks following its implementation. This eventually reduced to 100 tickets per year by the 1990s, but stricter implementation was revived thereafter with increasing fines (Silverstein, 1996, 105). In Florida, a pedestrian may cross mid-block or outside the area of a crosswalk only if the nearest intersection is unsignalled, but that pedestrian must yield to an approaching vehicle. If a pedestrian crosses at a crossing, drivers are obliged to yield to the pedestrian. Florida's jaywalking laws are contained in the Florida Uniform Traffic Control Law of Chapter 316 of the Florida Statutes, although the term jaywalking is not specifically used in this particular traffic code (Florida Pedestrian Law Enforcement Guide).

In the state of Idaho, jaywalking laws are contained in Title 49, Chapter 7 of the Idaho Code. Aside from setting out provisions for the right of way of pedestrians on crossings, the code also directs them to cross motorways at right angles to the curb, or to take the shortest route across to the curb, unless otherwise directed by traffic signals or the crossings themselves. Moreover, pedestrians are directed to use the right side of the crossing when crossing the street, and under no circumstances are they allowed to cross motorway intersections diagonally unless so authorised by traffic-control devices. Other lawful methods of pedestrian crossing on motorways include yielding the right of way to vehicles when crossing at points where there are no crossings, and where there are overhead pedestrian crossings or tunnels provided. Furthermore, when between two intersections run by traffic-control devices, pedestrians must cross only on crossings (Pedestrian-Related Idaho Code, Title 49, Chapter 7, 2008).

2.6.2.1 Present-day statistics on US pedestrian fatalities

Today, despite the success of anti-jaywalking campaigns, and the dissuading of the public regarding their former attitude towards pedestrian rights to one involving using of road-ways, pedestrian deaths still constitute 14% to 17% of all traffic fatalities since 1979. In 1991 alone, 5,797 pedestrians were killed in traffic accidents. This compelled the federal governments to prioritise pedestrian safety in their highway safety programmes. Some of the notable statistics on pedestrian fatalities in 1991, which could prove useful to studies on the matter, include the following: most pedestrian victims were male at 70%, most fatalities occurred on weekend nights at 60% (constituting double the number of weekday fatalities), 70% of fatalities occurred in urban areas, 82% happened in non-intersection areas, most fatalities were in the age bracket 65 and above, and children constituted 28% of overall fatalities (Law Enforcement Pedestrian Safety 4, 9–10).

The report from the Department of Transportation in April 2003 for the period between 1975 and 2000 claimed that almost 175,000 pedestrians died in vehicle accidents, with 162,000 killed in single-vehicle crashes. This report shares similarities with the preceding 1991 report, in that the majority of the fatalities occurred in urban areas, at non-intersection road-ways or at those without crossings, and at night-time. The report additionally indicated that the only action taken by pedestrians at the time of the accident was crossing the road. Ranking the fatalities according to state, New Mexico ranked the highest, with Arizona closely behind. However, many of the cities with the top fatality figures were found in Florida. An examination of the table for fatalities from 1991 to 2001 showed that fatalities averaged close to 5,000 a year, from a high of 5,801 in 1991, and a low of 4,763 in 2000. A look at the table provided by the report (see Table 2.2), which illustrates fatalities according to location; divided into intersection location and non-intersection location, showed that in all four years, from 1998 to 2001 inclusive, pedestrian deaths occurred more often in non-intersection areas than in intersection areas, with an average of at least a 3:1 ratio. At intersection locations, most of the accidents happened on crossings, whereas in non-intersection areas, the opposite was true. Accidents that took place on crossings in non-intersection areas were relatively insignificant, as compared to those that occurred on roads where crossings were not available (US Department of Transportation, 2003, 1–2, 13).

Table 2. 2: Pedestrian fatalities in single-vehicle crashes, 1998–2001

Pedestrian Location	1998	1999	2000	2001
Total Intersection Location	**1,069**	**938**	**989**	**940**
In Crosswalk	354	365	378	380
On Roadway, Not in Crosswalk	209	165	175	179
On Roadway, Crosswalk not Available	180	146	147	122
On Roadway, Crosswalk Availability Unknown	281	230	253	223
Not on Roadway	26	21	20	18
Unknown	19	11	16	18
Total Non-Intersection Location	**3,713**	**3,556**	**3,330**	**3,474**
In Crosswalk	41	36	43	38
On Roadway, Not in Crosswalk	539	484	516	601
On Roadway, Crosswalk not Available	2,032	1,924	1,736	1,834
On Roadway, Crosswalk Availability Unknown	697	663	617	591
In Parking Lane	11	9	10	6
On Road Shoulder	202	267	195	207
Bike Path	2	1	0	0
Outside Traffic-way	42	38	42	36
Other, Not on Roadway	130	115	149	144
Unknown	17	19	22	17
Unknown Location	**19**	**22**	**21**	**47**
Total	4,801	4,516	4,340	4,461
Source: NCSA, NHTSA, FARS 1998-2001				

Several states have changed their traffic laws over time; varying from having drivers yield to pedestrian rights of way on crossings, to having them stop entirely when they approach them. These states are Nebraska in 1979, Maryland in 1982, Washington in 1990, Georgia in 1995, Minnesota in 1996, Oregon in 2003, and Hawaii and the District of Columbia in 2005. Four of these states (Washington, Georgia, Minnesota and Oregon) were made the subject of a study by researchers, who were investigating whether the changes had an effect on pedestrian safety. Using analyses based on studies in a before and after, time-series, and of a cross-sectional nature, the study surmised that there was no conclusive evidence to show that the changes had effectively lessened pedestrian fatalities. The marked decrease in incidences was attributable to a general decreasing trend, which researchers ascribed to reduced walking activity (Kweon, Hartman, and Lynn, 2009, 1034–1039).

2.6.3 Jaywalking laws in Australia

In Australia, jaywalking is unlawful and drivers are required not only to yield to the right of way for pedestrians at crossings, but also to stop for them. Australian laws further state that pedestrians are to cross only on marked crossings if they are within 20m of them, and may only start to walk on a traffic-controlled ‘walk’ signal at intersections, finishing on a flashing ‘don’t walk’ signal, but must not, under any circumstances, start walking during a ‘don’t walk’ signals. Studies have shown that many Australian pedestrians are confused by traffic signals at intersections, especially the flashing ‘don’t walk’ signal, which they have often cited as a signal for them to hurry up. Some pedestrian confusion is also credited to the rights of way of left- and right-turning vehicles, pedestrian refuges, and zebra crossing procedures (Hatfield et al., 2006, 834).

2.6.3.1 Pedestrian accident statistics in Australia

In New South Wales, Australia, 70% of pedestrian fatalities in 2004 happened while crossing a road, mostly on unmarked crossings, although a significant number, concentrating mostly on the elderly also happened on crossings (Hatfield et al., 2006, 833). The *Sunday Mail’s* online news cited Adelaide’s fine for jaywalking to be $40 in 2009, which the Pedestrian Council were lobbying to increase this to curb pedestrian violations and to ensure safety in the streets (Castelo, 2009). In Melbourne, the capital of Victoria, the *Herald Sun*’s website reported a pedestrian blitz in 2007 by police, whereby fines of $55 were meted out against erring pedestrians (Hastie, 2007).

Economic costs as result of road crashes in Australia were estimated at $18 billion annually by the Australian Transport Safety Bureau in 2005. In 2000, the Australian Transport Council of Ministers adopted and endorsed The National Road Safety Strategy 2001–10 (NRSS), which provided the foundation for the commonwealth’s road safety strategy over the next decade. Its main objective was to reduce road deaths by 40%, or to take these below 5.6% for every 100,000 members of the population by 2010, through safer traffic strategies. Although the target was not met, there was a significant reduction in road deaths at 24.4%, or 7% of deaths per 100,000 members of the population, on the basis of the 1999 statistics. This tallied with the overall observation that countries that set lower pedestrian death targets have lower pedestrian death rates. The sector that benefited most from the NRSS programme was pedestrians, where a 27% reduction in deaths was seen by 2007. The lessons learned from the 2001–10 NRSS, as far as pedestrians are concerned, are: the significance of the factor of speed management in reducing pedestrian deaths. Alcohol intoxication occurred in four out of ten cases where pedestrians were killed, and one in every four pedestrian deaths happened in urban areas (ATC, 2008, 7–8, 48).

2.7 Pedestrian crossing facilities in the UK

In agreement with other countries in the EU, the UK outlined its own approach to improving pedestrian crossing facilities, in order to ensure better pedestrian visibility and to provide them with more safety from moving vehicles (ERSO, 2009). The UK currently has five types of formal pedestrian crossing: zebra, pelican, puffin, toucan, and Pegasus (driveandstayalive.com, 2003).

As figure 2.1 shown below, zebra crossings are indicated by black and white stripes across the road, with flashing amber beacons on either side that state drivers must give way to pedestrians (driveandstayalive.com, 2003).

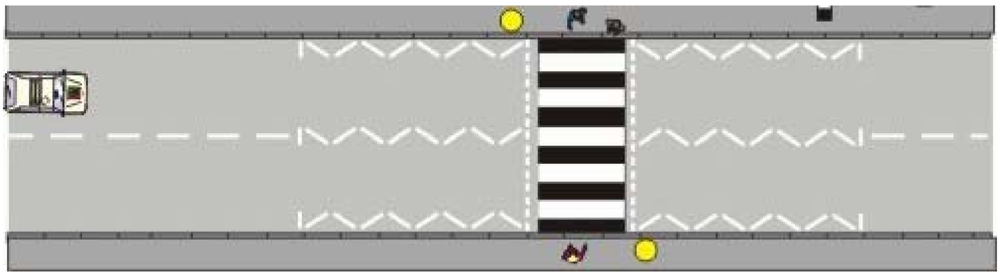

Figure 2. 1: Zebra crossings (source: driveandstayalive.com, 2003)

PELICAN (**Pe**destrian **Li**ght **Con**trolled) crossings have red, amber, and green signals that face drivers. They are triggered by a pedestrian pushing a button, which then alerts the drivers to stop (driveandstayalive.com, 2003). The Highway Code states that, when the steady red signal to traffic lights up, drivers must stop (driveandstayalive.com, 2003).

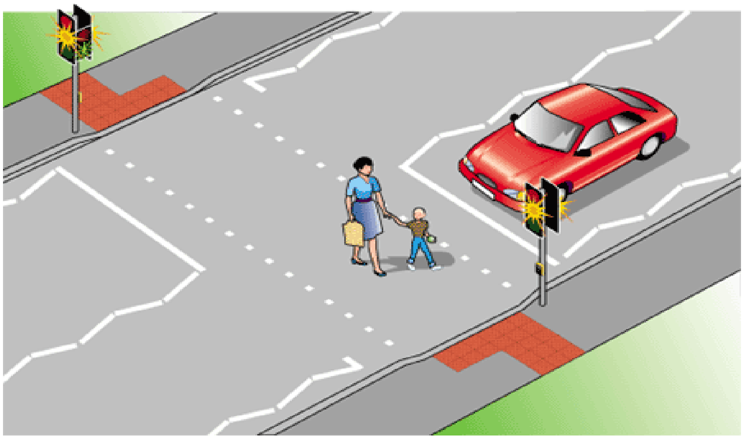

Figure 2. 2: Pelican crossing facility (source: Highway Code)

PUFFIN (**P**edestrian **U**ser-**F**riendly **In**telligent) crossings do not have a flashing green man or amber signal, but are instead controlled by on-crossing pedestrian detectors, which are triggered by a push-button unit combined with kerbside pedestrian detectors (driveandstayalive.com, 2003). As one study noted, 'this layout encourages pedestrians waiting at the crossing to look at the approaching traffic at the same time as looking at the red man/green man signal', which has caused many people to request that these replace the zebra-type crossings (driveandstayalive.com, 2003).

TOUCAN crossings have been developed for use by both pedestrians and cyclists, and are typically used adjacent to cycle-paths, which have a green cycle or a green man symbol, and have established on-crossing detectors, like the PUFFIN (driveandstayalive.com, 2003).

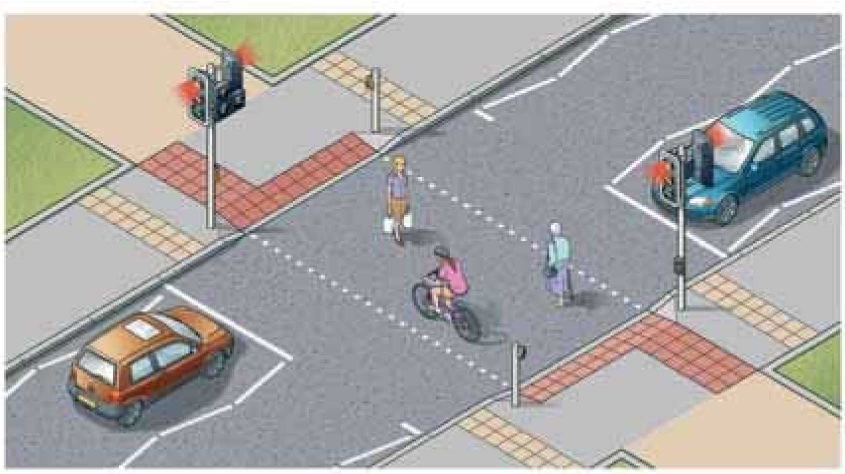

Figure 2. 3: Puffin crossing facility (source: Highway Code)

PEGASUS crossings are similar to TOUCAN crossings, but are used to allow horse riders to cross certain busy main roads (driveandstayalive.com, 2003).

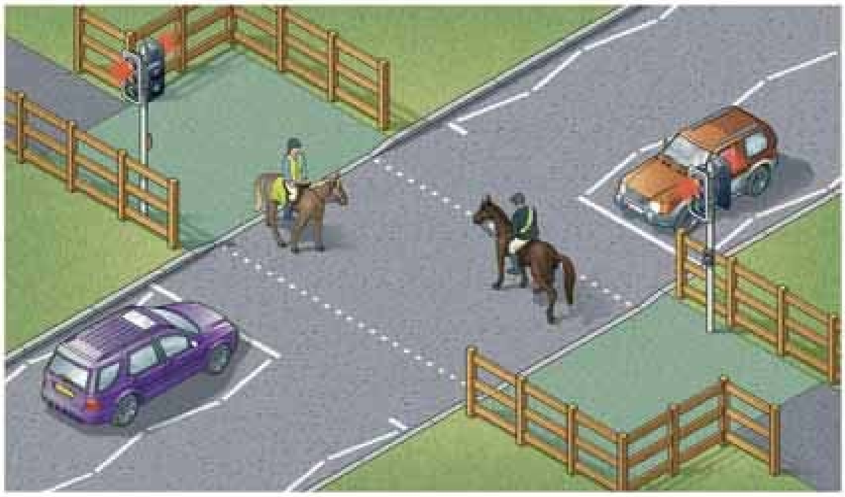

Figure 2. 4: Pegasus crossing facility (sources: Highway Code)

2.8 Modelling approaches for pedestrian accidents

This section provides a review of literature that examines accident risk exposure for pedestrians, pedestrian-vehicle collisions, and pedestrian severity of injury and contributing factors. It will review the studies of multivariate analyses that have utilised different econometric modelling techniques, in order to identify the determinants of injury severity. There also exists another type of study (e.g. Atkins et al., 1988), which adopted descriptive analyses as a means of aggregating crashes according to injury severity levels, and compared human, vehicle, weather, and environmental factors across the different injury severity categories; these are not reported in this section.

The review commences with the discrete-choice model that has been typically used to model accident severity. These multivariate studies are organised according to different road users (i.e. pedestrian, automobile, and motorcyclist or cyclist), within each section containing a certain type of model. This is followed by a review of studies that have developed different econometric structures (i.e. the extensions to the traditional discrete-choice models) for injury severity analysis. Non-parametric models that have occasionally been applied are also reviewed. A commentary on these models is provided to conclude.

2.8.1 Discrete-choice model

Multivariate studies of automobile accidents, or of injury severity, have employed different statistical modelling approaches, including the logistic regression model, the ordered response model (i.e. OP/OL: ordered probit/logit), and the unordered response model (i.e. the MNL: the multinomial logit model and nested logit model). There exist some other studies that have developed different econometric structures in order to overcome the limitations imposed by the typical discrete-choice model. A review of previous studies that have utilised these modelling techniques is provided below.

2.8.1.1 Logistic regression model

Among the multivariate modelling techniques, logistic regression has been commonly used when the representation of injury severity is in a binary form (such as fatal versus non-fatal, or injury versus non-injury). Examples of studies applying the logistic model to examine accident or injury severity in car to car accidents, or single-vehicle accidents, include the work by Jones and Whitfield (1988), Liu et al. (1988), Farmer et al. (1996), Hill and Boyle (2006), and Obeng (2007). These researchers estimated the logistic regression models to model the probability of a particular accident or injury severity level (e.g. fatal injury, or another severe characterisation of injury), conditioned on the occurrence of an accident and using variables of interest such as driver age, gender, vehicle mass, restraint system use, and point of impact.

Most former research on pedestrian accidents has been orientated towards the investigation of accident severity. When considering statistical models of injury severity in motor vehicle crashes, the models that are most often used are conditional on a crash having occurred. Such models hypothesise a function of observability (e.g. from police record) and unobservability (e.g. a person's characteristics) that affect the probability of a particular injury severity category.

For studies analysing accident or injury severities in cyclist- or pedestrian-car accidents, the logistic regression model has also been frequently estimated when injury severity levels are recorded in binary form (see, for example, Miles-Doan, 1996; Ballesteros et al., 2004; Henary et al., 2005; Roudsari et al., 2004, 2006; Sze and Wong, 2007). Generally, these researchers were attempting to model the probability of fatalities or severe injury, using a number of variables, such as junction control measures, the pre-crash movement of the car, age/gender of cyclist/pedestrian, and vehicle type. Alcohol-related pedestrian-vehicle crashes have not been as widely investigated as alcohol-related vehicle crashes (Joon-Ki Kim et al., 2008). The influences of other factors have been studied, such as traffic signal spacing (Shankar et al., 2003), crossings (Zeeger et al., 1996), intersections (Koepsell et al., 2002; Lee and Abdel-Aty, 2005) and pavements (McMahon et al., 2002) among others.

Pedestrian-vehicle crash research continues to progress; however, to date, these investigations have been limited in some way. For example, investigations into rights – of- way (ROW) for pedestrians and the subsequent impacts on pedestrian accidents, especially in the UK, have not been widely considered.

A univariate examination of accident severity for other types of road users (e.g. vehicle to vehicle, including motorbikes, has been reported (see, for example, Watson et al., 1980; Ouellet and Kasantikul, 2006). Compared to the multivariate studies of automobile accidents or of injury severity, relatively few studies have been conducted in the field of pedestrian safety using a true multivariate examination of the determinants of accident or injury severity (i.e. controlling all affecting factors). These studies include Gabella et al. (1995), Peek-Asa and Kraus (1996b), Lin et al. (2003), Keng (2005), Chang and Yeh (2006), and Zambon and Hasselberg (2006). They model the probability of fatalities, severe injuries, or severe head injuries using a wide range of factors, such as rider age/gender, helmet use, weather condition, and engine size.

2.8.1.2 The ordered response model

Since injury severity levels are typically progressive (ranging from no injury to fatality), ordered response models have come into relatively widespread use as a framework for analysing such responses. Researchers such as O'Donnell and Connor (1996), Duncan et al. (1998), Renski et al. (1999), Khattak (2001), Kockelman and Kweon (2002), Khattak and Rocha (2004), Yamamoto and Shankar (2004), Deng et al. (2006), Eluru and Bhat (2007), Rafaat and Chin (2007), Khattak and Fan (2008), and Nayens et al. (in press) are representative of the many that have applied this technique. These researchers assessed the probabilities of the entire range of injury severity levels as a function for a set of independent variables, using the ordered logit/probit specifications.

For cyclist- and pedestrian-car accidents, the ordered response model has been developed by several researchers (e.g. Klop and Khattak, 1999; Zajac and Ivan, 2003; Lee and Abdel-Aty, 2005; Siddiqui et al., 2006), in order to understand the effects of various factors on cyclist and pedestrian injury severity. A mixed generalised ordered response model for examining pedestrian and cyclist injury severity levels in traffic crashes has also been developed by Eluru et al. (2008). Other works include the application of the ordered probit model by Quddus et al. (2002) and Pai and Saleh (2007a, b; 2008), as a means of analysing motorcyclist injury severity.

2.8.1.3 The multinomial/nested logit model

The multinomial/nested logit models disregard the ordered nature of injury severity levels and treat them as an independent alternative. The MNL model suffers from the well-known independence of irrelevant alternative (IIA) assumptions (Ben-Akiva and Lerman, 1985). A thorough review of the IIA, which is the key assumption of the MNL model, is provided by Borooah (2001). Compared to the ordered response models, the multinomial/nested logit models require further estimation of parameters (in the case of three or more alternatives) (Kockelman and Kweon, 2002). However, they do avoid certain restrictions posed by the ordered response model, offering a more flexible and functional format, by providing consistent parameter estimates in the presence of the likely under-reporting of accident data not involving injury (see the work of Yamamoto et al. in press for a thorough discussion of the under-reporting effects that may not be captured by the ordered response model). In addition, the MNL model specifications relax the parameter restriction imposed by the ordered response model, which does not allow for a variable to simultaneously increase, or decrease, with high or low injury severities. That is, they allow the independent variables to have opposing effects regardless of injury order. This class of models still has a place in accident or injury severity analysis, therefore, it has been estimated by a number of researchers with considerable success. The monotonic effect of variables imposed by the ordered response model was methodically discussed in several studies (see, for example, Long, 1997; Washington et al., 2003; Eluru and Bhat, in press).

Past studies analysing accidents involving cars, motorcycles, or cyclists and pedestrians have shown the potential for the multinomial/nested logit specifications through use of environmental, geometric, weather, vehicle, and human factors, in order to develop predictive models of accident or injury severity. Examples of automobile severity studies include the work of Shankar et al. (1996), Chang and Mannering (1999), Lee and Mannering (2002), Ulfarsson and Mannering (2004), Abdel-Aty and Abdelwahab (2004a), and Holdridge et al. (2005).

For cyclist- and pedestrian-injury severity studies, the only work to have employed the unordered response model was that undertaken by Kim et al. (2007). They estimated the multinomial logit formulation of cyclist injury severity, considering cyclist or motorist characteristics, and vehicle, road-way, and environmental factors. Examples of motorcycle severity studies include the work of Shankar and Mannering (1996) and Savolainen and Mannering (2007b), in which the multinomial/nested logit models were estimated to understand the impact of helmet use, alcohol-impaired riding, and other factors on motorcycle accident severity, for single-motorcycle and multi-vehicle crashes.

2.8.1.4 Extensions to the discrete-choice models

Extensions to the OP/OL model specifications include the ordered mixed logit model (Srinivasan, 2002), the heteroscedastic ordered probit/logit model (Wang and Kockelman, 2005), and the mixed generalised ordered response model (Eluru et al., in press). These researchers developed different econometric structures for injury severity analysis at the level of individual accidents, which recognise the ordinal nature of the categories. These models also allow for flexibility in capturing the effects of the independent variables on each ordinal injury severity category, and can capture unobserved heterogeneity in thresholds across individual parties. The applications of the mixed logit models have also focused on unordered choice contexts (e.g. McFadden and Train, 2000; Milton et al., 2008) to overcome the IIA limitations of the MNL model.

Other researchers (e.g. Jones and Jørgensen, 2003; Huang et al., 2008) have argued that, since most modelling techniques, such as the logistic and MNL models, assume independence across subjects, they may not be adequate in terms of modelling individual injury severity in the presence of potential correlations between those involved in the same multi-vehicle crashes. Thus, correlation between samples may exist in a situation where, for example, the risk of fatality is dependent on the characteristics of the other vehicles. They pointed out that the models that did not consider the covariance between individuals in the same crashes, especially when the covariance is significant, would result in inaccurate or biased estimates of factor effects. Snijders and Bosker (2002) developed the hierarchical binomial logistic (HBL) model that allows hierarchical data structures to be easily specified and estimated. In traffic accident research, the HBL model has been applied to account for the hierarchical data structure in road crash frequency (e.g. Kim et al., 2007) and severity studies (e.g. Jones and Jorgensen, 2003; Lenguerrand et al., 2006).

2.8.2 Non-parametric models

Several researchers (e.g. Sohn and Shin, 2001; Sohn and Lee, 2003; Chang and Wang, 2006) have argued that most regression models have their own model assumptions and pre-defined underlying relationships between the target (dependent) variable and the predictors (independent variables). If the model assumptions are violated, the model could lead to erroneous estimations of the likelihood of injury severity. Artificial neural networks (ANNs) (Abdelwahab and Abdel-Aty, 2001 and '03; Abdel-Aty and Abdelwahab, 2004c; Delen et al., 2006) and classification and regression tree (CART) models are non-parametric; these do not reveal any pre-defined underlying relationships between the dependent and independent variables.

ANN models were specifically developed (Abdelwahab and Abdel-Aty, 2001 and '03; Abdel-Aty and Abdelwahab, 2004c; Delen et al., 2006) as a means of modelling the relationship between motorist injury severity and a variety of factors. In studies by Abdel-Aty et al., the prediction performance of ANNs was compared with ordered and unordered response models. Their results showed that, in general, ANN models had a slightly more accurate predictive capability over the ordered and unordered response models. As for predicting individual severity category, ANN models performed better than the traditional statistical models with regard to the more severe injury severity levels (i.e. fatal or severe injury), but the accuracy was still relatively low.

The studies by Sohn et al. (Sohn and Shin, 2001; Sohn and Lee, 2003) applied CART, ANN, and the logistic regression models to analyse motorist injury severity. The prediction performances (i.e. classification accuracy) of these three approaches were compared, with no significant differences found. The prediction performance of CART was examined by Chang and Wang (2006), who reported that, while the CART model performed well for the injury category with the largest percentage of subjects (i.e. no injury or slight injury), the model was unable to predict the less frequent injury category in general (i.e. fatality).

Although non-parametric models can provide a more accurate prediction capability over the traditional discrete-choice models, they have their disadvantages, as discussed by Harrel (2001). In the first instance, developing a non-parametric analysis can be very time consuming. For example, the time that is required to develop an ANN model depends on the size of training data and network structure; there is no general rule for determining the network structure, which can only be achieved through experimentation. Secondly, developing a CART model can be very costly. There is a lack of appropriate and commercially available software that can be used for this type of analysis. For example, the free software for CART analysis, such as Salford systems, is only workable over a short period of time. A further disadvantage of the non-parametric model is the difficulty encountered when conducting elasticity analysis, which provides valuable information as to the marginal effects of the explanatory variables on injury severity likelihood. The final drawback of non-parametric models is that they do not provide a probability level or confidence interval for risk factors and predictions.

2.9 Summary of literature review and research gaps

This chapter evaluated the available literature related to pedestrian-vehicle collisions, pedestrian severity of injury, Pedestrian behaviour, pedestrian right-of-way (ROW), and modelling approaches. Table 2.3 shows a summary of the range of measures used to represent exposure factors. There is a dearth in the literature that provides a single and precise definition of pedestrian exposure; most of the authors whose works were included in this review account for the lack of a collective and widely accepted definition to the abstract nature of the concept of pedestrian exposure. Despite the availability of a substantial body of literature on proxy or indicator measures of pedestrian exposure, there appears to be a *gap* in the knowledge in terms of the validity and reliability of such measures. There is also a lack of empirical evidence to support the soundness and accuracy of the indicator measures already formulated and established in previous research. Moreover, there is a need to expand the established measures to include new developments.

Table 2.3 below presents a summary of the measures that used in many literaturesto represent exposure factors.

Table 2. 3: A summary of the range of measures used to represent exposure factors

Exposure	Factors
1- vehicle	Distance travelled Duration Traffic volume
2- pedestrian	Number of residents in given areas or number of people in a specific demographic group Pedestrian volume Number of walking trips Crossing distance Time spent walking

In fact, the information regarding exposure measures that take into consideration the density of pedestrians who pass in pedestrian crossing areas (i.e. pelican or zebra crossings), and the volume of the vehicles that pass along the same area, is generally insufficient.

Thus, the current research has attempted to investigate and research into identifying factors or indicator measures of pedestrian exposure in order to fill current knowledge gaps on pedestrian exposure to accident risk.

The second section reviewed the literature available in relation to pedestrian-vehicle collisions and indicated that occurrences are influenced by a diverse range of factors (Campbell et al., 2004; Sideris, 2006). Moreover, few empirical studies have documented the effects of the distance of pedestrian accidents from pedestrian crossing areas or junctions (Ward et al., 1994; Department for Transport, 2004), wherein both findings suggested that the further the distance from road crossing facilities, the higher the likelihood of pedestrian accident. *Therefore, there is a research gap in terms of the investigations of the impact of the distance from road crossing facilities on accidents rates and severities. This research therefore, investigates the impact of the distance from road crossing facilities on pedestrian accidents.*

With respect to the influence of the types of pedestrian crossing on the incidences of pedestrian accident, a substantial body of the literature stated that the types of pedestrian crossing incidents indeed affected the frequency of collisions. Additionally, the studies all indicated the positive impact of signalised crossings on the reduction of pedestrian collision risk. *In this research, signalised pedestrian crossings (this includes junctions and pelicans and similar) have been investigated in more details to shed more light on the impact of pedestrian crossing type on accidents rates and severities.*

Furthermore, in terms of the enforcement of traffic laws, most authors agreed on the effectiveness of enforcing regulatory instruments for the reduction of the rates of collisions, casualties, and driving violations. Jaywalking laws had an inauspicious beginning; due to the belief that they represented interference to basic civil liberties and that automobile presence on the roads was an encroachment of that right. Pedestrian deaths, however, especially those of children, paved the way for a change of perspective, and jaywalking laws were eventually implemented in several countries, particularly in the US and in other jurisdictions such as Australia. Most jaywalking-related laws in these jurisdictions consist of rules and regulations regarding the manner in which pedestrians conduct themselves whilst crossing and walking on roads and motorways. The common provision in jaywalking laws is the limitation of pedestrians to designated crossings, as indicated by markings or zebra lines on the road's surface. In the US, crossings are located between two intersections controlled by traffic signal devices, or police personnel, whilst intersections themselves have traffic devices that indicate to pedestrians when to cross or when to wait. In Australia, similar provisions exist, giving pedestrians right of way when crossing at designated points. The latter jurisdiction obligates pedestrians to cross only those crossings that are flanked by controlled intersections, when available within 20m, from the location of the pedestrian.

The UK, for its part, has remained indifferent to the implementation of such laws in its jurisdiction, which is distressing in consideration of the fact that studies have shown Great Britain to have one of the worst pedestrian fatality records in Europe, according to a 2005 study. *The definition and regulations regarding the pedestrian right-of-way is severely under-researched in the UK. This study attempted to provide a definition of pedestrian right-of-way in the UK. Further investigation in this research investigated impact of right-of-way on pedestrians' accident rates.*

This chapter has reviewed the literature describing the modelling techniques that were adopted to analyse risk factors that influence injury severity. The modelling approaches that have been used include the discrete-choice and non-parametric models. The limitations and advantages of these models were discussed; it was found that the choice between the ordered response model and the unordered response model was likely to depend on the individual's preference. Although the prediction capability of the non-parametric models may be more accurate than that of the tradition discrete-choice models, those too, have their drawbacks.

Through reviewing the literature, several general observations regarding the selection of appropriate statistical techniques could be made. Firstly, injury severity research is seeing a movement toward multivariate analysis and is moving away from the descriptive or univariate/bivariate analysis, which was adopted in studies in the more distant past. Descriptive or univariate analysis was commonly employed in previous pedestrian-safety studies that have focused on the effectiveness of crossing facilities in reducing numbers of pedestrian fatalities. Secondly, among the multivariate modelling approaches, three preferred approaches have emerged in the statistical modelling of accident or injury severity data: the logistic regression model, the ordered response model (i.e. OP/OL: ordered probit/logit), and the unordered response model (i.e. the MNL or nested logit model). The logistic regression model has been extensively used when injury severity levels can be described in a binary form (e.g. fatal injury v. non-fatal injury, KSI v. no KSI, or injury v. non-injury). When the injury severity representation is recorded according to multiple categories (such as no injury, possible injury, non-incapacitating injury, incapacitating injury, and fatal injury), ordered or unordered response models have been widely based on estimate. In the literature, the choice between the ordered response model and the unordered response model was likely to be dependent on one individual's preference.

