An Analysis of Motorcyclist Injury Severity by Various Crash Configurations at T-junctions in the United Kingdom

Chih-Wei, PAI

M.Sc. (Civil)

A thesis submitted as fulfilment of the requirements for the degree of Doctor of Philosophy of the Napier University Edinburgh

NAPIER UNIVERSITY
EDINBURGH

TRi TRANSPORT RESEARCH INSTITUTE

Transport Research Institute
School of Engineering and the Built Environment
Napier University Edinburgh

March 2008

Dedicated to my parents

ABSTRACT

Motorcyclists that have no protective structures while motorcycling as other occupants of automobiles do can be particularly vulnerable to accident injuries (i.e., motorcycles are not as crashworthy as automobiles). Motorcyclists' susceptibility to accident injuries in nature may act synergistically with the complexity of conflicting manoeuvres between motorcycles and other motor vehicles to increase their injury severities in accidents that take place at junctions (e.g., T-junction or crossroad). Previous studies have applied crash prediction models to investigate influential factors on the occurrences of different crash configurations among automobiles but statistical models of motorcyclist injury severity resulting from different motorcycle-car crash configurations have rarely been developed.

This current research attempts to develop the appropriate statistical models of motorcyclist injury severity by various crash configurations conditioned on crash occurrence at T-junctions in the UK. T-junctions are selected in this study because such junctions represent the single greatest danger to motorcyclists – for junction-type accidents, the statistics from the UK Stats19 accident injury database over the years 1991 and 2004 suggested that T-junctions were ranked the highest in terms of injury severity (i.e., accidents at T-junctions resulted in approximately 65% of all casualties that sustained fatal or serious injuries) and accident occurrence (i.e., accidents at T-junctions accounted for 62% of all motorcyclist casualties). This may be in part because there is a comparatively large number of T-junctions in the UK. Although the author was unable to take into account the exposure factor due to the lack of such data (i.e., the total number of T-junctions, and the number of motorcycles travelling on these locations), it remains true that more severe accidents happen at T-junctions than any other type of junction. In this present study, motorcycle-car accidents at T-junctions were classified into several crash configurations based on two methods that have been widely used in literature. The first method is based on the conflicts that arise from the pre-crash manoeuvres of the motorcycle and car. The second method is on the basis of first points of impact of the motorcycle and car. The crash configurations that are classified in this current study based on the mixture of these two methods include (a) accidents involving gap acceptance (i.e., approach-turn crash

and angle crash), (b) head-on crash, and (c) same-direction crash (i.e., sideswipe crash and rear-end crash).

Since injury severity levels in traffic accidents are typically progressive (ranging from no injury to fatal/death), the ordered response models have come into fairly wide use as a framework for analysing such responses. Using the accident data extracted from the Stats19 accident injury database over 14-year period (1991~2004), the ordered probit (OP) model of motorcyclist injury severity were estimated because the dependent variable (i.e., no injury, slight injury, KSI: killed or seriously injured) is intrinsically discrete and ordinal. A set of the independent variables were included as the predictor variables, including rider/motorist attributes, vehicle factors, weather/temporal factors, roadway/geometric characteristics, and crash factors. The current research firstly estimated the aggregate OP model of motorcyclist injury severity by motorcycle-car accidents in whole. Additional disaggregate models of motorcyclist injury severity by various crash configurations were subsequently conducted.

It appears in this current research that while the aggregate model by motorcycle-car accidents in whole is useful to uncover a general overview of the factors that were associated with the increased motorcyclist injury severity, the disaggregate models by various crash configurations provide valuable insights (that may not be uncovered by an aggregate crash model) that motorcyclist injury severity in different crash configurations are associated with different pre-crash conditions. For example, the preliminary analysis by conducting descriptive analysis reveals that the deadliest crash manner in approach-turn crashes and angle crashes was a collision in which a right-turn car collided with an approaching motorcycle. Such crash patterns that occurred at stop-/give-way controlled junctions appear to exacerbate motorcyclist injury severity. The disaggregate models by the deadliest crash manners in approach-turn crashes and angle crashes suggest that injuries tended to be more severe in crashes where a right-turn motorist was identified to fail to yield to an approaching motorcyclist. Other disaggregate crash models also identified important determinants of motorcyclist injury severity. For instance, the estimation results of the head-on crash model reveal that motorcyclists were more injurious in collisions where curves were present for cars than where the bend was absent. Another noteworthy result is

that a traversing motorcycle colliding with a travelling-straight car predisposed motorcyclists to a greater risk of KSIs. These findings were clearly obscured by the estimation of the aggregate model by accidents in whole.

In the course of the investigation of the factors that affect motorcyclist injury severity, it became clear that another problem, that of a right-turn motorist's failure to yield to motorcyclists (for the deadliest crash patterns in both approach-turn crash and angle crash), needs to be further examined. The logistic models are estimated to evaluate the likelihood of motorist's right-of-way violation over non right-of-way violation as a function of human attributes, weather/temporal factors, roadway/geometric factors, vehicle characteristics, and crash factors. The logistic models uncover the factors determining the likelihood of motorists' failure to yield. Noteworthy findings include, for instance, teenaged motorists, elderly motorists, male motorists, and professional motorists (i.e., those driving heavy goods vehicles and buses/coaches) were more likely to infringe upon motorcycle's right-of-way. In addition, violation cases appeared to be more likely to occur on non built-up roadways, and during evening/midnight/early morning hours.

This present research has attempted to fill the research gaps that crash prediction models focused on analysing motorcyclist injury severity in different crash configurations have rarely been developed. The results obtained in this current research, by exploring a broad range of variables including attributes of riders and motorists, roadway/geometric characteristics, weather/temporal factors, and vehicle characteristics, provide valuable insights into the underlying relationship between risk factors and motorcycle injury severity both at an aggregate level and at a disaggregate level. This research finally discusses the implications of the findings and offers a guideline for future research.

Keywords: Motorcyclist injury severity; Crash type; T-junction

ACKNOWLEDGEMENT

I would like to express my most sincere thanks and gratitude to my supervisors, Dr. Wafaa Saleh and Prof. Mike Maher for their stimulating discussions, patient guidance, constructive comments, statistical direction, and critical reviews of my research throughout the course of this research work. This thesis would not have been possible at all without their continuous support and encouragement. Exceptional financial backing from Dr. Wafaa Saleh is also gratefully acknowledged. I am also gratefully acknowledged the PhD studentship provided by the National Science Council, Taiwan.

Particular thanks to TRi (Transport Research Institute) and SEBE (School of Engineering and the Built Environment) for providing sporadic but timely funding opportunities which helped me to attend several conferences and keep me in continuous employment as a part-time lecturer with Napier University.

Special thanks are extended to my colleagues and friends at Napier University namely, Mr. Thomas Reichert, Mr. Jan Weckondorf, Mr. Salem Abukersh, Mr. Shucheng Hu, Dr. Kathryn Stewart, Ms. Shenzhi Su, and Ms. Celine Garnier, for their enjoyable company and encouragement during the study period.

Many thanks are also due to all TRi and SEBE members. It has been my great pleasure to work with so many scholars and talented people.

Finally, I would like to dedicate this thesis to my beloved parents and sister. This thesis would not have been possible at all without their financial help and unlimited love.

Chih-Wei Pai
Transport Research Institute
School of Engineering and the Built Environment
Napier University Edinburgh

Table of Contents

List of Figures

List of Tables

List of Acronyms

ANN	: Artificial Neural Network
BAC	: Blood Alcohol Content
CA	: Classification Accuracy
CART	: Classification and Regression Tree
cdf	: Cumulative Distribution Function
CHMSL	: Centre High-Mounted Stoplight
DETR	: Department of Environment, Transport and the Regions
DF	: Degree of Freedom
DfT	: Department for Transport
DRL	: Daytime Running Light
DVLA	: Driver and Vehicle Licensing Agency
HBL	: Hierarchical Binomial Logistic
HGV	: Heavy Goods Vehicle
IIA	: Independence of Irrelevant Alternative
ISS	: Injury Severity Score
ITS	: Intelligent Transportation System
KSI	: Killed or Seriously Injured
LTV	: Light Truck Vehicle
ML	: Maximum Likelihood
MNL	: Multinomial Logit
n.s	: non statistically significant
NASS	: National Automotive Sampling System
NHS	: National Health Service
OL	: Ordered Logit
OP	: Ordered Probit
OR	: Odds Ratio
RLC	: Red Light Camera
SBZA	: Side Blind Zone Alert
SUV	: Sport Utility Vehicle
TRL	: Transport Research Laboratory
UK	: United Kingdom
US	: United States

CHAPTER 1
INTRODUCTION

1.1 Background

Motorcycle operation is a complex task that requires excellent motor skills and physical cooperation and balance (Rothe and Cooper, 1987). Alertness and concentration required to negotiate traffic patterns dominated by cars also make motorcycling a formidable skill challenge (Savolainen and Mannering, 2007a). The general perception of motorcycling is that motorcycle activity is a dangerous transportation mode. Given the dynamics and manoeuvrability of motorcycling (i.e., motorcycles are able to accelerate faster than other motorised vehicles and pull out into smaller gaps in traffic more often and overtake other vehicles more freely), the commission of an error when riding a motorcycle is likely to result in more severe accidents than making an error when driving an automobile (Elliott et al., 2007; Holst, 1993; Horswill and Helman, 2003; Mannering and Grodsky, 1995). Unlike other motorised vehicles that offer greater protection to car-occupants through metal structure or airbag (McCartt and Kyrychenko, 2007), motorcycle users are more susceptible to accident injuries than automobile-occupants (i.e., motorcycles are generally not as crashworthy as automobiles) (Hancock et al., 2005).

Motorcyclists' vulnerability to accident injuries may act synergistically with the complexity of conflicting movements and manoeuvres between motorcycles and automobiles to increase motorcyclist injury severity in junction accidents (e.g., T-junction or crossroad). A junction crash could be more severe to motorcyclists than a non-junction case as a result of the fact that some of the injurious crashes such as angle collision commonly take place. Research (e.g., Chipman, 2004; McLellan et al., 1996) suggested that in a car-car angle crash, the impact of intrusion into the passenger compartment may be reduced through its metal structure and/or side airbag. However there is no such protection for motorcycles. In addition to the absence of the measure that may absorb crash-impact for motorcycles, crashing into a car (i.e., motorcycle is the striking vehicle) in an angle crash may cause the rider to eject or tumble (Obenski et al., 2007). Head and chest injuries, which normally results in severe/fatal consequence, often occur with ejection when the motorcyclist impacts the ground or the car after being thrown from the bike (Peek-Asa and Kraus, 1996a).

The causation of motorcycle accidents can be a difficult task to study. One possible solution that has been commonly adopted is the use of methodology that investigates road crashes after they have taken place. Such approach involves the use of multi-disciplinary accident investigation teams who travel to the accident scene soon after they occur and subsequently collect data. Several disadvantages have been pointed out by Grayson and Hakkert (1987) for such a method. For example, operations costs were very high (e.g. manpower or necessary equipment for the in-depth observations of the accident scene) and very time-consuming. As a result, only a small number of accidents could be investigated. Another preferable approach (i.e., case study method) that analyses police accident/hospital reports has been successfully used in existing literature (e.g., Pai and Saleh, 2007a, b, 2008, in press). Such approach is benefited from the availability of multiple variables/factors in police accident or hospital reports, providing valuable insights into the underlying relationship between the risk factors and accidents. The statistical power by estimating econometric models can also be increased due to the large amount of accident data being available in accident/hospital reports, allowing more precise and conclusive modelling results.

1.2 Brief Overview of Past Studies

Recent studies relying on statistical analyses have identified several factors that contributed to an increased risk of involving in an accident. For example, Mannering and Grodsky (1995) reported that factors such as riding exposure, excessive speed, and improper lane changing/overtaking were recognised by motorcycle users to increase the likelihood of involving in a crash. The conclusions drawn by Mannering and Grodsky were generally supported by more recent studies (e.g., Lynam et al., 2001; Sexton et al., 2004; Elliott et al., 2007). Nevertheless, accident/injury severity (as opposed to the likelihood of an accident occurrence) presents another phenomenon that has been less understood. A research programme investigating the determinants of accident/motorcyclist injury severity, conditioned on an accident having occurred, has the potential to provide additional insights into the multiple factors (e.g., human factors, vehicle attributes, weather, roadway, and crash characteristics) that influence accident/injury outcome. A better understanding of such multiple factors may facilitate the identification of suitable countermeasures which may help prevent the hazards from occurring.

Most previous research on motorcycle accident severity has been oriented toward a univariate examination of accident severity, with focuses on helmet-related issues such as effectiveness of helmets in reducing both fatalities and severity of head injuries (see, for example, the work by Watson et al., 1980; Ouellet and Kasantikul, 2006). Compared with the multivariate studies of automobile accident/injury severity, relatively fewer studies have been conducted in the field of motorcycle safety using a true multivariate examination of the determinants of accident/injury severity (i.e., controlling for all factors that affect accident/injury severity).

To obtain an understanding of the causal factors that are associated with accident/injury severity and subsequently to identify prevention countermeasures, crash prediction models have been routinely developed for car-car accidents. Depending on the research objectives and available data, these studies can be generally divided into two types: crash prediction model at aggregate level (i.e., models were estimated by accidents in whole) and at disaggregate level (i.e., models were estimated by different crash types/configurations). Examples of studies at aggregate level include the work by Kockelman and Kweon (2002) that analysed car-occupant injury severity in car-car accidents in whole. Examples of disaggregate studies by crash configurations include the work by Khattak (2001) and Farmer et al. (1996) that examined the determinants of car-occupant injury severity resulting from car-car rear-end/angle collisions at intersections.

A major flaw of the published studies has been that while most of the aggregate or disaggregate studies have been directed towards car-car accidents at intersections, comparatively few have been for motorcycle-car accidents. Among the few studies for motorcycle-car accidents, most have been conducted at aggregate level (e.g., Quddus et al., 2002; Keng, 2005; Lapparent, 2006). There are at least two important and defensible reasons for estimating disaggregate models of motorcyclist injury severity in different crash configurations as a function of human, vehicle, roadway, and crash factors.

The first is motivated by the need to identify the factors that are associated with injury severity in different crash configurations but such information may not be revealed through crash models at aggregate level. For example, while crash models at aggregate level are useful to identify whether a crash configuration is more severe to motorcyclist than other crash configurations, one might expect an automatic signal may have different impact on riders in rear-end crashes from riders in angle crashes.

A second use of the disaggregate models by crash configurations is to gain an understanding of the differing effects of human, roadway, weather, and crash factors on injury severity in various crash configurations, so that countermeasure effects may be better understood. It is likely that countermeasures may affect only a subset of the accidents. For instance, it may be learned that surveillance cameras that aim to discourage red light running may reduce accident/injury severity resulting from angle crashes but may increase accident/injury severity resulting from rear-end crashes (either the involved motorcycle or car may have difficulty in taking evasive action when the car/motorcycle ahead stops suddenly due to the presence of the camera).

1.3 Relevant Statistics

UK government statistics (see DfT, 2006a, b; DETR, 2000) suggest that in the UK, motorcycles constitute approximately 4.8% of all motorised vehicles and account for 17% of total fatalities of traffic accidents (2006's data). Motorcyclists' relative risk of being killed or seriously injured (KSI) per kilometre travelled is more than twice that for cyclists and almost 50 times that for car drivers (DfT, 2006a, b; DETR, 2000).

In addition to government statistics, previous studies in literature (e.g., Horswill and Helman, 2001) also pointed out that motorcyclists in the UK experience a higher risk of involving in a KSI accident while exposure data were taken into account. A study by Horswill and Helman (2001) analysing motorcycle accidents for years 1997-1999 reported that motorcycles were 9.3 times (when controlling for time spent travelling) and 7.9 times (when controlling for distance travelled) more likely than other motorised vehicles to be involved in an injury/fatal accident. A more recent study by Broughton (2005) noted that the number of dead motorcyclists on British roads rose in most years since 1996, and by 2002 was 38% above its 1996 level – the highest total since 1990. Broughton attributed this to the faster growth in the number of registered machines of over 500cc engine capacity since 1997. He further revealed that the rate of fatalities per thousand machines rises with engine capacity, so this trend towards larger machines appears to have contributed to the increasing number of motorcyclist deaths.