Finally, more recent studies formulated non-parametric models as a means of identifying whether non-parametric models had more accurate prediction capability over the traditional discrete-choice models. Chang and Wang (2006) and Abdel-Aty and Abdelwahab (2004c) suggested that the CART and ANN models offered a good alternative for analysing injury severity in traffic accidents, whilst Sohn et al. (Sohn and Shin, 2001; Sohn and Lee, 2003) noted that there was no significant difference in the prediction performance of CART, ANN, and logistic regression models. However, one of the research *gaps* here is that there are very few if any, studies which carried out analysis and comparisons of various modelling approaches in the analysis and investigations of pedestrian accidents at pedestrian crossings. In this research therefore, an analysis of pedestrian accident rates and severities is carried out using four models; Binary Logit (BL), Multinomial (MNL), Ordinary Logit (OL) and Ordinary Probit (OP) models. The aim here has been to test data suitability and assessment of the four models.

Chapter 3

Methodology

3.1 Introduction

The methodology chapter will cover those methods that are used to achieve the aims and objectives of the current research. The primary aim of this research is to investigate pedestrian accidents and severity at pedestrian crossing facilities or within 50 metres of such facilities. The majority of the information in this research has been taken from the accident injury database STATS19 data that includes all needed information about pedestrian accidents. The proposed methodological approach, intended to achieve this aim consists of the following steps:

1- Investigate pedestrian accident data from STATS19.
2- Identify contributing factors from STATS19 that have led to pedestrian accidents at pedestrian crossing lines or within 50 metres of the same.
3- Identify the exact location of pedestrian crossing facility.
4- Identify a number of sites at which to carry out an investigation into the frequency and severity of pedestrian accidents on pedestrian crossing areas or within 50 metres the same.
5- Investigate right-of-way violations associated with pedestrian accidents at pedestrian crossing areas or within 50 metres.

Methods that are used in this research will be discussed in following subsections

3.2 Description of data used in this research

3.2.1 STATS19 DATA

3.2.1.1 General characteristics of STATS19

STATS19 data is primary data source that provides information on accidents involving serious injury that occur on the public highway in the Great Britain (McGrath and Tranter, 2008). Four conditions can be used to report accidents into STATS19: Road accidents involving death or personal injury; accidents that occur on highways; accidents of which the police are informed within 30 days; and accidents involving at least one or more vehicle. STATS19 provides details of personal injury accidents as reported by police, and consist of three files which are:

1) Accident record files, which contain general information regarding the accident itself, for example, date and time of accident, day of the week, type of road, crossing facility, speed limit, junction details, light conditions and weather, etc.

2) Vehicle record files that contain type of vehicle, manoeuvres, vehicle movement, first point of impact, gender and age of driver or rider, and other records related to the vehicle.

3) Casualty record files which contain casualty class (driver or rider, passenger, pedestrian), gender and age of casualty, severity of injury, pedestrian location, movement and direction, and other records related to any casualties (see appendix 1 for the STATS19 form).

According to instructions for the completion of road accident report (STATS20), "in terms of casualty that be reported in STATS19", persons killed or injured in road accident should be reported in STATS19. In addition to that:

"(a) A person who moves quickly to avoid being involved in an accident, is successful in that, but in doing so incurs an injury (e.g. twists an ankle). Also includes occupant of vehicle which manoeuvres or breaks suddenly to avoid an impact, but in so doing sustains an injury;

(b) A pedestrian who injures himself on a parked vehicle;

(c) A person who is injured after falling from a vehicle;

(d) A person who is injured boarding or alighting a bus or coach;

(e) A person injured whilst aboard a bus or coach, whether or not another vehicle is involved;

(f) A person who is injured away from the carriageway as a result of an accident which commenced on the public highway;

(g) All casualties in accidents arising from deliberate acts of violence involving a vehicle" (STATS20, 2005).

The severity of injury in the case of each pedestrian accident is classified within STATS19 into three levels; fatal, serious and slight injury. Pedestrians who die at the scene of the accident or within 30 days of the accident being recorded are categorised as fatal. Victims that suffer from internal injury severe cuts, crushing, concussion and fracture, are recorded as serious injuries. Examples of slight injury are slight cuts, bruises and sprains.

It should be noted here that pedestrian accident locations in STATS19 are classified as in the following table 3.1:

Table 3. 1: Description and codes of pedestrian location variable

CODES	Description
00	Not a pedestrian
01	On carriageway, crossing on pedestrian crossing facility
02	On carriageway, crossing within zigzag line at crossing approach
03	On carriageway, crossing within zigzag lines at crossing exit
04	On carriageway, crossing elsewhere within 50 metres of pedestrian crossing
05	On carriageway, crossing elsewhere
06	On footway or verge
07	On refuge, central island or central reservation
08	In centre of the carriageway, not on a refuge, central island or central reservation
09	In carriageway, not crossing
10	Unknown or other

However, in reality when a pedestrian accident happens it is possible that the person could be thrown away from the pedestrian crossing. Therefore in this research, pedestrian accidents are classified as “at a pedestrian crossing” *if they occur within 10 metres of the actual pedestrian crossing facility*. Beyond the 10 metre distance, accidents are classified as “in carriageway, crossing elsewhere within 50 metres of pedestrian crossing”. In the latter category, distances were further divided into intervals of 10 metres (i.e. 10-20, 20-30, 30-40 or 40-50) metres from the pedestrian crossing facilities as discussed later. The location of the accidents has then been identified using the grid reference of the accidents as recorded in 1.11 in STATS19 data.

3.2.1.2 Limitation of STATS19 for this study

Although STATS19 provides a wide range of information about road accidents, it is worth mentioning here some of the limitations that has limited the investigations and results of pedestrian accidents at pedestrian crossing facilities or within 50 metres of it, which are obtained in this study. Some of these limitations are briefly discussed below.

1. Location data

In term of exact location of accidents, there is no exact location data is reported in STATS19. Instead, in this research, to identify accident location in STATS19 the researcher used the "grid reference" which is reported in STATS19. The grid reference in STATS19 has 5 digits; either east or north. These digits do not help to get to exact point of pedestrian accidents because the last digit is rounded up (ten meters of the exact location). Therefore, the location of any accident is given in STATS19 to the nearest 10 meters.

2. Pedestrian crossing behaviour at the time of the accident

Regarding to the pedestrian behaviour, STATS19 has no variables that indicate pedestrian cross the road at pedestrian crossing illegally (against red man light) or legally (comply with green man light) or green light for drivers to allow them to pass pedestrian crossing line or red light to stop. Moreover, no variable in STATS19 indicates how pedestrian act before the accidents (i.e. if pedestrian had look either side before he/she cross the road).

3. Pedestrians and drivers under the influence of drugs or alcohol

Removal of data regarding the influence of drugs or alcohol for pedestrian and driver, although this variable used to be in STATS19 (2.23 breath test). Currently, this data is not available in STATS19 when downloaded from UK national statistics website.

4. Further pedestrian characteristics

Regarding further pedestrian characteristics such as education, ethical origin, income or social groups. Such characteristics might be relevant although there might be political issues about the collection of this type of data. Some of this data could also considered as exposure factors.

5. Physical pedestrian crossing facilities

In term of Type of signalised crossing: In STATS19, there is one category of combined (pelican, puffin, toucan or similar type of pedestrian crossing) (See appendix 1). The detailed classifications of these types would have been useful for further investigations of the impact of the type of crossing on pedestrian accidents rates and severity.

6. Pedestrian right-of-way at pedestrian crossing

In STATS19 there is no explicit information of the pedestrian right-of-way or pedestrian violation of right-of-way. This information needs a clear definition of the right-of-way then the relevant variables can be identified for inclusion in STATS19. A proposed definition of ROW is given in Section 3.3 below.

3.2.1.3 Relevant data of STATS19 for this study

It is worth mentioning here that this research are mainly based on STATS19 data for pedestrian accidents occurred on 1993 to 2006. Many data and pedestrian characteristics were able to be employed in this study. Most significantly the following data have been utilised in the general analysis and further modelling of pedestrian accidents at pedestrian crossing:

1. **Socio economic data**

This section include gender of casualty and driver, age of casualty and driver and combined age/ gender groups (e.g. old male, old female etc.).

2. **Vehicle characteristics data**

This section of data includes vehicle type, vehicle manoeuvres, speed limit and first point of impact.

3. **Environmental data**

This section includes the weather, road surface conditions, light, type of carriageway and width of carriageway, road type, road class and pedestrian crossing types

4. **Accident data**

This section include accident class of injury, casualty class, severity of casualty, time of accidents, date of accidents pedestrian movements and pedestrian location (i.e. on pedestrian crossing at the time of accident or away of crossing line).

5. **Location data**

The grid reference data has been used to identify the location of pedestrian accidents from the crossing line. This factor has been investigated as an exposure factor.

3.2.1.4 Investigation of exposure factors using STATS19 for this study

In this study, a number of factors have been investigated and considered for inclusion in the models to represent exposure factors. STATS19 data does not include many factors which can be considered as an exposure factors. Therefore it was decided to collect further data from traffic counting (pedestrian volumes) and from the city council (traffic volume). The problem with this data is that they are not gathered at the same time as accident data (which are available from STATS19 for 14 years.

The pedestrian volume count which have been collected by the researcher as part of this research has been used as an independent variable in the pedestrian severity models. However, this variable did not show any improvement of the model over that without that variable. There are possible few issues with this data;

1. The data has been collected in 2011 as part of this current research and therefore do not match up exactly with the test of the data which is collected over 14 years; this is of course will create statistical problems with the significant of the models.
2. There might be changes in the layout and engineering characteristics of the locations analysed

Therefore, the models with pedestrian volumes as variable are not much better than the models without it. The collected data has been tested in the models to represent exposure factors as discussed in Chapter 5.

Furthermore, other exposure data may include pedestrian volume disaggregated by time of day, age groups and gender groups. This data would provide greater understanding and more detailed information on the patterns of pedestrian volume and therefore could provide better understanding od pedestrian accidents at pedestrian crossing.

Other variables which could have been considered for inclusion in these models to represent exposure factors include traffic volume. Traffic flows, is one of the most commonly used factor as an exposure measure, especially where accidents data has been collected at various sites using camera etc. the problem with this variable at the approach in study is that traffic volume data, similar to pedestrian volume data would have been collected at a completely time frame than the STATS19 accidents severity data.

Another possible representative to an exposure factor would have been population data and their distributions with age group, gender etc in the different traffic zoned where accidents occurred, However, this type of data although might be availble, would probably not aggregated and will not be easy to use it in these type of models. The estimated risks of accident could have been investigated and disaggregated by sex and age and also examined by combining road accident data with survey data using the exposure measures “time spent walking” and “number of roads crossed, the type of journeys and the health status of pedestrians. The resulting measures of risk can be compared with one another and with the most common mode of presenting of pedestrian accident statistics, accidents *per capita*. The over-representation of any specific group of population in pedestrian accident statistics can also be further examined in light of their greater susceptibility to injury from a given accident. The relative importance of walking as a mode of transport can also be examined as one of the exposure measures, using further travel survey data. Finally, the risks of road accident when crossing at a zebra (unsignalized) crossing could have been compared with the risks of crossing elsewhere.

Moreover, other useful data can be included in this study such as pedestrian population for Edinburgh, traffic volume for Edinburgh and along the selected road, pedestrian volume on selected road and who crossed the road at crossing facilities, housing type around the selected roads and demographic area. all of these data could be included in this study but the absence of them made the researchers to concentrate on STATS19 data.

In this research, the researcher has collected some limited pedestrian volumes at the selected sites in Edinburgh because of limitations of time and resources. The data of pedestrian volume was used in modelling of severity of injury models and ROW models. However, the statistical significance of the models which include pedestrian volume as an independent variable did not show great statistical significance. This might be because of mainly because of the non representation of this data to the actual pedestrian volume during the time of accidents (1993 to 2006). Further work in this area is therefore encouraged

3.2.2 Further data collection

3.2.2.1 Data collection

The map locations for signalised pedestrian crossing facilities, signalised junctions and traffic volume have been provided by Edinburgh City Council.

In addition, the ordinance survey website has been used to identify the exact location of accidents and of signalised pedestrian facilities as well as road junctions. However, this grid referencing system is ineffective without a specific area code. Also, knowing the location of pedestrian crossings according to road name cannot help to identify the exact location of pedestrian crossings. Therefore, coordinating all the information was necessary in order to identify the exact location of each accident and also the exact location of pedestrian crossings and the signalised junctions.

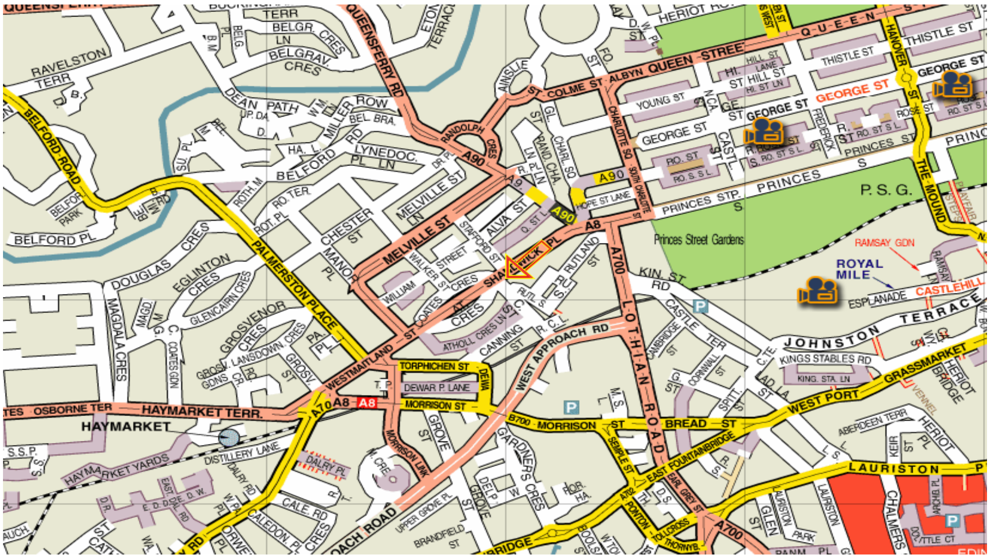

Figure 3. 1 Illustration of location of accidents using an ordinance survey website

3.2.2.2 Selected Sites:

Since this research was conducted in Edinburgh, it was more convenient to select local sites for the purposes of investigation. The number of pedestrian accidents in Edinburgh have been investigated and classified by location (i.e. road number). Table 3.2 below shows the roads which experienced the largest number of accidents over the 14-year period (1993-2006). Roads were compiled using the STATS19 database.

Table 3. 2: Illustrates the road and the number of pedestrian accidents

Road	Number of pedestrian Accidents
A8	614
A7	474
A702	314
A900	302
A700	173

Therefore, the five roads mentioned above were selected in Edinburgh in order to be used to carry out further investigations into pedestrian accidents and severities. This was because these five roads show the largest pedestrian accident volume that occurred on them. Incidentally, these five roads share similar general characteristics including mixed land use activities (residence and shopping), presence of a traffic junction and other pedestrian crossing facilities, e.g. pelican, puffin, and central location in Edinburgh. The first road is section of the A8 that begins in Princes Street at the junction with North Bridge in the New Town area and ends at the Newbridge roundabout. The length of the road is approximately 14 kilometres (Figure 3.2 shows a map of the road).

Figure 3. 2 A map of the A8 road section

The second road is section of the A7 that begins at the junction (A8/A7/A1) on North Bridge and ends at Cameron toll. The length of A7 is 3.2 kilometres and Figure 3.3 shows the map of the road

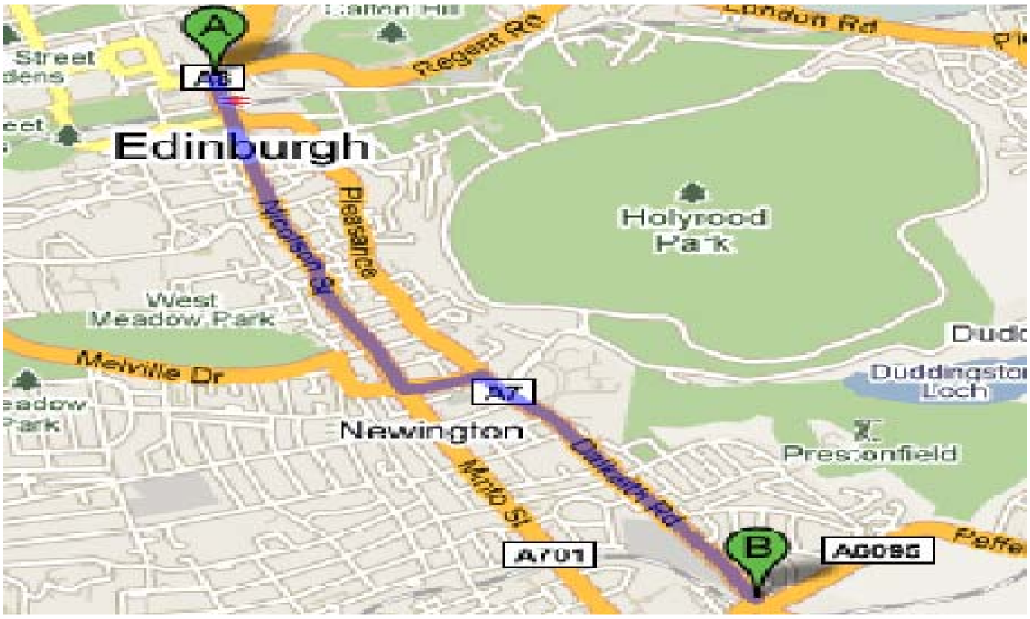

Figure 3. 3: A map of the A7 road section

The A700 road is the third selected section in this research. The section of the A700 begins at the junction of the A8/A700 in Newtown area and ends at A700/ Melville drive junction. The length of the road is 2.2 kilometres, see Figure 3.4 below.

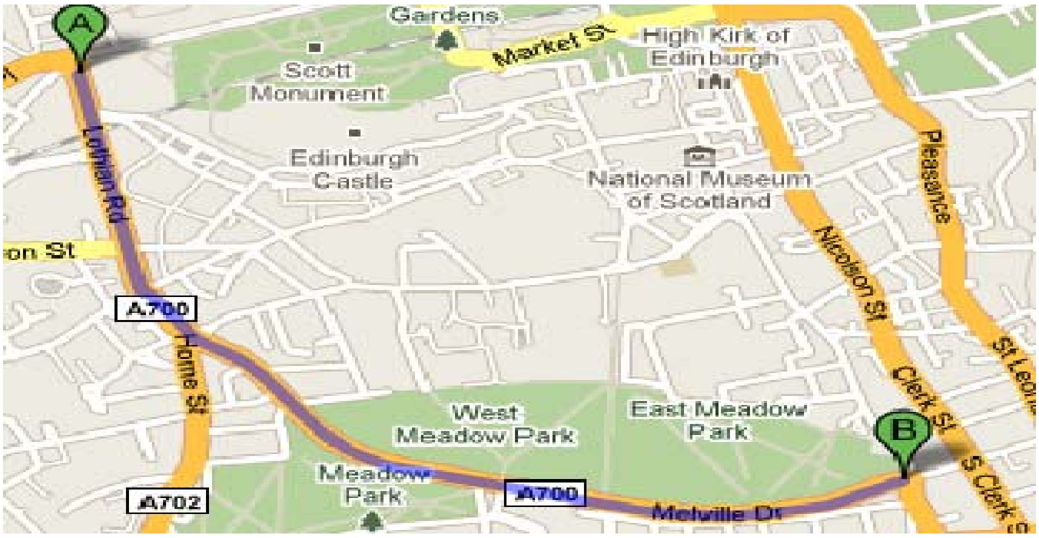

Figure 3. 4: A map of the A700 road section

The fourth road is the section of the A702 which begins from Tollcross junction (A700/A702) and ends at Fairmilehead junction. The length of this road is 5 kilometres.

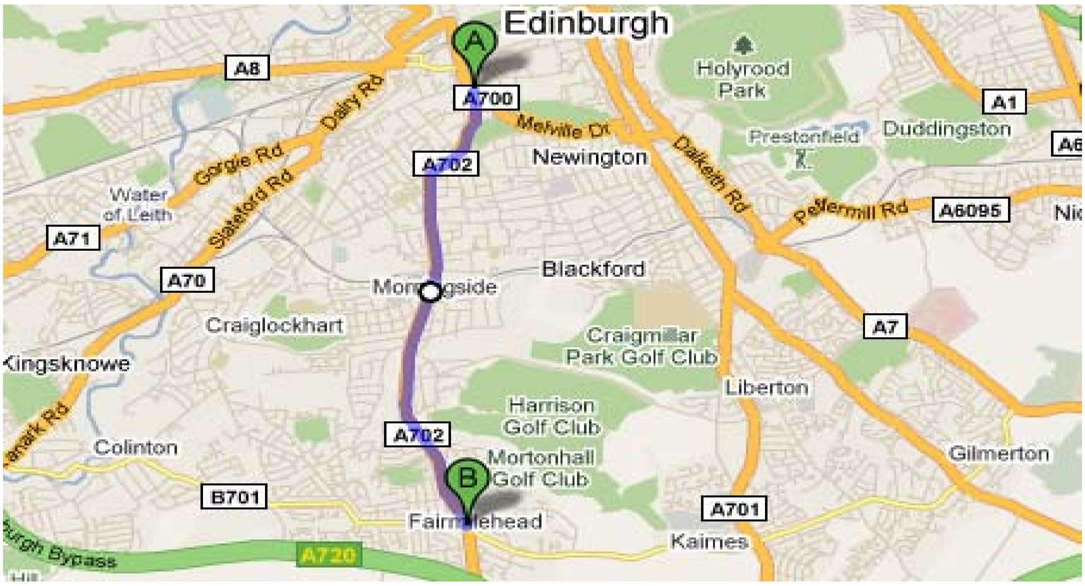

Figure 3. 5: A map of the A702 road section

The last road selected is section of the A900 road, which begins at the junction of the A8/A9/A7 and ends at (Constitution Street /Bernard) junction. The length of this road is 2.7 kilometres.

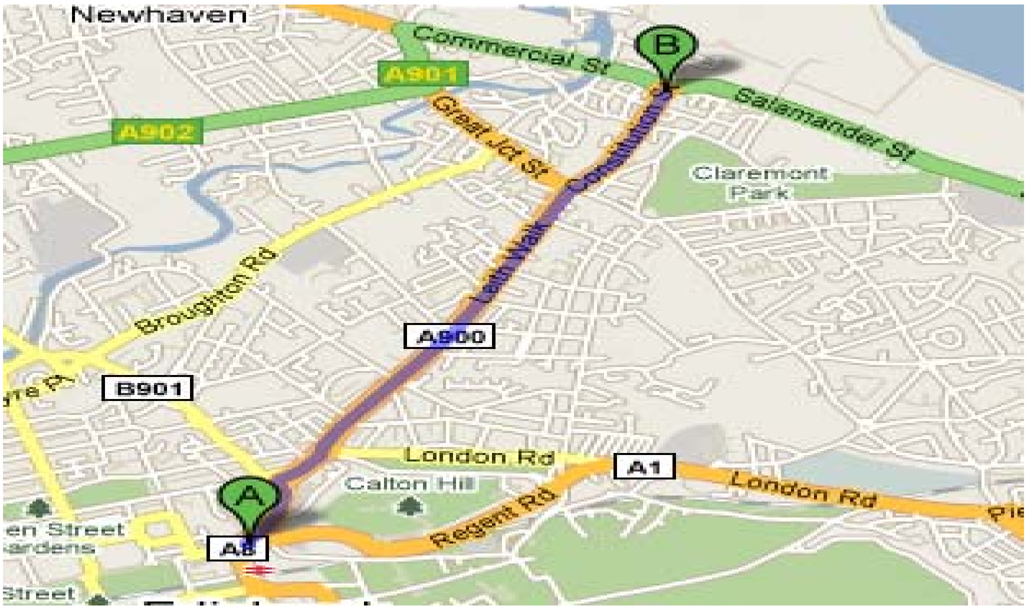

Figure 3. 6: A map of the A900 road section

3.3 Data relevant to ROW violation

As discussed in Section 2.6, pedestrian right-of-way violations, or jaywalking, commonly refer to a pedestrian crossing from one side of the road to another, in unauthorised areas or in violation of pedestrian laws. Different jurisdictions treat jaywalking in different ways. North American countries such as the US and Canada have laws that make jaywalking illegal, as does Australia. The UK, however, does not have anti-jaywalking laws, leaving pedestrians to exercise prudence when crossing roads and to act for their own safety.

In the UK, according to the Highway Code, pedestrians should use pedestrian crossing facilities when they cross roads and obey the instructions at each facility. Pedestrians are advised to cross the road wherever there are pedestrian crossing facilities, and if there are no facilities they should only cross with great care. Furthermore, pedestrians are permitted to cross the carriageway elsewhere, but should exercise care and take the distance and speed of any approaching vehicle into account. In general, the definition of pedestrian crossing regulations is the same as that in the Vienna Convention of 1968.

Investigation of Right-Of-Way violation (ROW) using the available data (e.g. STATS19 database) is not very straight forward. This is because such databases do not include direct information or variables which indicate who, whether the drivers or the pedestrians, actually has priority at a junction. However, it can be argued that priority or consideration in the street is always given to the pedestrian. This is obviously an area where there is a huge lack of research.

The ROW depends greatly on the specific instance under examination and on the specific national laws in operation. As stated previously different authorities are responsible for the drafting of regulations in given countries and the application of these rules will vary greatly, as they are dependent on the public's willingness to adhere to them in conjunction with their knowledge of the given regulations in question.

In the United Kingdom the laws pertaining to pedestrian rights are set out in a number of legislative documents (Department of Transport, 1997; Department of Transport, 1991), which are summarised in a concise easy to read manual 'The Highway Code'. As the Highway Code is not a legislative document in itself special care is taken in its production to ensure that all relevant legislation is quoted correctly and as a result this code "may be used in evidence in any court proceedings under the Traffic Acts" (Department of Transport, 2012). In this document specific attention is paid to the rights and codes to which the pedestrian must adhere. It can be seen that a major emphasis is placed on this information as it is the first section in the manual which insures that it is taken into account by all road users. In total there are 35 codes outlined, and these also reflect the responsibilities of pedestrians towards other road users in combination with the responsibilities of other road users to pedestrians. For the purpose of this document we shall be taking specific interest in rules: 7, 8, and 18-30 (Department of Transport, 2012). Rule 8 is of particular interest to us in this investigation as it states –

"*At a junction. When crossing the road, look out for traffic turning into the road, especially from behind you. If you have started crossing and traffic wants to turn into the road, you have priority and they should give way*"

This rule is of particular interest as it clearly indicates to us that a priority should be set for pedestrians crossing a roadway which does not have a specific pedestrian crossing in place. However this does not allow for the free unobstructed crossing of a road by pedestrians, as is clearly demonstrated prior to this rule in rule 7, which states: "*Do not cross until there is a safe gap in the traffic and you are certain that there is plenty of time*". The issues which can arise from this situation are the varying perceptions of what constitutes a 'safe gap in the traffic' and how far it can be proved at a later date that adequate time to cross has been provided. This therefore put the onus on the pedestrian, to ensure that they are capable of crossing the road without causing delays to other road users. Rules 204-210 (Department of Transport, 2012) place further emphasis on the importance of pedestrians to vehicle users, and their responsibility to beware of the presence of such individuals. It is clear from all of these measures that the pedestrians have right-of-way over vehicle users; however, this is not clearly stated in any area and can lead to a certain level of ambiguity. Although common sense should allow drivers to be capable of realising that should they injure a pedestrian to such an extent to which death results they are likely to face legal proceedings, further research and considerations of this issue are greatly needed.

In this research, pedestrian ROW violations as the case of a pedestrian accident at pedestrian crossing, will be defined as "*any pedestrian accident that occurs on pedestrian crossing areas or within ten metres of pedestrian crossing areas"*. In that case it is assumed that the pedestrian has right-of-way, and that there has been a violation to that right. On the other hand, any pedestrian accident that occurs outside the ten metre limit is called a non-pedestrian ROW (or driver ROW). In this case the pedestrian will be violating the right-of-way of the driver. Table 3.3 provides the description pertaining to ROW violation.

Table 3. 3: Description of pedestrian ROW violation

Variable	Description
Pedestrian ROW	Pedestrian accidents occurring on pedestrian crossing areas, zigzag lines and when pedestrians were crossing elsewhere within 10metres on both sides of the crossing or when pedestrians are walking along the side way walk.
Driver ROW	Pedestrian accidents occurring outside the pedestrian ROW area (pedestrian accidents occurring away) within 50 meters from the crossing line in both directions.

It is very important to note that the accidents which were selected for analysis in this research were those that had occurred on pedestrian crossing areas and up to 50 metres from the crossing line in both directions.

3.4 Econometric Framework

3.4.1 Logistic regression

Logistic regression (sometimes called the logistic model or logit model) is used for prediction of the probability of the occurrence of an event by fitting data to a logit function logistic curve. It is a generalised linear model used for binomial regression. Logistic regression makes use of several predictor variables that may be either numerical or categorical. Logistic regression may be useful when we are trying to model a categorical dependent variable as a function of one or more independent variables. For example, the probability that a person could be involved in an accident, or suffer slight, serious or fatal injuries might be predicted from the knowledge of the type of car involved in the accident, age, type of road or area, speed of vehicle, etc. Logistic regression is used extensively when modelling accidents severities for all types of road users.

In logistic regression, the goal is the same as in ordinary least squares (OLS) regression: the aim is to model a dependent variable in terms of one or more independent variables. However, OLS regression is for continuous (or nearly continuous) dependent variables; logistic regression is for dependent variables that are categorical. Dependent variables may fall into two categories (e.g. alive/dead; male/female; fatal/nonfatal) or more than two categories. If there are more than two categories these may be ordered (e.g. none/some/a lot) or unordered (e.g. married/single/divorced/widowed/other). In this research, we deal with modelling multiple categories with dependent variables (mainly ordered).

Logistic regression is favoured over OLS regression with categorical dependent variables because of the following:

1. The residuals cannot be normally distributed (as the OLS model assumes), since they can only assume one of several values for each combination of level of the independent variables.

2. The OLS model makes nonsensical predictions, since the dependent variable is not continuous - e.g. it may predict that someone does something more than ‘all the time’.

3. For nominal dependent variables, the coding is completely arbitrary, and for ordinal dependent variables it is (at least supposedly) arbitrary up to a monotonic transformation. Yet recoding the dependent variables will deliver very different results. Therefore, logistic regression deals with these issues by transforming the dependent variable. Rather than using categorical responses, it uses the log of the odds ratio of being in a particular category for each combination of values of the independent

variables. The odds are the same as in gambling; e.g. 3-1 indicates that the event is three times more likely to occur than not. The ratio of the odds is taken in order to allow for consideration of the effect of independent variables. Then, the log of the ratio is taken so that the final number goes from - ∞ to ∞ so that 0 indicates no effect, and so that the result is symmetric around 0, rather than 1. For more details regarding logistic regression see chapter 2.

As noted, ordinal logistic regression refers to a case where the dependent variable has an order; the multinomial case is covered below. The most common ordinal logistic model is the proportional odds model. If we posit that the dependent variable is really continuous, but is recorded ordinally (as might, for instance, happen if income were asked about in terms of ranges, rather than precise numbers) and has been divided into J categories then if the 'real' dependent variable is Y, the model is: $y\_i = x_i b + e_i$

3.4.2 The Ordered logit Model

When the categories of the dependent variable are clearly ordered, one should take account of the fact that the dependent variable is both discrete and ordinal. For this current research, suppose that there are N persons (indexed i =1, …, N) for each of whom an "injury" can occur. Suppose that this injury has three outcomes (no injury, slight injury, KSI). The outcomes are indexed j =1, 2, 3, where these outcomes are mutually exclusive and collectively exhaustive. Let the values taken by the variable Y_i represent these outcomes for person i such that: Y_i =1 if the first outcome occurs for this person (j =1); Y_i =2 if the second outcome occurs (j =2); and Y_i =3 if the last outcome occurs (j =3). These outcomes are inherently ordered, by which it is meant that the outcome associated with a higher value of the variable Y_i is ranked higher than the outcome associated with a lower value of the variable.