The statistics from the UK Stats19 accident injury database revealed that 63% of all motorcyclist casualties that sustained KSIs were as a result of collisions with cars (including passenger cars, heavy goods vehicles, buses/coaches), as shown in Figure 1.1. Single-motorcycle accidents (i.e., a motorcycle collides with no other road user but might either collide with a fixed object such as kerb or pole or merely lose control) resulted in approximately 26% of all motorcyclist victims that sustained KSIs. The rest are collisions with pedal cycle, pedestrian, or motorcycle (10.49%). The results clearly show that motorcycles in collisions with cars (in the rest of this thesis, "car/automobile" is used to represent cars, heavy goods vehicles, and buses/coaches) are a serious safety problem to motorcyclists.

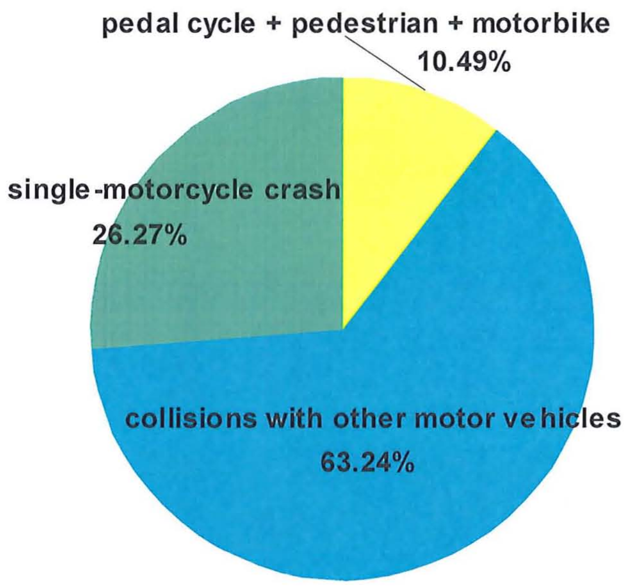


Figure 1.1: Distribution of types of motorcycle's collision partner in motorcycle-car accidents that cause motorcyclists to sustain KSIs (data extracted from the Stats19 accident injury database between years 1991-2004).

Figure 1.2 reports the information on the distribution of the first impact point of a motorcycle in a motorcycle-car accident that caused motorcyclists to have KSIs (data were abstracted from the UK Stats19 accident injury database). As illustrated in Figure 1.2, the front of motorcycle that was identified as the first impact point resulted in about 73% of the total number of KSIs. Several researchers (e.g., Peek-Asa and Kraus, 1996a; Hancock et al., 2005) found that the front part of motorcycle was frequently the first impact point when a car violated the right-of-way of an approaching motorcycle at an intersection by turning left (in the UK, it is turning right). Such crash type, which was normally termed as an approach-turn crash or an angle crash, has been identified by researchers in the US (e.g., Hurt et al., 1981; Preusser et al., 1995; Peek-Asa and Kraus, 1996a; Hancock et al., 2005) as the most common crash configuration of motorcycle-car accidents at junctions. Consistent conclusions have been drawn by researchers in the UK (e.g., Hole and Tyrrell, 1995; Lynam et al., 2001; Sexton et al., 2004; Clarke et al., 2007; Pai and Saleh, 2007a, 2008), and in Australia (e.g., Williams and Hoffmann, 1979a, b; Horswill et al., 2005). Such collision type was usually followed by the ejection of the motorcyclists from the motorcycles, resulting in serious injury outcome (Peek-Asa and Kraus, 1996a).

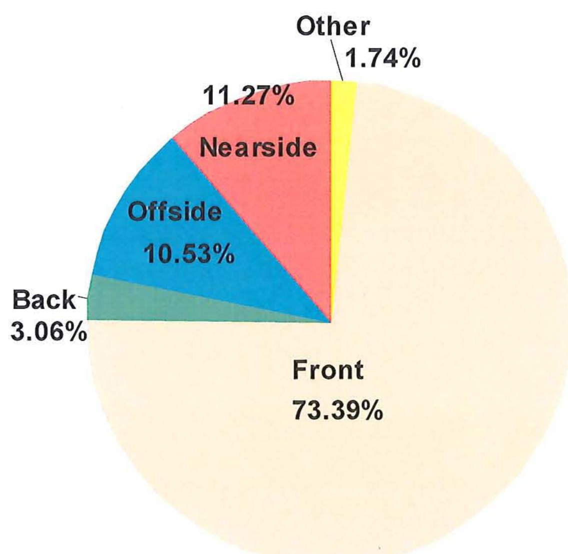


Figure 1.2: Distribution of the first impact point of a motorcycle in a motorcycle-car accident that cause motorcyclists to sustain KSIs (data extracted from the Stats19 accident injury database between years 1991-2004).

For junction accidents, the statistics from the Stats19 over years 1991 and 2004 suggested that T-junctions were ranked the highest in terms of injury severity (i.e., approximately 65% of all motorcyclist KSI casualties in motorcycle-car accidents were at T-junctions) and frequency (i.e., approximately 62% of all motorcycle-car accidents took place at T-junctions). This is probably in part because there is a comparatively large number of T-junctions in the UK (DfT, 2004). Although the author was unable to take into account the exposure factor due to the lack of such data (i.e., the number of motorcycles travelling on these locations), it remains true that more accidents happened at T-junctions than any other type of junction.

Overall, several observations regarding motorcycle safety in the UK may be made from the abovementioned statistics:

- Motorcyclists are the most vulnerable road users in the UK.
- Motorcycles in collisions with cars are a serious safety problem to motorcyclists (see Figure 1.1).
- The front of motorcycle as the first impact point resulted in about 73% of the total number of KSIs in motorcycle-car accidents (see Figure 1.2). This implies that an approach-turn crash and angle crash that involve a motorist's failure to give way to an approaching motorcycle are the most common crash configurations.
- T-junctions are the most hazardous junction type to motorcyclists and are clearly an important area for study.

1.4 Research Objectives

The overall aim of this research is to contribute to the field of motorcycle safety research by investigating the determinants of motorcyclist injury severity resulting from various crash configurations. The crash typology that comprises different crash configurations for motorcycle-car accidents at T-junctions will be developed (see section 4.3). The current study attempts to extend the empirical contributions of previous studies (drawing on past findings of automobile accident severity) by estimating an appropriate statistical model of motorcyclist injury severity that can be used to understand the effects multiple factors have on motorcyclist injury severity. Within this context, the present study relies on the real-life accident data (i.e., the Stats19 accident injury data that is widely recognised as an authoritative database) to analyse motorcycle-car accidents that occurred at T-junctions.

To achieve this aim, the following objectives are formulated. To:

- Review past studies that have developed the crash typology that consists of different crash configurations, as well as a review of literature documenting the factors that affect injury severities in different crash configurations.
- Review statistical modelling techniques which have been estimated in literature for examining injury severity.
- Employ an appropriate statistical model of motorcyclist injury severity in motorcycle-car accidents at T-junctions in the UK using the Stats19 accident injury database (a detailed description of the Stats19 accident injury data is provided in section 4.2.1).
- Draw general recommendations that provide a first step for the potential countermeasures to prevent the hazard(s) from occurring at an aggregate level (accidents in whole) and at a disaggregate level (various crash configurations).
- Provide a guideline for future research.

1.5 Outline of the Thesis

This thesis is organised into ten chapters. Chapter 1 provides the background to the study, a brief overview of past studies, relevant national statistics, research objectives, and the outline of the thesis. The rest of this thesis is structured as follows.

In Chapter 2, a review of pertinent past studies that developed a taxonomy of various crash configurations for accidents involving different road users such as cars, motorcycles, and bicyclists/pedestrians is provided. Such review can contribute to an understanding of how the crash typology was developed in extant literature, which can in turn provide a guideline on the classification of motorcycle-car accidents at T-junctions.

Chapter 3 provides a review of previous empirical studies that have developed different econometric approaches for understanding the multivariate relationship between accident severity/injury severity and the variables of interest in accidents that involved various road users. A review of these studies is expected to provide guidance on an appropriate statistical model that can be estimated in this present study.

Chapter 4 provides details of the methodology used in the current research to examine motorcyclist injury severity. In this chapter, the data source (i.e., the Stats19 accident injury database) and the empirical setting that consist of the variables considered in the analysis are firstly described. This is followed by a description and an illustration of how motorcycle-car accidents are classified into several crash configurations for the analysis in this present study. Finally a discussion of the proposed econometric framework is provided.

The primary aim of this research is to contribute to the field of motorcycle safety research by investigating the determinants of motorcyclist injury severity resulting from various crash configurations. To achieve this, the investigations of motorcyclist injury severity are then divided into three parts: part one, part two, and part three. Investigation part one represents a descriptive analysis of the variables that are associated with motorcyclist casualties resulting from motorcycle-car accidents at T-junctions, which is reported in Chapter 5. The descriptive analysis provides a general understanding of the univariate relationship between motorcyclist injury severity and the considered variables.

In addition to the investigation of the univariate relationship between motorcyclist injury severity and the considered variables (Chapter 5), investigation part two represents a multivariate examination of the determinants of motorcyclist injury severity (i.e., controlling for all factors that influence motorcyclist injury severity) at aggregate level (i.e., an econometric model by accidents in whole) and at an disaggregate level (i.e., the disaggregate models by various crash configurations). Investigations part two will be organised in Chapter 6 and Chapter 7. Chapter 6 presents the estimation results of the econometric model by accidents in whole, while Chapter 7 reports the estimation results of the disaggregate models by various crash configurations. The main aim of the aggregate model by accidents in whole is to identify whether a certain crash configuration is more severe to motorcyclists than other crash configurations. The primary aim of the disaggregate models by different crash configurations is to examine whether the considered variables affect motorcyclist injury severity in various crash configurations differently.

Chapter 8 presents the investigation part three that represents a summary of the findings obtained from the disaggregate models by various crash configurations, as well as a further examination of the considered variables amongst various crash configurations that led to KSIs. The summary of the estimation results of the disaggregate models by various crash configurations provides evidence that the considered variables affect motorcyclist injury severity in various crash configurations differently. The examination of the considered variables amongst various crash configurations leads to insights into whether a certain crash configuration is more likely than any other crash configuration to occur under a specific circumstance.

Chapter 9 discusses the implications of the investigation results in this present research, with particular emphasis being placed on the potential countermeasures that could be applied to prevent the hazards from occurring both at an aggregate level (accidents in whole) and at a disaggregate level (various crash configurations).

Ultimately in Chapter 10, the conclusions of this research and recommendations for future research are provided. This thesis ends with a list of publications that arise out of this research.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

Chapter 1 has set out the objectives of the thesis and outlined the importance of estimating disaggregate models by various crash configurations. This chapter firstly reviews existing studies that have developed a taxonomy of various crash configurations for accidents involving different road users such as automobile-occupants, motorcyclists, or bicyclists. Published studies were searched through the databases Medline, National Transportation Library, and cross references. The reviewed studies included laboratory simulations, computer simulations, self-report surveys, as well as those using mathematic modelling techniques of archival crash data from police accident reports, hospital data, or multidisciplinary crash investigations.

This chapter is structured as follows. A brief summary of how the crash typology was developed by previous studies in literature is first provided. Most of research that has developed the crash typology (or merely alluded to several crash configurations) has been the studies of automobile-automobile accidents. Studies that analysed accidents involving automobiles are therefore reviewed first, followed by those of accidents involving other road users (i.e., motorcycle-automobile, automobile-bicycle/pedestrian accidents). Studies that analysed motorcycle-related accidents in general (i.e., crash configurations were not the research focus in these studies) are also reviewed as these studies may still contribute to the understanding of the influential factors on motorcyclist injury severity resulting from various crash configurations. This chapter aims to uncover the flaws among existing studies in literature and provides reasoning for the methodological approach assumed within this thesis.

2.2 Classification of the Crash Configurations in Literature

The development of the crash typology has been most common for past studies of automobile-automobile accidents. These studies have in general developed the crash typology based on the conflicts that arise from the manoeuvres of the involved vehicles (i.e., travelling straight, turning right/left) prior to accidents or the first crash point. Some studies used a mixture of these two methods.

Crash configurations that have been routinely examined include:

- approach-turn and angle/left-turn/right-turn crashes;
  - these crashes were generally classified as accidents involving gap acceptance.
- head-on crashes;
  - a head-on crash occurs when two vehicles originally travelling from opposite directions collide with each other.
- same-direction crashes; and
  - a same-direction occurs when two vehicles originally travelling from same directions collide with each other. This can be a rear-end crash or a sideswipe crash.
- single-vehicle crashes.
  - a single-vehicle crash occurs when the vehicle collides with no other road user but may collide with some other on-/off-roadway objects (e.g., road sign or traffic island), or simply run out of roadway.

Among these crashes, the classification of an accident as an approach-turn crash is mainly based on the manoeuvre of the involved vehicles, while a rear-end crash, or sideswipe crash is categorised depending on the first impact point. Categorisation of an angle/turning crash and a head-on crash tends to be by either the movements of the involved vehicles or the first impact point. For example, some studies assumed that the classification of an accident as an angle/turning collision implies that the vehicles are travelling at right/left angles to each other or that most accidents involving left-/right-turn vehicles are categorised as turning crashes; and some studies assumed that an accident in which one vehicle was struck to its right/left side was classified as an angle crash.

In this current research, accidents involving motorcyclists and motorists will be classified into several crash configurations. The crash typology developed in this research will be fully discussed in Chapter 4.

2.3 Studies that Analysed Accidents Involving Automobiles

Past studies that have developed the crash typology or merely alluded to crash configurations for automobile-automobile accidents can be subdivided into several fundamental categories as follows:

- studies that developed the crash typology and examined the contributory factors to the occurrences of these crash configurations;
- studies that explored the multivariate relationship between injury severity and the variables of interest (the variable "crash configurations" is one of the variables of interest);
- studies that investigated the gap acceptance problem; and
- studies that explored the factors affecting the occurrence/severity of one or more certain crash type.

A review of these studies is provided in the next sections.

2.3.1 Studies that Developed the Detailed Crash Typology and Examined the Contributory Factors to the Occurrences of Various Crash Configurations

The development of the crash typology that consists of various crash configurations has been the subject of intense research in an effort to quantify the effects of some factors on the occurrences of those crash configurations (e.g., Hauer et al., 1988; Sparks et al., 1993; Wang and Knipling 1994; Shankar et al., 1995; Poch and Mannering, 1996; Persaud and Nguyen, 1998; Pernia et al., 2002; Retting and Kyrychenko, 2002; Retting et al., 2003; Golob and Recker, 2004; Persaud et al., 2005; Abdel-Aty et al., 2005; Ulfarsson et al., 2006; Kim et al., 2006; Huang et al., 2006; Kim et al., 2007; Shin and Washington, 2007; Neyens and Boyles, 2007; Wang and Abdel-Aty, 2008). These factors include, for instance, traffic flow, intersection geometric design features, traffic control and operational features, and in-/off-vehicle distraction factors. These studies have made an attempt to fill the research gaps that crash prediction models focused on predicting different crash configurations have rarely been developed.

Classification of crash configurations solely by the manoeuvres of the involved vehicles prior to the collisions was probably firstly developed by Hauer et al. (1988). A total of 15 crash patterns in which two automobiles collided at a four-legged signalised junction were categorised. They sought to relate accident frequency to the traffic flows to which the two colliding vehicles belong. They argued that when accidents were categorised by first crash point (rear-end, angle, or sideswipe crash, etc.), their cause-and-effect relationship with traffic flow was weakened. More recently other typical work that classified accidents by the manoeuvres of the involved automobiles include studies by, for example, Persaud and Nguyen (1998) and Wang and Abdel-Aty (2008). Aggregate and disaggregate statistical models were estimated by Persaud and Nguyen (1998) to examine the safety performance of three-legged and four-legged signalised junctions. Models were first estimated for all impact types and separately by three prominent crash configurations (i.e., rear-end, right-angle, and turning movement accidents). Models were then calibrated for other 15 main crash patterns that were defined by the manoeuvres of the involved automobiles prior to collisions. In the study of Wang and Abdel-Aty (2008), left-turning crashes at four-legged signalised junctions were classified into nine crash patterns based on the manoeuvres of the automobiles. Obvious differences in the factors affecting the occurrences of different left-turn crash patterns were observed.

Some other researchers conducted a mixture of methods to classify crash configurations (e.g., Sparks et al., 1993; Wang and Knipling, 1994; Shankar et al., 1995; Poch and Mannering, 1996; Pernia et al., 2002; Retting and Kyrychenko, 2002; Retting et al., 2003; Abdel-Aty et al., 2005; Ulfarsson et al., 2006; Kim et al., 2006; Huang et al., 2006; Kim et al., 2007; Shin and Washington, 2007; Neyens and Boyles, 2007) – by the manoeuvres of the automobiles prior to the accidents and by the first crash point. Among these researchers, several researchers such as Poch and Mannering (1996) and Kim et al. (2006) argued that modelling the total number of accidents that occurred at junctions may obscure the real relationship between the crash causes and the occurrences of various crash configurations. As a result, potential countermeasures that are specified towards certain crash configurations may therefore not be appropriately identified. A summary of these studies is provided below.

Through the use of the traditional count models (e.g., the Poisson, negative binomial, or zero-inflated count models), the abovementioned studies investigated the safety effects of a variety of factors on the occurrences of different crash configurations. A brief summary of the research findings of these studies regarding the effects of some selected factors is provided below.

In recent years increased attention has been directed at exploring the safety effects of crash countermeasures such as red light cameras (RLCs) and daytime running light (DRL) (Sparks et al., 1993; Retting and Kyrychenko, 2002; Retting et al., 2003; Persaud et al., 2005; Huang et al., 2006; Shin and Washington, 2007). RLCs were expected to play a role in discouraging red light running, thereby reducing angle crashes. The use of DRL was expected to improve conspicuity of an oncoming vehicle on the major road so that the turning motorist on the minor road can be more attentive to the oncoming vehicle and angle crashes could be reduced. RLCs were generally found to have the potential to reduce angle and left-turn crashes at signalised intersections but to increase rear-end crashes. The severity of rear-end crashes was reduced as a result of RLCs (Shin and Washington, 2007). DRL was beneficial in reducing car-car approach-turn collisions and right-angle collisions (Sparks et al., 1993).

Several studies have examined the effects of various junction control measures. Angle crashes appeared to be less likely to take place at signalised intersections than at unsignalised intersections, whereas there were more rear-end crashes at signalised intersections (Poch and Mannering, 1996; Kim et al., 2007).

The effects of several risk-taking/distraction factors were assessed by Ulfarsson et al. (2006) and Neyens and Boyles (2007). Intoxicated drivers were found to be more prone to pull out into oncoming traffic, resulting in more head-on collisions. Speeding tended to increase rear-end/sideswipe crashes, but decrease head-on/approach-turn/angle crashes (Ulfarsson et al., 2006). Neyens and Boyles (2007) concluded that teenage drivers that distracted at intersections by passengers or cognitively were more likely to be involved in rear-end and angle crashes relative to fixed-object collisions. Moreover, in-vehicle distractions resulted in more fixed-object crashes, and drivers distracted by mobile phones experienced more rear-end collisions.

The effects of geometric/weather factors were also received some attention in literature. Curved roadway sections were associated with a significantly increased probability of head-on crashes, with a slightly increased probability of rear-end/sideswipe crashes and decreased probabilities of approach-turn/angle collisions (Ulfarsson et al., 2006). The presence of upgrades or downgrades on the roadways was associated with a small increase in the probability of rear-end/sideswipe/head-on collisions and a decrease in the probability of approach-turn/angle collisions (Ulfarsson et al., 2006). Angle crashes were disproportionately represented during clear weather conditions, whilst rear-end collisions were less likely to occur during fine weather (Kim et al., 2007). Shankar et al. (1995) reported that maximum rainfall on any given day in the month was more prone to increase sideswipe crashes but decrease rear-end collisions. In addition, an increase in the number of rainy days in the month was likely to decrease sideswipe and rear-end crashes but increase fixed-object collisions. Icy/wet road surfaces and unlit roadways in darkness appeared to increase head-on crashes but reduce other collision types (Ulfarsson et al., 2006).

2.3.2 Studies that Analysed Motorist Injury Severity and Various Crash Configurations

A significant number of studies have alluded to crash configurations and explored the multivariate relationship between injury severity and the variables of interest. In some of these studies, crash configurations were included as one of the independent variables for statistical modelling. Some other studies conducted descriptive analysis to compare the severity of one certain crash type with that of other crash configurations. One of the objectives of these studies was to identify whether motorists involved in one specific crash type were more likely to be severely/fatally injured.

Crash configurations such as head-on, angle, rear-end, or rollover crash have been frequently compared. Although the research findings among the extant studies varied, depending on the crash configurations that were included in the studies, head-on crashes or vehicles that were rollovered were generally found to be the deadliest crash configurations (see, for instance, studies by Kim et al., 1994; O'Donnell and Connor, 1996; Kockelman and Kweon, 2002; Khattak and Rocha, 2004; Khattak and Targa, 2004; Abdel-Aty and Keller, 2005; Rifaat and Chin, 2007; Eluru and Bhat, 2007; Khattak and Fan, 2008). These two crash configurations also appeared to be deadly to elderly motorists (Zhang et al., 2000; Khattak et al., 2002; Hill and Boyle, 2006).

In a study by Toy and Hammitt (2003) who compared occupant injury severity for frontal crashes and side-impact crashes, injuries tended to be more severe to drivers whose vehicle was struck on the left side (i.e., driver side) due to direct intrusion towards drivers. The findings of Toy and Hammitt (2003) concur with those of Darzentas et al. (1980a, b, c) who analysed car-car accidents in the UK. Darzentas et al. reported that an angle crash was more severe in which one right-turn car originally travelling on the minor road collided with an oncoming vehicle on the major road. Khattak et al. (1998) compared motorist injury severity for single-vehicle crashes, two-vehicle rear-end crashes, and sideswipe crashes. They pointed out that single-vehicle crashes resulted in much more severe injuries than the other two crash configurations.

Manoeuvres that drivers were making prior to accidents, along with collision types, were also discussed by several researchers. Chang and Mannering (1999) suggested that drivers making right/left turn, rear-end, and opposite direction angle collisions resulted in more severe injuries. Some other researchers (e.g., Ulfarsson and Mannering, 2004; Khattak and Fan, 2008) observed that in two-vehicle car-SUV (sport utility vehicle) crashes, the most harmful manoeuvre involved left-turn cars encroaching into oncoming SUVs in angle crashes. Furthermore, passenger car drivers appeared to be more injurious when they made a turn, when they were involved in head-on collisions, and when their cars were rollovered.

2.3.3 Studies that Investigated the Gap Acceptance Problem

Driver's gap-accept manoeuvre is a complicated and risky driving behaviour, and has been widely investigated in traffic safety and operation studies. A common definition in most of the gap-acceptance studies has been that drivers base their decisions on the assessment of time to arrival, which is the time available before an approaching vehicle arrives at a potential conflict position (Davis and Swenson, 2004). Gap acceptance may also be used to predict the relative risk at junctions, where smaller gaps generally imply higher collision risk (Polus, 1985). At unsignalised junctions, for instance, a right-/left-turning driver on the minor road needs to make the use of a proper gap among the conflicting traffic to cross or merge into the major road. Rejecting an adequate gap can lead to needless delay, while accepting an inadequate gap may lead to an angle collision with an approaching vehicle. Similarly, a right-turn vehicle (or a U-turn vehicle) from the major road accepting an inadequate gap among the oncoming traffic may result in an approach-turn crash (see Keskinen et al., 1998 for a full discussion).

The earliest work in literature discussing gap acceptance may probably have been the studies conducted in 60s (e.g., Herman and Weiss, 1961; Solberg and Oppenlander, 1966; Drew, 1967; Tsongos and Weiner, 1969). This is followed by the studies of Spicer (1972), Cooper et al. (1976, 1977), Storr et al. (1979), Darzentas et al. (1980a, b, c), Mahmassani and Sheffi (1981), Maher and Dowse (1983), Polus (1983), Fitzpatrick (1991), Kita (1993), Madanat et al. (1994), Staplin (1995), Hamed et al. (1997), and Keskinen et al. (1998). Recent studies include the work by Davis and Swenson (2004), Spek et al. (2006), and Yan et al. (2007). By conducting field studies of gap-acceptance behaviours at junctions, the emphasis of these studies has focused specifically on observing a sequence of time gaps in a traffic stream, along with whether each gap was accepted by a turning driver. These researchers have shown that gap acceptance can be treated as a discrete-choice problem. This allows modelling of how variables such as driver individual differences (e.g., driver age, gender, waiting time, or trip purpose), temporal/environmental factors (e.g., daytime or nighttime, urban or rural areas, weather conditions), and road/vehicle factors (e.g., junction control measures, major-road vehicle speed or major-road vehicle types) may influence a turning driver's gap acceptance.

Several important conclusions have been drawn by these studies. For example, Solberg and Oppenlander (1966) compared time-interval acceptances by drivers making left-turn, right-turn, and through movements at stop-controlled junctions. Right-turning drivers and those crossing the junctions were found to have statistically equal median acceptance times. However, significant variations were observed between right-and left-turn drivers, and between drivers proceeding through the junctions and those making left-turn movements. Polus (1983) and the Highway Capacity Manual: Special Report 209 (1984) reported that the length of minimum accepted gap at a yield sign-controlled junction was shorter than that at a stop-controlled junction.

Eberts and MacMillan (1985) used slide presentations to test whether vehicle size affected distance judgement. They found that small cars may be perceived as being further away than they actually were, thereby affecting the turning driver's decision to proceed or not. Drivers in older cars accepted larger gaps than those in newer cars (Hamed et al., 1997).

Kita (1993) found that drivers merging onto an expressway were more likely to accept shorter gaps as they approached the end of the merging lane. Drivers having shopping as trip purpose were likely to accept larger gaps than were drivers travelling to or from work. Those driving during the p.m. non rush hours were more likely to accept short gaps than those travelling during the p.m. rush hours (Hamed et al., 1997).

Longer waiting time at the head of the queue, and higher traffic volumes on the major roads increased the likelihoods of a turning driver accepting smaller gaps and moving into the junction (Wagner, 1966; Adebisi and Sama, 1989; Kettelson and Vandehey, 1991). Alexander et al. (2002) suggested that the velocity of the approaching traffic was the variable that had the greatest effect on the median accepted gap size. Drivers accept shorter gaps as the speed of the oncoming vehicle increases (Mortimer et al., 1974; Ashworth and Bottom, 1977; Cooper et al., 1976, 1977; Storr et al., 1979; Darzentas et al., 1980a, b, c; Mahmassani and Sheffi, 1981; Madanat et al., 1994; Staplin, 1995; Alexander et al, 2002). Spek et al. (2006) concluded that the probability that a crossing vehicle collides with the major stream vehicle can be expected to increase when the speed of major traffic increases.

Research on median gap acceptance in relation to day or night-time conditions was found to be fairly inconsistent. It was found by Tsongos and Weiner (1969) that for gaps between 4 and 9 seconds, there was no significant difference in the median accepted gap size between night and day under low traffic volume conditions. However as traffic volume increased, there was a higher percentage of longer gaps accepted at night. Darzentas et al. (1980b, c) found that at lit junctions drivers appeared to accept shorter gaps at night. A field study by Lerner et al. (1995) found that the median acceptable gap was not associated with day or night-time conditions. More recently Keskinen et al. (1998) indicated that the time taken to cross an intersection was affected by whether it was day or night.

Other factors such as driver's age and gender difference in gap selection were also explicitly considered in literature. Older drivers have problems to adequately detect, perceive, and accurately judge the safety of a gap among the conflicting traffic. Not only are older drivers more likely to be involved in angle crashes, they are also more likely to be seriously injured or killed in these crashes (Laberge et al., 2006). This may be partly due to increases in frailty and functional disabilities that occur with age (Oxley et al., 2006; Murphy, 2005) that results in elderly drivers having less accurate judgement about whether a potential crash would occur. Darzentas et al. (1980a, b) found that male drivers generally had shorter mean crossing times than females. Elderly motorists executing left-/right turns had longer crossing time than young motorists (Hamed et al., 1997; Cox and Cox, 1998; Keskinen et al., 1998; Yan et al., 2007). Elderly drivers' tendency to underestimate higher speeds, combined with the fact that they cross and turn into a traffic stream more slowly, would be particularly hazardous to themselves particularly when approaching vehicles travel at higher speeds (Scialfa et al., 1991; Federal Highway Administration, 1993; Staplin, 1995; Alexander et al., 2002; Retting et al., 2003). Based on these reasons, elderly motorists are generally found to be overrepresented in right/left turn as well as angle crashes compared with those in other crash configurations (Mayhew et al., 2006; Chipman, 2004).

2.3.4 Studies that Explored the Factors Affecting the Occurrence/Severity of One or More Certain Crash Type

Factors determining the likelihood of deaths or serious injuries resulting from specific crash configurations or occurrences of such crash configurations have received considerable attention in engineering, human factors, and clinical science. These studies mainly relied on the conduct of instrumented crash tests, mathematical modelling, or computer simulations. The crash configurations examined include, for example, approach-turn crashes, angle (left-/right-turn) crashes, rear-end crashes, sideswipe crashes, and single-vehicle accidents. Some of the studies specifically analysed one certain crash type while some focused on several crash configurations. A brief review of these studies is organised by crash type and provided below.

2.3.4.1 Angle and approach-turn crash

Following the previous studies that have identified gap acceptance problem, accidents involving gap acceptance (i.e., angle, left-/right-turn, and approach-turn crash) have been gaining an increasing amount of attention in literature. There exists an abundance of research that examined the effect of various junction control measures on the occurrences of car-car angle collisions (but relatively few for approach-turn crashes). By estimating the negative binomial models and hierarchical logistic models, Poch and Mannering (1996) and Kim et al. (2007) suggested that signalised intersections (i.e., the intersections that are controlled by automatic signals) resulted in a significant decrease in angle collisions. However, automatic signals that were shifted into flashing operations during late-night and early-morning hours increased angle crashes (Wang and Abdel-Aty, 2007). Retting et al. (2003) found that approximately 70% of angle collisions were at stop-controlled junctions. Kim et al. (1994) noted that automatic signals as junction control measures could be an intervention measure to reduce car-car approach-turn crashes. The presence or absence of a traffic signal at junctions did not affect accident involvement of older drivers (Stamatiadis et al., 1991), although a recent study by Ulfarsoon et al. (2006) reported that older drivers experienced more angle collisions when traffic signal measures were present at junctions, relative to unsignalised junctions. An uncontrolled left-turn channels and an increase in signal phases of traffic signals tended to increase angle crashes at four-legged junctions (Mitra et al., 2002).

Songchitruksa and Tarko (2006) indicated that car-car angle collisions at four-legged junctions were often quite severe due to the high impact speed of vehicles colliding at right angles, and red light running was a contributing factor to such crashes. The presence of a red light camera was found to be effective in reducing angle collisions (Retting and Kyrychenko, 2002; Retting et al., 2003; Persaud et al., 2005; Huang et al., 2006; Shin and Washington, 2007). The effects of some other countermeasures such as headlights use during daytime and frontal/side air bags on the occurrence/severity of approach-turn/angle crashes were examined (e.g., Attwood, 1981; Mercier et al., 1999). Attwood found that increased conspicuity through the use of headlights during daytime may reduce the detection distances of approaching vehicles, which can translate into fewer accidents through the earlier detection of other vehicles. Mercier et al. reported that frontal air bags deployed were found to be protective to females only (less certain for males) in both angle and approach-turn crashes. Aside from these studies, Viano et al. (1990) examining fatal chest and abdominal injuries among vehicle-occupants in multi-vehicle angle collisions suggested that the risk of injury increases steadily with age, and the driver of the struck vehicle frequently caused the crash by driving error or traffic violation. The conclusions reached by Viano et al. partly correspond to those of Retting et al. (2003) and Ryan et al. (1998), who found that inability or failure to see approaching traffic often was cited as the cause to angle crashes, and teenage and elderly drivers were disproportionately found to be at fault in angle crashes at stop-controlled junctions.