Another way to express this ordinal nature is that stronger outcomes are associated with higher values of the variable. Nonetheless, this ordinal nature of the outcomes has no implication for differences in regards of the strength of the outcomes. That is, although the dependent categories are numbered sequentially, the outcome associated with Y_i =2 is not twice as strong as that associated with Y_i =1 (i.e. the values are only a ranking and have no cardinal significance). Therefore, the actual values taken by an ordered dependent variable are not relevant, as long as larger values correspond to stronger outcomes and smaller values correspond to weaker outcomes.

As discussed in Chapter 2, the unordered multinomial logit (MNL) or nested logit models have been widely adopted in literature to determine the factors that affect the injury severity sustained by various road users. These models, while accounting for the categorical nature of the dependent variable, treat ordinal dependent variables as if they are interval (Borooah, 2001; Long, 1997). That is, to estimate an econometric relation with an ordinal dependent variable, using the methods of the MNL or nested logit models would represent that the information conveyed by the ordered nature of the data is discarded.

The econometric models specifically designed for ordinal variables are the ordered response models, which are able to account for unequal differences between categories in the dependent variable (i.e. for this study the distance between no injury and slight injury is not the same as that between slight injury and KSI) and does not have the restriction of the IIA (the independence of irrelevant alternatives) as a multinomial logit model does (Borooah, 2001; Long, 1997). The ordered response models are introduced in more detail in the subsequent section.

3.4.3 The Ordered Response Model

Ordered response models can be derived from a measurement model in which a latent variable y^* ranging from $-\infty$ to $+\infty$ is mapped to an observed variable y. The variable y is thought of as providing incomplete information about the underlying y^*, according to the measurement equation:

$$y_i = m \quad \text{if } \mu_{m-1} < y_i^* \leq \mu_m \quad \text{for } m = 1 \text{ to } J \tag{1}$$

They μ's are called thresholds or cut points. The extreme categories 1 and J are defined by open-ended intervals with $\mu_0 = -\propto$, $\mu_J = +\infty$.

In order to illustrate the measurement equation (Eqn. 1), consider the dependent variable used in this current study. The data for pedestrian casualties resulting from pedestrian-vehicle accidents at signalised junctions was drawn from the STATS19 for a 14-year period between 1991 and 2004. Pedestrian injury severity resulting from these pedestrian-vehicle accidents is classified into three levels: slight injury, serious injury and fatal. Assume that this ordered variable is related to a continuous, latent variable y^*. Ordered response models are usually motivated in a latent (i.e. unobserved) variables framework. The general specification of each single-equation model is:

$$y_i^* = \beta' x_i + \varepsilon_i \tag{2}$$

where y_i^* is the latent and continuous measure of injury severity faced by accident victim *i* in an accident, β' is the vector of parameters to be estimated, and x_i is the (K x 1) vector of observed non-stochastic (i.e. non-random) explanatory variables, and ε_i is the normally distributed error term with zero mean and unit variance for the OP model, but logistically distributed for the OL model. Note here that the error terms for different accident victims are assumed to be uncorrelated (i.e. the disturbance term is assumed to be heteroskedastic, representing that the variance of the disturbance term can vary from one victim to another).

According to the measurement model (Eqn. 1), the observed and coded discrete injury severity, y_i, is determined from the model as follows:

$$y_i = \begin{cases} 1 \text{ if } -\infty < y_i^* \le \mu_1 \text{ (no injury)} \\ 2 \text{ if } \mu_1 < y_i^* \le \mu_2 \text{ (slight injury)} \\ 3 \text{ if } \mu_2 < y_i^* < +\infty \text{ (KSI)} \end{cases} \tag{3}$$

where the threshold values μ_1 and μ_2 are unknown parameters to be estimated. Figure 3.7 illustrates the correspondence between the latent, continuous underlying injury variable, y_i^*, and the observed injury severity class, y_i.

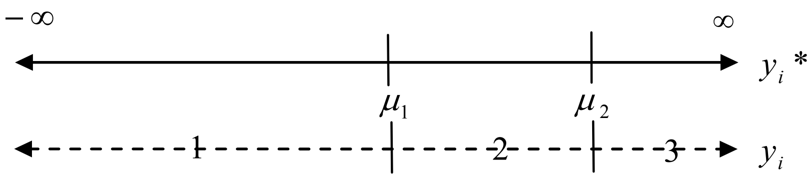

Figure 3. 7 Relationship between latent and coded injury variables

The solid line represents the latent variable y_i *. The cut points are indicated by the vertical lines marked μ_1 and μ_2 with $\mu_0 = -\infty$, $\mu_3 = +\infty$ and $\mu_1 < \mu_2$. Below this solid line a dotted line illustrates the values of the observed variable y_i over the range of y_i *.

The probability that an injury level sustained by a pedestrian i, for a given x_i is equal to the probability that the unobserved injury risk, y_i *, takes a value between two fixed thresholds. This is presented as follows:

Firstly, for the probability of a victim sustaining no injury, $y_i = 1$ is observed when y_i * falls between $\mu_0 = -\infty$ and μ_1. This implies that:

$$P(y_i = 1 | x_i) = P(\mu_0 < y_i * \leq \mu_1 \mid x_i) \tag{1}$$

Substituting y_i * into $\beta' x_i + \varepsilon_i$:

$$P(y_i = 1 | x_i) = P(\mu_0 < \beta' x_i + \varepsilon_i \leq \mu_1 \mid x_i) \tag{5}$$

Subtracting $\beta' x_i$ within the inequality:

$$P(y_i = 1 | x_i) = P(\mu_0 - \beta' x_i < \varepsilon_i \leq \mu_1 - \beta' x_i \mid x_i) \tag{6}$$

The probability that a random variable is between two values is equal to the difference between the cdf (cumulative density function of the normal distribution Φ) evaluated at these values. Thus,

$$P(y_i = 1 | x_i) = P(\varepsilon_i \le \mu_1 - \beta' x_i \mid x_i) - P(\varepsilon_i < \mu_0 - \beta' x_i) = \Phi(\mu_1 - \beta' x_i) - \Phi(\mu_0 - \beta' x_i) \qquad (7)$$

These steps can be generalised to derive the probability of any observed outcomes.
For this current study, the predicted probabilities of the three coded injury-severity levels by a victim i, for given x_i are:

$$P(y_i = 1 | x_i) = \Phi(\mu_1 - \beta' x_i)$$
$$P(y_i = 2 | x_i) = \Phi(\mu_2 - \beta' x_i) - \Phi(\mu_1 - \beta' x_i)$$
$$P(y_i = 3 | x_i) = 1 - \Phi(\mu_2 - \beta' x_i) \qquad \textbf{(8)}$$

Where $\Phi(u)$ denotes the cdf (cumulative density function) of the random error term, ε_i evaluated at u. It should be noted here that when computing $P(y_i = 1 | x_i)$, the second term on the right-hand side drops out since $\Phi(\mu_0 - \beta' x_i) = \Phi(-\infty - \beta' x_i) = 0$. Similarly, when computing $P(y_i = 3 | x_i)$, the first term on the left-hand equals 1 since $\Phi(\mu_3 - \beta' x_i) = \Phi(\infty - \beta' x_i) = 1$.

The method of maximum likelihood (ML) is used for estimating the parameters of the ordered response models. To use ML estimation, a specific random error term ε_i has to be assumed (Long, 1997). An OP model is the result of assuming that ε_i is normally distributed, while an OL model is the result of assuming that ε_i is logistically distributed. Other distributions for the error term have been considered, but are not widely used (see the work of McCullagh, 1980, or Amemiya, 1985, for a complete discussion of ML estimation in the context of statistical and econometric models).

For the OP model, ε_i is normally distributed with mean 0 and variance 1 and the cdf is:

$$\Phi(\varepsilon) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\varepsilon} \exp(-\frac{t^2}{2})dt \quad \textbf{(9)}$$

For the OL model, ε_i is logistically distributed with a mean of 0 and a variance of $\pi^2/3$ and the cdf is:

$$\Lambda(\varepsilon) = \frac{\exp(\varepsilon)}{1 + \exp(\varepsilon)} \quad \textbf{(10)}$$

A measure of model goodness-of-fit ρ^2 (McFadden, 1973) can be calculated as:

$$\rho^2 = 1 - [\ln(L_b) / \ln(L_0)] \quad \textbf{(11)}$$

Where $\ln(L_b)$ is the maximised likelihood and $\ln(L_0)$ is the likelihood value, assuming all the model slope coefficients are equal to 0.

In practice, the OP and OL formulations give very comparable results (O'Donnell and Connor, 1996). Therefore only the estimation results for the OP models are reported in the following chapters. It also merits mention that two categories (i.e. KSI vs. non KSI) can be considered as the dependent variables and the appropriate statistical for this would be binary logistic regression model, as discussed in Chapter 3. It was found that the estimation results, when adopting binary logistic regression, were fundamentally consistent with those when adopting OP models (e.g. riders were more injury-prone in approach-turn B crashes than those in other crash configurations). However, due to the binary level of the dependent variables, the whole spectrum of injury severity (i.e. the probabilities of sustaining no injury, slight or KSI separately) would be obscured. Such reasoning (i.e. the more injury severity information, that can be provided by using the ordered response models) is also supported by several researchers (e.g. Elure and Bhat, 2007).

3.5 Multicollinearity Problem

It is worth mentioning that, for models that have a set of explanatory variables; there is a possibility that some of the explanatory variables would be related; causing the problem known as multicollinearity. Although multicollinearity would not cause estimators to be biased, inefficient, or inconsistent, and does not affect the forecasting performance of the model, it might make coefficients appear less significant (Ramanathan, 1995).

Multicollinearity could be identified by the high value for correlation coefficients between variables. A correlation value between two variables that is 0.5 or above may result in a multicollinearity problem. In this present study, any cases where one variable is observed to be correlated with another variable with a correlation value of 0.5 or above, only one variable is maintained in the model to avoid the multicollinearity problem (see the work of Ramanathan, 1995 for a complete discussion of multicollinearity problems that arise from two variables with a correlation value of 0.5 or above). In this current study, a correlation matrix is systematically examined among the variables before they are incorporated into the models (see Chapter 5 and Chapter 6). The symptom of multicollinearity (e.g. wildly changing coefficients when an additional variable is included/removed or there are unreasonable coefficient magnitudes) is also examined, by observing whether the coefficients of the estimated models have meaningful signs and magnitudes. These approaches to avoiding multicollinearity have been adopted by several researchers (e.g. Jones and Jørgensen, 2003; Pai and Saleh, in press).

3.6 Interpretation of the Estimated Coefficients and Modelling Performance

Due to the increasing nature of the ordered levels in the dependent variable, the interpretation of the parameter β', is as follows: a positive value of an estimated coefficient implies that an increase in the variable will unambiguously increase the probability of the highest-ordered discrete category being selected (i.e. KSI), and unambiguously decrease the probability of the lowest-ordered discrete category (i.e. no injury).

As discussed in chapter 2, several disaggregated models for pedestrian accidents, including injury severity have been estimated. The estimation results for these models will be reported in Chapter 5.

A goodness-of-fit measure (ρ^2) as given in equation 11 is presented, It should be noted that there is no universally accepted goodness-of-fit measure for ordered response models (Long, 1997; Kennedy, 1993). A pseudo- ρ^2 measure, which has values between 0 and 1 has no natural interpretation, as its purpose is to measure the strength of the linear component models (Greene, 2003). That is, unlike the case of a linear regression model, where the coefficients are chosen to maximise pseudo- ρ^2; in ordered response models the estimates of coefficients do not maximise any goodness-of-fit measure. Thus, assessing nonlinear models like the ordered response model on the basis of the goodness-of-fit statistics may be misleading (Kennedy, 1993; Greene, 2003).

One alternative to the pseudo- ρ^2 measure proposed by Ben-Akiva and Lerman (1985) is a fit measure (i.e. CA: classification accuracy) that examines the percentage of outcomes of dependent variables that are correctly predicted. Model prediction accuracy is reported in the first table for each crash model. The interpretation of CA should proceed with caution since when analysing an imbalanced dataset, less frequent outcomes tend to have a low level of predictability (Cramer, 1999).

The models provide information on the probabilities of the three injury-severity levels. Researchers (e.g. Long, 1997; Eluru et al.,) have noted that, for the ordered response model, the estimated parameters on the explanatory variables do not directly provide a clear indication of how changes in specific independent variables affect the probabilities of intermediate ordered category (i.e. slight injury for this current research). Calculation of these probabilities as given in equation 8 allows a better understanding of the relative effectiveness of the independent variables on the probabilities of the three injury-severity levels affecting the present study.

A useful starting point for a discussion of injury probabilities is to consider the characteristics of the casualty when all variables in the models take the value of zero. The accident victim is termed as a “benchmark case” in this current research. To take an example of the model of pedestrian-vehicle accident, the MNL model has been used as an illustration as presented in Section 5.4. The changes in the probability levels of the dependent variables are also estimated, and are measured relative to the benchmark case. This allows one to interpret changes in the probability of the severity levels for a change in a given parameter, relative to the benchmark victim. The "benchmark case" approach was adopted in this research to discuss injury probabilities has also been employed by previous researchers (e.g. O'Donnell, and Connor, 1996; Pai and Saleh, 2007b). Such a benchmark case has the following characteristics:

a) Child aged (0-15)
b) Involved in accidents at night time.
c) Involved in a collision in which the pedestrian was crossing the road (either from driver nearside or offside.
d) Involved in a crash where the vehicle was performing a going ahead maneuver.
e) Involved in an accident in which the vehicle was heavy vehicles (i.e. bus or heavy goods vehicle).
f) Involved in a crash when the signalised crossing was a pelican or similar.
g) Involved in a crash on a 1-2 lanes single carriageway.
h) Involved in a crash on a weekday.
i) Involved in a crash in wet road conditions.
j) Involved in a crash on pedestrian crossing line or within 10m of one.

3.7 Summary

This chapter described the methodology used herein to examine pedestrian injury severity in pedestrian-vehicle accidents at signalised junctions. The proposed methodological approach achieves this by pedestrian-car accident data from the STATS19 database to explain pedestrian injury severity at signalised junctions, including pedestrian, motorist, vehicle, roadway, environmental, and crash characteristics, the investigation of right-of-way for both pedestrian and motorist, and the estimations of the appropriate econometric models to evaluate the determinants of pedestrian injury severity. As previously mentioned, the main objective of this thesis is to investigate the factors that affect pedestrian injury severity at signalised pedestrian crossings. To achieve this, the investigations included a descriptive analysis and the

econometric models of the variables associated with pedestrian casualties resulting from pedestrian-vehicle accidents at signalised junctions,
as reported in Chapter 5.

Chapter 4

General trends of pedestrian accidents at the selected sites

4.1 Introduction

For all the analysis in chapters 4, 5 and 6, the used data is the data set collected from the five Edinburgh sites. This chapter investigates the general characteristics of pedestrian accidents at these selected five sites in Edinburgh. These corridors are: Section of the A8 road, Section of the A7 road, Section of the A700 road, Section of the A702 road and section of the A900 road. Firstly, general statistics include the general trends describing pedestrian accidents that occurred over the past 14 years in these five corridors. The analysis includes socio-economic factors, vehicle related factors, environmental factors and road related factors are discussed. The rates and severities associated with pedestrian related accidents, at pedestrian crossings on the five selected corridors are investigated. Secondly, an investigation of ROW will be presented, and the variable representations of the ROW for pedestrians and for motorists will be included in the analysis. This general analysis is used to identify the most important factors which are relevant to pedestrian accident analysis and investigations. These factors are then included in the models of accidents severities and the ROW models (see Chapter 5&6). General analysis of pedestrian accidents at all pedestrian crossings in the UK and in Edinburgh, over the 14 year period are presented in Appendix A2.1 and A2.2 respectively.

4.2 General statistics for pedestrian’s accidents in the selected case study sites

To gain a better understanding of the factors which have led to an increase in the severity of injury on pedestrian crossing facilities, or within 50 metres of them, five roads in Edinburgh were selected for the purposes of investigation, as discussed earlier in Chapter 3. Therefore, in this section, the distribution of pedestrian accidents around the pedestrian crossing facilities, general trends explaining the severity of pedestrian injury on selected roads (on pedestrian crossing areas and within 50 metres around them) and violations of the rights of way of pedestrians or drivers are investigated here also.

As mentioned in the methodology chapter (Section 3.2.2.2), the A8, A7, A700, A702 and A900 roads were selected to conduct the investigation of pedestrian accidents around signalised pedestrian crossing facilities. There were 942 pedestrian accidents which occurred on pedestrian crossing lines or within 50 metres of the crossing lines along the selected five roads. Figure 4.1 below illustrates the distribution of pedestrian accidents that occurred on pedestrian crossing lines or within 50 metres of the crossing line. It appears that the numbers of pedestrian accidents that occurred on pedestrian crossing lines were the highest and the number of pedestrian accidents decreased when moving up to 50 metres from such pedestrian crossings.

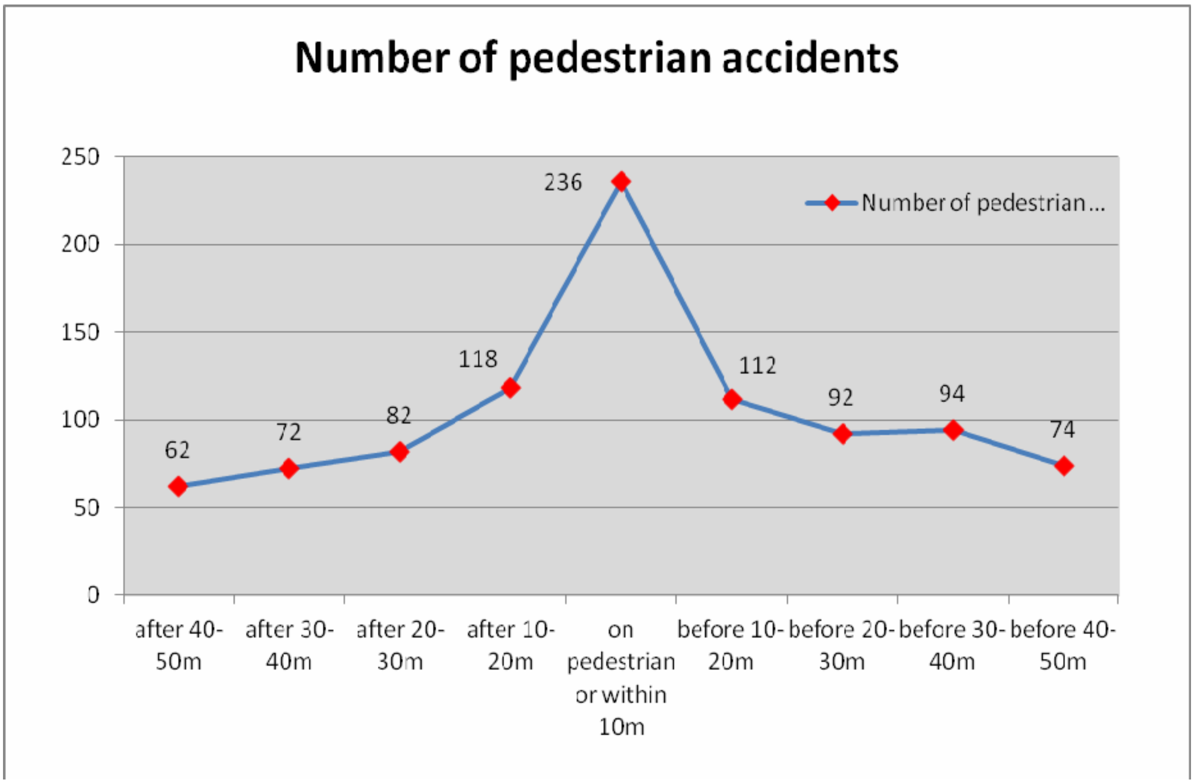

Figure 4. 1: Distribution of pedestrian accidents within 50 metres of the pedestrian crossing lines

Regarding the distribution of the severity of injury resulting from pedestrian accidents, the same situation was observed with a number of pedestrian accidents, in relation to the severity of injury sustained. According to STATS19 data, the number of those who were KSI increased on pedestrian crossing lines and decreased at a distance from such pedestrian crossing lines (Figure 4.2).

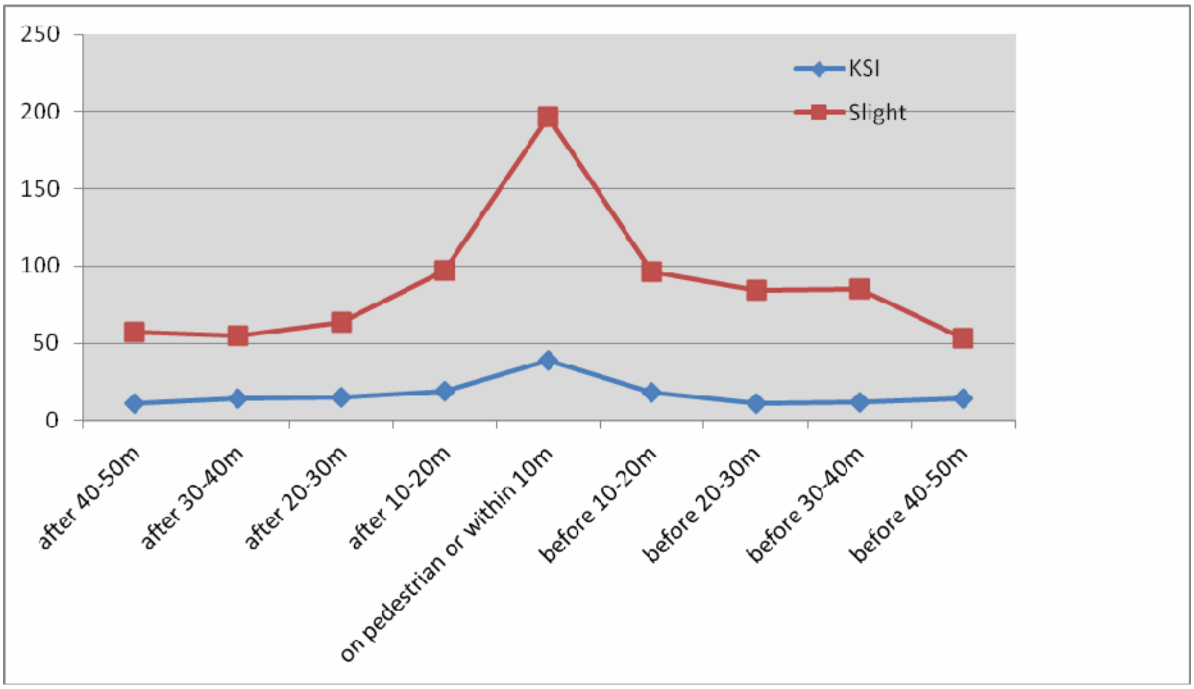

Figure 4. 2: Illustration of the distribution of the severity of injury

The severity of injury table (Table 4.1) below shows the severity of pedestrian injury resulting from pedestrian accidents which occurred on pedestrian crossing facilities or within 50 metres of them on selected roads. It can be seen that 154 individuals were KSI; and 771 were slightly injured (16.6% and 83.4% respectively).

Table 4. 1: Pedestrian severity of injury on selected roads

Variable		KSI		Slight		Total
Age group	Child (0-15)	13	12.4%	92	87.6%	105
	Adult (16-59)	116	15.9%	615	84.1%	731
	Elder (60+)	25	28.1%	64	71.9%	89
Gender	Male	92	16.2%	475	83.8%	567
	Female	62	16.6%	311	83.4%	373
Day	Weekend	43	16.2%	222	83.8%	265
	Week day	111	16.4%	566	83.6%	677
Pedestrian movement	Crossing	140	16.3%	625	81.7%	765
	Not crossing	14	7.9%	163	92.1%	177
Crossing	Driver offside	55	18.5%	243	81.5%	298
	Driver nearside	85	18.2%	382	81.8%	467
Vehicle manoeuvres	Going ahead	139	18.4%	615	81.6%	754
	Other	14	8.1%	158	91.9%	172
Type of vehicle	Motorcycle	3	16.7%	15	83.3%	18
	Car	99	16.3%	507	83.7%	606
	Bus	36	15.3%	200	84.7%	236
	Heavy goods	12	23.5%	39	76.5%	51
Time of accident	Night time	59	21.8%	212	78.2%	271
	Daytime	95	14.2%	576	85.8%	671
Light	Light	84	14.4%	500	85.6%	584
	Darkness	70	19.6%	288	80.4%	358
Weather	Fine	131	16.7%	652	83.3%	783
	Rain	21	15.6%	114	84.4%	135
Road condition	Wet	50	17.8%	231	82.2%	281
	Dry	104	15.8%	554	84.2%	658
Gender of driver	Male	123	17.35	587	82.7%	710
	Female	20	13.2%	132	86.8%	152
Month	Winter	40	16.8%	198	83.2%	238
	Spring	39	16.0%	205	84.0%	244
	Summer	41	17.0%	200	83.0%	241
	Autumn	34	15.5%	185	84.5%	219
Road type	One way street	3	21.4%	11	78.6%	14
	Dual cw**	26	19.8%	105	80.2%	131
	Single cw**	125	15.7%	669	84.3%	794
Driver's age	16-21	18	22.8%	61	77.2%	79
	22-59	119	16.9%	585	83.1%	704
	60+	5	9.3%	49	90.7%	54
Distance	On pedestrian or within 10m	39	16.5%	197	83.5%	236
	10-20	37	16.1%	193	83.9%	260
	20-30	26	14.9%	148	85.1%	174
	30-40	26	15.7%	140	84.3%	166
	40-50	26	19.1%	110	80.9%	136

*** Carriageway*

The associated factors which affect the severity of pedestrian injuries include: socio-economic factors, environmental factors and road and vehicular factors. These will be discussed in greater detail in the following section. These will be discussed in relation to the selected sites of the case studies with a reference to the general characteristics from all the UK data and all Edinburgh data as presented in Appendices A2.1 and A2.2.

4.2.1 Socio-economic factors

As discussed above, age group is one of the factors of relevance to variance in accident rates and severities. In terms of age groups and the severity of injuries, it was found that a greater number of pedestrian accidents occurred amongst the adult group (731 pedestrian accidents) than for children and the elderly (105 and 89 pedestrian accidents respectively). 12.4% of child pedestrian accidents resulted in KSI and 87.6% in individuals being slightly injured. In the adult group, almost 16% of the total number of pedestrian accidents involved KSI and 84% were slightly injured. KSI figures for the elderly group were 28.1% and 71.9% were slightly injured. From the total number of KSI, it was found that the percentage of KSI amongst the adult group was 75.3% when compared with that for children and the elderly (8.4 % and 16.2% respectively). These statistics show similar trends to the statistics from Edinburgh and the whole of the UK (see Tables A2.1b and A2.2a in Appendices A2.1 and A2.2 respectively).

Table 4. 2: Pedestrian age groups and severity of injury

Variable		**KSI**		**Slight**		**Total**
Age group	Child (0-15)	13	12.4%	92	87.6%	105
	Adult (16-59)	116	15.9%	615	84.1%	731
	Elder (60+)	25	28.1%	64	71.9%	89

The gender of the pedestrian is the second factor investigated in this section. From the table 4.3 below it appears that 60% of pedestrian accidents involved males and 40% involved females. 16.2% of the total number of male pedestrian accidents resulted in KSI and 83.8% in slight injuries. In the female group, it was found that 16.6% of KSI and 83.4% of those who were slightly injured involved female pedestrians. It appears that in terms of gender 59.7% of those KSI were males and 41.3% were females. Again these statistics are comparable with and show similar trends to the statistics from

Edinburgh and the whole of the UK (see Tables A2.1b and A2.2d in Appendices A2.1 and A2.2 respectively).

Table 4. 3: Pedestrian gender and severity of injury

Variable		**KSI**		**Slight**		**Total**
Gender	Male	92	16.2%	475	83.8%	567
	Female	62	16.6%	311	83.4%	373

Interaction analysis for pedestrian accidents and the severity of injury showed that male pedestrians from the child and adult groups received more severe injuries than those from the female groups. In the elderly group, female pedestrians were involved in more accidents and KSI than male pedestrians. It can be seen from the table that female pedestrians in the elderly group received more severe injuries (38.8%) than male pedestrians in the same group (with 15% KSI). Again, as from the above discussions, these statistics are comparable with and show similar trends to the statistics from Edinburgh and the whole of the UK (see Tables A2.1b and A2.2d in Appendices A2.1 and A2.2 respectively).

Table 4. 4: Interaction analysis of pedestrian gender/ age group and the severity of injury

Variable		**KSI**		**Slight**		**Total**
Gender/age group	Child male	10	17.5%	47	82.5%	57
	Child female	3	6.5%	43	93.5%	46
	Adult male	76	16.6%	381	83.4%	457
	Adult female	40	14.6%	234	85.4%	274
	Elderly male	6	15.0%	34	85.6%	40
	Elderly female	19	38.8%	30	61.2%	49

In terms of the age of drivers, it was found that more pedestrian accidents were caused by drivers aged between 22 and 59. The table below shows that 119 severe injuries resulted from pedestrian accidents caused by young drivers. The percentage of KSI (78.1%) caused by young drivers (22-59) was the highest amongst these groups. Male drivers caused more than 82% of pedestrian accidents on pedestrian crossing facilities or within 50m of them. It should be noted here that it was not possible to carryout comparisons with similar statistics from Edinburgh and the whole of the UK data since statistics are not available.

Table 4. 5: Driver age groups /gender and severity of injury

Variable		KSI		Slight		Total
Age of driver	Novice 16-21	18	22.8%	61	77.2%	79
	Young 22-59	119	16.9%	585	83.1%	704
	60+	5	9.3%	49	90.7%	54
Gender of driver	Male	123	17.35	587	82.7%	710
	Female	20	13.2%	132	86.8%	152

4.2.2 Environmental factors

Presence of light and time of the accidents involving pedestrian is very important and relevant. Previous research has shown that the severity of accidents may have an impact predominantly in daylight hours (e.g. King et al., 2009). This may be for a number of reasons, including constraints on the availability of human resources outside of these hours, or the fact that the majority of pedestrian accidents occur during this time (King et al., 2009). Table 4.6 below shows that a greater number of pedestrian accidents actually occurred during the daytime (671 pedestrian accidents) than at night (271). That is about 250% more accidents during day time hours than at night time. Similarly, the number of KSI was higher in daytime (95 KSI) than those at night time (59 KSI), or 160% higher during day time. This is of course as a result of the fact that the number of pedestrian crossings during day time is much higher than those crossing during night time. In other words, the impact of exposure has to be considered. Another relevant factor, is in terms of accidents occurring in the presence of light. It was found that 62% of pedestrian accidents occurred when light was present and 38% occurred during times of darkness. Pedestrian accidents that occurred in daylight resulted in 84 KSI and 500 slight injuries; whilst during darkness there were 70 KSI and 288 people suffering slight injuries. That means that 120% more KSI were reported during daylight conditions and about 170% more slight injuries were reported during daylight conditions.

In terms of weather; some of previous studies have shown the presence of rain impacts on the severity of accidents suffered by pedestrians (Lee and Abdel-Aty, 2005). Conversely, Zajac and Ivan (2003) did not find weather to be a significant factor in injury severity in incidents where a pedestrian was injured. Table 4.23 shows that a greater number of pedestrian accidents occurred when the weather was fine (783) than when it was raining (135). It was found that there were 131 KSI and 652 slight injuries when the weather was fine (16.7% and 83.3%, respectively); whilst in rainy weather there were 21 KSI and 114 slight injuries (15.6% and 84.4% respectively). Regarding the time of accidents, although the number of accident that occurred at night time was lower, the percentage of KSI resulting from pedestrian accidents that occurred at night were higher than day time (21.8% and 14,2% respectively). These statistics are comparable with and show similar trends to the statistics from Edinburgh and the whole of the UK (see Tables A2.1j and A2.2c in Appendices A2.1 and A2.2 respectively). In general, more accidents occur during daylight and during fine weather. This is of course because of the fact that there is higher traffic during fine weather and during daylight.