In order to develop efficient countermeasures for left-turn accidents and improve safety at signalised intersections, left-turn accidents were classified into nine crash patterns by Wang and Abdel-Aty (2008) depending on the manoeuvres of the involved vehicles prior to the accidents. Approach-turn collisions, one of the nine crash patterns in the crash categorisation, accounted for more than 70% of all crashes. They observed that there were obvious differences in the factors that affect the occurrences of the nine crash patterns. For instance, the effectiveness of the left-turning signal appeared inconsistent for different crash patters. They suggested that left-turn accidents be considered in different patterns.

There also exists a great deal of research (see, for example, Otte et al., 1984; Partyka, 1991; Huelke and Compton, 1992; Haland et al., 1993; Eguakun and Wilson, 1995; McLellan et al., 1996; Farmer et al., 1997; Abdelwahab and Abdel-Aty, 2004b; McCartt and Kyrychenko, 2007) that investigated the effects of several factors such as compatibility, first crash point, or victims' seated positions on injury severity or a certain pattern of organ injury in side-impact angle crashes. Classification of an accident as an angle crash in these studies was mainly based on the first crash point, rather than the manoeuvres of the involved vehicles before collisions. Therefore, analyses in these studies may not have been limited to accidents involving gap acceptance. Instead, accidents in which one vehicle that was struck to its left or right sides by another vehicle in a sideswipe collision may have been included in the analyses.

Fairly similar conclusions have been drawn from these studies. For example, occupants seated on the struck side and occupants of lightweight passenger-vehicles were more likely to be severely injured; struck-side occupants of cars were much more injurious than struck-side occupants of light trucks (i.e., light trucks are much more crashworthy than passenger cars); and perpendicular collision-angle was more deadly than oblique collision-angle. McCartt and Kyrychenko found that making side airbags with head protection available may be beneficial in reducing the risk of car and SUV driver death in driver-side collisions. The injured body regions of the accident casualties resulting from side-impact collisions were compared with those in frontal crashes (Dischinger et al., 1993; McLellan et al., 1996). They noted that compared with those in vehicles that were struck to frontal parts, drivers in angle collisions were more likely to sustain thorax, and abdominal injuries, resulting in a higher mortality rate. They attributed such effects to the less vehicle structure between the striking force and the occupants, resulting in significant passenger compartment intrusion and direct loading of the impact onto the occupant's chest and abdomen.

2.3.4.2 Head-on crash

Considerable past research (e.g., Agent and Deen, 1975; Clissold, 1976; Zegeer et al., 1981; Al-Senan and Wright, 1987; Zhang and Ivan, 2005) has concentrated on examining the factors that are associated with the occurrences/severity of car-car head-on crashes. Most of these studies have focused on the roadway geometric features that may explain the incidence of head-on crashes and several important conclusions have been drawn. For example, there was a decrease in head-on crashes with increases in lane width (Zegeer et al., 1981; Al-Senan and Wright, 1987) but an increase in head-on crashes with increases in the number of horizontal curves and grade changes; fatal head-on crashes were more likely to take place on roadways with high posted speed limits (Al-Senan and Wright, 1987) and passing zones (Agent and Deen, 1975); there were proportionately more head-on crashes on wet road surfaces and on rainy days (Clissold, 1976); and roadway segments with high density access points were likely to lead to more head-on crashes (Al-Senan and Wright, 1987).

With respect to the factors influencing the severity of head-on crashes, air bag deployment and seat belt use has received additional attention in literature. Air bag deployment was associated with substantial reductions in fatalities among right front passenger in head-on crashes (Crandall et al., 2001). Older women appeared to receive fewer protections from the use of lap and shoulder restraints but more protections from air bags than do older men (Mercier et al., 1997). Deng et al. (2006) concluded that factors such as wet road surfaces, narrow road segments, high density access points, and accidents that occurred at night were significantly related to more severe injuries. However, wider lanes and shoulder, contrary to Deng et al.'s expectation, resulted in a reduced possibility of more severe crashes. While their initial expectation was that wider pavement would create a favourable driving environment that induces drivers to travel faster, their reason for the unexpected estimation results was that more spacious driving space may provide a buffer area for avoiding a direct head-on impact.

There is evidence in research (e.g., Braver et al., 1997; Wittenberg et al., 2001; Durbin et al., 2004) that children involved in frontal crashes and seated on right front positions were more injury-prone. Occupants in large vehicles tended to have more protections from air bags than those in smaller ones (Zador and Ciccone, 1993). It merits mention that classification of an accident as a head-on collision in these studies was mainly based on the first crash point, rather than the manoeuvres of the involved vehicles before collisions. Therefore, analyses in these studies may not have been limited to accidents in which two cars originally travelling from opposite directions collided with each other. Instead, a frontal crash in which one vehicle head-to-sided another vehicle in an angle collision may have been analysed.

Relying on laboratory simulations, Mizuno and Kajzer (1999) were in an attempt to compare different vehicle types with respect to their crashworthiness (self-protection) and aggressivity (risk to other vehicles) in two-vehicle head-on crashes. They reported that a larger and heavier car involved in a head-on crash was more crashworthy than a smaller car but this came at the price of greater aggressivity towards a smaller car. This is, the heavier vehicle drives the lighter one backward, decreasing forces inside the heavy vehicle and increasing forces in the lighter one. The findings of Mizuno and Kajzer correspond to those of other researchers (e.g., Evans and Wasielewski, 1987; Mayrose and Jehle, 2002; Broyles et al., 2001, 2003; Acierno et al., 2004; Broughton, 2007).

2.3.4.3 Sideswipe and rear-end crash

A number of previous studies analysing car-car sideswipe crashes (e.g., Chovan et al., 1994; Shankar et al., 1995; Clarke et al., 1998; Li and Kim, 2000; Sen et al., 2003; Kim et al., 2006; Pande and Abdel-Aty, 2006) has sought to model the occurrence of such crash type, with focuses on the effects of geometric, environmental factors, or pre-crash manoeuvres. Pande and Abdel-Aty, together with some other researchers (e.g., Chovan et al., 1994; Li and Kim, 2000), concluded that lane-changing manoeuvres, variation in traffic flow, and peak-/off-peak hours were associated with the occurrences of sideswipe crashes. Shankar et al. found that adverse weather conditions (e.g., maximum daily rainfall or number of snowy days) increased risks of sideswipe collisions. Clarke et al. noted that sideswipe accidents frequently occurred when an overtaking vehicle collided with a right-turn vehicle in the front, and this type of crash tended to happen either because a young driver made a faulty overtaking decision, or an older driver made a faulty right turn. Kim et al. revealed that median width on major roads is negatively associated with sideswipe crashes, and two engineering measures (i.e., the presence of a left-turn lane and number of nearby driveways) caused more sideswipe collisions. To the author's knowledge, there seems to be a shortage of research in literature that has attempted to explore the determinants of the severity of sideswipe crashes.

Turning to rear-end crashes, there have been many studies in literature analysing the relationship between a set of variables and accident frequency/severity of such crash type (see, for example, Duncan et al., 1998; Khattak, 2001; Abdel-Aty and Abdelwahab, 2003, 2004; Abdelwahab and Abdel-Aty, 2004a; Yan et al., 2005; Yan and Radwan, 2006; Wang et al., 2003; Kim et al., 2007; Harb et al., 2007). Abdel-Aty and his colleagues applied several statistical modelling approaches to study the effect of the increased percentage of LTVs in traffic on fatalities in car-LTV rear-end collisions, and to investigate the effect of the geometric incompatibility of LTVs on drivers' visibility of other regular passenger cars involved in four rear-end crash configurations (i.e., TwoCars, CarTrk, TrkCar, and TwoTrks rear-end collisions). The CarTrk category represents that a regular car strikes an LTV (i.e., a following car collided with a leading LTV). Important findings include that TrkCar rear-end crashes had the highest death rate, TwoTrks configuration had the lowest death rate, driver's visibility and inattention in the following vehicle have the largest effect on being involved in a rear-end CarTrk crash, a sudden stop of a leading LTV may deprive the following driver of a sufficient response time, which may result in high probability of a rear-end crash, and LTVs appeared to produce more rear-end collisions at unsignalised intersections due to horizontal visibility blockage and due to the following drivers' behaviours when driving behind a LTV.

Yan and his colleagues (Yan et al., 2005; Yan and Radwan, 2006) attempted to identify the contributory factors to the occurrences of two-vehicle rear-end crashes for striking and struck drivers/vehicles at signalised junctions. Noteworthy findings include that large vehicles were more likely to strike other vehicles in the rear than they were struck by other vehicles, female drivers were less likely to strike other vehicles but more likely to be struck, and elderly drivers were most likely to strike other vehicle whilst struck vehicles were most likely to be driven by mid-aged drivers.

The occurrences of rear-end accidents were studied by Wang et al. (2003) considering the probability of encountering an obstacle vehicle and the probability of a driver failing to react fast enough to avoid colliding with the obstacle vehicle. In their models, the probability of encountering an obstacle vehicle was assumed to be a function of the frequency of disturbances that cause the leading driver in a vehicle to decelerate. The probability of the following vehicle's driver failing to respond is the probability that this driver's needed perception/reaction time is less than the available perception/reaction time. One of the main findings is that an increase in speed limit appeared to decrease the probability of encountering an obstacle vehicle, but increase the probability of a driver failure. More recently Kim et al. (2007) extended the methodology of Wang et al. to analyse freeway rear-end collisions. Kim et al. concluded that several factors had dual impact. For example, an increase in daily vehicle miles travelled per lane decreased the probability of the leading vehicle becoming an obstacle, but increased the probability of the following vehicle failing to avoid a crash with a leading vehicle ahead.

Regarding the studies that examined the factors affecting the severity of rear-end collisions, typical studies in recent years include Duncan et al. (1998) and Khattak (2001). These researchers employed the ordered probit models of automobile-driver injury severity and successfully isolated the factors that led to severe injuries. For example, Khattak concluded that in a two-vehicle rear-end crash the leading driver in the struck vehicle had more risks in sustaining more severe injuries, while in a three-vehicle rear-end crash, the driver in the middle vehicle was more injurious than the first and third drivers; and Duncan et al. suggested that occupants in the struck passenger cars to the rear appeared to be more severely injured than those in the cars striking a truck to the rear.

2.3.4.4 Single-vehicle accident

Crashes involving single-vehicles that either ran off the highway or crashed into a fixed object such as a tree or pole have been attracting increased attention from researchers (e.g., Renski et al., 1999; Ray, 1999; Krull et al., 2000; Lee and Mannering, 2002; Dissanayake and Lu, 2002a, b; Holdridge et al., 2005; Yamamoto and Shankar, 2004; Islam and Mannering, 2006). These studies have been in an attempt to better understand the nature of single-vehicle accidents, focusing on the effects of rollovers (Krull et al., 2000; Islam and Mannering, 2006) or an increase in speed limit (Renski et al., 1999) on automobile-occupant injury severity.

The findings of these studies tended to be relatively consistent, providing a useful picture of what factors were significantly associated with more severe injuries resulting from such crash type. For instance, older drivers were most likely of other age groups to be fatally injured in a rollovered vehicle. Automobile-occupants involved in run-off-roadway accidents appeared to be more injurious than those in non run-off-roadway accidents, and collisions with certain objects (e.g., leading ends of guardrails, bridge rails, trees, or utility poles) were found to increase the probability of fatal injury. Other contributory factors to more severe injuries include excessive speeds, drivers being intoxicated, accidents that occurred on weekdays, drivers falling asleep, drivers that were ejected, and unbelted driving. Ray (1999) further observed that an impact point centred on the occupant and positioned on the front door is the worst-case impact location for such crash type. Ray attributed this to the fixed objects that resulted in significant passenger compartment intrusion and direct loading of the impact onto the small areas.

2.4 Studies that Analysed Accidents Involving Motorcycles

Motorcycle accidents involving gap acceptance (i.e., approach-turn crash and angle crash) have been attracting increased attention since 1970s. Past studies that have discussed gap acceptance problem in motorcycle-automobile accidents include research work by Hurt and his colleagues in USA (e.g., Hurt and DuPont, 1977, Hurt et al., 1981, 1984), Nagayama and his colleagues in Japan (Nagayama et al., 1980; Nagayama, 1984), and researchers in Australia (e.g., Williams and Hoffmann, 1979a, b; Haworth et al., 2005). These researchers highlighted the high frequency of right-of-way violation accidents at junctions, which results in an approach-turn or angle collision.

Approach-turn crashes accounted for up to half of all motorcycle-car junction accidents (Wulf et al., 1989a, b; Hurt et al., 1981, 1984; Hancock et al., 1986, 1989, 1990, 2005; Thomson, 1980; Rahimi, 1989). These researchers have consistently suggested that the possible mechanisms behind right-of-way violations were the failure of a turning driver to see an approaching motorcycle. This has been termed as a "look-but-fail-to-see" error (Brown, 2002; Herslund and Jørgensen, 2003; Koustanaï et al., 2008). Some other researchers (e.g., Peek-Asa and Kraus, 1996a) argued that turning motorists may not adequately judge the time available to clear the junction. Automobile-drivers involved in such crashes normally stated that they did not see motorcycles when making manoeuvres until the last moment before collisions (Hurt et al., 1981, 1984; Cercarelli et al., 1992; Obenski et al., 2007). Hancock et al. (1989) further pointed out that for approach-turn crashes, turning manoeuvres by automobile-drivers involved a higher probability of structural interference (i.e., detection failure due to frequent head reversal movements by looking in the other direction rather than motorcycle direction) to visual information processing and increase in mental load compared to travelling-straight manoeuvres. Such effects may be implicated in increased detection failure among the conflicting traffic, particularly motorcycles. Olson et al. (1981) suggested that the fact that most motorcycles have single head lamp and smaller frontal area lead motorcycles to have poorer conspciuity than automobiles. Being less conspicuous also makes motorcycles more difficult to detect and their approaching speed is more difficult to determine (Hurt and DuPont, 1977; Hole and Tyrrell, 1995; Hole et al., 1996). Efforts to decrease motorcycle-automobile crashes involving gap acceptance have concentrated on the manipulations that may increase detection frequency through improvements in motorcycle/motorcyclist conspicuity (Wulf et al., 1989a, b; Donne, 1990).

Research into motorcycle safety can be classified into several fundamental categories as follows:

- studies that identified the gap acceptance problem;
- studies that developed the crash typology; and
  - studies that compared the injury severity or a certain pattern of organ injury among different crash configurations; and
  - studies that examined the mechanisms behind the occurrences of various crash configurations.
- studies that explored the univariate/multivariate relationship between injury severity and the variable(s) of interest (e.g., helmet use).

A review of these studies is provided in the next sections.

2.4.1 Studies that Identified the Gap Acceptance Problem

Previous studies have identified gap acceptance problems in approach-turn or angle crashes involving automobiles and motorcycles (e.g., Olson, 1989; Keskinen, 1998; Horswill et al., 2005; Caird and Hancock, 1994, 2002). Automobile drivers have been observed to adopt smaller safety margins when pulling out in front of motorcycles compared with cars. Influential factors resulting in shorter gap accepted by automobile-drivers in front of motorcycle have been routinely researched (e.g., Hancock et al., 1991). Among these studies, Nagayama and his colleagues (Nagayama et al., 1980; Nagayama, 1984) reported the findings of two experiments in which they attempted to measure the misjudgement of speed and distance to which an oncoming motorcycle was subject. They found that drivers' median gap was larger at night than that at daytime. Hancock and Caird (1993) pointed out that, given the choice to pull into a traffic stream or not to, older drivers and younger drivers appeared to choose to turn more frequently in front of motorcycles than in front of automobiles. A turning driver was also more likely to accept shorter gap size when the velocity of an approaching motorcycle was high (Hancock et al., 1991).