Table 4. 6: Environmental variables and severity of injury

Variable		KSI		Slight		Total
Time of accident	Night time	59	21.8%	212	78.2%	271
	Daytime	95	14.2%	576	85.8%	671
Light	Light	84	14.4%	500	85.6%	584
	Darkness	70	19.6%	288	80.4%	358
Weather	Fine	131	16.7%	652	83.3%	783
	Rain	21	15.6%	114	84.4%	135

With regards to the type of vehicles involved, it was found that cars were responsible for a greater number of pedestrian accidents than any other type of vehicle. Of the total number of pedestrian accidents that involved vehicles, cars were the cause of 606 pedestrian accidents (66%), and of that number there were 99 KSI and 507 with slight injuries (16.5% and 83.7%, respectively). Buses were involved in 236 pedestrian accidents (25%) resulting in 36 KSI and 200 in slight injuries (15.3% and 84.7% respectively). Heavy goods vehicles were involved in 51 pedestrian accidents (5.6%) and of that number 12 were KSI and 39 involved slight injuries (23.5% and 76.5%, respectively). Motorcycles were involved in 18 pedestrian accidents (3.4%) and the result of these accidents was 3 KSI and 15 with slight injuries (16.7% and 83.3% respectively). Again these statistics are comparable with and show similar trends to the statistics from Edinburgh since there is more cars on the roads than buses or heavy good vehicles. See Table A2.2d in Appendix A2.2. No analysis of similar UK statistics has been produced here.

In terms of vehicle manoeuvre, Table 4.7 below shows that going ahead as a vehicle manoeuvres contributed to the increase in the number of KSI pedestrian accidents. It was found that of the total number of pedestrian accidents caused by going ahead was 754 and the total number caused by other vehicle manoeuvres was 172 (81.4% and 18.6%, respectively). More than 90% of KSI resulted from going ahead vehicle manoeuvres; whilst other vehicle manoeuvres were caused by only 10% of KSI.

In consideration of the road type, it was found that a greater number of pedestrian accidents took place on single carriageways (794) than on one-way streets or dual carriageways (14 and 131, respectively). On single carriageways, there were 125 KSI in comparison with 669 experiencing slight injuries (15.7 and 84.3, respectively). In respect of dual carriageways there were 26 KSI and 105 with slight injuries. Three KSI and 11 slight injury accidents happened on one way roads. The highest percentage of accidents resulting in KSI occurred on the following road types: single carriageways with 81.1%, dual carriageways with 16.2% and one-way streets with 2.7%. With regards to road conditions; there was a higher frequency of accidents when the roads were dry (658) than when they were wet (281). 104 KSI and 554 slight injuries occurred on dry roads; whilst in wet conditions there were fewer injuries (50 KSI and 231 slight injuries). In terms of the distance of pedestrian accidents from pedestrian crossing facilities, it was found that almost the same number of pedestrian accidents occurred on pedestrian crossing lines or within 10 metres of them (236); and the number of accidents occurring between 10 and 20 metres from the pedestrian crossing lines were 230. Analysis of the incidence of such accidents was made with regards to distances beyond 20 metres to 50 metres as follows: 20-30, 30-40 and 40-50 with 174, 166 and 136 accidents, respectively. The table below shows that there were 39 KSI and 197 slight-injury pedestrian accidents on pedestrian crossing lines or within 10 metres (16.5% and 83.5%, respectively). Pedestrian accidents that occurred between 10 and 20 metres from the crossing led to 37 (16.1%) KSI and 193 (83.9%) slight injuries. It was discovered that there was the same number of KSI (26) resulting from pedestrian accidents at these distances 20-30, 30-40 and 40-50 metres. These statistics are comparable with and show similar trends to the statistics from Edinburgh and the whole of the UK (see Tables A2.1b and A2.2d in Appendices A2.1 and A2.2 respectively). In general, more accidents occur on single carriageway since most of the local streets are in this class of roads.

Table 4. 7: Vehicular/ road factors and severity of injury

Variable		KSI		Slight		Total
Vehicle manoeuvres	Going ahead	139	18.4%	615	81.6%	754
	Other	14	8.1%	158	91.9%	172
Type of vehicle	Motorcycle	3	16.7%	15	83.3%	18
	Car	99	16.3%	507	83.7%	606
	Bus	36	15.3%	200	84.7%	236
	Heavy goods	12	23.5%	39	76.5%	51
Road condition	Wet	50	17.8%	231	82.2%	281
	Dry	104	15.8%	554	84.2%	658
Road type	One way street	3	21.4%	11	78.6%	14
	Dual cw**	26	19.8%	105	80.2%	131
	Single cw**	125	15.7%	669	84.3%	794
Distance	On pedestrian or within 10m	39	16.5%	197	83.5%	236
	10-20	37	16.1%	193	83.9%	230
	20-30	26	14.9%	148	85.1%	174
	30-40	26	15.7%	140	84.3%	166
	40-50	26	19.1%	110	80.9%	136

**Carriageway

4.2.3 Other factors

The days of the week were also considered to be a factor, and the data revealed that pedestrian accidents, including KSI, occurred more frequently during the week than at weekends. On weekdays there were 111 (16.4%) instances of KSI and 566 (83.6%) slight-injury pedestrian accidents. Whereas there were 43 KSI and 222 slight injuries at the weekend (16.2% and 83.8%, respectively).

The table below (Table 4.8) indicates that pedestrians who crossed the road were at greater risk than those who did not cross the road but may have been standing in or walking along the carriageway. It was found that there were 140 KSI when pedestrians crossed the road, as opposed to 14 who were not crossing. Moreover, the number of pedestrians involved in slight injuries was 625 whilst they were crossing the road and was greater than those who were not crossing at 163. Of those who crossed the road, it was found that more were involved in accidents when they crossed the road from the driver's nearside (467) than those who crossed from the driver's offside (298). Pedestrian KSI numbered 85 with 382 slight injuries when they crossed the road from the driver's nearside (18.2% and 81.8%, respectively); in contrast to 55 KSI and 243 slight injuries when crossing the road from the driver's offside (18.5% and 81.5%, respectively). These statistics are only available for the selected sites in this analysis and therefore no comparable statistics are available from Edinburgh data or from the whole of the UK data. These statistics are comparable with and show similar trends to the statistics from Edinburgh since there is more cars on the roads than buses or heavy good vehicles. See Table A2.2d in Appendix A2.2. No analysis of similar UK statistics has been produced here.

Table 4. 8: Pedestrian behaviour and severity of injury and other factors

Variable		**KSI**		**Slight**		**Total**
Day	Weekend	43	16.2%	222	83.8%	265
	Weekday	111	16.4%	566	83.6%	677
Pedestrian movement	Crossing	140	16.3%	625	81.7%	765
	Not crossing	14	7.9%	163	92.1%	177
Crossing	Driver offside	55	18.5%	243	81.5%	298
	Driver nearside	85	18.2%	382	81.8%	467

4.3 General statistics of Right-of-Way violation

The general classifications of these accidents in relation to other variables available in this database are summarised in Table 4.9 below. It should be noted here therefore that this analysis is specific now to the five-sites data. This analysis is not generally performed in summary statistics, so there is no all-UK comparison which could be made.

It should be noted here that this analysis is not generally performed in summary statistics for the UK or for Edinburgh. Therefore, there is no all-UK nor Edinburgh comparison which could be made in this section.

Table 4. 9: General classifications of accidents in relation to ROW violation and other variables in the data set

Variable		Pedestrian (ROW).	Accident Rate.	%	Driver (ROW)	Accident Rate	%	Total.
Age	Child	36	18	34.3	69	8.6	65.7	105
	Adult	172	86	23.5	559	69.9	76.5	731
	Elderly	24	12	27.0	65	8.1	73.0	89
Severity	KSI	39	19.5	25.3	115	14.4	74.7	154
	Slight	197	98.5	25.0	591	73.9	75.0	788
Gender	Male	129	64.5	22.8	438	54.8	77.2	567
	Female	107	53.5	28.7	266	33.3	71.3	373
Time of accident	Night times	60	30	22.1	211	26.4	77.9	271
	Day times	176	88	26.2	495	61.9	73.8	671
Type of vehicle	Light	166	83	26.6	458	57.3	73.4	624
	Heavy	62	31	21.6	225	28.1	78.4	287
Day	Weekend	58	29	21.9	207	25.9	78.1	265
	Weekdays	178	89	26.3	499	62.4	73.7	677
Light	Lightness	150	75	25.7	434	54.3	74.3	584
	Darkness	86	43	24.0	272	34	76.0	358
Weather	Fine	187	93.5	23.9	596	74.5	76.1	783
	Raining	41	20.5	30.4	94	11.75	69.6	135
Road condition	Wet	82	41	29.2	199	24.9	70.8	281
	Dry	154	77	23.4	504	63	76.6	658
Crossing	Offside	87	43.5	29.2	211	26.4	70.8	298
	Nearside	114	57	24.4	353	44.1	75.6	467
Driver gender	Male	173	86.5	24.4	537	67.1	75.6	710
	Female	42	21	27.6	110	13.8	72.4	152
Driver age	0-21	18	9	22.8	61	7.6	77.2	79
	22-59	167	83.5	23.7	537	67.1	76.3	704
	60<	21	10.5	38.9	33	4.1	61.1	54
Road type	One way street	7	3.5	50.0	7	0.9	50.0	14
	Dual cw	35	17.5	26.7	96	12	73.3	131
	Single cw	194	97	24.4	600	75	75.6	794

Overall, the percentage of pedestrian accidents that occurred outside pedestrian's ROW was found to be greater than the accidents which occurred within pedestrian ROW, for all variables. it was found that the accident rates for pedestrian accidents occurred within pedestrian ROW for all age groups and were greater than the accident rate of pedestrian accidents for those outside the pedestrian ROW. The accident rates in table 4.10 below show that there were 18 pedestrian accidents that occurred within the pedestrian ROW area; whilst outside the pedestrian ROW there were 8.6 accidents for the child group. 86 pedestrian accidents occurred within the pedestrian ROW amongst the adult group; whilst outside the pedestrian ROW area there were 69.9 pedestrian accidents. For the elderly group there were 12 pedestrian accidents which occurred within the pedestrian ROW and 8.1 pedestrian accidents which occurred outside the pedestrian ROW.

Table 4. 10: Pedestrian age groups and ROW violation.

Variable		Pedestrian (ROW)	Accident Rate	%	Driver (Row)	Accident Rate	%	Total
Age	Child	36	18	34.3	69	8.6	65.7	105
	Adult	172	86	23.5	559	69.9	76.5	731
	Elderly	24	12	27.0	65	8.1	73.0	89

In terms of the severity of the injury resulting from pedestrian accidents, table 4.11 below shows that the percentages of pedestrian accidents have indicated that a greater number of severe and slight injuries occurred where the pedestrian were observed to not having the ROW (pedestrian ROW: KSI 25.3% and slight 25%). Outside pedestrian ROW: KSI was 74.7%, and slight injury was 75%). Conversely, the accident rate of those who were killed or with serious injuries occurred on the pedestrian ROW area more often than that outside the pedestrian ROW area. Thus 19.5 KSI resulted from pedestrian accidents and 14.4 KSI resulted from pedestrian accidents, respectively. Additionally, 98.5 slight injuries resulted from pedestrian accidents happening within pedestrian ROW; whilst 73.9 slight injuries resulted from pedestrian accidents occurring outside the pedestrian ROW.

Table 4. 11: Severity of injury and ROW violation

Variable		Pedestrian (ROW)	Accident Rate	%	Driver (ROW)	Accident Rate	%	Total
Severity	KSI	39	19.5	25.3	115	14.4	74.7	154
	Slight	197	98.5	25.0	591	73.9	75.0	788

Table 4.12 below shows the relationship between ROW and gender characteristics. From the Table it is apparent that 22.8% of male pedestrian accidents occurred within the pedestrian ROW zone; whilst 77.2% of them occurred outside the pedestrian ROW

zone. For female pedestrian accidents these percentages were 28.7% and 71.3%. The figures indicate that the accident rates for males within and out with the pedestrian ROW areas were 64.5 and 54.8, respectively. Accident rates for females within and out with the pedestrian ROW areas were 53.5 and 33.3, respectively.

Table 4. 12: Gender and ROW violation

Variable		Pedestrian (ROW)	Accident Rate	%	Driver (ROW)	Accident Rate	%	Total
Gender	Male	129	64.5	22.8	438	54.8	77.2	567
	Female	107	53.5	28.7	266	33.3	71.3	373

In terms of the time of pedestrian accidents, it was found, as shown in table 4.13 below, that a greater number of pedestrians were involved in accidents outside the pedestrian ROW than within the pedestrian ROW either in the daytime or at night time. Figures for the accident rates illustrate that pedestrians were involved in accidents within pedestrian ROW areas (night time: 30; daytime: 88) more than outside the pedestrian ROW (night time: 26.4; daytime: 61.9).

Table 4. 13: Time of accidents and ROW violation

Variable		Pedestrian (ROW)	Accident Rate	%	Driver (ROW)	Accident Rate	%	Total
Time of accident	Night time	60	30	22.1	211	26.4	77.9	271
	Daytime	176	88	26.2	495	61.9	73.8	671

From table 4.14 below, it appears that pedestrians were involved in accidents with light vehicles more frequently within the pedestrian ROW than outside of the pedestrian ROW (83 and 57.3, respectively); whilst the figures for pedestrian accidents involving heavy vehicles were almost the same in the pedestrian ROW and outside the pedestrian ROW, at 31 and 28.1%, respectively.

Table 4. 14: Type of vehicle and ROW violation

Variable		Pedestrian (ROW)	Accident Rate	%	Driver (ROW)	Accident Rate	%	Total
Type of vehicle	Light	166	83	26.6	458	57.3	73.4	624
	Heavy	62	31	21.6	225	28.1	78.4	287

Table 4.15 below shows correlations between ***Day of the week and ROW violation.*** From the table it appears that 21.9% of pedestrian accidents occurred within the pedestrian ROW zone on weekend days; whilst 78.1% of them occurred outside the pedestrian ROW zone. For the pedestrian accidents which occurred on weekdays these percentages were 26.3% and 73.7%. The figures indicate that the accident rates for pedestrian accidents, which occurred on weekend days within and out with the pedestrian ROW areas were 29 and 25.9, respectively. Accident rates for pedestrian accidents which occurred on weekdays within and outside the pedestrian ROW areas were 89 and 62.4%, respectively.

Table 4. 15: Day of the week and ROW violation

Variable		Pedestrian (ROW)	Accident Rate	%	Driver (ROW)	Accident Rate	%	Total
Day	Weekend	58	29	21.9	207	25.9	78.1	265
	Weekdays	178	89	26.3	499	62.4	73.7	677

In term of lighting, table 4.16 shows that although the percentage of pedestrian accidents which occurred within the pedestrian ROW in light or darkness was less than those that occurred outside the pedestrian ROW, the accident rate showed that pedestrian accidents occurred within pedestrian ROW to a greater extent than those which occurred outside the pedestrian ROW see Table 4.16 below.

Table 4. 16: Lightness and ROW violation

Variable		Pedestrian (ROW)	Accident Rate	%	Driver (ROW)	Accident Rate	%	Total
Light	Lightness	150	75	25.7	434	54.3	74.3	584
	Darkness	86	43	24.0	272	34	76.0	358

Figures for the accident rate in Table 4.17 below show that in fine weather; there were 93.5 pedestrian accidents within the pedestrian ROW and 74.5 pedestrian accidents outside the pedestrian ROW. In terms of rainy weather there were 20.5 pedestrian accidents within the pedestrian ROW and 11.75 pedestrian accidents outside the pedestrian ROW.

Table 4. 17: Weather and ROW violation

Variable		Pedestrian (ROW)	Accident Rate	%	Driver (ROW)	Accident Rate	%	Total
Weather	Fine	187	93.5	23.9	596	74.5	76.1	783
	Raining	41	20.5	30.4	94	11.75	69.6	135

Table 4.18 below shows the statistics relating to the relationship of ROW and the road conditions. From the table, it appears that the figures indicate that the accident rate for the pedestrian accidents that occurred in wet road conditions within and out with the pedestrian ROW areas were 41 and 24.9, respectively. Accident rates for pedestrian accidents which occurred in dry road condition within and out with the pedestrian ROW areas were 77 and 63, respectively.

Table 4. 18: Road conditions and ROW violation

Variable		Pedestrian (ROW)	Accident Rate	%	Driver (ROW)	Accident Rate	%	Total
Road conditions	Wet	82	41	29.2	199	24.9	70.8	281
	Dry	154	77	23.4	504	63	76.6	658

In terms of pedestrian movements (Table 4.19), either crossing from the driver nearside or offside, figures for the accident rate for pedestrians crossing from the driver offside showed that 43.5 of pedestrian accidents occurred within the pedestrian ROW areas; 26.4 pedestrian accidents occurred outside the pedestrian ROW. A value of 57 pedestrian accidents occurred within the pedestrian ROW when pedestrians crossed the road from the driver nearside whilst 44.1 of pedestrian accidents have occurred outside the pedestrian ROW.

Table 4. 19: Pedestrian crossing behaviour and ROW violation

Variable		Pedestrian (ROW)	Accident Rate	%	Driver (ROW)	Accident Rate	%	Total
Crossing	Offside	87	43.5	29.2	211	26.4	70.8	298
	Nearside	114	57	24.4	353	44.1	75.6	467

The figures in Table 4.20 indicate that the accident rate caused by male drivers within the pedestrian ROW was 86.5 for pedestrian accidents; and 67.1 pedestrian accidents were outside the pedestrian ROW. There were 21 pedestrian accidents caused by female drivers within the pedestrian ROW and 13.8 pedestrian accidents outside the pedestrian ROW.

Table 4. 20: Gender of driver and ROW violation

Variable		Pedestrian (ROW)	Accident Rate	%	Driver (ROW)	Accident Rate	%	Total
Driver's gender	Male	173	86.5	24.4	537	67.1	75.6	710
	Female	42	21	27.6	110	13.8	72.4	152

In terms of the driver age group, table 4.21 below shows that figures for accidents rate for the older driver group indicate that this group were involved in 10.5 pedestrian accidents within the pedestrian ROW and 4.1 pedestrian accidents occurred outside the pedestrian ROW. With regards to the driver age groups less than 22 and between 22 and 59 were involved in 9 pedestrian accidents and 83.5 pedestrian accidents respectively within the pedestrian ROW; there were 7.6 pedestrian accidents for the driver age group less than 22 and there were 67.1 pedestrian accidents for drivers in the age group between 22-59 outside the pedestrian ROW.

Table 4. 21: Driver age group and ROW violation

Variable		Pedestrian (ROW)	Accident Rate	%	Driver (ROW)	Accident Rate	%	Total
Driver's age	0-21	18	9	22.8	61	7.6	77.2	79
	22-59	167	83.5	23.7	537	67.1	76.3	704
	60<	21	10.5	38.9	33	4.1	61.1	54

Table 4.22 below shows that one way street accident rate figures indicate that there were 3.5 pedestrian accidents, which occurred within the pedestrian ROW and 0.9 pedestrian accidents which occurred outside the pedestrian ROW. Figures describing the accident rate for dual carriageways have indicated that there were 17.5 pedestrian accidents, which occurred within the pedestrian ROW and 12 pedestrian accidents which occurred outside the pedestrian ROW. The single carriageway accident rate indicated that there were 97 pedestrian accidents within the pedestrian ROW and 75 pedestrian accidents which have occurred outside the pedestrian ROW.

Table 4. 22: Road type and ROW violation

Variable		Pedestrian (ROW)	Accident Rate	%	Driver (ROW)	Accident Rate	%	Total
Road type	One way street	7	3.5	50.0	7	0.9	50.0	14
	Dual cw**	35	17.5	26.7	96	12	73.3	131
	Single cw**	194	97	24.4	600	75	75.6	794

** Carriageway

4.4 Summary

In this chapter, preliminary investigations of three important statistical trends describing pedestrian accidents have been undertaken. General statistical trends for pedestrian accidents that occurred in the selected sites have been presented and compared, where feasible with similar statistics of overall accidents in Edinburgh and those of the whole of the UK over 14 years have been presented. These general trends covered socio-economic factors, vehicle factors, environment factors and road factors. In general, all the statistics obtained for the selected sites strongly agrees with the overall statistics for the Edinburgh city and for the whole of the UK. For example, in terms of age groups and the severity of injuries, it was found that a greater number of pedestrian accidents occurred amongst the adult group than for children and the elderly. The gender of the pedestrian is the second factor investigated, and results show that higher percentages of pedestrian accidents involved males than involved females. In addition, statistics show that a greater number of pedestrian accidents actually occurred during the daytime and caused by the car.

Finally, the investigation of the ROW of pedestrians at the signalised pedestrian crossing has been discussed and investigated. Investigations of all the factors obtained from STATS19 database has been carried out in relation to the ROW.

Chapter 5
Modelling pedestrians' injury severity

5.1 Introduction

Chapter 4 presented a descriptive analysis of the variables that are considered to be associated with pedestrian injury severity and right-of-way violations at signalised pedestrian crossings. The descriptive data that was presented in Chapter 4 provided a general examination of the univariate relationship between pedestrian injury severity and the independent variables considered. This chapter presents a multivariate examination of the determinants of pedestrians' injury severity (i.e. controlling for all factors that influence pedestrian injury severity) according to car accidents involving pedestrians, using four different modelling approaches. In most of previous research in this area, one or two modelling approaches have been used, based on the preference of the researcher, or her/his experience. Therefore, there is an opportunity to assess and investigate the data set available using the four different models.

5.2 Investigation of correlations

Before the investigation of the calibrated models describing injury severity and pedestrian accidents, the correlations between the independent variables considered in these models are assessed. Table 5.1 below shows the correlation matrix of these variables to assess the presence of multicollinearity. In the case where multicollinearity is observed between some variables, there might be problems with the calibrated models (e.g. wildly changing coefficients when an additional variable of the highly correlated variables is included/ removed or unreasonable coefficient magnitudes will be obtained). No variables were found to be correlated with each other (i.e. correlation that is over 0.5 can cause multicollinearity with the exception of the two values discussed below).

It should be noted here that two correlation values were found to be higher than 0.5. Firstly, a correlation value of 0.682 was observed for the variables "Old gender" and the "Age groups". This might highlight the positive correlation between these two variables (see also interactive tables in chapter 4, table 4.4). The second high correlation value of 0.772 was found between “Type of Road” and “Width of lane”. This high correlation may also be a result of the positive correlation between both variables, as discussed above in reference to table 4.4. Despite these high correlations, the variables have been maintained in the models, while caution has been employed when interpreting the results.

Table 5.1: Correlation matrix between the variables in the model of pedestrian vs. car accidents.

Variables	Severity	Casualties age groups	Old gender group	Drivers age groups	Accident time	Pedestrian movement	Vehicles manoeuvres	Vehicle type	Crossing type	Road type	Width	Drivers offside	week day	Road conditions	Weather	Distance
Severity	1	-.110**	.086**	.069*	.100**	.099**	.104**	.031	.109**	.051	-.071*	-.031	-.005	.041	.027	-.011
Casualties' age groups		1	-.682**	.004	-.019	.042	.030	-.118**	.011	.007	-.067*	-.015	.002	-.074*	.061	.016
Old gender group			1	-.043	-.120**	-.011	-.040	.049	-.021	-.013	.039	-.001	-.033	.046	-.090**	-.004
Drivers' age groups				1	.126**	-.006	.059	-.088*	-.037	-.008	-.005	.027	.075*	.046	-.035	-.057
Accident time					1	.096**	.083*	-.257**	.023	.023	-.012	-.102**	.306**	.128**	-.022	.010
pedestrian movement						1	.037	-.344**	.067*	.054	-.060	-.327**	.011	.084**	.001	.097**
Vehicles manoeuvres							1	-.124**	.092**	-.046	.043	-.073*	.041	.027	-.021	-.044
Vehicle type								1	-.029	-.054	.028	.215**	-.085**	-.103**	.050	-.112**
Crossing type									1	.051	-.075*	-.019	.037	.043	.004	.076*
Road type										1	-.772	-.069*	.063	.013	.033	.048
Width											1	.101**	-.022	.043	-.021	-.010
Drivers offside												1	.004	-.135**	.070*	-.100**
Week day													1	.073*	-.045	-.038
Road conditions														1	-.395**	.060
Weather															1	-.089**
Distance																1

5.3 Model Calibrations for severity of injury

The first set of models presented here is the model detailing pedestrians' injury severity in pedestrian vs. car type accidents. A preliminary analysis (i.e. descriptive analysis) of these variables has been conducted in Chapter 4. These variables include pedestrians/motorist attributes, vehicle characteristics, roadway/geometric factors, weather/temporal factors and crash characteristics. The following sections present and discuss the calibrated models Table 5.2 below shows the Definition of all variables that used in the models.

Table 5.2: Variables' definition used in models

Variable	Category
Age group	Child (0-15)
	Adult (16-59)
	Elder (60+)
Gender	Male
	Female
Day	Weekend
	Week day
Pedestrian movement	Crossing
	Not crossing
Crossing	Driver offside
	Driver nearside
Vehicle manoeuvres	Going ahead
	Other
Type of vehicle	Motorcycle
	Car
	Bus
	Heavy goods
Time of accident	Night time
	Daytime
Light	Light
	Darkness
Weather	Fine
	Rain
Road condition	Wet
	Dry
Gender of driver	Male
	Female
Month	Winter
	Spring
	Summer
	Autumn
Road type	One way street
	Dual carriage way
	Single carriage way
Driver's age	16-21
	22-59
	60+
Distance	On pedestrian or within 10m
	10-20
	20-30
	30-40
	40-50

5.3.1 Multinomial Logit Model

The first model calibrated in this section is the multinomial logit model. In this model, we assume that the dependent variable consists of several categories and that these have no natural ordering. Thus, we used a maximum likelihood estimator (MNL). As discussed earlier, the MNL model has been reported in the literature in a number of investigations of accidents and injury severities (see for example, Kockelman and Kweon, 2002).

For the MNL model estimated here, there are three categories for the dependent variable. These are: fatal, serious and slight. The slight category was used as a reference category. The discussions of the results are presented in this section. A total of 942 pedestrian casualties resulting from the pedestrian-vehicle accidents that took place at signalised junctions were extracted. Of these pedestrian casualties involved in vehicle-pedestrian accidents at signalised junctions, 1% are classified as fatal (nine observations), 15.4% are classified as serious injuries (145 observations), and 83.7% are classified as slight (788 observations). Table 5.2 provides a list of the independent variables that have been included in the model while Table 5.3 below shows the coefficients' estimated results for the MNL model, the p-values (measure of significance), the ρ^2 and the Log-likelihood values. The model has a pseudo- ρ^2 measure of 0.194. As for predicting each injury-severity category, the classification accuracy for fatal, serious and slight was 33.3%, 4.6%, and 99% respectively. These percentages don not seem to be logical or as expected, since the percentage of predicted serious injuries should be more proportionate to the number of observations for that category, and should be higher than that of the fatal injuries. The results do not show the expected pattern. This might be a result of the known weakness of the multinomial logit model where there exists any correlation between the categories of dependent variable; in this case there is an order, or correlation between the three categories of injury severities and therefore, the results are not very accurate.

Table 5.3: Summary statistics and estimation results of the MNL aggregate model in pedestrians-car accidents

Variable	Categories of each variable	Frequency (%)	Fatal			Serious		
			Coefficients	(p-value)	Odds	Coefficients	(p-value)	Odd
Intercept	---	----	-29.09	(0.976)	--	-16.69	(0.000)	--
Age group	Child (0-15)	105 (11.1%)	-14.36	(0.965)	5.79	-1.60	(0.001)	0.202
	Adult (16-59)	731 (77.6)	-3.34	(0.010)	0.35	-1.55	(0.000)	0.212
	Old (60+)	89 (9.4)	0	0	--	0	0	--
Old gender	Old female(60+)	49 (6.8)	1.34	(0.433)	3.815	-1.59	(0.015)	0.205
	Old male	40 (6.7)	0		---	0	0	--
Time of accidents	Night time	271 (28.8)	3.38	(0.003)	29.310	0.52	(0.03)	1.689
	Day time	671 (71.2)	0	0	--	0	0	--
Pedestrian movement	Crossing	765 (81.2)	1.44	(0.26)	4.206	1.39	(0.001)	4.007
	Not crossing	177 (18.8)	0	0	--	0	0	--
Vehicle manoeuvre	Going ahead	754 (80.0)	2.80	(0.071)	16.452	0.96	(0.004)	2.598
	Other	172 (18.3)	0	0	--	0	0	--
Type of vehicle	Bus and goods vehicles	287 (30.5)	5.37	(0.003)	214.916	0.39	(0.119)	1.476
	Other	655 (69.5)	0	0	--	0	0	--
Crossing type	Pelican	232 (24.6)	1.32	(0.123)	3.731	0.49	(0.026)	1.630
	Junction	710 (75.4)	0	0	--	0	0	--
Road width	1-2 lanes	582 (61.8)	-1.19	(0.267)	0.305	(0.112)	0.687	(0.112)
	3-4 lanes	212 (22.5)	0	0	--	0	--	0
First impact	Crossing from driver offside	298 (31.6)	0.27	(0.789)	1.312	0.04	(0.839)	1.045
	Other	644 (68.4)	0	0	--	0	0	--
The day of accidents	Weekend	265 (28.1)	-1.30	(0.238)	0.273	-0.11	(0.639)	0.895
	Weekdays	677 (71.9)	0	0	--	0	0	--
Road condition	Wet	281 (29.8)	0.14	(0.902)	1.148	0.19	(0.476)	1.213
	Dry	658 (69.9)	0	0	--	0	0	--
Location of pedestrian accidents	On pedestrian or within 10 m	236 (25.1)	0.54	(0.64)	1.719	-0.31	(0.331)	0.733
	10-20	230 (24.4)	-0.02	(0.986)	0.978	-0.27	(0.402)	0.767
	20-30	174 (18.5)	-0.95	(0.514)	0.387	-0.24	(0.475)	0.784
	30-40	166 (17.6)	-3.02	(0.189)	0.049	-0.24	(0.488)	0.790
	40-50	136 (14.4)	0	0	--	0	0	--

Summary Statistics

-2 Log-likelihood at zero = 744.108
-2 Log-likelihood at convergence = 637.766
Log-likelihood ratio index (ρ^2) = 0 .194
The number of fatal accidents that were correctly predicted: 3 (33.3%)
The number of serious injuries that were correctly predicted: 6 (4.6%)
The number of slight injuries that were correctly predicted: 663 (99%)
Observations = 942 (Fatal: 1%; Serious: 15.4%; Slight: 83.7%)

With regards to age group, the negative sign of the coefficient for child and adult groups indicates that for one unit increase in pedestrian accidents that involved the child and adult groups, the relative risk of being involved in a slight accident is higher than the risk of fatality. That indicates that the relative risk is decreased when pedestrian accidents that involved child and adult age groups is increased by exp (-14.36 and -3.34) = 5.79 and 0.04 respectively. Moreover, the same age groups were more in risk to involve in slight accidents than serious accidents. Therefore, the relative risk is decreased when pedestrian accidents that involve child and adult age groups increased by exp (-1.60 and -1.55) = 0.20 and 0.21 respectively. However, this variable is not statistically significant in the model at a 95% level of significance for the child age group in the fatal category (p-value = 0.965) while it statistically significant in the serious category.

In terms of the older gender based groups, the positive sign of the coefficient for old females indicates that for one unit increase in old female group, it is expected that the ratio of relative risk of being involved in fatal accidents over those causing slight injury is higher than for the group of males by exp (1.34) = 3.81. On the other hand, the negative sign for old females regard to serious injury; indicates that for one unit increase in pedestrian accidents involving old females, it is expected that for a dichotomous predictor variable such as the old female group, the ratio of relative risk of being involved in a serious incident decreased, as did that of slight injury for females with exp (-1.59) = 0.21. Again, this variable is not statistically significant in the model at a 95% level of significance for the fatal category (p-value = 0.433).

In terms of the time frame in which pedestrian accidents take place, the positive sign of the coefficient for the night time indicates that for one unit increase in pedestrians involved in accidents at night time, it is expected that a ratio of relative risk of being involved in fatal accidents at night time over slight injury is higher than in the day time and is equal to exp (3.38) = 29.31. Moreover, for the ratio of relative risk of being involved in a serious injury at night time increased over slight injury is exp (0.52) = 1.69. This variable is statistically significant in the model at 95% level of significance (p-value = 0.003).