Hancock and his colleagues (Hancock et al., 1990; Caird and Hancock, 1994, 2002), together with Horswill et al. (2005), discussed the time-to-arrival illusion (i.e., size-arrival effect) that automobile-drivers have when judging whether there is sufficient time to pull out safely in front of an approaching motorcycle. These researchers consistently concluded that drivers may estimate the arrival time of motorcycles to be later than cars. In an experimental study to examine turning drivers' perception and appraisal of approaching motorcycles at T-junction, Crundall et al. (in press) further pointed out that drivers may have difficulties in perceiving motorcycles that were particularly at far distances (motorcycles were spotted less by their participants than cars at far distances, and correct response times were slower).

Several researchers identified the likely mechanisms behind the size-arrival effect that lead drivers to choose smaller gaps in front of motorcycles. First, Delucia and his colleagues (Delucia and Warren, 1994; Delucia, 2004) argued that there might be a size-distance coupling, which may make smaller objects appear further away than larger objects. A second possibility is that Treisman (1996) pointed out that drivers tend to rapidly scan the traffic scene for a single feature of a potential hazard such as proximity, and decide to proceed without noticing the presence of a more distant object. Finally attitudinal factors may influence drivers' judgements on motorcycle's distance or arrival time (Hancock et al., 1990; Caird and Hancock, 1994). Which is, approaching vehicles that are larger may appear more threatening than approaching motorcycles so drivers waiting to merge with or pull out into the conflicting traffic might be more cautious when intersecting with trucks than motorcycles (Sparrow, 1985).

2.4.2 Studies that Developed the Crash Typology

The crash typology that consists of various crash configurations was developed by several researchers (e.g., Peek-Asa et al., 1994; Peek-Asa and Kraus, 1996a) in an effort to compare the injury severity or a certain pattern of organ injury among various crash configurations, or to identify the mechanisms behind the occurrences of different crash configurations. A mixture of classification of crash configurations by the first crash point and by the manoeuvres of the automobiles and motorcycles prior to the accidents has been commonly adopted. Similar to crash configurations that have been classified in the previous studies of car-car accidents, crash configurations that have been classified in the studies of motorcycle-car accidents include:

- approach-turn and angle crashes;
- head-on crashes;
- sideswipe/rear-end crashes; and
- single-vehicle crashes.

A review of these studies is presented below.

2.4.2.1 Studies that compared injury severity or a certain pattern of organ injury among different crash configurations

To the author's knowledge, there exist two studies in literature that compared motorcyclist injury severity and the injured body-regions among various crash configurations (i.e., head-on, sideswipe, rear-end, single-motorcycle, approach-turn collisions). These two studies were conducted by Peek-Asa and her colleagues (Peek-Asa et al., 1994; Peek-Asa and Kraus, 1996a). Peek-Asa et al. specifically examined the injured anatomic location and severity of lower extremity injuries, while Peek-Asa and Kraus compared driver features, such as helmet and alcohol use, and crash features, such as speeding and ejection from the motorcycle, for approach-turn and other crash configurations that occurred at four-legged junctions.

Main conclusions drawn in these two studies include that riders in head-on crashes had the highest percentage of chest, abdomen, spine, and lower extremity injuries, and riders were found to be ejected most often from the machines than those in other crash configurations. Peek-Asa et al. (1994) pointed out that potential countermeasures, as suggested by Haddon (1973), include modifications in rider apparel such as reinforced boots and legwear for upper/lower extremity injuries, a restraint mechanism to prevent ejection from the machine, or an airbag to cushion the impact force. For approach-turn crashes, motorcyclists involved in such crash type were most likely to sustain serious upper extremity injuries than those in other crash configurations except for head-on collisions. In approach-turn accidents, the car was much more frequently the turning vehicle than the motorcycle, and when the car was the turning vehicle, the motorcycle was the striking vehicle in over 70% of such crashes. They pointed out that in such crash type the turning vehicle may have already entered the intersection earlier than the motorcycle by infringing upon motorcycle's right of way. They further noted that approach-turn crashes in which the car was turning caused more injuries than those in which the motorcycle was turning; and the highest risk for lower extremity fractures was observed among riders in approach-turn crashes in which the approaching motorcycle was struck on its side by a turning vehicle. They suggested modifications in vehicle design and apparel such as better retention of the leg position and protection of the leg are needed to prevent some lower extremity injuries in such crash.

For an approach-turn crash, the average Injury Severity Score (ISS) was 16.34 when the automobile was turning compared to 11.26 when the motorcycle was turning. For an approach-turn crash in which one turning automobile collided with an approaching motorcycle, injuries were more severe when the motorcycle was the striking vehicle

(ISS 16.7) than when the motorcycle was struck by the car (ISS 14.5). For an approach-turn crash, an oncoming motorcycle that struck a turning automobile was more likely to be speeding than a motorcycle that was struck by a turning automobile, and controlling motorcycle's speed may be beneficial in reducing motorcycle's involvement in such crash type. The average ISS, percent of fatally injured, average days in the hospital, and average number of injuries are greater for motorcyclists in approach-turn collisions than for those in other crash configurations.

2.4.2.2 Studies that examined the mechanisms behind the occurrences/severity of certain crash configurations

Past studies have sought to examine the mechanisms behind the occurrence/severity of a certain crash type that was analysed as a certain crash type (or sometimes more than two) as a specific subset of all crash configurations. Single-motorcycle accidents were the focus in the studies by Shankar and Mannering (1996) and Chang and Yeh (2006) who have sought to identify the factors that were associated with motorcyclist injury severity in such crash type. Through the use of the multinomial logit models and binary logistic regression models respectively, similar results were found by these researchers. For instance, speeding or intoxicated motorcyclists, unhelmeted riders, older riders, or larger motorcycle engine size were found to increase the likelihood of fatalities. However helmeted-riders in collisions with fixed objects appeared to increase the probability of fatal injuries. Shankar and Mannering attributed this to the risk compensation that the increased likelihood could be the outgrowth of helmeted riders tending to ride more recklessly in response to that added sense of security a helmet provides.

A recent study by Savolainen and Mannering (2007b) estimated the nested logit and standard multinomial logit models to explore the multivariate relationship between injury severity in single- and multi-vehicle crashes and variables of interest. They separated their models by single- and multi-vehicle crashes because they assumed there were substantially different causality mechanisms and factors involved in these two crash configurations. Crash configurations were included as one of the independent variables in the models (e.g., run-off-roadway crash v.s. non run-off-roadway crash for single-motorcycle crash model; and head-on, right-angle and rear-end collisions for multi-vehicle crash model). Their modelling results suggested that a wide-range of factors significantly influence injury-severity probabilities in single- and multi-vehicle accidents in different ways. Injuries to motorcyclists appeared to be greatest while involved in run-off-roadway collisions (for single-motorcycle collisions) and head-on collisions (for multi-vehicle crashes).

The characteristics of several crash configurations were examined by Preusser et al. (1995), with a focus on crash configurations such as run-off-roadway crashes, oncoming collisions (i.e., head-on and sideswipe opposite-direction crashes) approach-turn crashes, and lane-changing accidents. Differences were observed for the mechanisms behind the occurrences of these crash configurations. For example, run-off-roadway accidents and oncoming collisions typically involved motorcyclists who left the appropriate travel lanes and subsequently ran off the road or struck automobiles travelling from the opposite direction. Both crash types tended to take place more frequently in rural areas, on roadways with higher speed limits, and at curves. Run-off-road accidents were significantly related to alcohol consumption, but approach-turn crashes were less often alcohol related. For approach-turn crashes potential countermeasures proposed by Preusser et al. include improved signal timing, enforcement of stop and yield obligations, and improved sight distances at intersections particularly in cases where the smaller motorcycle may remain blocked behind larger vehicles and suddenly become visible by its traversing manoeuvres (e.g., overtaking or lane changing). Preusser et al. further suggested that motorcyclists may be less likely to be involved in approach-turn crashes by wearing conspicuous clothing, and by avoiding excessive speed when approaching an intersection. The problem of sight distances or obstruction was also addressed by Ouellet (1982) and Hurt et al. (1981). They suggested that automobiles in traffic stream and parked automobiles were the one of the main causes of view obstructions.

Similar to the work by Preusser et al. (1995), a more recent study by Clarke et al. (2007) investigated the role of motorcyclist and other driver behaviour in three types of motorcycle accidents in the UK: accidents involving right-of-way violation, accidents involving loss of control on bends, and rear-end accidents. Different characteristics that affect the occurrences of these three types of accidents were discovered. For instance, super-sport bikes were overinvolved in curve/bend accidents but had a significantly lower propensity than other types of motorcycle for being involved in both rear-end and right of way violation accidents. On average drivers at fault (i.e., drivers that infringe upon motorcycle's right of way) tended to be older; the majority of right-of-way violation accidents took place at urban T-junctions; and most of curve/bend accidents occurred in rural areas. Sexton et al. (2004), together with Lynam et al. (2001), similarly found that accidents on built-up roads tended to be the fault of motorists "turning or u-turning in front of motorcyclists".

Impaired-riding crashes were treated as one specific subset of the crash configurations by Kim et al. (2002), as alcohol use by motorcyclists was found to be one of the important factors contributing to more severe injuries (Williams and Hoffmann, 1979b; Luna et al., 1984; Ouellet et al., 1987a; Peek-Asa and Kraus, 1996b; Shankar, 1999; Kim et al., 2000; Kasantikul et al., 2005; Nakahara et al., 2005). Kim et al. (2002) found that those conducting risky road behaviours and riding in the night were more likely to be involved in alcohol-impaired crashes. Other researchers (e.g., Peek-Asa and Kraus, 1996b; Kasantikul et al., 2005) reported that there were different driver and crash characteristics among intoxicated riders and sober riders. For example, drunk riders were far more likely than non drinkers to have single-motorcycle crashes (i.e., capsizing or running off the roadway), to be speeding, to crash in the evening/mid-night/early morning, and less likely to wear a helmet.

Factors determining the likelihoods of being at fault in motorcycle-car accidents were specifically examined by Kim and Boski (2001). They noted that motorcyclists conducting risky road behaviours (e.g., speeding, improper overtaking, or tailgating one vehicle ahead too closely) were more likely to be at fault in motorcycle-car accidents. Automobile-drivers, on the other hand, were more prone to be at fault if they failed to yield to motorcyclists, if their visions were impaired, or if they were intoxicated. A more recent study by Su et al. (2006) further pointed out that motorcyclists tailgating/overtaking other vehicles ahead caused significant safety concerns.

2.4.3 Studies that Explored the Univariate/Multivariate Relationship between Injury Severity/Accident Occurrence and the Variable(s) of Interest

The univariate relationship between helmet use and motorcyclist injury severity/head injuries has received extensive attention in literature (e.g., Evans and Frick, 1986; Weiss, 1992; Kraus et al., 1994; Peek-Asa and Kraus, 1997; Richter et al., 2001; Ouellet and Kasantikul, 2006). There has been overwhelming evidence in literature that helmets were beneficial in reducing head injuries and fatalities, although non-standard helmets appeared to offer little head protection (Peek-Asa et al., 1999). Some other studies (e.g., Aldman et al., 1981; Ross, 1983; Hurt et al., 1986; Ouellet et al., 1987b; Chinn et al., 1989; Harms, 1989) examined the performance of machine design such as crash bars and rider apparel such as leather trousers or gloves on motorcyclist limb injuries. Past studies of the multivariate relationship between injury severity and the variables of interest have also evaluated the effectiveness of helmet uses on injury severity/head injuries (e.g., Gabella et al., 1995; Rowland et al., 1996; Lin et al., 2003; Keng, 2005; Nakahara et al., 2005; Zambon and Hasselberg, 2006). Zambon and Hasselberg (2006) and Lin et al. (2003), focusing on young motorcyclists, consistently found that riding unhelemted was indeed a deadly factor to young riders, with other findings that riding on rural roads/in midnight, higher riding speeds, and dry road surfaces were associated with more severe/fatal injuries.

Other typical studies that investigated the multivariate relationship between injury severity/accident occurrence and the variables of interest include research work by, for instance, Mannering and Grodsky (1995), Umar et al. (1996), Quddus et al. (2002), and Lapparent (2006). These studies have conducted multivariate analyses of the factors that were associated with more severe injuries (Quddus et al., 2002; Lapparent, 2006), factors that affect the occurrences of conspicuity-related accidents (Umar et al., 1996), or motorcyclists' perceived likelihood of being involved in an accident (Mannering and Grodsky, 1995). Accidents in whole were analysed by these researchers rather than specific crash configurations (i.e., these studies have not alluded to crash configurations or a certain crash type was not examined as subset of all crash configurations).

Factors generally found to lead to increases in the probability of severe/fatal injuries include increased engine size, headlight not being used during daytime, riding in mid-night/early morning, riding on dry road surfaces, the presence of surveillance camera, female riders, older riders, and riders being identified as a offender (Quddus et al., 2002; Lapparent, 2006). Headlight use during daytime was found to reduce the conspicuity-related accidents (Umar et al., 1996). Such finding is in agreement with some other studies (e.g., Thomson, 1980; Muller, 1984; Zador, 1985) who reported that headlight use during daytime may be beneficial in reducing the number of motorcyclist fatalities or motorcycle accidents. Noteworthy findings in the study of Mannering and Grodsky (1995) include that motorcyclists were generally found to have a reasonable understanding of the factors that increased the likelihood of accident involvement. For instance, motorcyclists were more likely to perceive their accident likelihood in the high-risk category if they regularly rode above the speed limit, or had overtaking manoeuvres on the road shoulders or between traffic lanes.

2.5 Studies that Analysed Automobile-Bicycle/Pedestrian Accidents

Studies of automobile-bicycles/pedestrians accidents in literature can be subdivided into several fundamental categories as follows.

- studies that examined the gap acceptance problem;
- studies that developed the crash typology or alluded to crash configurations; and
- studies that explored the multivariate relationship between injury severity/accident occurrence and the variables of interest.

A review of these studies is provided.

2.5.1 Studies that Identified the Gap Acceptance Problem

Similar to previous studies of gap acceptance problem in automobile-automobile or motorcycle-automobile accidents, pedestrian/bicyclist gap acceptance problem has been attracting attention in literature. Researchers (e.g., Oxley et al., 1997, 2001, 2005;

Lobjois and Cavallo, 2007) examined age differences in the ability of pedestrians to choose safe time gaps in simulated road-crossing tasks. They argued that, for all age groups, gap selection was based primarily on vehicle distance rather than time of arrival. Younger age group (between 30 and 45 years old) were able to process both distance and speed of vehicles in very short period of time, although they based their crossing decisions primarily on vehicle distance. Older age groups (75 years and older), on the other hand, depended more on longer observation times. They pointed out that older pedestrians tended to have longer crossing time, overestimate their crossing speed, and being more likely to make wrong judgement on vehicles' speed and distance. A handful of studies have addressed children's road-crossing judgements while walking/cycling across traffic (e.g., Lee et al., 1984; Connelly et al., 1998; Pitcairn and Edlmann, 2000; Plumert et al., 2004; Kearney et al., 2006). Younger children were generally found to be more likely than older children to accept gaps that were too small for safe crossing. Children chose the same size gaps as adults did, but those gaps may be inadequate for safe crossing as it may take longer for children to cross the road.

2.5.2 Studies that Developed the Crash Typology or Alluded to Crash Configurations

Research (e.g., Ashton et al., 1978; Lane et al., 1994; Ashton, 1979, 1982; Kajzer et al., 1992) has suggested that the vast majority of automobile-pedestrian collisions involved the pedestrians being struck by the front of a car, and front/side of a car was also found to be the most common crash area in bicycle-automobile collisions (Maki et al., 2003; Stone and Broughton, 2003). Classification of pedestrian-/bicyclist-automobile accidents has been mainly based on the movements of the pedestrians/bicyclists and cars prior to crashes rather than first crash point. For automobile-pedestrian accidents, several researchers (e.g., Miles-Doan, 1996; Roudsari et al., 2006; Huang et al., in press) classified accidents depending on the manoeuvres of automobiles and pedestrians such as turning right/left and travelling straight at junctions. Miles-Doan and Roudsari et al. consistently reported that injuries were most severe to pedestrians in crashes where cars collided straight ahead with the pedestrians. They suspected that this increased injury-severity level was probably as a result of higher impact speed at the time of crash. Huang et al. concluded that the two most common crash patterns were identified as cars entering and leaving intersections colliding with pedestrians crossing the roads.