With regards to the movement of pedestrians, a positive sign for the crossing movement indicates that for one unit increase in pedestrian accidents while crossing, it can be said that the ratio of relative risk of being involved in a fatal incident when crossing a road increases the risk of fatal injury over slight injury more than standing or walking in the pavement; exp (1.39) = 4.21. With regard of serious injury, , it can be expected that the ratio of relative risk of being involved in a serious injury when pedestrians are crossing the road increased the seriousness of the injury beyond slight injury, comparing standing or walking on the pavement with exp (1.39) = 4.01. In terms of the statistical significance of this variable, the p-value is only statistically significant at 95% level for the serious category (p= 0.001).

For vehicle manoeuvre, a positive sign for the going ahead manoeuvre indicates that for one unit increase in pedestrians hit by going ahead vehicle manoeuvres, it can be said that the ratio of relative risk to be involved in a fatal incident during a going ahead manoeuvre increases over slight injury than during other vehicle manoeuvres is exp (2.80) = 16.45. This could also be a result that most vehicles will be performing a “going ahead” action, rather than “other” manoeuvres types. Also, it could be said that the ratio of relative risk of being involved in a serious incident when performing an ahead manoeuvre is increased over slight injury when compared with other vehicle manoeuvres with exp (0.96) = 2.59. In terms of the statistical significance of this variable, the p-value is statistically significant.

In terms of type of vehicle (light vehicles and heavy vehicles), the positive sign of the coefficient for buses and heavy goods vehicles indicates that for one unit increase in pedestrians involved in accidents with buses and heavy goods vehicles, the ratio of relative risk of being involved in a fatal incident is higher than slight by exp (5.37) = 214.92. The same results can be said for the serious injury when pedestrian were hit by heavy vehicles (buses and heavy goods vehicles) over slight injury with exp (0.39) = 1.48. This coefficient of this variable is statistically significant in the fatal category at 95% level of significance (p-value = 0.003).

In regards to the type of pedestrian crossing facility, the results show that pelican crossings or (similar type of crossing) are more likely to be associated with fatal accidents; this is indicated by the positive sign of the coefficient for pelican or similar crossings. For one unit increase in pedestrian accidents crossing at a pelican crossing (or similar crossing facility), the ratio of relative risk of fatal accidents for pedestrians involved in an accident over slight injury accident is 3.7 ($= e^{1.32}$). Moreover, it can be expected that the ratio of relative risk rises for pedestrian who are involved in pedestrian accidents on pelican or similar type crossings, over slight injury for pedestrians who were involved in pedestrian accidents on junctions; exp (0.49) = 1.63. The coefficients of this variable are not statistically significant in the fatal/ serious categories at 95% level of significance.

In terms of the width of a single carriageway, the ratio of relative risk of being involved in a fatal accident decreases when more pedestrians are hit in one to two lanes, over the slight injury as a consequence of pedestrian accidents with three to four lanes is exp (-1.19) = 0.31. with regards of being involved in serious accidents, the ratio of relative risk of suffering a serious injury decreased when more pedestrians were hit in one or two lanes, over slight when pedestrian accidents occurred over three or four lanes with exp (-.38) = 0.69. In regards to the day of the week on which pedestrians were involved in accidents, the ratio of relative risk of fatality decreased when pedestrians were involved in incidents at weekends over slight injury than accidents occurring on week days is exp (-1.30) = 0.3. Moreover, the ratio of relative risk of seriousness decreased when pedestrians were involved in accidents at the weekends as compared to slight injury when accidents occurred on week days with exp (-.11) = 0.9. Again, the coefficients of this variable are not statistically significant in the fatal/ serious categories at 95% level of significance.

In summary, the overall statistical significance of the MNL model in terms of the ρ^2 is reasonably good. However, the statistical significance of the independent variables is not very good. This could be a result of the known characteristics of the MNL model and the restricted assumptions about the error terms in the MNL model. In this case, most of the independent variables are not statistically significant in the model at 95% level. The statistically significant variables in both fatal and serious categories in the MNL model are the adult age group, the time of accident and vehicle manoeuvre. Because of the nature of the data, and that there is an order in the three categories of the dependent variable, the ordered logit and ordered probit modelling approaches might provide better results. These models' results are presented in the following sections.

5.3.2 The Ordinal Logit/ Probit Models

The second set of models calibrated in this section is the Ordinal Logit/Probit model. As discussed earlier, the ordinal model has been reported in the literature in a number of investigations of accident injury severities (see for example Zajac and Ivan, 2003; Lee and Abdel-Aty, 2005; Siddiqui et al., 2006). In this case, injury severities have been considered as falling into three categories (fatal, serious and slight). Due to the increasing nature of the ordered levels in the dependent variable, the interpretation of the parameter β', is as follows: A positive value of an estimated coefficient implies that an increase in the variable will unambiguously increase the probability of the highest-ordered discrete category being selected (i.e. fatal), and unambiguously decrease the probability of the lowest-ordered discrete category (i.e. slight). As discussed earlier in Chapter 3, the Pseudo ρ^2 values should be assessed with care. Logistic regression does not have an equivalent to the R^2 that is found in OLS regression; however, many people have tried to devise one. There are a wide variety of pseudo ρ^2 statistics which can give contradictory conclusions. Because these statistics do not represent the same as R^2 in OLS regression (the proportion of variance of the response variable explained by the predictors), it is normally suggested that interpretation of these values should be undertaken with great caution. In general, the values of ρ^2 are expected to be lower than those of the R^2 in OLS.

As discussed earlier, a pseudo- ρ^2 (goodness-of-fit) measure is presented even though there is no universally accepted goodness-of-fit measure for the ordered response models (Kennedy, 1993; Long, 1997). A pseudo- ρ^2 measure that has values between zero and one has no natural interpretation as its purpose is to measure the strength of linear component models (Greene, 2003). That is, unlike the case of the linear regression model, where the coefficients are chosen to maximise pseudo- ρ^2, in ordered response models the coefficient estimates do not maximise any goodness-of-fit measure. For regression models with a categorical dependent variable, it is not possible to compute a single ρ^2 statistic that has all of the characteristics of R^2 in the linear regression model, so these approximations are computed instead. There are a number of possible methods presented in the literature to calculate the coefficient of determination. Cox and Snell's ρ^2 (1989) is based on the log likelihood for the model compared to the log likelihood for a baseline model. However, with categorical outcomes, this has a theoretical maximum value of less than one, even for a "perfect" model. Nagelkerke's

R^2 (1991) is an adjusted version of the Cox and Snell ρ^2 that adjusts the scale of the statistic to cover the full range from zero to one. McFadden's ρ^2 (1974) is another version, based on the log-likelihood kernels for the intercept-only model and the full estimated model. In this research, however, Nagelkerke's ρ^2 is selected for comparisons of the models.

Another additional parameter to measure statistical significance of the model proposed by Ben-Akiva and Lerman (1985) is a fit measure (i.e. CA: classification accuracy); this examines the percentage of outcomes of dependent variables that are correctly predicted. The model's prediction accuracy is reported in table form for each crash model. The interpretation of CA should proceed with caution, since while analysing imbalanced datasets, the less frequent outcome tends to be predicted very poorly (Cramer, 1999).

Similar to the case of the MNL model, a total of 942 pedestrian casualties resulting from pedestrian-vehicle accidents that took place at signalised junctions were extracted (of these pedestrian casualties that were involved in vehicle-pedestrian accidents at signalised junctions, 1% are classified as fatal (nine observations), 15.4% were classified as serious injury (145 observations), and 83.7% were classified as slight (788 observations). In this case, the slight category is taken as the reference case. Table 5.4 below shows the coefficients' estimated results of the Ordinal response models, the p-values (measure of significance), the ρ^2 and the Log-likelihood values. See Table 5.2 for the independent variables included in the ordinal logit and ordinal probit models.

The ordinal logit model has a pseudo- ρ^2 measure of 0.137 and the ordinal probit has a pseudo- ρ^2 measure of 0.141. For predicting each injury-severity category, the classifications accuracy for fatal, serious and slight injuries in both models were 1%, 15.4%, and 83.7%, respectively. These predictions, unlike those obtained from the MNL model, are more logical and proportionate to the distribution of accidents in these three categories.

Table 5.4: Summary statistics and estimation results of the Ordinal Logit/ Probit aggregate models by pedestrian vs. car accidents

Variable		Categories of each variable	Frequency (%)	Ordinal Logit	Ordinal Probit
				Coefficient (p-value)	Coefficient (p-value)
Intercept	Fatal	--	--	-20.234 (0.000)	-7.947 (0.000)
	Serious	--	--	-17.171 (0.000)	-7.947 (0.000)
Factors	Age group	Child (0-15)	105(11.1%)	1.734 (0.000)	0.954 (0.000)
		Adult (16-59)	731 (77.6)	1.687 (0.000)	0.945 (0.000)
		Old (60+)	89 (9.4)	0	0
	Old gender	Old female (60+)	49 (6.8)	1.185 (0.035)	0.636 (0.043)
		Old male(60+)	40 (6.7)	0	0
	Driver age group	16-21	79 (8.4)	-0.958 (0.092)	-0.539 (0.075)
		22-59	704 (74.7)	-0.572 (0.254)	-0.331 (0.207)
		60+	54 (5.7)	0	0
	Time of accidents	Night time	271 (28.8)	-0.702 (0.003)	-0.428 (0.001)
		Day time	671 (71.2)	0	0
	Pedestrian movement	Crossing	765 (81.2	-1.259 (0.001)	-0.598 (0.002)
		Not crossing	177 (18.8)	0	0
	Vehicle manoeuvre	Going ahead	754 (80.0)	-0.993 (0.002)	-0.536 (0.001)
		Other	172 (18.3)	0	0
	Type of vehicle	Bus and goods vehicles	287 (30.5)	-0.620 (0.010)	-0.345 (0.009)
		Other	655 (69.5)	0	0
	Type of signalized pedestrian crossing	Pelican	232 (24.6)	-0.557 (0.009)	-0.317 (0.008)
		Junction	710 (75.4)	0	0
	Type of road	One way street	14 (1.5)	-14.113 (0.000)	-4.752 (0.000)
		Dual carriageway	131 (13.9)	-13.926 (0.000)	-4.738 (0.000)
		Single carriageway	794 (84.3)	-13.930	-4.697
		Other	3 (0.3)	0	0
	Width of single carriageway	1-2 lanes	582 (61.8)	0.464 (0.044)	0.248 (0.052)
		3-4 lanes	212 (22.5)	0	0
	The day of accidents	Weekend	265 (28.1)	0.176 (0.444)	-4.752 (0.000)
		weekdays	677 (71.9)	0	-4.738 (0.000)
	Road condition	Wet	281 (29.8)	-0.233 (0.376)	-4.697(0,408)
		Dry	658 (69.9)	0	0
	Location of pedestrian accidents	On pedestrian crossings or within 10m	236 (25.1)	0.258 (0.405)	0.187 (0.275)
		10-20	230 (24.4)	0.265 (0.391)	0.174 (0.308)
		20-30	174 (18.5)	0.262 (0.432)	0.189 (0.305)
		30-40	166 (17.6)	0.288 (0.386)	0.207 (0.260)
		40-50	136 (14.4)	0	0

Summary Statistics
-2 Log-likelihood at zero = 744.108
-2 Log-likelihood at convergence = 670.671
Log-likelihood ratio index-logit (ρ^2) = 0.137, Log-likelihood ratio index-probit (ρ^2) = 0.141
Observations = 942 (Fatal: 1%; Serious: 15.4%; Slight: 83.7%)

It should be noted here that the discussion in this section will be specific to the ordinal logit model's results. The ordinal probit model results are very similar, and therefore are not repeated here, unless otherwise reported. The absolute value of the constants in the ordinal logit model (-20.234 (fatal) and -17.171 (serious) are higher than they are in the ordinal probit model, which shows slight improvement of the overall goodness of fit of the ordinal probit model over the ordinal logit model. For the statistical significance of the coefficients of the independent variables, the following discussions are provided.

While the coefficients of fatal and serious for the age groups are negative, it is expected to have a positive sign for child and adult groups. The coefficient signs presented in table 5.4 for child and adult (1.73 and 1.69 respectively), which is agreeable with expectations. This indicates that those groups were more involving in slight injury than fatal or serious. On other hand, old pedestrian group were in greater risk of involve in fatal or serious injury. The coefficients of this variable are all statistically significant in all categories of the model at 95% level of significance (p-value = 0.000). This is obviously an improvement in the statistical significance of the model over the MNL model as discussed. The indication of negative sign of coefficient for driver age group between 16-21 and 22-59 that those driver age group are more likely to be involved in fatal or serious accidents. One-unit increase in driver age groups (16-21 and 22-59), it is expected that a 0.09 and 0.25 respectively will occur, increasing the log odds of fatal and serious injury, given all the other variables in the model are held to be constant. The coefficients of this variable are less statistically significant especially for the driver age group of 22-59. This might be a result of the large variations/sample size in this age group which represents 74.7% of the whole data set. The Ordinal Probit model has very similar results to those of the Ordinal Logit model.

In consideration of the severity of injury related to accidents time, the negative sign of the coefficient for time of accident presented in table 5.4 shows that more KSI accidents in the night time than those occurred in the time. For one-unit increase in pedestrian accidents during the night time, a 0.70 increase in log odds of fatal and serious injury would be expected, given that all of the other variables in the model are held to be constant. Again, this variable is statistically significant in the model at 95% level of significance. The negative sign for the coefficient for the pedestrian movement (crossing the road or not crossing), indicates that the pedestrians who crossed the road from the driver's nearside and driver's offside were more likely to be involved in fatal or serious accidents than pedestrians who were standing or walking along the carriageway. For a one-unit increase in crossing pedestrians, a 1.26 increase in likelihood of the pedestrian having a fatal or serious injury is expected, assuming all the other variables in the model are held constant. The statistical significance of this variable is acceptable at 95% level of significance.

From the results obtained from the model, it appears that pedestrian were more likely to be involved in fatal or serious accidents when the vehicle is going ahead than performing other manoeuvres. For a one-unit increase in pedestrians that were involved in going ahead manoeuvre accidents, a 0.99 increase in log odds of fatal and serious injury is expected, given all of the other variables in the model are held constant, and the coefficient of the variable is also statistically significant in the model at 95% level of significance. For the type of vehicle, as expected, heavy vehicles are involved in more fatal or serious accidents than light vehicles. The negative sign of the coefficient of heavy goods vehicles and buses indicates that one unit increase in these vehicles being involved in pedestrian accidents, a 0.62 increase in pedestrians with a fatal or serious injury is expected, given all of the other variables in the model are held constant, which is also statistically significant in the model. The type of crossing facilities and the width of carriageway variable are found to be statistically significant in the model at 95% level. Therefore, pelican or similar types of crossing were more associated with fatal or serious accidents than those accidents occurred around junction crossings. one-unit increase in the pedestrian accidents that occurred at pelican, puffin and toucan crossings, a 0.56 increase in log odds of being fatal and serious injury is expected, given all of the other variables in the model are held constant. Pedestrians were more in risk to be involved in fatal or serious accidents in three or more lanes in single carriageway than one or two lanes. A one unit increase in pedestrian accidents occurring over one or two lanes, a 0.46 decrease in pedestrians with a fatal or serious injury is expected, given all of the other variables in the model are held constant.

The above discussed results seem to be show improvements in the results of the ordinal response models over those results obtained from the MNL model in terms of the statistical significance of the independent variables. The overall goodness of fit of those models however is less statistically significant than the case of the MNL (0.194) model. This is despite that the ordered probit model (0.141) shows slightly better goodness of fit over that of the ordered logit model (ρ^2=0.137). However, the two statistical criteria should be taken into consideration for the assessment f the models. Moreover, the statistical significance of the independent variables in the model are very important. The binary model has also been tested using the same data set. The following section presents the results obtained from this model.

5.3.4 Binary Logit regression:

In logistic regression, one model measures the dependent variable in terms of one or more independent variables. If the dependent variable has just two categories then it is a binary model. A binary model for the severity of injury resulting from pedestrian accidents that occurred on pedestrian crossing areas or within 50 metres of them is calibrated. In this case, the KSI category is taken as the reference case. The model's results are presented in Table 5.6 below. The total of 942 pedestrians' casualties used in previous models, is used also in the calibration of the binary logit model. As discussed above, Table 5.2 shows the definition of the independent variables that included in this model.

In this analysis, the binary logit model has a pseudo-R^2 measure of 0.138, which is very similar to the value obtained from the ordered logit model, but lower than values obtained from both MNL and ordinal probit models. The positive statistically significant at 95% level, sign for the coefficient for age groups (child and adult groups) indicates that child and adult groups are more likely to be involved in accidents leading to slight injury than KSI, when compared with the elder group, which is more likely to be involved in KSI accidents than those resulting in slight injury. The odds ratios for the child group indicates that when holding all predictors constant, the child group is 5.36 times more likely to be involved in slight accidents than other age groups. The adult group is 5.09 times more likely to be involved in incidents leading to slight injury.

Regarding the gender of the casualty, the coefficient is statistically significant and has negative signs indicate that the older female group is more likely to be involved in KSI accidents than the older male group. The older female group is 3.68 times more likely to be involved in KSI injury than the old male group. The negative sign of the coefficient for time of accidents indicates that there were more KSI accidents at night than in the day time. Inverting the odds ratio for the time of accident reveals that pedestrians are 0.52 more likely to be involved in KSI accidents in the night time than in the day time.

Table 5. 5: Summary statistics and estimation results for the Binary Logit aggregate model by pedestrians' car accidents

Variable		Categories of each variable	Frequency (%)	Coefficients (p-value)	Odds
Factors	**Intercept**	--	--	23.472 (1.000)	1.56
	Age group	Child (0-15)	105 (11.1%)	1.679 (0.000)	5.362
		Adult (16-59)	731 (77.6)	1.627 (0.000)	5.089
		Old (60+)	89 (9.4)	0	--
	Old gender	Old female (60+)	49 (6.8)	-1.304 (0.025)	3.684
		Old male	40 (6.7)	0	--
	Driver age group	16-21	79 (8.4)	-0.941 (0.097)	0.390
		22-59	704 (74.7)	-0.562 (0.260)	0.570
		60+	54 (5.7)	0	--
	Time of accident	Night time	271 (28.8)	-0.659 (0.005)	0.517
		Day time	671 (71.2)	0	--
	Pedestrian movement	Crossing	765 (81.2	-1.260 (0.001)	0.284
		Not crossing	177 (18.8)	0	--
	Vehicle manoeuvre	Going ahead	754 (80.0)	-0.995 (0.002)	0.370
		Other	172 (18.3)	0	--
	Heavy vehicles	Bus and goods vehicles	287 (30.5)	-0.550 (0.023)	0.577
		Other	655 (69.5)	0	--
	Type of signalised pedestrian crossing	Pelican	232 (24.6)	-0.525 (0.014)	0.592
		Junction	710 (75.4)	0	--
	Width of single carriageway	1-2 lanes	582 (61.8)	0.425 (0.066)	1.529
		3-4 lanes	212 (22.5)	0	--
		Other	148 (15.7)	0	--
	First impact of pedestrian accidents	Crossing from driver offside	298 (31.6)	-0.076 (0.724)	0.927
		Other	644 (68.4)	0	--
	Day of accident	Weekend	265 (28.1)	0.166 (0.473)	1.181
		Weekdays	677 (71.9)	0	--
	Road condition	Wet	281 (29.8)	-0.217 (0.413)	0.805
		Dry	658 (69.9)	0	--
	Weather	Fine	783 (83.1)	-0.529 (0.529)	0.589
		Rain	135 (14.3)	-0.062 (0.942)	0.940
		Other	24 (2.5)	0	--
	Location of pedestrian accidents	On pedestrian or within 10m	236 (25.1)	0.294 (0.345)	1.342
		10-20	230 (24.4)	0.274 (0.376)	1.315
		20-30	174 (18.5)	0.271 (0.418)	1.311
		30-40	166 (17.6)	0.293 (0.378)	1.341
		40-50	136 (14.4)	0	--

Summary Statistics
-2 Log-likelihood at zero 745.783
-2 Log-likelihood at convergence 675.661
Log-likelihood ratio index (ρ^2) = 0.138
Observations = 942 (Fatal: 1%; Serious: 15.4%; Slight: 83.7%)

In terms of pedestrian movement (crossing the road or not crossing), the negative sign indicates that pedestrians who crossed the road from the driver's nearside and driver's offside were more likely to be involved in KSI accidents than pedestrians who were standing or walking along the carriageway. The odds ratio for pedestrian movement indicates that pedestrians who crossed the road were 0.28 times more likely to be involved in KSI accidents than those who were standing or walking along the carriageway. In consideration of vehicle manoeuvres, the negative sign indicates that when the vehicle is going ahead it is more likely to be involved in KSI accidents than when it performs other manoeuvres (turning, reversing and starting). The odds ratio for the manoeuvring of vehicles shows that the going ahead manoeuvre means that more KSI accidents than other manoeuvres (0.37). Both coefficients of the variables are statistically significant in the fatal category at 95% level of significance (p-values = 0.001 and 0.002).

Regarding the type of vehicle, the coefficient is statistically significant and has a negative sign indicated that heavy goods vehicles and buses were more likely to be involved in KSI accidents than cars, taxis and motorcycles. The odds ratio for this category is 0.57. The negative sign for pedestrian crossing facilities indicates that more KSI accidents occurred at pelican, puffin and toucan crossings than at junctions. The odds ratio for pedestrian crossing facilities indicates that at pelican, puffin and toucan crossings there are 0.59 times more KSI accidents than slight. The coefficient is also, statistically significant. The positive signs for the number of lanes in a single carriageway indicate that on single carriageways there were more slight accidents over one or two lanes than over three or more lanes. Inverting the odds ratios for the number of lanes indicates that 1.53 more slight accidents occurred on one or two lane single carriageways than on other types. Regarding the day on which the accidents occurred the positive signs indicate that pedestrians who were involved in accidents over the weekend period were more likely to be involved in slight accidents than those injured on weekdays. The odds ratio for this category is 1.18. However, the coefficients of this variable are not statistically significant in the model.

5.4 Benchmark case analysis:

A benchmark case (see section 3.6 for a discussion of the benchmark case) was generated in order to discuss the probabilities of the three levels of injury occurring, and was derived by holding all dummy variables to 0. The analysis is presented for the fatal and serious injuries while the slight is considered the reference category. In this analysis, the MNL model (Table 5.3) only has been used for illustration purpose. Further future investigations could be carried out using the other models. Such benchmark case had the following characteristics:

a) Child aged (0-15)
b) Involved in accidents at night time.
c) Involved in a collision in which the pedestrian was crossing the road (either from driver nearside or offside.
d) Involved in a crash where the vehicle was performing a going ahead maneuver.
e) Involved in an accident in which the vehicle was heavy vehicles (i.e. bus or heavy goods vehicle).
f) Involved in a crash when the signalised crossing was a pelican or similar.
g) Involved in a crash on a 1-2 lanes single carriageway.
h) Involved in a crash on a weekday.
i) Involved in a crash in wet road conditions.
j) Involved in a crash on pedestrian crossing line or within 10m of one.

As shown in Tables 5.6, estimates of the probabilities that the benchmark case would sustain three injury-severity levels are reported in the last two columns. Estimates of the injury probabilities are subsequently presented. The changes in the probabilities of injury-severity levels are then calculated relative to this benchmark case. This allows for an interpretation of changes in the probabilities of the injury-severity levels and a change in given parameters, relative to the benchmark case.

From the table, it appears that the heavy vehicles are the most significant contributing factor for fatal injuries, while the impact of this variable on the serious injuries is not very significant (the percentage change relative to the bench mark case is 214.94). This factor appears to also have important impacts on the serious accidents. Secondly, the time of the accident is an effective factor, in specifically in terms of the fatality and seriousness of injury severity (the percentage change relative to the bench mark case is 29.31 and 1.69 respectively). Thirdly, the vehicle maneuver seems to affect the fatality and seriousness of the severity with a percentage of 16.45 and 2.6 respectively. The age of pedestrian injured is also effective in terms of accident fatality; with the percentage change relative to benchmark case is 5.79. In terms of effect on the seriousness of the injury severity, this factor has less impact with a percentage change relative to the benchmark case of 0.20. This type of analysis is interesting and useful in highlighting the relative importance of the different factors, instead of just looking at the values of the coefficients which could will be misleading.

Table 5. 6: Pedestrian injury severity probabilities in pedestrian accidents in whole (MNL model)

Variable		Percent change relative to benchmark case (%)	
		Fatal	**Serious**
Benchmark case			
Age group of pedestrian injury	Child (0-15)	**5.79**	0.20
Time of accidents	Night time	**29.31**	**1.69**
Pedestrian movement	Crossing	4.21	4.00
Vehicle maneuver	Going ahead	**16.45**	**2.60**
Type of vehicle	Heavy vehicles	**214.94**	**1.84**
Type of signalised pedestrian crossing	Pelican or similar types	3.73	**1.63**
Width of single carriageway	1-2 lanes	0.31	0.69
Day of accidents	Weekend	0.27	0.98
Road condition	Wet	1.15	1.21
Location of accidents	On pedestrian crossing or within 10m	1.72	0.73

5.5 Summary and overall comparisons of the models' results

Table 5.7 below shows overall comparisons for the models' results. From the table, it seems that all the models are similar in terms of the impacts of the variables on accident severity (i.e. in terms of the logical signs of the independent variables). In other words, the signs for the coefficients correctly reflect, for all the four models, the expected impact of each of the individual factors. The overall goodness of fit of the MNL model (ρ^2) is higher than it is for each of the three other models. However, the more detailed investigation of the statistical significance (p-values) of the statistical significance of the independent variables shows that OL and the OP models have better statistical significance, with the ordinal probit model is slightly superior than the ordinal logit. This might be a result of the known nature and assumptions implied by the error terms for the MNL model. Therefore, it might be concluded here that the ordinal response models are more appropriate to be used in cases where the dependent variable is categorical and there is an order in the nature of its categories.

Therefore, the ordered models (i.e. ordered logit and ordered probit) could be more appropriate to be used to model injury severity since, when the data used is in ordered format. This is based on the obtained p-values and the logical signs of the coefficients in the discussed models above.

It should be noted here that all the above models do not include variables that represent exposure factors (see further discussions in Section 2.2), apart from the location variable (location of accidents from the pedestrian crossing point. Further variables might include such as pedestrian volume, distances traveled and distances crossed. In many cases, these variables are difficult to obtain and most of these factors are not readily available in the accident databases such as the UK STATS19. In this research however, a number of exposure factors have been tested for inclusion in the models but were not statistically significant. For example pedestrian volume has been counted manually at the selected traffic sites and was tested in a number of model forms but the variable was not statistically significant (see appendix 3 for an example of the resulted models). As a result, these models were not included in this thesis. Further research in the area of exposure factors is strongly recommended therefore.

Finally, a benchmark case was generated in order to discuss the probabilities of the three levels of injury occurring, and was derived by holding all dummy variables to 0 for one model only for illustration; that is the MNL model in this case. Such benchmark case analysis shows that the heavy vehicles, time of accident, vehicle maneuver and injured age are the most important factors, which have impact of the fatality of the injury

Table 5. 7: Overall comparison of the models' results

Variables		MNL	Ordinal		BL
			Logit	Probit	
R^2		0.194	0.137	0.141	0.138
Coefficient (p-values)	Fatal /(KSI)	-29.09 (0.976)	-20.234 (0.000)	-7.947 (0.000)	23.472 (1.000)
	Serious	-16.69 (0.000)	-17.171 (0.000)	-6.440(0.000)	--
Age group	Child	-14.36 (0.965)/ -1.60 (0.001)	1.734 (0.000)	0.954 (0.000)	1.679 (0.000)
	Adult	-3.34 (0.010)/ -1.55 (0.000)	1.687 (0.000)	0.945 (0.000)	1.627 (0.000)
Old gender	Old female	1.34 (0.433)/ -1.59 (0.015)	1.185 (0.035)	0.636 (0.043)	-1.304 (0.025)
Accident time	Night time	3.38 (0.003)/ 0.52 (0.03)	-0.702 (0.003)	-0.428 (0.001)	-0.659 (0.005)
Pedestrian movement	Crossing the road	1.44 (0.26)/ 1.39 (0.001)	-1.259 (0.001)	-0.598 (0.002)	-1.260 (0.001)
Vehicle manoeuvre	Going ahead	2.80 (0.071)/ 0.96 (0.004)	-0.993 (0.002)	-0.536 (0.001)	-0.995 (0.002)
Type of vehicle	Heavy vehicle	5.37 (0.003)/ 0.39 (0.119)	-0.620 (0.010)	-0.345 (0.009)	-0.550 (0.023)
Type of crossing facility	Pelican	1.32 (0.123)/ 0.49 (0.026)	-0.557 (0.009)	-0.317 (0.008)	-0.525 (0.014)
Width of road	1-2 lanes	-1.19 (0.267)/ -0.38 (0.112)	0.464 (0.044)	0.248 (0.052)	0.425 (0.066)
Day of the week	weekend	-1.30 (0.238)/ -0.11 (0.639)	0.176 (0.444)	0.121 (0.341)	0.166 (0.473)

Chapter 6

Modelling right-of-way (ROW) violation and pedestrian accidents

6.1 Introduction

The final aim of this research has been to investigate and model the right-of-way (ROW) and right-of-way violations of pedestrians at pedestrian crossings. The research question defined for this aim has been on the definition and the availability of appropriate regulations regarding pedestrian right-of-way in the UK, as well as the factors which contribute to the pedestrian right-of-way at pedestrian crossing. The definition of pedestrians' ROW has been discussed in Section 3.3. This chapter presents a multivariate examination of the determinants of pedestrians' ROW violation taking into account all factors that influence pedestrians' accidents. The chapter presents the estimation results using the four models employed in Chapter 5; the Multinomial Logit model (MNL), Ordinal Logit (OL), Ordinal Probit (OP) and Binary Logit (BL) models. The obtained aggregate models are useful to obtain good understanding of the impacts of the factors on the ROW violations (i.e. human, vehicle, environmental, weather, or geometric factors) at pedestrian crossings. In this ROW analysis it could be argued that "exposure" at sights in question is relatively constant and that the ROW analysis being conducted here is independent of exposure. However, a number of variables to represent exposure could have been considered here such as pedestrian volume and traffic volume, both of which will have impact on pedestrian ROW and ROW violation. Further discussions of these variable are presented in Section 3.2.1.4.

While pedestrian ROW violations have attracted lot of attention from researchers in the USA, Australia, Canada and elsewhere, researchers and regulating bodies in the UK have not focused on this issue. As discussed earlier, in the UK, according to the Highway Code, pedestrians should use pedestrian crossing facilities when they cross roads and obey the instructions at each facility. Pedestrians are advised to cross the road wherever there are pedestrian crossing facilities, and if there are no facilities they should only cross with great care. Furthermore, pedestrians may cross the carriageway elsewhere, but should then exercise care and take the distance and speed of any approaching vehicle into account. In this section, the ROW of pedestrians has been further investigated.

Further consideration, definitions and regulations regarding pedestrians right-of-way and right-of-way violation (ROW) are indeed needed. Once the definition and the required regulations are in place, the appropriate data relevant to the ROW can be identified and collected. Currently, there is no data available on pedestrians' ROW in the UK STATS19 database This is because this database does not include direct information or variables which indicate who, whether the drivers or the pedestrians, actually has priority at pedestrian crossings, etc. This is obviously an area where there is a huge lack of research. Further discussions on the limitations of STATS19 is given in Section 3.2.

6.2 Modelling right-of-way (ROW) and right-of-way violation:

Modelling of ROW and ROW violation at signalised pedestrian crossing junctions and pelican or similar including variables to represent the factors discussed in Chapter 4 is discussed in this section. This is in order to investigate whether there is any influence or impact of these factors on ROW. The dependent variable "ROW", which is incorporated into the model calibration, as defined and discussed in Section 3.3. Pedestrian ROW (in BL model) and ROW1 (in MNL, OL and OP) is defined as any pedestrian accident that occurs on a pedestrian crossing area, or within ten metres of a pedestrian crossing area. ROW2 (in MNL, OL and OP) is defined as any pedestrian accident that occurs between 10 and 20 metres of a pedestrian crossing area. ROW3 (in MNL, OL and OP) is defined as any pedestrian accident that occurs between 20 metres and 50 metres of a crossing. Non pedestrian ROW (in BL models) is defined as any pedestrian accident that occurs outside the ten metre limit. The primary aim of the estimation of the aggregate crash model is to examine whether ROW has an impact on accident severity while controlling for other variables. As in the previous analysis, a number of models have been calibrated in this investigation using the MNL, OL, OP and BL models. This is in order to investigate the outcome from these models and assess the outcome from the four of them. The results obtained from each of these models is discussed below. Table 6.1 below shows the definition of all variables that used in the models.

Table 6. 1: Variables' definition

Variable	Category
Age group	Child (0-15)
	Adult (16-59)
	Elder (60+)
Gender	Male
	Female
Day	Weekend
	Week day
Pedestrian movement	Crossing
	Not crossing
Crossing	Driver offside
	Driver nearside
Vehicle manoeuvres	Going ahead
	Other
Type of vehicle	Motorcycle
	Car
	Bus
	Heavy goods
Time of accident	Night time
	Daytime
Light	Light
	Darkness
Weather	Fine
	Rain
Road condition	Wet
	Dry
Gender of driver	Male
	Female
Road type	One way street
	Dual carriageway
	Single carriageway
Driver's age	16-21
	22-59
	60+

6.2.1 Modelling ROW using the Multinomial Logit Model

The MNL models reported in the literature cover a number of investigations of accidents and injury severities (see for example, Kockelman and Kweon, 2002). As discussed above, in relation to the multinomial logit model, it is assumed that there is no natural ordering between the dependent variable's categories (more than two categories). In this section, the dependent variable has three categories (ROW1, ROW2 and ROW3). ROW3 is considered as the reference category. A total of 942 pedestrian casualties that had resulted from the pedestrian-vehicle accidents that took place at signalised pedestrian crossings were extracted. Of those pedestrian casualties that were involved in vehicle-pedestrian accidents at signalised pedestrian crossings, 25.1% have been classified as ROW1, 24.4 % have been classified as ROW2, and 50.5% have been classified as ROW3. Table 6.2 below shows the coefficient' estimates of the MNL model, the p-values (measure of significance), the ρ^2 and the log-likelihood values.

Table 6. 2: Summary statistics and estimation results of the ROW MNL aggregate model

Variable	Categories of each variable	Frequency (%)	ROW1			ROW2		
			Coefficients	(p-value)	Odds	Coefficients	(p-value)	Odds
Intercept	---	----	-13.42	(0.000)	--	-12.68	(0.000)	--
Age group	Child (0-15)	105(11.1%)	0.56	(0.142)	1.758	-0.17	(0.694)	0.847
	Adult (16-59)	731 (77.6)	0.24	(0.436)	1.275	0.23	(0.462)	1.255
	Old (60+)	89 (9.4)	0.00	0.00	--	0.00	0.000	--
Gender	Female	327(40.5)	0.35	(0.055)	1.426	0.12	(0.534)	1.122
	Male	481 (59.5)	0.00	0.00	--	0.00	0.000	--
Driver's age group	16-21	79 (8.4)	-0.69	(0.117)	0.499	-0.21	(0.656)	0.808
	22-59	704 (74.7)	-0.62	(0.073)	0.540	-0.05	(0.894)	0.949
	60+	54 (5.7)	0.00	0.000	--	0.00	0.000	--
Time of accident	Night time	271 (28.8)	-0.16	(0.478)	0.853	0.21	(0.317)	1.239
	Day time	671 (71.2)	0.00	0.000	--	0.00	0.000	--
Pedestrian movement	Crossing	765 (81.2	0.20	(0.468)	1.226	0.25	(0.353)	1.288
	Not crossing	177 (18.8)	0.00	0.000	--	0.00	0.000	--
Vehicle manoeuvre	Going ahead	754 (80.0)	-0.40	(0.081)	0.668	-0.40	(0.079)	0.673
	Other	172 (18.3)	0.00	0.000	--	0.00	0.000	--
Heavy vehicles	Bus and goods vehicles	287 (30.5)	-0.40	(0.073)	0.669	-0.28	(0.207)	0.758
	other	655 (69.5)	0.00	0.000	--	0.00	0.000	--
Type of signalised pedestrian crossing	Pelican	232 (24.6)	0.73	(0.000)	2.073	0.02	(0.941)	1.016
	Junction	710 (75.4)	0.00	0.000	--	0.00	0.00	--
Type of road	One way street	14 (1.5)	15.09	(0.000)	--	13.08	(0.000)	--
	Dual carriageway	131 (13.9)	13.61	(0.000)	--	12.63	(0.000)	--
	Single carriageway	794 (84.3)	13.64	--	--	12.50		--
	Other	3 (0.3)	0.00	0.00	--	0.00	0.000	--
Width of single carriageway	1-2 lanes	582 (61.8)	0.19	(0.392)	1.205	0.25	(0.241)	1.290
	3-4 lanes	212 (22.5)	0.00	0.000	--	0.00	0.000	--
First impact of pedestrian accidents	Crossing from driver nearside	298 (31.6)	0.27	(0.175)	0.762	0.28	(0.161)	0.756
	Other	644 (68.4)	0.00	0.000	--	0.00	0.00	--
The day of accidents	Weekend	265 (28.1)	-0.18	(0.397)	0.833	0.06	(0.768)	1.062
	weekdays	677 (71.9)	0.00	0.000	--	0.00	0.00	--
Road condition	Wet	281 (29.8)	0.27	(0.290)	1.307	0.08	(0.749)	1.084
	Dry	658 (69.9)	0.00	0.000	--	0.00	0.00	--
Weather	Fine	783 (83.1)	-0.67	(0.327)	0.511	-0.60	(0.377)	0.549
	Rain	135 (14.3)	-0.61	(0.377)	0.544	-0.76	(0.271)	0.466
	other	24 (2.5)	0.00	0.000	--	0.00	0.00	--

Summary Statistics
-2 Log-likelihood at zero = 1.343E3
-2 Log-likelihood at convergence = 1.279R3
Log-likelihood ratio index (ρ^2) = 0.086
Observations = 942 (ROW1: 25.1%; ROW2: 24.4%; R0W3:50.5%)

This section provide a discussion of the results of the model. Mainly, the logical signs of the independent variables and statistical significance of them are discussed. The age group has a positive sign in the model. The positive sign for this factors indicates that for a one-unit increase in the age groups (child and adult), it is expected that the relative risk of these groups (child and adult) being involved in an accident in ROW1 is lower than in the other age group. Therefore, the relative risk of being involved in an accident for child and adult groups decreases when these groups cross in ROW1 by exp (0.56 and 0.24) = 1.76 and 1.28 respectively. With regard to occurrence of an accidents in ROW2, the indication of negative sign for child group that the child group in higher risk to be involved in an accident in ROW2 than ROW3. Therefore, the ratio of relative risk of being involved in pedestrian accidents for the child group is increased when the child group crosses in ROW2 by an exp (0.167) = 0.85. On the other hand, the positive sign for the coefficient indicates that adult group is in the lower risk to be involved in an accident in ROW2 than they are in ROW3. The relative risk of being involved in accidents for the adult group decreases when the adult group crosses at the pedestrian crossing in ROW2 by an exp (0.23) = 1.26.

In term of gender group, the positive sign for the coefficient of female group indicates that for a one-unit increase in the female group, it is expected that the relative risk of being involved in a pedestrian accident in ROW1 is lower than it is in the male group. The ratio of relative risk of being involved in an accident in ROW1 decreases by an exp (0.36)=1.43. Moreover, Table 6.2 above shows that the relative risk for female group of being involved in a pedestrian accidents in ROW2 is lower than it is in ROW3. The ratio of relative risk of being involved in pedestrian accident in ROW2 decreases by an exp (0.12) = 1.12.

Regarding the driver's age, the negative signs for young drivers (16-21) and adult drivers (22-59) for both ROW1 and ROW2 indicate that for a one-unit increase in these groups, it is expected that the relative risk of being involved in a pedestrian accident in ROW1 and ROW2 is higher than it is in the elderly group. The ratio of the relative risk of being involved in a pedestrian accident in ROW1 increases by exp (0.69 and 0.62)=0.49 and 0.54 respectively and also increases in ROW2, by an exp (0.21 and 0.1)=0.81 and 0.95 respectively.

In terms of time at which pedestrian accidents occur, the negative sign for coefficient of night time indicates that for a one-unit increase in night time accidents, it is expected that the relative risk of being involved in pedestrian accidents at night in ROW1 is higher than it is in the daytime. The ratio of relative risk of being involved in accidents in ROW1 increases by an exp (0.16)=0.85. On the other hand, the indication of the positive sign for the coefficient of night time that the ratio describing being involved in accidents in ROW2 decreases by exp (0.22) = 1.23.

Regarding the movement of pedestrians (crossing the road or not crossing), the positive sign indicates that for a one-unit increase in pedestrians crossing the road from the driver's nearside and offside, it is expected that the relative risk of being involved in a pedestrian accident in ROW1 is lower than it is in ROW3. The ratio of relative risk of being involved in pedestrian accidents for pedestrians crossing the road in ROW1 decreased by exp (0.20) = 1.23. Similarly, the ratio for the relative risk of being involved in pedestrian accidents in ROW2 for pedestrians who crosses the road is decreased by an exp (0.25)=1.28.

In term of vehicle manoeuvres, the negative sign of the coefficient of going ahead indicates that for a one-unit increase in the going ahead manoeuvre in ROW1 and R0W2, it is expected that the relative risk of being involved in pedestrian accidents in ROW1 and ROW2 is higher than for any other manoeuvres. The ratio of relative risk of being involved in pedestrian accidents for going ahead manoeuvre in ROW1 increases by exp (0.40)=0.67 and in ROW2 increases by an exp (0.39) = 0.67.

In terms of the type of vehicle (light vehicles and heavy vehicles), the negative sign for heavy vehicles (heavy goods vehicle and buses) indicates that for a one-unit increase in heavy vehicles in ROW1, it is expected that the relative risk of being involved in a pedestrian accident in ROW1 is higher than for light vehicles. This result reinforces the results of injury severity and heavy vehicles as discussed in Chapter 5. The ratio of the relative risk of being involved in an accident if heavy vehicles are involved increased by an exp (0.40)=0.67. Similarly, the ratio of relative risk of being involved in an accident if heavy vehicles were involved in pedestrian accidents in ROW2 increased by an exp (0.28)=0.76.

Regarding the type of pedestrian crossing facility, the positive sign of pelican, puffin and toucan crossings indicates that for a one-unit increase in accidents that occurred at those types of crossings in ROW1, it would be expected that the relative risk of being involved in a pedestrian accident in ROW1 would be lower than for pedestrian accidents occurring at junction crossing areas. The ratio of relative risk of being involved in pedestrian accidents at pelican, puffin and toucan crossings decreased by an exp (0.73)=2.07. Moreover, the ratio of relative risk when an individual is involved in pedestrian accidents at pelican, puffin and toucan crossings in ROW2 decreased by an exp (0.02) = 1.02.

In terms of the width of the single carriageway, the positive sign for one and two lanes on a single carriageway indicate that for a one-unit increase over one and two lanes, it would be expected that the relative risk of being involved in pedestrian accidents in ROW1 is lower than in ROW3. The ratio of relative risk of being involved in pedestrian accidents on one and two lanes of a single carriageway decreased by exp (0.19) = 1.21. The positive sign of the coefficient for one or two lanes in ROW2 indicates that the ratio for the relative risk of being involved in pedestrian accidents on one or two lanes of single carriageway decreased by an exp (0.25) = 1.29.

In consideration of the first impact point in pedestrian accidents, the positive sign indicates that for a one-unit increase in crossing from the driver's offside in ROW1 and ROW2, it would be expected that the relative risk of being involved in pedestrian accidents in ROW1 and ROW2 is lower than the movement of the pedestrian. The ratio of relative risk when involved in pedestrian accidents for pedestrians who cross from the driver's offside in ROW1 and ROW2 decreased by exp (0.27) = 0.76 and an exp (0.28)=0.76 respectively.

Regarding the day of the week that pedestrians were involved in accidents, the negative sign indicates that for a one-unit increase in pedestrian accidents that occurred over the weekend in ROW1, it would be expected that the relative risk of being involved in pedestrian accidents in ROW1 is higher than in ROW3. The ratio of relative risk when involved in pedestrian accidents over the weekend increased by exp (0.18)=0.83. On the other hand, negative sign of the coefficient of the weekend indicates that the relative risk of being involved in pedestrian accidents in ROW2 is higher than in ROW3. The ratio of relative risk of being involving in pedestrian accidents over the weekend decreased by an exp (0.06)=1.06.

In terms of the road conditions, the positive sign for wet roads indicates that for a one-unit increase in pedestrian accidents occurring on wet roads in ROW1 and ROW2, it would be expected that the relative risk of being involved in pedestrian accidents in ROW1 and ROW2 is lower than in ROW3. The ratio of relative risk of being involved in pedestrian accidents on wet roads in ROW1 decreased by exp (0.27) = 1.31 and decreased by exp (0.08)=1.08.

Finally, regarding the weather, the negative signs for fine and rainy weather indicate that for a one-unit increase in pedestrian accidents occurring during fine and rainy weather in ROW1, it would be expected that the relative risk of being involved in pedestrian accidents during ROW1 is higher than for ROW3. The ratio of the relative risk of being involved in pedestrian accidents during fine and rainy weather increased by exp (0.67 and 0.61)=0.51 and 0.54 respectively. Similarly to the ROW2, it expected that the relative risk of being involved in pedestrian accidents in ROW2 is higher than in ROW3. The ratio of relative risk when involved in pedestrian accidents in fine and rainy weather increased by exp (0.60 and 0.76)=0.55 and 0.47 respectively. It should be noted here that the gender, the type of crossing and type of road coefficients were statistically significant in the above models at 95% level. The rest of the variables are not statistically significant.

6.2.2 The Ordinal Logit/ Probit Models

As mentioned in the severity of injury section, the ordinal logit/ Probit model assumes that the dependent variable has several categories and that these categories have a natural order. In this section the dependent variable has been considered across three categories (ROW1, ROW2 and ROW3). ROW3 has been taken as the reference category for this model. A total of 942 pedestrian casualties resulting from the pedestrian-vehicle accidents that took place at signalised junctions were extracted (of those pedestrian casualties that were involved in vehicle-pedestrian accidents at signalised junctions: 25.1% were classified as ROW1, 24.4 % were classified as ROW2, and 50.5% were classified as ROW3). The ordinal logit model has a pseudo- ρ^2 measure of 0.062 and the ordinal probit has a pseudo- ρ^2 measure of 0.063.

Table 6.3 below shows the coefficients' estimate results of the OL model, the p-values (measure of significance), the ρ^2 and the Log-likelihood values. See Table 6.1 for the independent variables that have been included in this model.

Table 6.3: Summary of statistics and estimation results of the Ordinal Logit/ Probit aggregate model by pedestrians'-car accidents

Variable		Categories of each variable	Frequency (%)	Logit	Probit
				Coefficient (p-value)	Coefficient (p-value)
Intercept	Row1	--	--	-14.77 (0.000)	-5.72(0.000)
	Row2	--	--	-13.64 (0.000)	-5.04 (0.000)
Factors	Age group	Child (0-15)	105(11.1%)	-0.39 (0.194)	-0.25 (0.177)
		Adult (16-59)	731 (77.6)	-0.21 (0.375)	-0.13 (0.362)
		Old (60+)	89 (9.4)	0.00	0.00
	Gender	Female	327(40.5)	-0.26 (0.065)	-0.16 (0.063)
		Male	481 (59.5)	0.00	0.00
	Driver age group	16-21	79 (8.4)	0.60 (0.083)	0.35 (0.098)
		22-59	704 (74.7)	0.52 (0.061)	0.30 (0.074)
		60+	54 (5.7)	0.00	0.00
	Time of accidents	Night time	271 (28.8)	0.05 (0.756)	0.04 (0.696)
		Day time	671 (71.2)	0.00	0.00
	Pedestrian movement	Crossing	765 (81.2	-0.21 (0.326)	-0.12 (0.327)
		Not crossing	177 (18.8)	0.00	0.00
	Vehicle manoeuvre	Going ahead	754 (80.0)	0.30 (0.086)	0.19 (0.069)
		Other	172 (18.3)	0.00	0.00
	Type of vehicle	Bus and goods vehicles	287 (30.5)	0.34 (0.047)	0.20 (0.051)
		other	655 (69.5)	0.00	0.00
	Type of signalised pedestrian crossing	Pelican	232 (24.6)	-0.51 (0.001)	-0.32 (0.001)
		junction	710 (75.4)	0.00	0.00
	Type of road	One way street	14 (1.5)	-15.39 (0.000)	-6.11 (0.000)
		Dual carriageway	131 (13.9)	-14.30 (0.000)	-5.44 (0.000)
		Single carriageway	794 (84.3)	-14.29	-5.44
		Other	3 (0.3)	0.00	0.00
	Width of single carriageway	1-2 lanes	582 (61.8)	-0.18 (0.268)	-0.11 (0.292)
		3-4 lanes	212 (22.5)	0.00	0.00
	First impact point of pedestrian accidents	Crossing from driver offside	298 (31.6)	-0.23 (0.137)	-0.14 (0.134)
		Other	644 (68.4)	0.00	0.00
	The day of accidents	Weekend	265 (28.1)	0.10 (0.533)	0.06 (0.508)
		weekdays	677 (71.9)	0.00	0.00
	Road condition	Wet	281 (29.8)	-0.19 (0.334)	-0.12 (0.315)
		Dry	658 (69.9)	0.00	0.00
	Weather	Fine	783 (83.1)	0.46 (0.369)	0.29 (0.353)
		Rain	135 (14.3)	0.44 (0.397)	0.28 (0.383)
		other	24 (2.5)	0.00	0.00

Summary Statistics
-2 Log-likelihood at zero = 1342.759
-2 Log-likelihood at convergence = 1297.799
Log-likelihood ratio index logit (ρ^2) = 0.062, Log-likelihood ratio index probit (ρ^2) = 0.063
Observations = 942 (ROW1: 25.1%; ROW2: 24.4%; ROW3:50.5%)

It should be noted here that the same discussions for the ordinal probit model will be very similar to the discussions related to the ordinal logit model and therefore, only discussions of the ordinal logit model will be reported here, unless otherwise reported.

In the ordinal logit model, the absolute value of the constants in the (-14.77 (ROW1) and -13.64 (ROW2) are higher than they are in the ordinal probit model, which shows slight improvement of the overall goodness of fit of the ordinal probit model over the ordinal logit model. According to Table 6.3 above, the factors that more likely to be involved in ROW1 and ROW2 are: child and adult groups, female group, old driver group, daytime, pedestrian crossing the road, light vehicles (car, motorcycle and taxi), Pelican or similar type of crossings, weekday, one or two lanes and wet road condition. For the statistical significance of the coefficients of the independent variables, the following discussions are provided.

In terms of casualty's age groups, the negative sign of the coefficient for age groups (child and adult) indicates that the child and adult groups are more likely to be involved in accidents in ROW1 and ROW2 than in ROW3. From the Table 6.3 above, it can be said that for each one-unit increase in the child and adult groups, an (0.39 and 0.21, respectively) increase in log odds of those involved in pedestrian accidents is expected, given all other variables in the model are held to be constant. Regarding the gender of any casualty, negative sign of the coefficient of female group indicates that female is more likely to be involved in accidents in ROW1 and ROW2 than ROW3. For a one-unit increase in females in ROW1 and ROW2, a 0.26 increase in log odds of those involved is expected, assuming all the other variables in the model are remain constant.

The positive sign of the coefficient for driver age group indicates that drivers in the age group between 16-21 and 22-59 are more likely to be involved in accidents in ROW3 than ROW1 and ROW2. It can be said that for a one-unit increase in driver age groups (16-21 and 22-59) in ROW3, a 0.60 and 0.52 respectively increase in the log odds of being involved in a pedestrian accident is expected, assuming all of the other variables in the model remain constant. Similarly, the positive sign of the coefficient for night time accidents indicates that there were more accidents at night in ROW3 than in ROW1 and ROW2. For a one-unit increase in pedestrian crossings at night in ROW3, a 0.05 increase in log odds of fatal and serious injury is expected, assuming all of the other variables in the model remain constant.

In terms of pedestrian movement (crossing the road or not crossing), the negative sign indicates that pedestrians who crossed the road from the driver's nearside and driver's offside were more likely to be involved in accidents in ROW1 and ROW2 than in ROW3. It can be said that for a one-unit increase in crossing pedestrians in ROW1 and ROW2, a 0.20 increase in pedestrian accidents is expected, when all of the other variables in the model remain constant.

In consideration of vehicle manoeuvres, the positive sign for going ahead manoeuvres indicate that when the vehicle is going ahead it is more likely to be involved in pedestrian accidents in ROW3 than in ROW1 and ROW2. For a one-unit increase in the going ahead manoeuvre in ROW3, a 0.29 increase in log odds of a pedestrian being involved in an accident is expected, when all of the other variables in the model remain constant. Regarding the type of vehicle, the positive sign of heavy vehicles (heavy goods vehicles and buses) indicates that heavy goods vehicles and buses are more likely to be involved in accidents than cars, taxis and motorcycles in ROW3 than in ROW1 and ROW2 violations. These results compare positively with the results obtained from the MNL analysis. For a one-unit increase in heavy goods vehicle and buses involved in pedestrian accidents in ROW3, a 0.34 increase in pedestrian accidents is expected, when all the other variables in the model are constant.

The negative signs for pelican, puffin and toucan crossings indicate that more pedestrian accidents occurred at pelican, puffin and toucan areas than at junction crossings in ROW1 and ROW2. For a one-unit increase in pedestrians that cross the road around pelican, puffin and toucan crossings in ROW1 and ROW2, a 0.52 increase in log odds of being involved in pedestrian accidents is expected, when all of the other variables in the model are held constant. Parallelly, the negative sign for one and two lanes on a single carriageway indicate that on single carriageways there are more pedestrian accidents than occur across three or more lanes in ROW1 and ROW2. It can be said that for a one-unit increase in pedestrians who cross the road on one and two lanes in ROW1 and ROW2, a 0.18 increase in pedestrian accidents is expected; given all of the other variables in the model are held constant.

The negative sign for pedestrians who cross the road from the driver's offside indicate that more pedestrian accidents occurred in ROW1 and ROW2 cases than ROW3, when pedestrians cross the road from the driver's offside. For a one-unit increase in pedestrians crossing the road from the driver's offside in ROW1 and ROW2, a 0.23 increase in pedestrian accidents is expected, when all of the other variables in the model remain constant.

The positive sign for the coefficient of weekends indicates that more pedestrian accidents occurred over the weekend in ROW3 than ROW1 and ROW2. For a one-unit increase in pedestrians who cross the road at the weekend in ROW3, a 0.10 increase in pedestrian accidents is expected, when all of the other variables in the model remain constant

The negative sign for the coefficient of wet road conditions indicates that more pedestrian accidents occurred on wet roads in ROW1 and ROW2 cases than ROW3. For a one-unit increase in pedestrians crossing the road in wet conditions in ROW1 and ROW2, a 0.19 increase in pedestrian accidents is expected, where all the other variables in the model hold constant.

The positive sign for the coefficient of fine and rainy weather indicates that more pedestrian accidents occurred when the weather is fine than when there was rain in ROW3 than ROW1 and ROW2. For a one-unit increase in pedestrians crossing the road when the weather is fine or raining in ROW3, a 0.46 and 0.44 respective increase in pedestrian accidents is expected, given all of the other variables in the model hold constant.

It should be noted here that the coefficient of the type of vehicle, type of crossing and type of roads are statistically significant in the above models. All the other variables are not statistically significant at 95% level of significance. The following section presents the results of the ordinal probit model.

6.2.4 Binary logit:

As discussed in reference to the severity of injury, the relevant section in the Binary Logit (BL) model assumes that the dependent variable falls into two categories. I this analysis, the dependent variable is represented by two categories of ROW and non ROW. A total of 942 pedestrian casualties resulting from the pedestrian-vehicle accidents that took place at pedestrian crossing were extracted of those pedestrian casualties that were involved in vehicle-pedestrian accidents at pedestrian crossing: 25.1% were classified as ROW1 and 74.9% were classified as non ROW. Table 6.5 below shows the coefficients' estimated results of the Binary Logit model, the p-values (measure of significance), the ρ^2 and the Log-likelihood values. Table 6.1 provides a list of the independent variable that are included in this model.

Table 6. 4: Summary of statistics and estimation results of the Binary Logit aggregate model by pedestrians'-car accidents

Variable		Categories of each variable	Frequency (%)	Coefficients (p-value)	Odds
Factors	Age group	Child (0-15)	105 (11.1%)	-0.61 (0.093)	0.544
		Adult (16-59)	731 (77.6)	-0.17 (0.570)	0.846
		Old (60+)	89 (9.4)	0	--
	Gender	Female	327(40.5)	-0.32 (0.068)	0.728
		Male	481 (59.5)	0	--
	Driver age group	16-21	79 (8.4)	0.63 (0.127)	1.873
		22-59	704 (74.7)	0.60 (0.056)	1.823
		60+	54 (5.7)	0	--
	Time of accident	Night time	271 (28.8)	0.24 (0.262)	1.267
		Day time	671 (71.2)	0	--
	Pedestrian movement	Crossing	765 (81.2	-0.13 (0.631)	0.878
		Not crossing	177 (18.8)	0	--
	Vehicle manoeuvre	Going ahead	754 (80.0)	0.27 (0.217)	1.304
		Other	172 (18.3)	0	--
	Heavy goods vehicles	Bus and goods vehicles	287 (30.5)	0.32 (0.137)	1.374
		Other	655 (69.5)	0	--
	Type of signalised pedestrian crossing	Pelican	232 (24.6)	-0.72 (0.000)	0.486
		junction	710 (75.4)	0	--
	Type of road	One way street	14 (1.5)	-22.02 (1.000)	--
		Dual carriageway	131 (13.9)	-20.70 (1.000)	--
		Single carriageway	794 (84.3)	-20.78 (1.000)	--
		Other	3 (0.3)	0	--
	Width of single carriageway	1-2 lanes	582 (61.8)	-0.11 (0.610)	0.900
		3-4 lanes	212 (22.5)	0	--
		Other	148 (15.7)	0	--
	First impact of pedestrian accidents	Crossing from driver offside	298 (31.6)	00.17 (0.353)	1.190
		Other	644 (68.4)	0	--
	The day of accidents	Weekend	265 (28.1)	0.20 (0.322)	1.224
		weekdays	677 (71.9)	0	--
	Road condition	Wet	281 (29.8)	-0.24 (0.306)	0.785
		Dry	658 (69.9)	0	--
	Weather	Fine	783 (83.1)	0.40 (0.504)	1.491
		Rain	135 (14.3)	0.28 (0.636)	1.329
		Other	24 (2.5)	0	--
	Intercept	--	--	21.23 (1.000)	1.652

Summary Statistics
-2 Log-likelihood at zero = 906.53
-2 Log-likelihood at convergence = 861.351
Log-likelihood ratio index (ρ^2) = 0.081
Observations = 942 (Row1: 25.1%; non-pedestrian ROW:74.9))

The negative sign for the coefficient for age groups (child and adult groups) indicates that the child and adult groups are more likely to be involved in accidents in pedestrian ROW than the older group. The odds ratios for the child group indicate that when assuming all predictors are constant, the child group is 0.54 times more likely to be involved in accidents in ROW than the non-pedestrian ROW. The adult group is 0.85 times more likely to be involved in accidents involving pedestrian ROW situations than non-pedestrian ROW.

Regarding the gender of casualties, the negative signs indicate that the female group is more likely to be involved in accidents than the male group in pedestrian ROW. The female group is 0.73 times more likely to experience pedestrian accidents in the pedestrian ROW than the male group. The positive sign for the coefficient of the driver age group (young driver 16-21 and adult driver 22-59) indicates that these age groups are more likely to be involved in pedestrian accidents in non-pedestrian ROW areas. Driver age groups (young and adult) are 1.87 and 1.82 times, respectively, more likely to be involved in pedestrian accidents in non-pedestrian ROW areas than the elderly group.

The positive sign for the coefficient for accidents at night indicate that there were more accidents at this time in non-pedestrian ROW areas than in pedestrian ROW areas. Inverting the odds ratio for night accidents reveals that pedestrians are 1.27 times more likely to be involved in accidents in non-pedestrian ROW areas. In terms of pedestrian movement (crossing the road or not crossing), the negative signs indicate that pedestrians who crossed the road from the driver's nearside and driver's offside were more likely to be involved in accidents involving pedestrian ROW than pedestrians who were standing or walking along the carriageway. The odds ratio for pedestrian movement indicates that pedestrians who crossed the road in pedestrian ROW incidents were 0.88 times more likely to be involved in accidents than those who were standing on, or walking along the carriageway.

In consideration of vehicle manoeuvres, the positive signs indicate that when the vehicle is travelling ahead it is more likely to be involved in accidents involving non-pedestrian ROW than when performing other manoeuvres (turning, reversing and starting). The odds ratio for manoeuvres involving vehicles show that the going ahead manoeuvre caused more accidents than other manoeuvres (1.30). Regarding the type of vehicle, the positive sign indicates that heavy goods vehicles and buses are more likely to be involved in pedestrian accidents in non-pedestrian ROW than cars, taxis and motorcycles. The odds ratio for this category is 1.37.

The negative sign for pedestrian crossing facilities indicates that more pedestrian accidents occurred within pelican, puffin and toucan areas than at junction crossings in pedestrian ROW cases. The odds ratio for pedestrian crossing facilities indicate that at pelican, puffin and toucan crossings there are 0.49 times more accidents than at junctions in pedestrian ROW accidents. The positive sign for the coefficient for one and two lanes in a single carriageway indicate that on single carriageways there were more pedestrian accidents over one and two lanes in the non-pedestrian ROW than occurred over three or more lanes. Inverting the odds ratios for one and two lanes indicated that 0.90 more slight accidents occurred on one and two lane single carriageways than on other types.

The positive sign for the coefficient when crossing the road from the driver's offside area indicates that more pedestrian accidents occurred in non-pedestrian ROW areas when pedestrians crossed the road from the driver's offside area. The odds ratio for this category is 1.19. Regarding the day on which accidents occurred, the positive sign for the weekend indicates that pedestrians who were involved in accidents at the weekend were more likely to be involved in accidents in non-pedestrian ROW areas, than those that happened on the weekdays. The odds ratio for this category is 1.22.

In consideration of the road condition, the negative sign for wet road condition indicates that there were more pedestrian accidents occurring in pedestrian ROW areas than non-pedestrian ROW. The odds ratio for road conditions showed that wet roads caused more accidents in cases of pedestrian ROW than road conditions (0.79). The positive sign for the coefficient of fine and rainy weather indicates that more pedestrian accidents occurred in fine and rainy weather in non-pedestrian ROW areas. The odds ratio for these categories are 1.49 and 1.33 respectively.

6.3 Summary and overall comparison of the models' results

The main aim of this chapter has been to investigate and model the right-of-way (ROW) and right-of-way violations of pedestrians at pedestrian crossings. A multivariate examination of the determinants of pedestrians' ROW violation has been investigated in this chapter taking into account all factors that influence pedestrians' accidents. Four modelling approaches have been used to calibrate the relationship between the ROW and the independent variables. The models used are the MNL, OLM, OPM and the BL models. The obtained models, which are aggregate in nature provide a useful tool to allow further understanding of the impacts of the independent variables factors on the ROW violations (i.e. human, vehicle, environmental, weather, or geometric factors) at pedestrian crossings. Pedestrian ROW (in BL model) and ROW1 (in MNL, OL and OP) are defined as any pedestrian accident that occurs on a pedestrian crossing area, or within ten metres of a pedestrian crossing area. ROW2 (in MNL, OL and OP) is defined as any pedestrian accident that occurs between 10 and 20 metres of a pedestrian crossing area. ROW3 (in MNL, OL and OP) is defined as any pedestrian accident that occurs between 20 metres and 50 metres of a crossing. Non pedestrian ROW (in BL models) is defined as any pedestrian accident that occurs outside the ten metre limit.