The earliest work that has developed the crash typology for accidents involving bicyclists and motorists was probably by Cross and Fisher (1977). In an attempt to identify the causes of automobile-bicycle accidents in four locations within the U.S., Cross and Fisher developed a taxonomy of 25 crash configurations mainly based on the manoeuvres of the involved automobiles and bicycles before collisions. A same-direction crash (i.e., a sideswipe and a rear-end crash) was identified as one of the most common crash type for automobile-bicycle collisions, followed by an accident involving gap acceptance (i.e., angle/approach-turn crash). They observed that traversing manoeuvres played a part in the occurrence of a same-direction crash in which a bicyclist (particularly young bicyclists), without being attentive to the traffic behind and without signalling, executed a turning manoeuvres and was struck by an overtaking automobile from behind. The overtaking automobile-drivers observed the bicyclist well in advance, but had lesser evasive reaction once the bicyclist initiated a turn. Recommended countermeasures for such sudden turning manoeuvres by bicyclists include rear-vision devices equipped with bicycles, increased conspicuity of bicycles or bicyclists, and the education of juvenile bicyclists. A later study by Atkinson and Hurst (1983) adopted the similar crash typology by Cross and Fisher in an attempt to examine the characteristics of automobile-bicycle accidents in New Zealand. Atkinson and Hurst reported that HGVs commonly caused bicyclist deaths by side impact in overtaking-accidents, and the majority of bicyclists died from multiple injuries through being run over by the wheels of the HGVs.

Much more recent studies (see, for instance, the work by McCarthy and Gilbert, 1995; Summala et al., 1996; Stone and Broughton, 2003; Wang and Nihan, 2004; Walker, 2007) classified car-bicycle accidents into several sub-crashes, with focuses on accidents that occurred at roundabouts, T-junctions, and signalised four-legged junctions. Stone and Broughton found that the most frequent car-bicycle accident type at T-junctions and roundabouts were accidents in which an entering/turning-right automobile collided with a circulating/travelling-straight bicycle. Walker pointed out that overtaking motorists may pass closer to a bicyclist when the bicyclist was helmeted, riding away from the curb of the road, was male, or the drivers were professional drivers (e.g., bus or heavy goods vehicle). McCarthy and Gilbert noted that poor conspicuity of bicycles or bicyclists was a concern especially when motorists were overtaking bicycles that were frequently in the blindspot of motorists.

Factors contributing to the accidents where a circulating bicycle collided with an entering automobile at roundabouts were further investigated by several researchers in Finland and Demark (e.g., Summala et al., 1996; Räsänen and Summala, 1998, 2000; Herslund and Jørgensen, 2003). Herslund and Jørgensen (2003) concluded that motorists that looked but failed to see bicycles were found to be a causation factor for such crash configurations; experienced drivers may be more likely to make such error than inexperienced drivers; and drivers tended to accept larger gap towards bicyclists if there was another car nearby. Summala et al. (1996) and Räsänen and Summala (1998, 2000) further noted that at high speeds much of the driver's attention was focused on the most relevant direction or the most hazardous object (i.e., automobile), and ignored the less relevant direction or the less hazardous object (i.e., bicycle). This may result in the faster drivers looking to the right less often and showing a tendency to yield to the bicyclist less often (Räsänen and Summala, 1998, 2000), irrespective of whether the bicyclist approaching from the right or left arm of junction (Preusser at al., 1982).

2.5.3 Studies that Explored the Multivariate Relationship between Injury Severity/Accident Occurrence and the Variable(s) of Interest

There is a lengthy literature investigating the factors that were associated with the pedestrian/bicyclist injury severity or accident occurrences by conducting laboratory/computer simulations, self-report survey, mathematic modelling techniques of archival crash data from police accident reports, hospital data, or multidisciplinary crash investigations. These studies include those mainly relying on laboratory simulation (e.g., Mizuno and Kajzer, 1999) and those estimating econometric models of pedestrian/bicyclist injury severity or accident occurrences (e.g., Pitt et al., 1990; Li and Baker, 1994; Wachtel and Lewiston, 1994; Kim and Li, 1996; Klop and Khattak, 1999; Zajac and Ivan, 2003; Ballesteros et al., 2004; Noland and Quddus, 2004; Roudsari et al., 2004; Paulozzi, 2005; Lee and Abdel-Aty, 2005; Henary et al., 2006;

Siddiqui et al., 2006; Kim et al., 2007; Sze and Wong, 2007; Hatfield and Murphy, 2007; Kim et al., in press; Eluru et al., in press).

Overall, the variables of interest in these studies were bicyclist/pedestrian/driver factors (e.g., driver age, gender), distraction factors (e.g., mobile phone use while walking), temporal/environmental factors (e.g., daytime or nighttime, urban or rural areas, weather conditions, speed limit), vehicle factors (e.g., junction control measures, vehicle type/speed), and road/geometric factors (e.g., junction control measure or light condition). Noland and Quddus (2004) specifically examined the effects of medical technology improvements on the likelihood of KSIs and slight injuries while Kim and his colleagues (e.g., Kim and Li, 1996; Kim et al., in press) examined the likelihood of bicyclists/pedestrians being at fault in bicycle-automobile collisions. General findings with regard to the factors associated with more serious injuries include that, for example, pedestrians/bicyclists were more severely injured while they were struck by heavier/larger vehicles, they/drivers were intoxicated, they were older pedestrians/bicyclists, accidents occurred on wider roadway width, speed limits/vehicle speeds were higher, it was inclement weather, accidents took place on the curved roadways, and while bicyclists were riding against the traffic. Noland and Quddus found that more serious pedestrian injuries were generally associated with lower-income areas, increases in percent of local roads, increased per capita expenditure on alcohol, and increased vehicle age. Similar factors were found to be associated with bicyclist KSIs, with additional variables such as increased NHS (National Health Service) staff per thousand population, increased percentage of motorway/trunk roads, and increases in percentage of population ages 0-14 and 65 or over.

2.6 Research Gaps

The overview of the literature indicates that, while not all work was empirical or employed statistical modelling approaches, there has been an abundant volume of articles analysing automobile-automobile accidents. These studies have increasingly estimated the multivariate modelling techniques and provided an understanding of the multivariable relationship between accident occurrence/severity and the variables of interest. The following research gaps are found in literature:

- Studies of motorcycle-car accidents.
  - Studies analysing motorcycle-car accidents appear to be much fewer compared with those of car-car accidents, let alone studies applying the multivariate modelling techniques to examine motorcyclist injury severity.
- Classification of motorcycle-car accidents.
  - Compared with past studies of car-car accidents, classification of motorcycle-car accidents was less frequently developed. Research analysing motorcycle-car accidents tended to develop aggregate models by accidents in whole and a real picture of the factors that are associated with more severe motorcyclist injuries resulting from different crash configurations may be obscured.
- Some other important factors are generally overlooked.
  - Past studies such as Peek-Asa et al. (1994), Peek-Asa and Kraus (1996a), and Preusser et al. (1995) are among the few studies of motorcycle-car accidents that have developed the crash typology. These researchers were in an attempt to understand the mechanisms behind the accident occurrence, as well as comparing driver/crash features and injury severity/specific injury pattern among various crash configurations. Nevertheless, these studies tended to overlook the effects of some other important factors, such as junction control measures, speed limits, motorist attributes, or right-of-way violation.
- Accidents that occurred at T-junctions were rarely researched.
  - Although motorcycle-car accidents at four-legged intersection were researched, T-junction cases have not been fully researched in literature (see Chapter 1 for the explanations on why T-junction is an important area for this study).

2.7 The Current Research

The current research is expected to add to the extant literature on motorcyclist injury severity in several ways. Firstly, motorcycle-car accidents are disaggregated into several crash configurations based on a mixture of two methods (i.e., the manoeuvres of the involved motorcycles and automobiles prior to collisions, as well as the first crash impact). There exist comparatively few past studies that explicitly classified motorcycle-car accidents.

Secondly, through the use of an appropriate statistical modelling technique, a set of contributory factors is included in this study to investigate motorcyclist injury severity resulting from various crash configurations. An aggregate model is first estimated to identify whether motorcyclists in a specific crash type are most likely of all other crash configurations to be injurious, while controlling for other factors. Additional disaggregate models by various crash configurations are then estimated. Factors found in past studies to affect the occurrence/consequence of the certain car-car/motorcycle-car crash configurations are incorporated into the disaggregate models for examining their effects on motorcyclist injury severity. For example, motorists' failure to give way was found to be a contributory factor to the occurrences of motorcycle-car approach-turn/angle crashes; and traversing manoeuvres (e.g., overtaking or lane changing) were associated with a higher risk of being involved in car-car sideswipe/rear-end crashes. The effects of right-of-way violation and traversing manoeuvres on motorcyclist injury severity in approach-turn/angle crashes and sideswipe/rear-end crashes are examined in this current study.

Thirdly, given that research has reported that turning motorists adopted smaller margin in front of motorcycles compared with cars, an appropriate statistical model is employed to examine the likelihood of motorists failing to yield as a function of rider/motorist attributes, vehicle factors, environmental, and roadway factors. This may enable the possible countermeasures that aim to curb right-of-way violations to be directed towards certain circumstances. For instance, compared with drivers of other age groups, elderly motorists may have more difficulties in intersecting with and detecting oncoming motorcycles, thereby being more likely to fail to give way to motorcycles.

Finally, the investigations of motorcycle-car accidents in the current study are limited to accidents that took place at T-junctions, where the statistics suggested that T-junction accidents are the most hazardous to motorcyclists than any other junction case.

2.8 Summary

This chapter has provided a background of research shortage through a review of past studies that have developed a taxonomy of various crash configurations for different road users. When reviewed together, the flaws of the existing studies had led to the conclusion that there is shortage in literature developing crash configurations and conducting research programmes for analysing motorcycle-car accidents at T-junctions. Findings in literature with regard to the factors determining the accident likelihoods or likelihoods of more severe injuries/deaths in the non-junction case may still contribute to the understanding of the factors that affect motorcyclist injury severity in T-junction cases. These factors include, for example, drivers violating motorcycles' right of way was found to contribute to the occurrences of motorcycle-car accidents that involve gap acceptance. This chapter has also positioned the current study.

The next chapter (Chapter 3) presents a review of previous empirical studies that have developed different econometric modelling techniques for understanding the multivariate relationship between accident severity/injury severity and the variables of interest. A review of these studies is expected to provide guidance on an appropriate statistical model that can be estimated in this study.

CHAPTER 3
A REVIEW OF STUDIES ESTIMATING VARIOUS ECONOMETRIC MODELS

3.1 Introduction

Chapter 2 has provided a review of literature examining the factors that affect injury severity among various road users. This chapter reviews the studies of the multivariate analyses that utilised different econometric modelling techniques to identify the determinants of injury severities. There also exists another type of studies (e.g., Atkins et al., 1988) adopting descriptive analyses to aggregate crashes by injury severity levels and compare human, vehicle, weather, environmental factors across the different injury-severity categories. These studies are not reported in this chapter as they were based on univariate or bivariate associations at an aggregate level.

The review is organised as follows. Firstly the typical discrete-choice model that has been widely used is reviewed. These multivariate studies are organised by different road users (i.e., automobile, motorcycle, and bicyclist/pedestrian) within each section that contains one certain type of model. This is followed by a review of studies that developed different econometric structures (i.e., the extensions to the traditional discrete-choice models) for injury severity analysis. Also non-parametric models that have occasionally been applied are reviewed. Finally general observations from the review are provided in the last section.

3.2 Discrete-Choice Model

Multivariate studies of automobile accident/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; nested logit model). There exist some other studies that developed different econometric structure to overcome the limitations imposed by the typical discrete-choice model. A review of past studies utilising these modelling techniques is provided below.

3.2.1 the Logistic Regression Model

Among the multivariate modelling techniques, the logistic regression has been commonly used when the injury-severity representation 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/injury severity in car-car accidents or single-automobile 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 one certain accident/injury severity level (e.g., fatal injury or some other severe characterisation of injury) conditioned on the occurrence of an accident using the variables of interest such as driver age, gender, vehicle mass, restraint system use, and impact point.

Most previous research on motorcycle accident severity has been oriented toward a univariate examination of accident severity, with focus on helmet-related issues such as effectiveness of helmets in reducing both fatalities and severity of head injuries (see, for example, Watson et al., 1980; Ouellet and Kasantikul, 2006). Compared with the multivariate studies of automobile accident/injury severity, relatively fewer studies have been conducted in the field of motorcycle safety using a true multivariate examination of the determinants of accident/injury severity (i.e., controlling for all factors affecting accident/injury severity). Past studies undertaken by Goldstein (1986) has made important contributions on the multivariate analysis by modelling the multiple effects of several variables on motorcycle accident severity. Goldstein conducted a tobit model to investigate different injured body regions, while the logistic regression models were also successfully applied by other researchers when the injury-severity representation is in binary form. These researchers include, for instance Gabella et al. (1995), Peek-Asa and Kraus (1996b), Lin et al. (2003), Keng (2005), Chang and Yeh (2006), and Zambon and Hasselberg (2006) to model the probability of fatalities/severe injuries/severe head injuries using a wide-range of factors such as rider age/gender, helmet use, weather condition, and engine size.

For studies analysing accident/injury severities in bicyclist-/pedestrian-automobile accidents, the logistic regression model has also been frequently estimated when the 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 in an attempt to model the probability of fatalities/severe injuries using a variety of variables such as junction control measures, pre-crash movement of the car, age/gender of bicyclist/pedestrian, and vehicle type.

3.2.2 The Ordered Response Model

Since injury severity levels are typically progressive (ranging from no injury to fatal/death), the ordered response models have come into fairly wide 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 some of the many that have applied this technique. These researchers assessed the probabilities of the entire range of injury severity levels as a function of a set of independent variables using the ordered logit/probit specifications.

To the author's knowledge, the first work applying the ordered response model to examine motorcyclist injury severity was probably by Weiss (1992) who investigated the severity of head injuries using Hurt data (Hurt et al., 1981). More recently, the ordered probit models have been utilised by Quddus et al. (2002) and Pai and Saleh (2007a, b, 2008, in press) to analyse motorcyclist injury severity.

For bicyclist-/pedestrian-car accidents, the ordered response model has been developed by several researchers (e.g., Klop and Khattak, 1999; Zajac amd Ivan, 2003; Lee and Abdel-Aty, 2005; Siddiqui et al., 2006) to understand the effects of various factors on bicyclist/pedestrian injury severity.

3.2.3 The Multinomial/Nested Logit Model

The multinomial logit (MNL) and nested logit models disregard the ordered nature of injury severity levels and treat them as independent alternatives. The MNL model suffers from the well-known independence from irrelevant alternatives (IIA) assumptions (Ben-Akiva and Lerman, 1985). A thorough review of the IIA that 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 estimation of more 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 – offer a more flexible functional form by providing consistent parameter estimates in the presence of the likely underreporting of accident data that do not involve injury (see the work of Yamamoto et al., in press for a thorough discussion of the underreporting 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 that does not allow a variable to simultaneously increase (or decrease) both high and low injury severities. That is, they allow the independent variables to have opposing effects regardless of injury order. Thus, this class of models still have a place in accident/injury severity analysis that has been estimated by a number of researchers with considerable success. The monotonic effect of variables imposed by the ordered response model was thoroughly 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 bicyclists/pedestrian, have shown the potential of the multinomial/nested logit specifications by using environmental, geometric, weather, vehicle, and human factors to develop the predictive models of accident/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).

Examples of motorcycle-severity studies include the work by Shankar and Mannering (1996) and Savolainen and Mannering (2007b) in which the multinomial/nested logit models have been estimated to understand the impacts of helmet use, alcohol-impaired riding, and other factors on motorcycle accident severity for single-motorcycle and multi-vehicle crashes. For bicyclist-/pedestrian-injury severity studies, the only work that has employed the unordered response model was by Kim et al.

(2007). They estimated the MNL formulation of bicyclist injury severity considering bicyclist/motorist characteristics, vehicle, roadway and environmental factors.

3.2.4 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 that recognise the ordinal nature of the categories. These models also allow flexibility in capturing the effects of the independent variables on each ordinal injury-severity category and can capture unobserved heterogeneity in thresholds across individuals. The applications of the mixed logit models have also been focused on unordered choice contexts (e.g., McFadden and Train, 2000; Milton et al., 2008) to overcome the IIA limitations of the MNL model.

Some other researchers (e.g., Jones and Jørgensen, 2003; Huang et al., 2008) argued that since most modelling techniques such as the logistic model and MNL model assume independence across subjects, they may not be adequate in modelling individual injury severity in the presence of potential correlations between those involved in the same multi-vehicle crashes. Which is, the correlation between samples may exist in the situation that, for example, the risk of fatality was dependent on the characteristics of the other vehicles. They pointed out that the models without considering 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).

3.3 Non-parametric Models

Several researchers (e.g., Sohn and Shin, 2001; Sohn and Lee, 2003; Chang and Wang, 2006) 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) (see, for instance, the work of Abdelwahab and Abdel-Aty, 2001, 2003; Abdel-Aty and Abdelwahab, 2004c; Delen et al., 2006) and classification and regression tree (CART) model (see, for example, the work of Chang and Wang, 2006) are non-parametric models that do not have any pre-defined underlying relationship between the dependent and independent variables.

ANN models were specifically developed by Abdel-Aty and other researchers (Abdelwahab and Abdel-Aty, 2001, 2003; Abdel-Aty and Abdelwahab, 2004c) and Delen et al. (2006) to model the relationship between motorist injury severity and a variety of factors, which were collected specifically for their studies. In the studies of Abdel-Aty and his colleagues, the prediction performance of ANNs was compared with the ordered/unordered response models. Their results showed that, in general, ANN models had slightly more accurate prediction capability over the ordered/unordered response models. As for predicting individual severity category, ANN models performed somewhat better than the ordered/unordered response models for the more severe injury-severity levels (i.e., fatal/severe injury), but the accuracy was still relatively low.

However, as discussed by Sohn and his colleagues (Sohn and Shin, 2001; Sohn and Lee, 2003) who 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 and no significant differences were found. The prediction performance of CART was examined by Chang and Wang (2006). They reported that while the CART model performed well for the injury category that has the largest percentage of subjects (i.e., no injury, slight injury), the model in general was unable to predict the less frequent injury category (i.e., fatality).

Although the non-parametric models may provide more accurate prediction capability over the traditional discrete-choice models, they have their disadvantages, as discussed by Harrel (2001). Firstly, developing non-parametric analysis can be very time-consuming. For instance, 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 in determining the network structure and it can only be done by experimentation. Secondly, developing the CART model can be very costly. There is a lack of appropriate and commercially available software which can be used for this type of analysis. For example, the free software for the CART analysis such as Salford systems is only workable for a short period of time (see the work of Chang and Wang, 2006, for a complete discussion). A further disadvantage of the non-parametric model is the difficulty in conducting elasticity analysis. Elasticity analysis provides valuable information on the marginal effects on the explanatory variables on injury severity likelihood. The final drawback of the non-parametric models is that they do not provide a probability level or confidence interval for the risk factors and predictions.

3.4 General Observation

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 away from the descriptive or univariate/bivariate analysis that were adopted in the studies in the more distance past. Descriptive or univariate analysis has been commonly employed in past motorcycle-safety studies that have focused on the effectiveness of helmet on reducing the severity of head injury and fatalities.

Secondly, among the multivariate modelling approaches, three preferred approaches have emerged in the statistical modelling of accident/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 has been extensively used when the injury severity levels are in a binary form (e.g., fatal injury v.s. non fatal injury, KSI v.s. no KSI, or injury v.s. non injury). When the injury severity representation is recorded in multiple categories (such as no injury, possible injury, non-incapacitating injury, incapacitating injury, and fatal injury), the ordered/unordered response model have been widely estimated. The choice between the ordered response model and the unordered response model in literature was likely to depend on one individual's preference (Borooah, 2001).

Finally, more recent studies formulated non-parametric models to identify 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 were a good alternative for analysing injury severity in traffic accident, whilst Sohn and his colleagues (Sohn and Shin, 2001; Sohn and Lee, 2003) noted that there was no significant difference in the prediction performance among CART, ANN, and the logistic regression models.

3.5 Summary

This chapter reviewed the literature on modelling techniques that have been adopted for analysing the risk factors that influence injury severity. The modelling approaches that have been used include the discrete-choice models and non-parametric models. The limitations and advantage of these models were discussed. The choice between the ordered response model and the unordered response model in literature was likely to depend on one individual's preference. Although the prediction capability of the non-parametric models was found by several researchers to be somewhat accurate than that of the tradition discrete-choice models, they have their own drawbacks. Due to limitations on time and funding, it is decided to adopt the ordered response model to analyse the risk factors and motorcyclist injury severity in this current research. The subsequent chapter will describe the ordered response model in detail, as well as the proposed methodology for the development of this present research.

CHAPTER 4
RESEARCH METHODOLOGY

4.1 Introduction

The flaws among the extant studies in literature have been uncovered, as discussed in Section 2.6. The primary aim of this current research is to fill the research gap that crash prediction models of motorcyclist injury severity in different crash configurations have rarely been estimated. Using accident data which have been extracted from the Stats19 accident injury database, this present study attempts to investigate the factors that affect motorcyclist injury severity resulting from various crash configurations at T-junctions. The proposed methodological approach that achieves this consists of the following steps:

- Investigation of the motorcycle-car accident data from the Stats19.
- Identification of a comprehensive set of contributing factors from the Stats19 to explain motorcyclist injury severity at T-junctions, including rider, motorist, vehicle, roadway, environmental, and crash characteristics
- Development of motorcycle-car accident typology.
- Estimations of the appropriate econometric models to evaluate the determinants of motorcyclist injury severity.
    - an aggregate model by motorcycle-car accidents in whole is estimated first to uncover a general picture of the determinants of motorcyclist injury severity.
    - additional models by different crash configurations are subsequently calibrated to identify whether the identified variables affect motorcyclist injury severities in different crash configurations differently.
- Interpretation of the modelling estimation results.
- Conclusions and recommendations for further research to be drawn.

The methodology will be fully discussed in the subsequent sections.

4.2 Empirical Setting

4.2.1 Data - Stats19 Accident Injury Database

This study uses a large sample of motorcyclists that were involved in motorcycle-car accidents at T-junctions for whom crash information is available from the comprehensive police crash data (i.e., Stats19 accident injury database). The Stats19 accident injury database for collection of road accident information was established in 1949, and has been periodically reviewed and modernised by Department for Transport, Great Britain. Following every road traffic accident which becomes known to the local police and involves personal injury, appropriately qualified and experienced police accident investigators complete the Stats19 forms that comprise three files: accident file, vehicle file, and casualty file. The Accident File contains general information on time/date of accident occurrence, weather, road and light conditions, posted speed limit, and road type; the Vehicle File records vehicle and driver details, such as age and gender of driver/rider, vehicle type, first impact point of vehicle, vehicle's orientation, and vehicle's manoeuvres; and the Casualty File reports details for each casualty such as injury-severity level, age and gender.

The injury severity of each individual involved in the accident is classified into four levels: fatal, serious, slight, and no injury. Fatal injury includes only those cases where death occurs within 30 days as a result of the accident. Example of serious injury includes those victims suffering from fracture, internal injury, severe cuts and lacerations, concussion, or any injury requiring detention in hospital. Slight injury is classified for those casualties who sustain sprains, bruises, cuts judged not to be severe and slight shock requiring roadside attention.

For an individual accident, there are at least two vehicles involved in a multi-vehicle accident, and there might be more than one casualty within each involved vehicle. The characteristics of each accident (e.g., time/date of accident occurrence, weather, and light conditions), the involved vehicles (e.g., vehicle type, and engine size), and casualties (e.g., sex and gender are mutually exclusive) are recorded in the Accident File, Vehicle File, and Casualty File separately. The variable "Accident Reference Number" is the identifier for each individual accident within the years. The variable "Vehicle Reference Number" is the unique identifier for the vehicles within each individual accident, with the variable "Type of Vehicle" indicating the type of vehicle. The variable "Casualty Number" is the unique identifier for the casualties within each vehicle. The variable "Other Vehicle Hit – Reference Number of Other Vehicle" is the identifier that indicates with which vehicle the subject vehicle collides with (i.e., the subject vehicle's crash partner). The variable "Accident Reference Number" is used to merge the three record files from the same year.

Consider a typical motorcycle-car accident where one motorbike with engine size of over 125 cc (coded as "04" in the variable "Type of Vehicle" in the Stats19) collides with a car (coded as "09" in the variable "Type of Vehicle" in the Stats19). The motorbike bears two casualties and the car bears one casualty respectively, as shown in Figure 4.1. Through the use of the variable "Accident Reference Number", the accident, vehicle, and casualty files can be merged into one individual file as shown in Table 4.1.

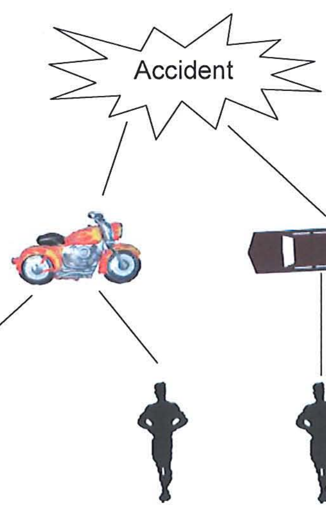


Figure 4.1: A typical situation of casualties within each vehicle.

Table 4.1: An example of the merged file in the Stats19.

Accident Reference Number	Vehicle Reference Number	Vehicle Type	Other Vehicle Hit – Reference Number of Other Vehicle	Casualty Reference Number
A000001	001	04	002	001
A000001	001	04	002	002
A000001	002	09	001	003

A sample of the record forms for the Accident File, the Vehicle File, and Casualty Files is provided in Appendix A.

4.2.2 Variables Considered

Several types of variables obtained from the Stats19 were considered in the empirical analysis, including rider/motorist attributes, vehicle factors, roadway/geometric characteristics, weather/temporal factors, and crash characteristics. These variables have been examined in past multivariate studies of automobile/motorcycle accident/injury severity, as discussed in Chapter 2. For instance, it was found by Shankar and Mannering (1996) that elderly riders tended to have severe injuries once in an accident, and motorcycles with higher engine sizes posed a greater risk of severe forms of injury to riders (Quddus et al., 2002). These studies have the potential to provide some general insights into the factors that determine motorcyclist injury severity.

The categorisations of the variables considered in the empirical analysis were guided by prior studies. For instance, time of day was classified into four categories (evening: 6 p.m. to midnight; late night and early morning: midnight to 06:59; rush hours: 7 a.m. to 08:59 and 4 p.m. to 17:59; and non rush hours: 9 a.m. to 15:59). This is because past studies (e.g., Kasantikul et al., 2005) concluded that injuries to riders tended to be much more severe in accidents that occurred in mid-night/early morning.

The categorisations of the variables considered in the empirical analysis were also based on the examination of whether the variables were significant in explaining motorcyclist injury severity, relative to the reference cases. Which is, the categorisations of the variables were based on a systematic process of combining categories in one variable when their effects were not significantly different from the reference cases.

It merits mention here that the selection of a reference case within one variable is guided by prior studies (i.e., prior beliefs), as well as for the ease of interpretation. For example, extensive research (e.g., Evans and Frick, 1992) has found that crashes involving heavier vehicles generally resulted in more severe accident/injury outcome.

A category that has been assigned as a reference case within one variable was the one found to impose less impact on injury severity. In the case of the effect of motorcycle's collision crash partner, assigning "car" as the reference case can provide a clear picture of the prior belief that heavier vehicles would result in more severe accident/injury outcome, relative to cars. Another example is the effect of speed limit on injury severity. Higher posted speed limits were generally found to increase car-occupant injury-severity levels (Renski et al., 1999). The category "built-up roadway (i.e., speed limit up to 40mph)" has been assigned as the reference case, which can provide a clear picture of the prior belief that non built-up roadways (i.e., speed limit over 40mph) would result in more severe accident/injury outcome, relative to built-up roadways.

This current research sought to include as many relevant explanatory variables as possible from the Stats19. Variables that are not statistically significant were still retained in the models as it is considered in this current research that all variables have their effects on injury outcome. Such approach to retain the variables with low statistical significance has been adopted by several researchers (e.g., Kockelman and Kweon, 2002).

Variables considered for the empirical analysis are described further in the subsequent sections.

4.2.2.1 Rider/motorist attributes

Rider and motorist attributes include demographics information such as age and gender. The continuous data for rider/motorist age were transformed into categorical data for the ease of modelling interpretation. Rider/motorist age is divided into three age groups: teenager (up to 19), middle-aged rider (20-59), and the elderly (60+). This present study treats riders/motorists aged 60 or above as the elderly, which is in accordance with the categorisation of age in DfT (2006b). For middle-age riders, more age groups of smaller ranges by 10 years, for instance, had been considered in this research. Nevertheless, partitioning the data of middle-age riders/motorists into subgroups was found to yield less statistically significant results. As a result, it was decided to include the three age categories as the most reasonable categories.

4.2.2.2 Vehicle attributes

The vehicle attributes include engine size of motorcycle, and type of motorcycle's collision partner. There exist three sizes of motorcycle engine capacity in the Stats19: moped, motorcycle with engine size up to 125cc, and motorcycle with engine size over 125cc. It has been decided to combine the categories "moped" and "motorcycle with engine size up to 125cc" into one single category "motorcycle with engine size up to 125cc". This is because the category "moped" was generally found to be insignificant in explaining injury severity in the estimated models. This has yielded two categories for the variable "motorcycle engine size": motorcycle with engine size up to 125cc, and motorcycle with engine size 125cc or above.

The type of motorcycle's crash partner considered includes heavy goods vehicle (HGV), bus/coach, and private car.

4.2.2.3 Roadway/geometric characteristics

The roadway/geometric characteristics considered in the analysis are speed limit, junction control measures, the presence of curvature for motorcycle or for car, and street light conditions. The variable "speed limit" comprises two categories: built-up roadway (speed limit <= 40mph) and non built-up roadway (40mph+). The variable "road types" (i.e., one way street, dual carriageway, and single carriageway) was considered but it was found to be correlated with the variable "speed limit". Therefore it was not considered in the analysis. The variable "junction control measure" includes three categories: signalised junction, stop-/give-way controlled junction, and uncontrolled junction. The data for the presence of bend on the roadway were extracted from the variable "2.7 Manoeuvres" in which the categories "Going ahead left hand bend" and "Going ahead right hand bend" provide such data. Additional geometric characteristics such as grade, shoulder widths, or alignment of roadways, could not be included due to the absence of these data in the Stats19. The variable "street light condition" includes several categories: daylight, street light lit/unlit in darkness, and street light unknown.

4.2.2.4 Temporal/weather factors

Temporal/weather factors related to the crash include day of week (weekend and weekday), time of day represented in four categories (evening: 6 p.m. to midnight; late night and early morning: midnight to 06:59; rush hours: 7 a.m. to 08:59 and 4 p.m. to 17:59; and non rush hours: 9 a.m. to 15:59), accident month represented in two categories (spring/summer: March to August; and autumn/winter: September to February), and weather conditions (fine weather; adverse weather: windy, rainy, or stormy; and unknown).

4.2.2.5 Crash characteristics

Crash characteristics which are considered include the number of vehicles involved (two-vehicle crash; and three vehicles+), and crash configurations represented as four categories (head-on crash; same-direction crash; approach-turn A crash; approach-turn B crash; angle A crash; and angle B crash). The categorisation of the crash configurations is described in detail in 4.3 Classification of the crash configurations.