The results of the models are encouraging in terms of the logical signs obtained for all the independent variables. However, the statistical significance of the independent variables and the overall goodness of fit of the models are not very good. This is because of the absence of some of the very important factors which impact on the understanding of pedestrian behaviour at pedestrian crossing. These factors include for example pedestrian behaviour factors as well as exposure factors. Pedestrian behaviour include detailed information on how pedestrians cross the road at pedestrian crossing during the pedestrian crossing phase. Exposure behaviour factors on the other hand include pedestrian volume, traffic volumes and pedestrian density at the pedestrian crossing for example. All this data was not available from STATS19 data or any other available data source for this research. As a result, the above models do not include variables that represent exposure factors. Further research in these areas is strongly recommended therefore.

Further consideration, definitions and regulations regarding pedestrians right-of-way and right-of-way violation (ROW) are indeed needed. Once the definition and the required regulations are in place, the appropriate data relevant to the ROW can be identified and collected. Currently, there is no data available on pedestrians' ROW in the UK STATS19 database This is because this database does not include direct information or variables which indicate who, whether the drivers or the pedestrians, actually has priority at pedestrian crossings, etc. This is obviously an area where there is a huge lack of research. Further discussions on the limitations of STATS19 is given in Section 3.2.

Table 6.5 below shows an overall summary of the statistics represented by the models calibrated in this section. The Table shows an overall comparison of the models' results. From the Table, it appears that all the models are similar in terms of the impact of the variables on accident severity. In other words, the signs for the coefficients correctly reflect, in all four models, the expected impact of each of the individual factors. The overall statistical significance of the MNL model (ρ^2) is slightly higher than it is for the other models. However, the statistical significance (p-values) of all the independent variables are not very good as presented in the Tables. Inclusion of further relevant variables might improve the statistical significance of these models. Therefore, it is difficult, based on these results, to conclude that one model is more superior to the others in the cases investigated in this research.

Table 6. 5: Overall comparison of the models' results

Variables		MNL	Ordinary		BL
			Logit	Probit	
R^2		0.086	0.062	0.063	0.081
Coefficient (p-value)	Fatal /(KSI)	-13.42 (0.000)	-14.77 (0.000)	-5.72 (0.000)	21.23 (1.000)
	Serious	-12.68 (0.000)	-13.64 (0.000)	-5.04 (0.000)	--
Age group	Child	0.56 (0.142)/-0.17 (0.694)	-0.39 (0.194)	-0.25 (0.177)	-0.61 (0.093)
	Adult	0.24 (0.436)/ 0.23 (0.462)	-0.21 (0.375)	-0.13 (0.362)	-0.17 (0.570)
Gender	Female	0.35 (0.055)/ 0.12 (0.534)	-0.26 (0.065	-0.16 (0.063)	-0.32 (0.068)
Driver age group	16-21	-0.69 (0.117)/ -0.21 (0.656)	0.60 (0.083)	0.35 (0.098)	0.63 (0.127)
	22-59	-0.62 (0.073)/ -0.05 (0.894)	0.52 (0.061)	0.30 (0.074)	0.60 (0.056)
Accident time	Night time	-0.16 (0.478) / 0.21 (0.317)	0.05 (0.756)	0.04 (0.696)	0.24 (0.262)
Pedestrian movement	Crossing the road	0.20 (0.468) / 0.25 (0.353)	-0.21 (0.326)	-0.12 (0.327)	-0.13 (0.631)
Vehicle manoeuvre	Going ahead	-0.40 (0.081) / -0.40 (0.079)	0.30 (0.086)	0.19 (0.069)	0.27 (0.217)
Type of vehicle	Heavy vehicle	-0.40 (0.073) / -0.28 (0.207)	0.34 (0.047)	0.20 (0.051)	0.32 (0.137)
Type of crossing facility	Pelican	0.73 (0.000) / 0.02 (0.941)	-0.51 (0.001)	-0.32 (0.001)	-0.72 (0.000)
Width of road	1-2 lanes	0.19 (0.392) /0.25 (0.241)	-0.18 (0.268)	-0.11 (0.292)	-0.11 (0.610)
Day of the week	Weekend	-0.18 (0.397) / 0.06 (0.768)	0.10 (0.533)	0.06 (0.508)	0.20 (0.322)
Road condition	Wet	0.27 (0.290) / 0.08 (0.749)	-0.19(0.334)	- 0.12(0.315)	-0.24 (0.306)

Chapter 7
Discussions and conclusions

7.1 Introduction

This study has investigated pedestrian accidents at signalised pedestrian crossings at five selected sites in Edinburgh that occurred between 1993 and 2006. The first aim of this research has been to investigate and model pedestrian accidents injury severities at signalised pedestrian crossings. The second aim has been to investigate the impacts of location and distance from the crossing point, or within 50 meters from it, on pedestrian accident severities. The final aim of the research has been to investigate the right-of-way (ROW) and right-of-way violations of pedestrians at pedestrian crossings. Further, modelling pedestrian right-of-way taking into account the different factors affecting pedestrian accidents is also presented. This chapter presents the final discussions and conclusions from the research.

The first section of this chapter will discuss the findings of the investigations and model results of pedestrian accidents severities at signalised pedestrian crossings. The second section of this chapter presents the results of investigation of the impacts of location and distance from the crossing point, or within 50 meters from it, on pedestrian accident rates and severities. Section three summarises the investigation of the right-of-way (ROW) and right-of-way violations of pedestrians at pedestrian crossings as well as the results of the modelling of ROW. Final sections present the implication, limitation, recommendation and conclusions obtained from the research.

7.2 Summary of results of investigations of pedestrians' accident severities at pedestrian crossing sites

The investigation, analysis and modelling of pedestrian accident severities at pedestrian crossings have been presented in Chapters 3, 4 and 5. As discussed, four modelling approaches have been utilised (MNL, OL, OP & BL) to assess the impact of a number of independent variables including socio-economic, road, vehicle and environmental variables (see Table 4.1). From the results it seems that all the models are similar in terms of the impacts of the variables on accident severity (i.e. in terms of the logical signs of the independent variables and the values of coefficients). In other words, the signs for the coefficients correctly reflect, for all the four models, the expected impact of each of the individual factors. The overall goodness of fit of the MNL model (ρ^2) is higher than it is for each of the three other models. However, the more detailed investigation of the statistical significance (p-values) of the statistical significance of the independent variables shows that OL and the OP models have better statistical significance, with the ordinal probit model is slightly superior than the ordinal logit. This might be a result of the known nature and assumptions implied on the unobserved terms for the MNL model, which is known as the Independence from Irrelevant Alternatives (IIA). Therefore, it might be csusuiosly concluded here that the ordinal response models are more appropriate to be used in cases where the dependent variable is categorical and there is an order in the nature of its categories. Therefore, the ordered models (i.e. ordered logit and ordered probit) could be more appropriate to be used to model injury severity since, when the data used is in ordered format. This is based on the obtained p-values and the logical signs of the coefficients in the discussed models above.

From the results of the models, severity of injuries models illustrate that: (a) child and adult groups are more likely to be involved in accidents involving slight injury than KSI, when compared to the older group, which are more likely to be involved in KSI accidents than slight injury accidents; (b) the older female group is more likely to be involved in KSI accidents than the older male group; (c) pedestrians who have crossed the road from the driver's nearside and offside were more likely to be involved in KSI accidents than pedestrians who were standing or walking along the carriageway; (d) there were more KSI accidents at night than daytime (e) when a vehicle is moving straight ahead, it is more likely to be involved in KSI accidents than when it is performing other manoeuvres (turning, reversing and starting); (f) on single carriageways, there were slightly more accidents on two lane roads than those with three or more lanes; (g) heavy goods vehicles and buses are more likely to be involved in KSI accidents when compared to cars, taxis and motorcycles; and (h) more slight accidents occurred at junction crossings than at pelican, puffin and toucan areas; while more KSI accidents occurred at pelican, puffin and toucan areas; (i) driver age group (16-21) and (22-59) are more likely to be involved in KSI accidents than the older driver age group (over 60).

One of the predictors that was developed in Severity of Injuries Models was that 'child and adult groups are more likely to be involved in slight injury accidents compared to the elder group, which is more likely to be involved in KSI accidents than slight injury accidents.' This predictor is supported by the data on pedestrian accidents that occurred in Edinburgh from 1993-2006 which showed that: (1) pedestrians from the child or adult groups had accidents resulting in slight injuries; and (2) pedestrians from the older group received more severe injuries than those from the other groups. In particular, statistical data indicated that pedestrians under the age of 16 were involved in 3,875 accidents, 81% of which resulted in slight injuries. Moreover; pedestrians aged 16-59 were involved in approximately 5,112 pedestrian accidents, of which 80.9 % were slightly injured. On the other hand, pedestrians aged 60 and over were involved in 1,678 accidents, of which 33.2% resulted in KSI accidents. This particular predictor of the model is supported by various empirical findings, showing that the age of the pedestrians is positively correlated with the severity of injury. For instance, Zajac and Ivan (2003), and Sze and Wong (2007) found strong evidence that those aged over 65 years were at increased risk of more severe injuries. According to Sze and Wong (2007), those aged 15 and under were at reduced risk of severe accident. In addition, the model developed by Lee and Abdel-Aty (2005) showed that those aged 65 years and over have the highest risk of sustaining serious injury; in contrast, those aged 15 to 24 years have the lowest risk of sustaining serious injury. Moreover, Kim et al. (2008) stressed that the risk of severe injury increases significantly as pedestrian age increases. According to Lee and Abdel-Aty (2005), the predisposition of older pedestrians to sustain severe injuries following accidents as pedestrians may reflect lower levels of health in the older population. This claim is supported by the findings from other studies, which have shown that the elderly are more likely to suffer with increased frequencies of serious injuries in road accidents, as compared to younger pedestrians (Yee et al., 2006). Chan and Duque (2002) elucidated that this is most likely due to changes in the composition of the bone associated with aging, which may place older pedestrians at a greater risk of serious fracture. Najjar et al. (2005) and Colloca et al. (2010) explained that associated with the aging process are changes in arterial and organ tissues which may place various physical structures in a position of greater exposure during accidents and this then reduces the likelihood of recovery.

Another predictor of these models is that ‘pedestrians who crossed the road from the driver’s nearside and offside were more likely to be involved in KSI accidents than pedestrians who were standing or walking along the carriageway.’ This predictor was supported in the work of King et al. (2009) who maintained that a higher proportion of pedestrian accidents occurred when the pedestrian crossed legally than at any other time. Several research findings have also shown that actually crossing the road places the pedestrian at a greater risk of sustaining severe injury than simply walking along the roadside (Kim et al, 2008). Moreover, data obtained from selected roads in Edinburgh showed that there were 140 KSI accidents, which resulted from pedestrians crossing the road, as opposed to 14 KSI accidents which occurred when pedestrians simply stood or walked beside the carriageway.

These models also predicted that ‘there were more KSI accidents in night time than at day time.’ This prediction was supported by statistical data from STATS19, which showed that between 1993 and 2006 accidents during hours of darkness were more severe than those in the day time. The percentage of KSI pedestrians during hours of darkness accounted for 40.2% of accidents which is double the percentage of pedestrian accidents during daytime which accounted for 21.29% of the total figures. Moreover, statistical data obtained from Edinburgh during the same period indicated that the frequency count for killed and seriously injured pedestrians involved in night-time accidents was higher than the frequency count for KSI accidents that occurred in the day time (24.8% and 20.1% respectively). This particular prediction also supports the findings of various studies. Lee and Abdel-Aty (2005) and Kim et al. (2008) concluded that levels of light have been indicated as important factors in determining the severity of injuries suffered by pedestrians in road accidents. Johansson et al. (1963) explained that night-time accidents occur as a result of the reduced line of sight, which is of further influence on drivers in darker conditions and significantly impairs their ability to stop in time.

Another prediction of these models is that ‘when the vehicle is moving straight ahead, it is more likely to be involved in KSI accidents than when it is performing other manoeuvres (turning, reversing and starting).’ Although there is a dearth of available research findings regarding the influence of vehicular direction on the severity of pedestrian injury during pedestrian vs. motor vehicle collisions, it has been well-documented that the speed at which the car is travelling may be one of the most critical factors in determining the severity of injury for pedestrians. This has been confirmed by different models, including the model cited by Garder (2004) and Lee and Abdel-Aty (2005). It would be safe and logical to assume that the magnitude of the speed of a vehicle that is moving straight ahead is greater than that involved in other manoeuvres such as turning, reversing and starting. Furthermore, data obtained from selected roads in Edinburg have indicated that the total number of pedestrian accidents caused when going ahead was 754 and the total number caused during other vehicle manoeuvres was 172 (81.4% and 18.6% respectively). More than 90% of KSI resulted from going ahead vehicle manoeuvres, while other vehicle manoeuvres caused only 10% of KSI accidents.

These models likewise predicted a finding that ‘in single carriageways, there were more slight accidents in two lanes than those occurring in three or more lanes.’ This particular prediction was supported by Zajac and Ivan (2003), whose work highlighted the strong influence of the width of the road on accident severity, especially in cases where pedestrians crossed the road without the aid of a designated crossing site. This was also confirmed by Garder (2004) and Kim et al. (2008) who found road width and the number of lanes on the road suitable predictors of the severity of pedestrian injury. This prediction was also supported by the statistical data from STATS19, which showed that between 1993 and 2006, single carriageways were associated with the highest incidence of fatalities. In particular, approximately 75% and 83% of all recorded fatal and serious accidents occurred on single carriageways during this period. The next highest number of percentages occurred (20% fatal accidents and 10% serious injury) on dual carriageways.

These models also predicted that ‘heavy goods vehicles and buses are more likely to be involved in KSI accidents compared to cars, taxis and motorcycles.’ This was supported by the findings of Lee and Abdel-Aty (2005), who identified vehicle type as an important factor in predicting the severity of injuries suffered by pedestrians. This contribution of Lee and Abdel-Aty (2005) was largely based on an analysis of data obtained from the Florida Traffic Crash Records Database, which utilised an ordered probit model. Such an approach has also been used by several other researchers who have investigated crash impact factors and the impact of different factors on injury severity. Other studies have also supported the importance of vehicle type as a predictor of pedestrian injury severity (Zajac and Ivan, 2003). For instance, Ballesteros and others

(2004) found that pedestrians hit by sports utility vehicles or pick-up trucks in the US were most likely to die. However when controlling for the weight of the vehicle and speed they found there to be no significant difference between vehicle type and the risk of fatal injury. This would therefore appear to indicate that the weight of the vehicle may be more significant than the type of vehicle. Roudsari et al. (2004) found that larger vehicles pose a higher risk of severe injury to pedestrians compared to passenger vehicles, when controlling for speed.

Lastly, these models predict that ‘more slight accidents occurred at junction crossings than in pelican, puffin and toucan areas; while more KSI accidents occurred at these areas. This prediction is supported by various researchers. For instance, the influence of the type of pedestrian crossing on the severity of pedestrian injury was explored by Greenshields et al. (2006), who tabulated the different advantages and disadvantages of various types of pedestrian crossing. They also provided guidance as to the legal instruments covering the different crossing types; and the various design standards for pedestrian crossing facilities. Moreover, Hunt (1998) found that “80% of pedestrian casualties occurred while pedestrians were crossing the carriageway and, that more than 12% of these pedestrian casualties were at or within 50m of a Pelican or Zebra crossing.” Hunt (1998) explained that from 1975 to 1985, there was an increase in the number of pedestrian casualties at or close to pelican crossings. In addition, statistical data from STATS19 showed that between 1993 and 2006, nearly 13794 accidents out of a total of 54645 (25.24 %) were considered severe or fatal and these occurred at pelican crossings. On the other hand, data from the same period indicated that out of the total accidents that occurred at junction crossings which reached a frequency count of 41123, only 9631 (23.41%) resulted in KSI.

7.3 Summary of results of the investigation of the impacts of location and distance on pedestrian accident rates and severities

In order to further investigate the factors which lead to an increase in the severity of injury on pedestrian crossings, or within 50 metres of them, five roads in Edinburgh were selected for the purposes of investigation, as discussed earlier in Chapter 3. Therefore, in this section, the distribution of pedestrian accidents around the pedestrian crossing facilities, investigating the location of pedestrian accidents and the distance from the pedestrian crossings are presented.

There are 942 pedestrian accidents which occurred on pedestrian crossing lines or within 50 metres of the crossing lines along the selected five roads. Figure 7.1 (re copied from Figure 4.1 for completeness) below shows the distribution of pedestrian accidents that occurred on pedestrian crossing lines or within 50 metres of the crossing line. It appears that the number of pedestrian accidents that occurred on pedestrian crossing lines were the highest and the number of pedestrian accidents decreased when moving up to 50 metres from such pedestrian crossings.

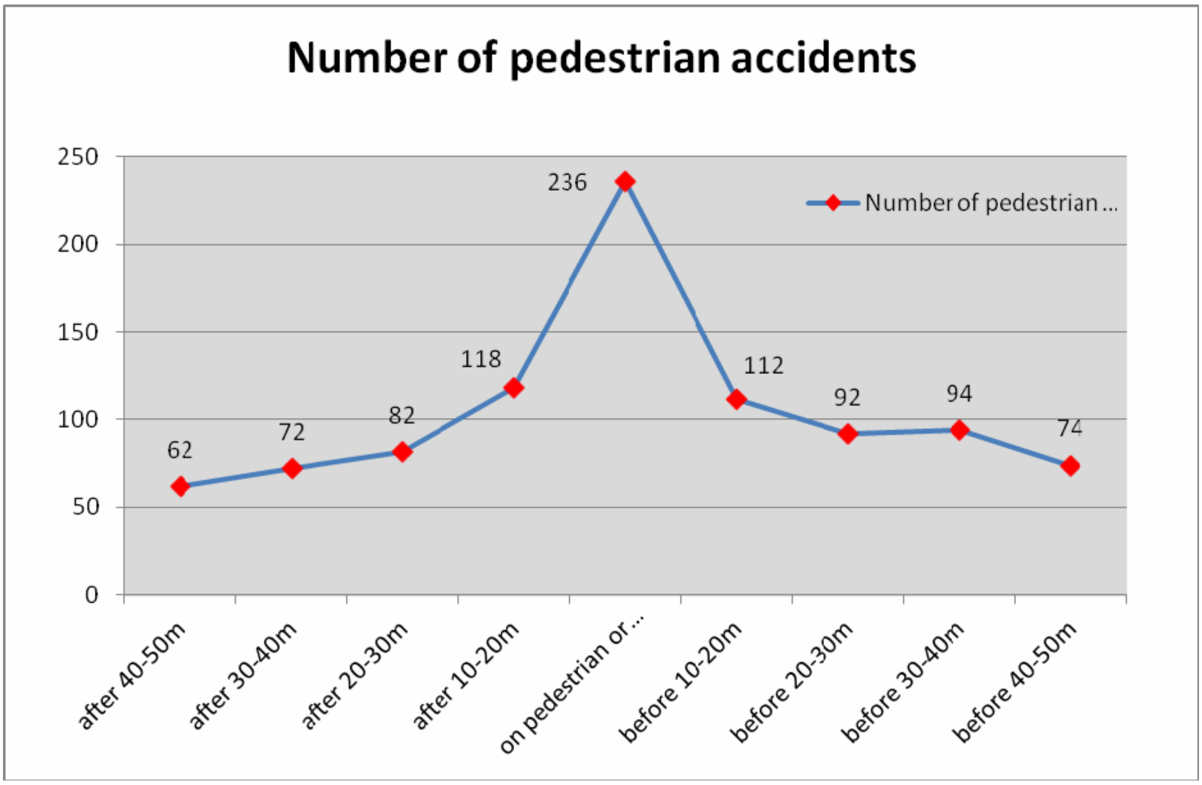

Figure 7. 1: Distribution of pedestrian accidents within 50 metres of the pedestrian crossing lines

Regarding the distribution of the severity of injury resulting from pedestrian accidents, the same situation was observed with a number of pedestrian accidents, in relation to the severity of injury sustained. According to STATS19 data, the number of those who were KSI increased on pedestrian crossing lines and decreased at a distance from such pedestrian crossing lines (Figure 7.2).

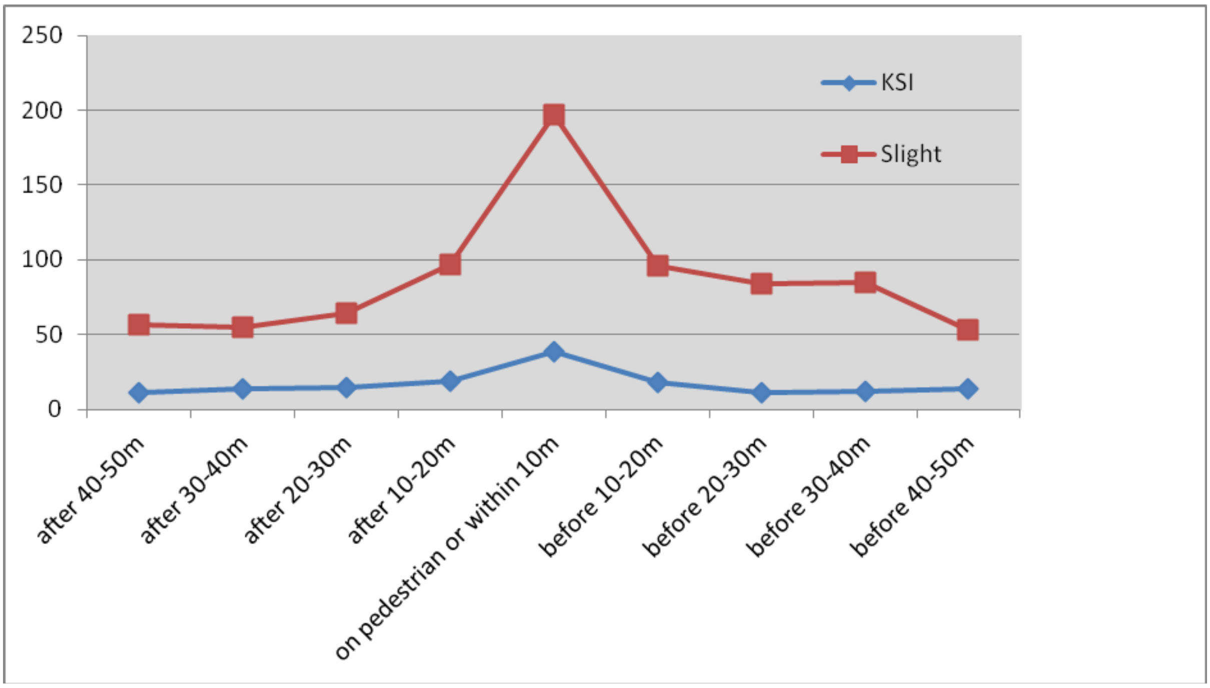

Figure 7. 2: Illustration of the distribution of the severity of injury

As discussed in Section 7.2, pedestrians' injury severity in pedestrian vs. car type accidents has been modelled using four different modelling techniques. In these models, the variable representing the distance from the pedestrian crossing point, has been included. In the models, it is expected that the location of pedestrian accident relative to the pedestrian crossing line has an impact on accident severities. As expected, in the model, the coefficient of the "on pedestrian crossing or within ten meters" in the fatal category has a positive value, and that it has a negative value in the other categories of this variable. In other words, the model predicts that the ratio of relative risk of being involved in a fatal incident increased when pedestrians were involved in pedestrian accidents on a pedestrian crossing area, as opposed to slight injury when accidents occurred between 10m and 50m of pedestrian crossing areas is exp (0.54) =1.72. This is comparable with the results presented in the graphs 7.1 and 7.2. For the serious category of this variable, the sign is negative however which does not conform to the expected results. This might be as a result of the knows characteristics of the MNL model (i.e. the IIA) as discussed in Chapter 5 and 6, where there are any correlations between the categories of the dependent variables.

7.4 Summary of results of the investigation of Right-of-Way violation

As discussed in Section 2.6 and 3.3, In general the term of jaywalking refer to a pedestrian crossing from one side to other in unauthorised areas or in violation of pedestrian regulation. however, in the UK pedestrian always has priority or consideration in the street and they exercise prudence when crossing roads and to act for their own safety. The definition of pedestrian crossing regulations in the UK is the same as that in the Vienna Convention of 1968. From pedestrian rules that stated in the Highway Code, It is clear that the pedestrians have right-of-way over vehicle users; however, this is not clearly stated in any area and can lead to a certain level of ambiguity. Although common sense should allow drivers to be capable of realising that should they injure a pedestrian to such an extent to which death results they are likely to face legal proceedings.

In this research, pedestrian ROW violations as the case of a pedestrian accident at pedestrian crossing, has been defined as "*any pedestrian accident that occurs on pedestrian crossing areas or within ten metres of pedestrian crossing areas*". it was included a Pedestrian accidents occurring on pedestrian crossing areas, zigzag lines and when pedestrians were crossing elsewhere within 10metres on both sides of the crossing, or when pedestrians are walking along the side way walk. On the other hand, any pedestrian accident that occurs outside the ten metre limit is called a non-pedestrian ROW (or driver ROW). In this case the pedestrian will be violating the right-of-way of the driver. it is included a Pedestrian accidents occurring outside the pedestrian ROW area (pedestrian accidents occurring away) within 50 meters from the crossing line in both directions.

From the results of the models, it was shown that drivers falling into the age group 16-21 and 22-59 are more likely to be involved in accidents where pedestrians have no right-of-way to cross the road, as compared to drivers over 60. This prediction was supported by the data obtained at the selected roads, which showed that accident rates when the drivers are aged 16-21 and between 22 and 59 where pedestrians have ROW are 22.8 and 23.7 respectively. In particular, the older drivers' group was reported to have been involved in 10.5% of pedestrian accidents within pedestrian right-of-way and the accident rate was 38.9 (see table 4.21). Drivers aged less than 22 and between 22 and 59 were involved in 9% of pedestrian accidents and 83.5% of pedestrian accidents respectively, within pedestrian ROW.

Another prediction made was that 'turning manoeuvres (either right or left) are more likely to violate pedestrian ROW and cause pedestrian accidents than going ahead manoeuvres'. This was posited by Hatfield et al. (2006), who maintained that pedestrian confusion may also be attributed to right-of-way of left and right turning vehicles. This prediction was supported by the general trend for ROW violation observed at the selected roads in Edinburgh. Data obtained regarding the selected roads showed that the pedestrians were involved in accidents with turning manoeuvres (51.1%) more than in pedestrian ROW; as compared to accidents that occurred when there was no pedestrian ROW. It is logical to expect that turning manoeuvres (either right or left) would be more likely to violate pedestrian ROW and cause pedestrian accidents compared to other types of manoeuvres, since such manoeuvres tend to require more space and take up the space specifically allotted for pedestrian's ROW. Moreover, pedestrians are likely to become confused when predicting the exact direction of movement of turning vehicles.

This model also showed that 'more females are involved in pedestrian accidents in pedestrian right-of-way areas compared to their male counterparts'. This is in contrast to the general trend of ROW violation. In particular, the data obtained at the selected roads showed that male pedestrians figured in 129 accidents in pedestrian ROW areas, compared to their female counterparts who figured in 107 accidents in the same areas. Moreover, figures indicated that the accident rate for males within the pedestrian ROW areas was 64.5%; while accident rates for female within the pedestrian ROW areas was 53.5. Conversely, it appears that from table 4.12 in chapter 4, that the percentage of female pedestrians involved in accidents in right of way areas was higher than that for male pedestrians (28.7 for female and 22.8 for male).

This model also showed that 'heavy goods vehicles and buses were more likely to be involved in accidents in non pedestrian ROW, compared with other types of vehicles, such as motorcycles and cars. This prediction appears to be support the general trend for right-of-way violation observed in selected roads in Edinburgh. Data obtained from the selected roads showed that accident rate for pedestrians with ROW which involved in accidents with light vehicles were 83 accidents more often than with heavy vehicles 31 accidents (See Table 4.14).

7.5 Implications and contribution of the research

In the light of the above results, the models developed to profile pedestrian accidents in Edinburgh appear to be useful and applicable for many applications. It seems reasonable to assume that this research may represent a point of reference for transport planners when they are seeking to adjust or redesign pedestrians crossing facilities as discussed below**.**

The first research question of this research was related to the investigation of the factors that affect pedestrian accident severities at pedestrian crossings.

In terms of severity of injuries models, it was shown that pedestrians from the older group received more severe injuries, compared with those from younger groups. One important implication of this observation is the need for the formulation and subsequent enforcement of traffic laws that protect and promote the safety of older pedestrians (i.e. those aged 60 and above). In the same vein, since the model showed that the weight of the vehicle is a predictor of the severity of pedestrian injury, stricter regulations must be imposed on heavier vehicles; for example in the form of more stringent speed limits. The model also showed an association between the severity of injury and the type of pedestrian crossing. Since more KSI accidents have been associated with pelican crossings, there may be a need to undertake a massive information and education campaign for the benefit of pedestrians. Such a campaign must centre on educating pedestrians regarding: (1) the correct manner of activating traffic signals; (2) how to best avoid crossing when a red figure shows; and (3) checking that the traffic has stopped before crossing with care when the green figure begins to flash.

The second research question of this research is related to the impact of distance from the pedestrian crossings on crash severities.

The review of available literature related to pedestrian accidents indicates that the occurrences of pedestrian accidents are influenced by a diverse range of factors (Campbell et al., 2004; Sideris, 2006). Moreover, few empirical studies have documented the effects of distance of pedestrian accidents from pedestrian crossing area or junction (Ward et al., 2004; and Department for Transport, 2004) wherein both findings suggest that the longer the distance from road crossing facilities, the higher the likelihood of a pedestrian accident. With respect to the influence of the type of pedestrian crossing on the incidence of pedestrian accidents, a substantial body of literature has found that the types of pedestrian crossing indeed affect the frequency of pedestrian collisions. Additionally, the available studies reviewed all indicated the positive impact of signalised crossings on the reduction of pedestrian collision risk.

Findings from this research suggest that the highest number of pedestrian accidents occurred at pedestrian crossing lines; and that the number of pedestrian accidents decreased when moving away from pedestrian crossing lines or within 50 metres of pedestrian crossing lines have serious implications in terms of the planning and design of pedestrian crossings. Improvements to pedestrian crossing facilities are surely still needed that can then ensure better pedestrian visibility and provide the public with more protection from moving vehicles.

The third research question has been on the enforcement of traffic laws and pedestrians' ROW at pedestrian crossings.

Most authors agreed on the effectiveness of enforcing regulatory instruments in reference to reducing the rates of collisions, casualties and driving violations. Another implication of this finding is that more stringent regulatory instruments must be developed, since there are no laws to prevent pedestrians from crossing the road at certain points; the only laws being enforced in the UK, are those relating to the prohibition of walking on motorways or slip roads but not regarding loitering on pedestrian crossings. Most of what available, are only guidelines specified in the Highway Code to deal with pedestrian behaviour while crossing the road. More rigorous regulations are certainly needed.

In terms of ROW Models; it was shown that turning manoeuvres (either right or left) were more likely to violate pedestrian's ROW and result in accidents than other types of manoeuvres. Moreover, the model showed that light vehicles (cars, taxi and motorcycle) are more likely to be involved in accidents associated with the pedestrian's ROW, as compared to other types of vehicles, such as heavy goods vehicles and buses. The various issues related to accidents resulting from pedestrian right-of-way can be effectively resolved by rationalisation of pedestrian crossing types; and provision of education with regards to the rules and responsibilities of both pedestrians and drivers at all available crossings. Moreover, in order to reduce the rate of incidence of pedestrian accidents resulting from the violation pedestrian right-of-way, anti-jaywalking laws must be developed and implemented in parts of the UK.

7.6 Limitations of this study

As discussed in chapter 3, there are some limitations in the current research to be noted for future consideration.

Firstly, the main source of data in this study is the UK's STATS19 database, which has its limitations. Pedestrians and drivers under the influence of drugs or alcohol data, while very relevant to this study and should have been taken into consideration, are not currently available in STATS19. The absence of this data no doubt has affected the accuracy of the data in general.

To locate pedestrian accident, this research relied on factor 1.11 in the STATS19 data (the grid reference), which consists of ten figures (five figures represent easterly and five figures representing northern directions). By using the grid reference, the most accurate location that could be obtained was within 10 metres, which is not very accurate for this type of analysis. More accurate data would have been more valuable, and certainly the use of GPS equipment, which is technically available should be utilised.

Another limitation of this study, which is also relevant to STATS19 data is the absence of factors that represent exposure. In this study, a number of factors have been investigated and considered for inclusion in the models to represent exposure (e.g. pedestrian population in the study area, traffic volume along the selected road, pedestrian volume on the selected sites, pedestrian volumes crossing the road at the crossing facilities, housing type around the selected roads and demographic area). Any of these data could be included in this study if were available. STATS19 data, although very useful and provide large amount of data relate to accident crash severity, does not include exposure factors. Therefore, in this research, it was decided to collect further data using traffic and pedestrian counting as well as traffic volume data that was obtained from the local city council. The problem with this data is that they have not been gathered at the same time as accident data (which are available from STATS19 for 14 years). The collected data has been tested in the models to represent exposure factors as discussed in Chapter 5. However, the obtained models did not provide any improvements in terms of the their statistical significant over those models without exposure factors. Further research in this area is therefore strongly recommended.

The investigation of ROW violations has relied on logical assessment and the common sense of the analyst; which brings some subjectivity to the analysis. Using more accurate data, such as data obtained from video filming would have enhanced the results. The other limitation related to the extent to which the findings can be generalised beyond the cases studied, is the too small number of cases for broad generalisations. Further empirical studies and evaluations are therefore, needed to replicate the findings in different contexts.

7.8 Recommendations for further research and the way forward

There is a dearth in available literature providing a single and precise definition of pedestrian exposure. Most of the authors whose works were included in this review accounted for the lack of a collective and widely accepted definition to the abstract nature of the concept of pedestrian exposure. Despite the availability of a substantial body of literature on proxy or indicator measures of pedestrian exposure, there appears to be a gap in the knowledge in terms of the validity and reliability of such measures. There is a lack of empirical evidence that buttresess the soundness and accuracy of the indicator measures already formulated and established in prior research. Moreover, there is a need to expand established measures to include new ones. In fact, there is insufficient information regarding exposure measures in terms of considering the density of pedestrians who pass over crossing areas (i.e. pelican or zebra crossing) and the volume of the vehicles that pass along the same area. Thus, future research needs to be oriented towards the formulation of valid and reliable exposure measures to assist other researchers to compare data and methods; and to fill current knowledge gaps on pedestrian exposure to accident risk.

Considerable research has been carried out in recent years to establish the relationships that exist between crashes involving pedestrians and traffic flow, geometric infrastructure characteristics and environmental factors for urban and rural roads. Crash-prediction models focusing on pedestrian behaviour, however, have rarely been investigated. In addition, most research has paid little attention to the safety effects of variables such as stopping distance and line of sight and pavement surface characteristics. More attention should be paid to these areas in future research. Moreover, statistical approaches have generally included MNL, OL, OP, BL, Poisson and Negative Binomial regression models. However, other models may also be useful for investigating Negative Multinomial regression models; these have been used to a lesser extent. Moreover, as far as most authors are aware, crash prediction models involving all the above-mentioned factors have still not been developed in the majority of developing countries. It is the author's intention to extend this analysis into the UAE once he has returned there.

This thesis has contributed to research work in the area of investigations of pedestrian accidents injury severities at pedestrian crossing in a number of dimensions. The addition to the literature in the novel analysis of defining and predicting pedestrian ROW violations is one of those dimensions. Secondly, the contribution to knowledge and practice in being able to investigate and analyse a number of modelling techniques using the same data set is another point of novelty of this research. Further, the development of methodology which attempts to combine available data and statistics of pedestrian accidents as well as data related to exposure factors is very interesting and should provide potential improvement to the analysis of pedestrian accident severities. Finally, the potential of transferability of research methodology and outputs to other countries with similar accident collection data-bases is also an attractive dimension of the contribution of this research.

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Appendices:

Appendix 1: STATS 19 Form

Accident Record Attendant Circumstances

1.1 Record Type [1][ ]

11 New accident record
15 Amended accident record

1.2 Police Force [ ][ ]

1.3 Accident Ref No [ ][ ][ ][ ][ ][ ][ ]

1.5 Number of Vehicle Records [ ][ ][ ]

1.6 Number of Casualty Records [ ][ ][ ]

1.7 Date (Day Month Year) [ ][ ] [ ][ ] [ ][ ]

1.9 Time of Day (Hours Mins, 24 hour) [ ][ ] [ ][ ]

1.10 Local Authority [ ][ ][ ]

1.11 Location
10 digit OS Grid Reference number
[ ][ ][ ][ ][ ] [ ][ ][ ][ ][ ]
Easting

1.12 1st Road Class [ ]

1 Motorway
2 A(M)
3 A
4 B
5 C
6 Unclassified

1.13 1st Road Number [ ][ ][ ][ ]

1.14 Road Type [ ]

1 Roundabout
2 One way street
3 Dual carriageway - 2 lanes
4 Dual carriageway - 3 or more lanes
5 Single carriageway - single track
6 Single carriageway - 2 lanes (one in each direction)
7 Single carriageway - 3 lanes (two capacity)
8 Single carriageway - 4 or more (two way capacity)
9 Unknown

1.15 Speed Limit (mph) [0][ ][ ]

1.16 Junction Detail [0][ ]

00 Not at or within 20 metres of
01 Roundabout
02 Mini roundabout
03 T or staggered junction
05 Slip road
06 Crossroads
07 Multiple junction
08 Using private drive or entrance
09 Other junction

Junction Accidents Only

1.17 Junction Control [ ]
1 Authorised Person
2 Automatic traffic signal
3 Stop sign
4 Give way sign or
5 Uncontrolled

1.18 2nd Road Class [ ]
1 Motorway
2 A(M)
3 A
4 B
5 C
6 Unclassified

1.19 2nd Road Number [ ][ ][ ][ ]

1.20a Pedestrian Crossing - Human Control [ ]

0 No crossing facility within 50 physical crossing facility not by authorised person
1 Control by school crossing patrol
2 Control by other authorised

1.20b Pedestrian Crossing - Physical Facilities [ ]

0 No physical crossing facility within 50 metres
1 Zebra crossing
4 Pelican, puffin, toucan or similar junction pedestrian light crossing
5 Pedestrian phase at traffic signal junction
8 Central refuge - no other controls
9 Footbridge or subway

1.21 Light Conditions [ ]

1 Daylight: street lights present
2 Daylight: no street lighting
3 Daylight: street lighting unknown
4 Darkness: street lights present
5 Darkness: street lights present but
6 Darkness: no street lighting
7 Darkness: street lighting unknown

1.22 Weather [ ]

1 Fine without high winds
2 Raining without high winds
3 Snowing without high winds
4 Fine with high winds
5 Raining with high winds
6 Snowing with high winds
7 Fog or mist - if hazard
8 Other
9 Unknown

1.23 Road Surface Condition [ ]

1 Dry
2 Wet / Damp
3 Snow
4 Frost / Ice
5 Flood (surface water over 3cm
6 Oil or diesel
7 Mud

1.24 Special Conditions at Site [ ]

0 None
1 Automatic traffic signal out
2 Automatic traffic signal partially
3 Permanent road signing or marking defective or obscured
4 Roadworks present
5 Road surface defective

1.25 Carriageway Hazards [ ]

0 None
1 Dislodged vehicle load in
2 Other object in carriageway
3 Involvement with previous accident
4 Dog in carriageway
5 Other animal or pedestrian in

1.26 Place Accident Reported [ ]

1 At scene
2 Elsewhere

1.27 DETR Special Projects [ ][ ][ ][ ]

Vehicle Record

2.1 Record Type [2][ ]

21 New vehicle record
25 Amended vehicle record

2.2 Police Force

2.3 Accident Ref No

2.4 Vehicle Ref No

2.5 Type of Vehicle

01 Pedal cycle
02 Moped
03 Motor cycle 125 cc and under
04 Motor cycle over 125cc
08 Taxi
09 Car
10 Minibus (8 - 16 passenger seats)
11 Bus or coach (17 or more passenger seats)
14 Other motor vehicle
15 Other non-
16 Ridden horse
17 (includes
18 Tram / Light rail
19 Goods tonnes mgw
20 Goods tonnes and tonnes mgw
21 Goods tonnes mgw and over

2.6 Towing and Articulation

0 No tow or articulation
1 Articulated vehicle
2 Double or multiple trailer
3 Caravan
4 Single trailer
5 Other tow

2.7 Manoeuvres

01 Reversing
02 Parked
03 Waiting to go ahead but held up
04 Stopping
05 Starting
06 U turn
07 Turning left
08 Waiting to turn left
09 Turning right
10 Waiting to turn right
11 Changing lane to left
12 Changing
13 Overtaking vehicle on its offside
14 vehicle on
15 Overtaking
16 bend
17 Going ahead hand bend
18 Going ahead

2.8 Vehicle Movement Compass Point [ ] From [ ] To

1 N
2 NE
3 E
4 SE
5 S
6 SW
7 W
8 NW

Parked:
not at kerb [0][0]
at kerb [*][0]
* code 1 - 8

2.9a Vehicle Location at Time of Accident - Road

1 Leaving the main road
2 Entering the main road
3 On the main road
4 On the minor road

2.9b Vehicle Location at Time of Accident - Restricted Lane/ Away from Main Carriageway

0 On main carriageway - not in restricted lane
1 Tram / Light rail track
2 Bus lane
3 Busway (including guided busway)
4 Cycle lane (on main carriageway)
5 Cycleway (separated from main carriageway)
6 On lay-by or hard shoulder
7 Entering lay-by or hard shoulder
8 Leaving lay-by or hard shoulder
9 Footway (pavement)

2.10 Junction Location of Vehicle at First Impact

0 Not at junction (or within 20 metres)
1 Vehicle approaching junction or parked at junction approach
2 Vehicle in middle of junction
3 Vehicle cleared junction or parked at junction exit
4 Did not impact

2.11 Skidding and Overturning

0 No skidding, jack-knifing or overturning
1 Skidded
2 Skidded and overturned
3 Jack-knifed
4 Jack-knifed and overturned
5 Overturned

2.12 Hit Object in Carriageway

00 None
01 Previous accident
02 Roadworks
03 Parked vehicle - lit
04 Parked vehicle - unlit
05 Bridge - roof
06
07 Bollard / refuge
08 Open door of
09 Central island roundabout
10 Kerb
11 Other object

2.13 Vehicle Leaving Carriageway

0 Did not leave carriageway
1 Left carriageway nearside
2 Left carriageway nearside and rebounded
3 Left carriageway straight ahead at junction
4 Left carriageway offside onto central reservation
5 Left carriageway offside onto central reservation and rebounded
6 Left carriageway offside and crossed central reservation
7 Left carriageway offside
8 Left carriageway offside and rebounded

2.14 Hit Object Off Carriageway

00 None
01 Road sign / Traffic signal
02 Lamp post
03 Telegraph pole / Electricity pole
04 Tree
05 Bus stop / Bus shelter
06 Central crash barrier
07 Nearside or offside crash barrier
08 Submerged in water (completely)
09 Entered ditch
10 Other permanent object

2.16 First Point of Impact

0 Did not impact
1 Front
2 Back
3 Offside
4 Nearside

2.17 Other Vehicle Hit
Ref no of other vehicle

2.18 Part(s) Damaged

0 None
1 Front
2 Back
3 Offside
4 Nearside
5 Roof
6 Underside
7 All four sides

2.21 Sex of Driver

1 Male
2 Female
3 Not traced

2.22 Age of Driver
Estimated if necessary
Years

2.23 Breath Test

0 Not applicable
1 Positive
2 Negative
3 Not requested
4 Refused to provide
5 Driver not at
6 Not provided (medical

2.24 Hit and Run

0 Other
1 Hit and Run
2 Non-stop not hit

2.25 DETR Special Projects

2.26 Vehicle Registration Mark (VRM)

Special codes:
2 Foreign / Diplomatic
3 Military
4

2.27 Driver Postcode

Special codes:
1 Unknown
2 Non-UK resident
3 Parked and

Casualty Record

3.1 Record Type [3][ ]

31 New casualty record
35 Amended casualty record

3.2 Police Force [ ][ ]

3.3 Accident Ref No [ ][ ][ ][ ][ ][ ][ ]

3.4 Vehicle Ref No [ ][ ][ ]

3.5 Casualty Ref No [ ][ ][ ]

3.6 Casualty Class [ ]

1 Driver or rider
2 Vehicle or pillion passenger
3 Pedestrian

3.7 Sex of Casualty [ ]

1 Male
2 Female

3.8 Age of Casualty [ ][ ] Years
Estimated if necessary

3.9 Severity of Casualty [ ]

1 Fatal
2 Serious
3 Slight

3.10 Pedestrian Location [ ][ ]

00 Not a pedestrian
01 In carriageway, crossing on crossing facility
02 In carriageway, crossing within zig-lines at crossing approach
03 In carriageway, crossing within zig-lines at crossing exit
04 In carriageway, crossing elsewhere within 50 metres of pedestrian
05 In carriageway, crossing elsewhere
06 On footway or verge
07 On refuge, central island or central reservation
08 In centre of carriageway, not on central island or central
09 In carriageway, not crossing
10 Unknown or other

3.11 Pedestrian Movement [ ]

0 Not a pedestrian
1 Crossing from driver's nearside
2 Crossing from driver's nearside - by parked or stationary vehicle
3 Crossing from driver's offside
4 Crossing from driver's offside - by parked or stationary vehicle
5 In carriageway, stationary - not (standing or playing)
6 In carriageway, stationary - not (standing or playing), masked by parked or stationary vehicle
7 Walking along in carriageway - facing traffic
8 Walking along in carriageway - back to traffic
9 Unknown or other

3.12 Pedestrian Direction [ ]

Compass point bound

1 N
2 NE
3 E
4 SE
5 S
6 SW
7 W
8 NW
9 Unknown
0 Standing still

3.13 School Pupil Casualty [ ]

1 School pupil on journey to or from school
0 Other

3.15 Car Passenger [ ]

0 Not a car passenger
1 Front seat passenger
2 Rear seat passenger

3.16 Bus or Coach Passenger [ ]

0 Not a bus or coach passenger
1 Boarding
2 Alighting
3 Standing passenger
4 Seated passenger

3.17 DETR Special Projects [ ][ ][ ][ ]

3.18 Casualty Postcode [ ][ ][ ][ ] [ ][ ][ ]

Special codes:
1 Unknown
2 Non-UK resident

Appendix 2:

Appendix 2.1: General statistics of pedestrian's accidents in the UK

Table A2.1a below illustrates the classification of the severity of pedestrian accidents from 1993 to 2006.

Table A2.23a: Classification of pedestrian-motor vehicle severity (1993-2006).

Variables		Fatal	Serious	Slight	Total	KSI	%
Pedestrians	1993	1241	11422	35456	48128	12663	26.31
	1994	1124	11806	35765	48695	12930	26.55
	1995	1038	11259	34786	47083	12297	26.11
	1996	997	10615	34838	46450	11612	24.99
	1997	973	10053	34575	45601	11026	24.17
	1998	906	9575	34405	44886	10481	23.35
	1999	870	8955	33063	42888	9825	22.90
	2000	857	8641	32535	42033	9498	22.59
	2001	826	8238	31513	40577	9064	22.33
	2002	775	7856	30153	38784	8631	22.25
	2003	774	7159	28472	36405	7933	21.79
	2004	671	6807	27403	34881	7478	21.43
	2005	671	6458	26152	33281	7129	21.42
	2006	675	6376	23931	30982	7051	22.75

A2.1.1 Socio-economic factors

Table A2.1b below illustrates the summary of pedestrian accidents that occurred in the UK from 1993 -2006 in relation to the factors investigated.

Table A2.1b: Summary of pedestrian accidents in the UK from 1993-2006 and the factors investigated.

Variables		**Description**	**Min**	**Max**	**mean**	**KSI**
Age	Child (0-15)	Child =1; other = 0	0	1	0.42	0.34
	Adult (16-59)	Adult =1; other = 0	0	1	0.43	0.44
	Old (60<)	Old =1; other = 0	0	1	0.15	0.22
Gender	Male	Male =1; other =0	0	1	0.58	0.61
	Female	Female =1; other = 0	0	1	0.42	0.39
Severity	KSI.	KSI=1; other = 0	0	1	0.24	_
	Slight	Slight =1; other = 0	0	1	0.76	_
Road Type	Single carriageway	Single cw* =1; other = 0	0	1	0.86	0.84
	Dual carriageway	Dual cw *=1; other = 0	0	1	0.08	0.11
	One way street	One way =1; other=0	0	1	0.06	0.05
Pedestrian location	On pedestrian	Dry =1; other=0	0	1	0.11	0.13
	Within 50 m	Wet =1; other=0	0	1	0.08	0.13
	Elsewhere	Elsewhere =1; other =0	0	1	0.81	0.74
Road surface	Dry	Dry =1; other = 0	0	1	0.73	0.70
	Wet	Wet =1; other = 0	0	1	0.26	0.29
	Snow	Snow =1; other = 0	0	1	0.01	0.01
Light condition	Daylight	Daylight =1; other = 0	0	1	0.72	0.65
	Darkness	Darkness=1; other = 0	0	1	0.28	0.35

*Carriageway

Table A2. 1c: Gender, age group and casualty types

Variables			**Fatal**	**Serious**	**Slight**	**Total**	**KSI**	**%**
Gender & Age	<16	Male	1053 (0.8%)	30299 (21.6%)	108994 (77.7%)	140346 (24.9%)	31352	22.33
		Female	616 (0.7%)	17481 (18.7%)	75211 (80.6%)	93308 (16.6%)	18097	19.39
	16 - 59	Male	3954 (2.7%)	33776 (22.6%)	111434(74.7%)	149164 (26.5%)	37730	25.29
		Female	1233 (1.3%)	17061 (17.8%)	77492 (80.9%)	95786 (17.0%)	18294	19.09
	>60	Male	2901 (7.5%)	10502 (27.2%)	25241 (65.3%)	38644 (6.9%)	13403	34.68
		Female	2573 (5.6%)	13932 (30.1%)	29725 (64.3%)	46230 (8.2%)	16505	35.70

A2.1.2 Road related factors

Table A2.1d illustrates the road type and the severity of accidents.

Table A2. 1d: Road type and severity of accident.

Variables		**Fatal**	**Serious**	**Slight**	**Total**	**KSI**	**%**
Road type	Roundabout	94	1457	6420	7971	1551	19.45
	Dual carriageway	2335	11970	30829	45134	14305	31.69
	Single carriageway	8477	98974	351224	458675	107451	23.42
	One way street	338	5423	25779	31540	5761	18.26
	Unknown	40	761	4943	5744	801	13.94

Table A2. 1e: Road class and severity of accident.

Variables		Fatal	Serious	Slight	Total	KSI	%
Road class	Motorway	294	325	404	1023	619	60.50
	A (m)	23	45	58	126	68	53.96
	A	6120	47673	144637	198430	53793	27.10
	B	1420	14180	46853	62453	15600	24.97
	C	847	10556	38137	49540	11403	23.01
	Unclassified	2580	45810	189111	237501	48390	20.37

Table A 2.1f: Speed limits and severity of accidents.

Variables		Fatal	Serious	Slight	Total	KSI	%
Speed limits	<30	27	468	2214	2709	495	18.27
	30 -39	7431	103751	389737	500919	111182	22.19
	40-49	1213	7462	15228	23903	8675	36.29
	50	224	756	1212	2192	950	43.33
	60	1453	4961	9424	15838	6414	40.49
	70	936	1191	1385	3512	2127	60.56

Table A2.1g: Area of pedestrian accidents.

Pedestrian crossing physical facility	Number of casualties	%	KSI	%
No crossing facilities	409474	81.5%	95603	23.34%
Crossing facility	109039	19.5%	26751	24.53%

Table A2.1h: Numbers and percentages of pedestrian accidents at physical crossing facilities.

Variables		**Number of accidents**	**%**	**KSI**	**%**
Pedestrian crossing-physical facilities	Zebra.	28328	20%	6107	21.55
	Pelican	54645	39%	13794	25.24
	Junction	41123	30%	9631	23.41
	Central refuge	13214	10%	3922	29.68
	Footbridge or subway	1883	1%	712	37.81

A2.1.3 Environmental factors

Table A2.1i: Classification of road surface conditions and severity of accidents.

Variables		Fatal	Serious	Slight	Total	KSI	%
Road surface conditions	Dry	7393 (1.8%)	84019 (20.9%)	310647 (77.3%)	402059 (73.3%)	91412	22.73
	Wet	3813 (2.7%)	33330 (23.7%)	103729(73.6%)	140872 (25.7%)	37143	26.36
	Snow	15(0.9%)	315 (18.3%)	1389 (80.8%)	1719 (0.3%)	330	19.19
	Frost or ice	53 (1.5%)	778 (21.9%)	2716 (76.6%)	3547 (0.6%)	831	23.42

Table A2.1j: Classification of light condition and severity of accidents:

Variables		Fatal	Serious	Slight	Total	KSI	%
Light conditions	Day light	5770	78243	310541	394554	84013	21.29
	Darkness	5512	40339	108636	154487	45851	42.20

Table A2.1k: Month and severity of accidents.

Variables		Fatal	Serious	Slight	Total	KSI	%
Accident month	January	1179 (2.6%)	10413 (22.6%)	34551 (74.9%)	46143 (8.4%)	11592	25.1
	February	954 (2.2%)	9479 (22.0%)	32585 (75.7%)	43018 (7.8%)	10433	24.3
	March	853 (1.8%)	10122 (21.5%)	36144 (76.7%)	47119 (8.6%)	10975	23.3
	April	757 (1.8%)	9348 (21.6%)	33145 (76.6%)	43250 (7.9%)	10105	23.4
	May	691 (1.5%)	9743 (21.0%)	35927 (77.5%)	46361 (8.4%)	10434	22.5
	June	730 (1.7%)	9228 (21.0%)	33956 (77.3%)	43914 (8.0%)	9958	22.7
	July	735 (1.7%)	8648 (20.1%)	33544 (78.1%)	42927 (7.8%)	9383	21.9
	August	814 (2.0%)	8554 (21.4%)	30590 (76.6%)	39958 (7.3%)	9368	23.4
	September	850 (1.9%)	9592 (21.1%)	34996 (77.0%)	45438 (8.3%)	10442	23.0
	October	1026 (2.1%)	10673 (21.7%)	37433 (76.2%)	49132 (8.9%)	11699	23.8
	November	1279 (2.5%)	11183 (21.7%)	39073 (75.8%)	51535 (9.4%)	12462	24.2
	December	1416 (2.8%)	11606 (23.1%)	37256 (74.1%)	50278 (9.2%)	13022	25.9

Table A2.1l: Week and severity of accidents.

Variables		Fatal	Serious	Slight	Total	KSI	%
Day of the week	Weekday	8191 (2.0%)	87888 (21.0%)	323429 (77.0%)	419508 (76.4%)	96079	22.9
	Weekend	3093 (2.4%)	30701 (23.7%)	95771 (73.9%)	129565 (23.6%)	33794	26.1

Table A2.1m: Particular day of the week and severity of accidents.

Variables		Fatal	Serious	Slight	Total	KSI	%
Day of the week	Sunday	1269 (2.5%)	12199 (24.4%)	36534 (73.1%)	50002 (9.1%)	13468	26.9
	Monday	1520 (2.0%)	15736 (20.5%)	59394 (77.5%)	76650 (14.0%)	17256	22.5
	Tuesday	1499 (1.9%)	16364 (20.5%)	61815 (77.6%)	79678 (14.5%)	17863	22.4
	Wednesday	1478 (1.8%)	16691 (20.7%)	62333 (77.4%)	80502 (14.7%)	18169	22.6
	Thursday	1647 (1.9%)	17637 (20.8%)	65463 (77.2%)	84747 (15.4%)	19284	22.8
	Friday	2047 (2.1%)	21460 (21.9%)	74424 (76.0%)	97931 (17.8%)	23507	24.0
	Saturday	1824 (2.3%)	18502 (23.3%)	59237 (74.5%)	79563 (14.5%)	20326	25.5

Appendix 2.2: General statistics of pedestrian's accidents in Edinburgh

A2.2.1General statistics of pedestrian's accidents in Edinburgh

Figure 1 presents the reduction of pedestrian accidents between 1993 and 2006.

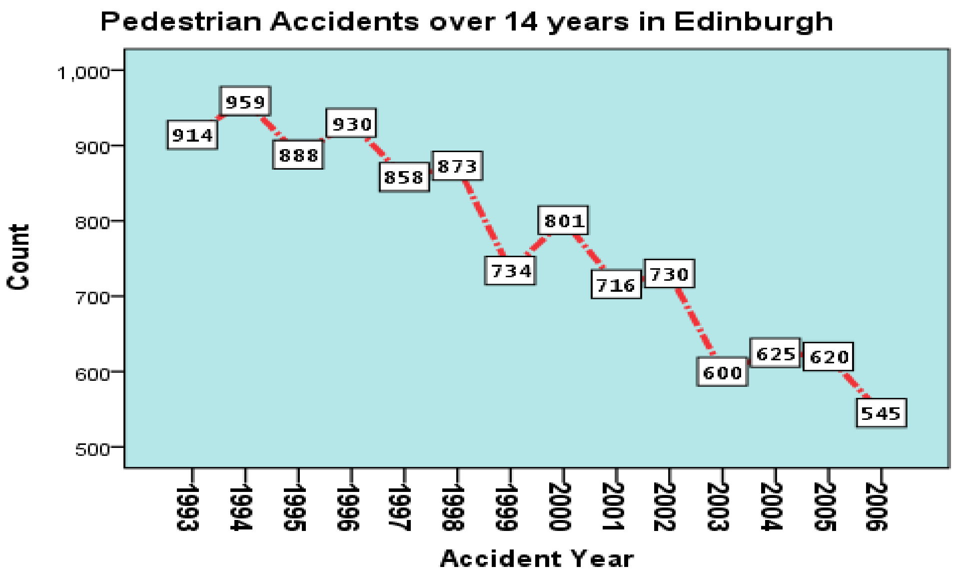

Figure 1: Illustration of pedestrian accidents occurring in Edinburgh between 1993 and 2006.

A2.2.2 Socio-economic factors

Table A2.2a: Pedestrian age group and severity of injury.

Variable		KSI	%	Slight	%
Age group	Child (0-15)	736	19.0%	3139	81.0%
	Adult(16-59)	978	19.1%	4134	80.9
	Old (60<)	556	33.2	1121	66.8

A2.2.3 Road related factors

Table A2.2b: Type of crossing facility and numbers of pedestrian accidents

Variable		Number of accidents	%
Type of crossing facility	Non-signalised crossing.	183	5.8%
	Signalised crossing	2972	94.2%

A2.2.4 Environment factors

Table A2.2c: Time of accidents and severity of injury.

Variable		KSI	%	Slight	%
Time of accident	Daytime	1740	20.1%	6906	79.9%
	Night time	533	24.8%	1614	75.2%

The following table shows a summary of accident characteristics in Edinburgh over the period 1993-2006.

Table A2.2d: Summary of pedestrian accidents occurring in Edinburgh from 1993-2006.

Variables		Description	Min	Max	mean	KSI
Age.	Child (0-15)	Child =1; other = 0	0	1	0.36	0.32
	Adult (16-59)	Adult =1; other = 0	0	1	0.48	0.42
	Old (60 +)	Old =1; other = 0	0	1	0.16	0.25
Gender.	Male	Male =1; other = 0	0	1	0.59	0.60
	Female	Female =1; other = 0	0	1	0.41	0.40
Accident hour	Daytime	Daytime =1; other = 0	0	1	0.80	0.77
	Night time	Night time=1; other = 0	0	1	0.20	0.23
Severity	KSI	KSI=1; other = 0	0	1	0.22	------
	Slight	Slight =1; other = 0	0	1	0.78	------
Crossing area	Crossing on or within 50m	Crossing on or within 50m =1; other = 0	0	1	0.29	0.27
	Crossing elsewhere	Elsewhere =1; other = 0	0	1	0.71	0.73
Road surface	Dry	Dry =1; other = 0	0	1	0.71	0.69
	Wet	Wet =1; other = 0	0	1	0.28	0.30
	Snow	Snow =1; other = 0	0	1	0.01	0.01
Vehicle type	Car	Car =1; other = 0	0	1	0.80	0.80
	Bus	Bus =1; other = 0	0	1	0.10	0.08
	Goods vehicle	Goods vehicle =1; other = 0	0	1	0.08	0.10
	Motor cycle	Motor cycle =1; other = 0	0	1	0.02	0.02
Road type	Single carriageway	Single cw* =1; other = 0	0	1	0.93	0.91
	Dual carriageway	Dual cw*=1; other = 0	0	1	0.04	0.07
	One way street	One way street=1; other = 0	0	1	0.03	0.02

*Carriageway

Appendix 3: An example of a resulted model which include pedestrian volume as an exposure variable.

Variable		Categories of each variable	Frequency (%)	Ordinal logit	Ordinal probit
				Coefficient (p-value)	Coefficient (p-value)
Intercept	**Fatal**	--	--	**-17.98 (0.000)**	**-6.353 (0.000)**
	Serious	--	--	**-15.10 (0.000)**	**-4.860 (0.000)**
Factors	**Age group**	**Child (0-15)**	**21 (6.8)**	**1.91 (0.069)**	**1.027 (0.076)**
		Adult (16-59)	**268(86.5)**	**2.32 (0.003)**	**1.166 (0.007)**
	Old gender	**Old male (60+)**	**8 (2.5)**	**1.47 (0.200)**	**0.783 (0.226)**
		Old female	**13 (4.1)**	**0.00**	**0**
		Other	**299 (93.4)**	**0.00**	**0**
	Driver age group	**16-21**	**29 (10.0)**	**-2.59 (0.049)**	**-1.430 (0.049)**
		22-59	**252 (86.6)**	**-0.98 (0.430)**	**-0.560 (0.413)**
		60+	**10 (3.4)**	**0.00**	**0**
	Time of accidents	**Night time**	**117 (36.6)**	**-0.02 (0.959)**	**0.058 (0.820)**
		Day time	**203 (63.4)**	**0.00**	**0**
	Pedestrian movement	**Crossing**	**255 (82.0)**	**-1.17 (0.126)**	**-0.644 (0.093)**
		Not crossing	**56 (28.0)**	**0.00**	**0**
	Vehicle maneuver	**Going ahead**	**252(81.6)**	**-2.48 (0.023)**	**-1.236 (0.012)**
		Other	**58 (29.4)**	**0.00**	**0**
	Heavy goods vehicles	**Bus and goods vehicles**	**96 (31.2)**	**-0.36 (0.452)**	**-0.206 (0.422)**
		other	**212 (78.8)**	**0.00**	**0**
	Type of signalized pedestrian crossing	**Pelican**	**165 (51.6**	**-0.84 (0.048)**	**-0.484 (0.031)**
		junction	**155 (48.4)**	**0.00**	**0**
	Type of road	**One way street**	**3 (0.9)**	**-1.89 (0.231)**	**-1.065 (0.236)**
		Dual carriageway	**4 (1.3)**	**16.37 (0.993)**	**5.637 (0.994)**
		Single carriageway	**313 (97.8)**	**0.00**	**0**
		Other	**0**	**0**	**0**
	Width of single carriageway	**1-2 lanes**	**219 (68.4)**	**0.45 (0.309)**	**0.177 (0.458)**
		3-4 lanes	**94 (29.4)**	**0.00**	**0**
		Other	**7 (2.2)**	**0.00**	**0**
	The day of accidents	**Weekdays**	**237 (79.1)**	**-0.23 (0.657)**	**-0.101 (0.712)**
		weekend	**83 (25.9**	**0.00**	**0**
	Road condition	**Dry**	**220 (68.8)**	**-12.21 (0.000)**	**-3.194 (0.000)**
		Wet	**98 (30.6)**	**-12.67**	**-3.451**
		other	**2 (0.6)**	**0.00**	**0**
	Location of pedestrian accidents	**On pedestrian accidents or within 10m**	**69 (21.6)**	**1.09 (0.219)**	**0.628 (0.196)**
		10-20	**76 (23.8)**	**0.74 (0.267)**	**0.334 (0.337)**
		20-30	**65 (20.3)**	**0.76 (0.235)**	**0.425 (0.221)**
		30-40	**50 (15.6)**	**0.54 (0.440)**	**0.278 (0.465)**
		40-50	**60 1 (8.8)**	**0.00**	**0**
	Pedestrian volume	**Low**	**219 (68.4)**	**1.59 (0.059)**	**0.878 (0.058)**
		Medium	**49 (15.3)**	**0.93 (0.225)**	**0.464 (0.269)**
		High	**52 (16.3)**	**0.00**	**0**