Additional variables are incorporated into the disaggregate models by crash configurations, which will be presented in Chapter 7. These variables include, for instance, motorist's failure to give way that was found in the literature to contribute to the occurrences of approach-turn/angle collisions (Hurt et al., 1981; Hancock, 2005). The effect of motorist's failure to give way on motorcyclist injury severity will be examined in approach-turn/angle crash model. Another example of the additional variables is the pre-crash manoeuvres of the car and the motorcycle. There is evidence in the literature suggesting that car-car/motorcycle-car same-direction crashes (i.e., sideswipe/rear-end crashes) were associated with improper overtaking or changing lane manoeuvres (Clarke et al., 1998, 1999). The effects of pre-crash manoeuvres by motorcycle and car on motorcyclist injury severity will be investigated in same-direction crash model. These additional variables will be fully described in the Chapter 7.

The categories of each variable considered in the empirical analysis, together with its frequency, are presented in Table 4.2.

Table 4.2: The categories of the variables.

Variable			Frequency (%)
Rider/motorist attributes	Gender of rider	1. male	93667 (92.0%)
		2. female	8174 (8.0%)
	Age of rider	1. 60 above	2469 (2.4%)
		2. up to 19	21970 (21.6%)
		3. 20~59	77402 (76.0%)
	Gender of collision partner	1. untraced	4528 (4.4%)
		2. male	67434 (66.2%)
		3. female	29879 (29.3%)
	Age of collision partner	1. untraced	9403 (9.2%)
		2. 60 above	10412 (10.2%)
		3. up to 19	5557 (5.5%)
		4. 20~59	76469 (75.1%)
Vehicle characteristics	Engine sizes	1. motorcycle over 125cc	72741 (71.4%)
		2. motorcycle 125 cc or under	29100 (28.6%)
	Collision partners	1. heavy good vehicle	7483 (7.3%)
		2. bus/coach	1359 (1.3%)
		3. car	92999 (91.3%)
Crash characteristics	No. of vehicle involved	1. >=3	6770 (6.6%)
		2. two vehicles only	95071 (93.4%)
Roadway/geometric factors	Bend for motorcycle	1. bends	4935 (4.8%)
		2. non bends	96906 (95.2%)
	Bend for car	1. bends	2107 (2.1%)
		2. non bends	99734 (97.9%)
	Junction control measures	1. uncontrolled	12440 (12.2%)
		2. stop, give-way sign or markings	83712 (82.2%)
		3. automatic traffic signals	5689 (5.6%)
	Light conditions	1. darkness: street lights unknown	958 (0.9%)
		2. darkness: street lights lit	23845 (23.4%)
		3. darkness: street lights unlit	2198 (2.2%)
		4. daylight	74840 (73.5%)
	Speed limit	1. non built-up roads (>40mph)	12022 (11.8%)
		2. built-up roads (<=40mph)	89819 (88.2%)
Weather factor	Weather conditions	1. other or unknown	2039 (2.0%)
		2. fine weather	87704 (86.1%)
		3. bad weather	12098 (11.9%)
Temporal factors	Accident time	1. evening (1800~2359)	27807 (27.3%)
		2. midnight; early morning (0000~0659)	3138 (3.1%)
		3. rush hours (0700~0859; 1600~1759)	33977 (33.4%)
		4. non rush hours (0900~1559)	36919 (36.3%)
	Accident day of week	1. weekend (Sat~Sun)	21696 (21.3%)
		2. weekday (Mon~Fri)	80145 (78.7%)
	Accident month	1. spring/summer (Mar~Aug)	52286 (51.3%)
		2. autumn/winter (Sep~Feb)	49555 (48.7%)
Total			101841 (100%)

It should be noted here that "unknown" or "untraced" categories are retained in some variables (e.g., motorist attributes, light conditions, and weather conditions), but not for some other variables (e.g., rider attributes, day of week). Whether the "unknown" or "untraced" data were included in one variable or not is dependent on two criteria. Firstly, it is dependent on whether such data resulted in a large fraction of data in other variables. For instance, the data for unknown age and gender of rider were excluded because these missing data were found to be largely represented in other variables (e.g., engine size, speed limit, time of accident, etc.) in the dataset. On the other hand, the data for unknown age and gender of motorist were remained because these data did not result in other missing data in other variables.

The second criterion is that it is examined whether the missing data is reasonable. For example, missing data for temporal factors are considered to be unreliable data, as it seems unrealistic that the time/date of the accident was unknown. Thus, missing data for temporal factors could not be included, while unknown weather conditions were still retained in the analysis.

4.2.3 Variables Not Considered

Some other variables (e.g., 2.27 Driver Postcode, 2.23 Breath Test, 1.23 Road Surface Condition, as shown in Appendix A) are readily available from the Stats19 but they were excluded from the analysis. It may be reasonable to hypothesise that these variables may have impact on injury outcome. The reasons for the exclusion of each of these variables from the analysis are justified in the subsequent sections.

4.2.3.1 Driver postcode

Previous work by Quddus et al. (2002) concluded that motorcyclists whose nationality were not Singaporean were more likely to be fatally injured given an accident has occurred. For this current study, it would have been reasonable to assume that motorcyclist injury severity may be associated with driver postcode that indicates where the involved rider and driver are from. However, such data were not available to the public due to confidentiality – they were only available to those who carried out research for DfT.

4.2.3.2 Breath test

As for alcohol use, evidence in literature (e.g., Nakahara et al., 2004; Kasantikul et al., 2005) revealed that intoxication was one of the contributory factors to motorcyclist fatalities, especially during evening/mid-night hours. Data for breath test were available for the latest Stats19 data (i.e., 2005 and 2006), but it was decided not to include the latest Stats19 data of year 2005 and 2006 with the data of 1991-2004. This is because data of year 2005 and 2006 became available while this thesis that analysed the data of 1991-2004 has been finalised. However, this would make an interesting future study to analyse the breath test data of year 2005 onwards by applying the methodology applied in the present study."

4.2.3.3 Road surface condition

As for road surface condition, inconsistent research findings were drawn in literature regarding the effects of road surface condition on motorcycle accident outcome. For instance, while Broughton (1988) concluded that riders of heavier motorbikes were less injurious in an event of a single-motorcycle accident that occurred on slippery roadways, Savolainen, Mannering (2007b) indicated that road surface conditions were not significant in explaining motorcyclist injury severity in multi-vehicle accidents. Similar to the conclusions drawn in the study of Savolainen, Mannering, road surface conditions were found to be insignificant in affecting motorcyclist injury severity in the present study and therefore the variable "road surface condition" was removed from the final models.

4.3 Classification of the Crash Configurations

Since there is no variable in the Stats19 that explicitly indicates the crash configurations, attempts have been made to classify motorcycle-car accidents into several crash configurations by using other variables that are readily available. It has been decided to develop the crash typology depending on the conflicts that arise from the intended/actual path of the motorcycle and car prior to the accidents.

The variables "Vehicle Movement Compass Point" and "Manoeuvres" in the Stats19 are used for the assignment of the intended/actual path of the motorcycle and car. The variable "Vehicle Movement Compass Point" (see Figure 4.2) indicates the vehicle's orientation, while the variable "Manoeuvres" indicates the pre-crash manoeuvres of the involved vehicles. It should be noted here that the original manoeuvres in the Stats19 consist 18 manoeuvres. For the assignment of the movement of the involved vehicles, these manoeuvres were classified into two categories: going straight and turning. Table 4.3 and Table 4.4 report the information on the original manoeuvres in the Stats19 (and their counts), and the merged categories (and their counts) for motorcycles and cars respectively. Of 18 manoeuvres, only 16 manoeuvres were used for the classification of crash configurations. Two manoeuvres (i.e., Reversing and Parked) were removed as these manoeuvres are unrelated to the crash configurations being considered.

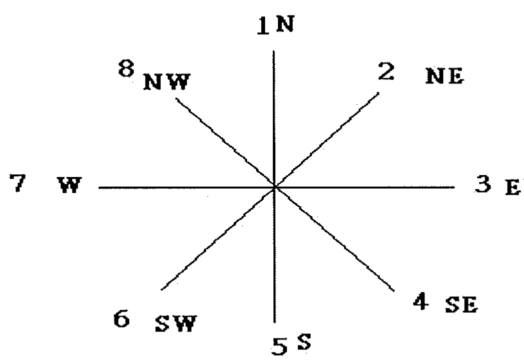


Figure 4.2: The variable "Vehicle Movement Compass Point" in the Stats19 that indicates the car's and motorcycle's orientation.

Table 4.3: Manoeuvres that are merged from the original manoeuvres (for motorcycles) in the Stats19 for the classification of crash configurations.

Manoeuvre code in the Stats19	Original manoeuvres in the Stats19		Manoeuvres that are merged for the classification of crash configurations	
	Manoeuvres	Frequency (%)	Manoeuvres	Frequency (%)
1	Reversing	Not considered in this research		
2	Parked			
3	Waiting to go ahead but held up	1911 (1.9%)	Going straight	92836 (91.2%)
4	Stopping	1246 (1.2%)		
5	Starting	286 (0.3%)		
11	Changing lane to left	212 (0.2%)		
12	Changing lane to right	344 (0.3%)		
13	Overtaking moving vehicle on its offside	11529 (11.3%)		
14	Overtaking stationary vehicle on its offside	5733 (5.6%)		
15	Overtaking on nearside	1866 (1.8%)		
16	Going ahead left hand bend	2688 (2.6%)		
17	Going ahead right hand bend	2247 (2.2%)		
18	Going ahead	64774 (63.6%)		
6	U-turning	170 (0.2%)	Turning	9005 (8.9%)
7	Turning left	1854 (1.8%)		
8	Waiting to turn left	500 (0.5%)		
9	Turning right	5452 (5.4%)		
10	Waiting to turn right	1029 (1.0%)		

Table 4.4: Manoeuvres that are merged from the original manoeuvres (for cars) in the Stats19 for the classification of crash configurations.

Manoeuvre code in the Stats19	Original manoeuvres in the Stats19		Manoeuvres that are merged for the classification of crash configurations	
	Manoeuvres	Frequency (%)	Manoeuvres	Frequency (%)
1	Reversing	Not considered in this research		
2	Parked			
3	Waiting to go ahead but held up	2907 (2.9%)	Going straight	28828 (28.3%)
4	Stopping	1659 (1.6%)		
5	Starting	1736 (1.7%)		
11	Changing lane to left	921 (0.9%)		
12	Changing lane to right	1586 (1.6%)		
13	Overtaking moving vehicle on its offside	1141 (1.1%)		
14	Overtaking stationary vehicle on its offside	614 (0.6%)		
15	Overtaking on nearside	254 (0.2%)		
16	Going ahead left hand bend	564 (0.6%)		
17	Going ahead right hand bend	1543 (1.5%)		
18	Going ahead	15903 (15.6%)		
6	U-turning	3328 (3.3%)	Turning	73013 (71.7%)
7	Turning left	5721 (5.6%)		
8	Waiting to turn left	378 (0.4%)		
9	Turning right	60396 (59.3%)		
10	Waiting to turn right	3190 (3.1%)		

An interesting observation may be made from Table 4.3 and Table 4.4. Which is, more than 91% of all motorcyclist casualties were resulting from accidents in which motorcycles were travelling straight (see Table 4.3), whilst more than 71% of all motorcyclist casualties were resulting from accidents in which cars were making a turn (see Table 4.4). This implies that a travelling-straight motorcycle colliding with a turning car can be a typical safety problem to motorcyclists. An angle/approach-turn crash arises from the combination of these two manoeuvres (a travelling-straight motorcycle collides with a turning car). This crash type was discussed and examined by Pai and Saleh (2008) in more details and is investigated further in this thesis.

In this current research, analysis is limited to motorcycle-car accidents that involve two or more vehicles. That is, it could be a two-vehicle crash, or a multi-vehicle crash that involve more than two vehicles. The classification of the crash configurations is based on the first vehicle with which a motorcycle had collided in the case of a multi-vehicle crash that involved more than two vehicles (i.e., not the second or third vehicle with which such motorcycle had collided in a crash involving more than two vehicles).

Motorcycle-car accidents that occurred at T-junctions are classified into the following four crashes configurations:

- crashes that involve gap acceptance (angle crash and approach-turn crash),
- crashes in which one motorcycle and car originally travelling from opposite directions collided with each other (head-on crash),
- crashes in which one motorcycle and car originally travelling from same directions collided with each other (same-direction crash), and
- other crash configurations.

These four crash configurations are illustrated in Figure 4.3 and Figure 4.4 and are explained further below.

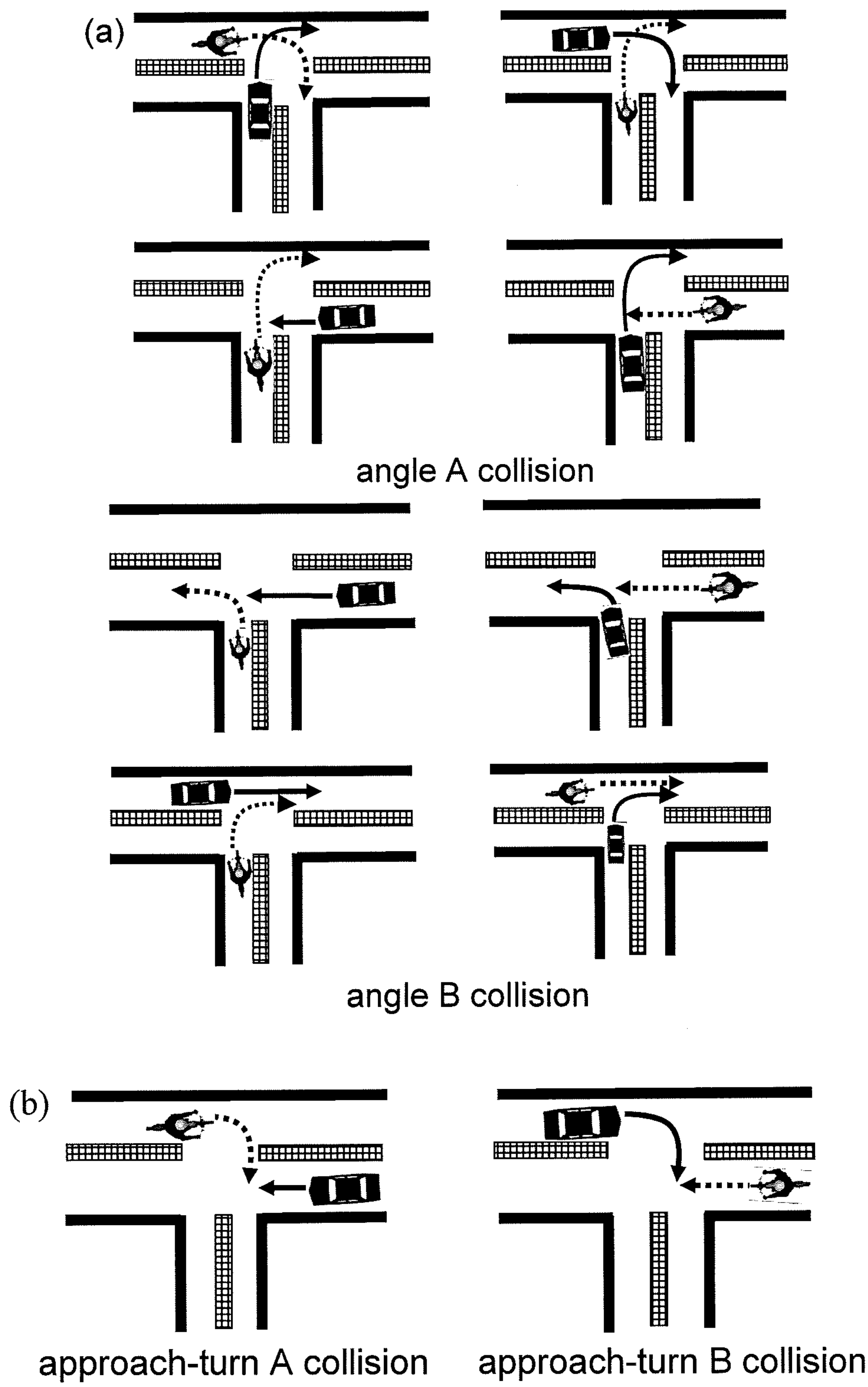


Figure 4.3: Schematic diagram of various crash configurations at T-junctions. (a) angle A crash and angle B crash; (b) approach-turn A crash and approach-turn B crash. Note: pecked line represents the intended/actual path of a motorcycle and solid line represents the path of a car.

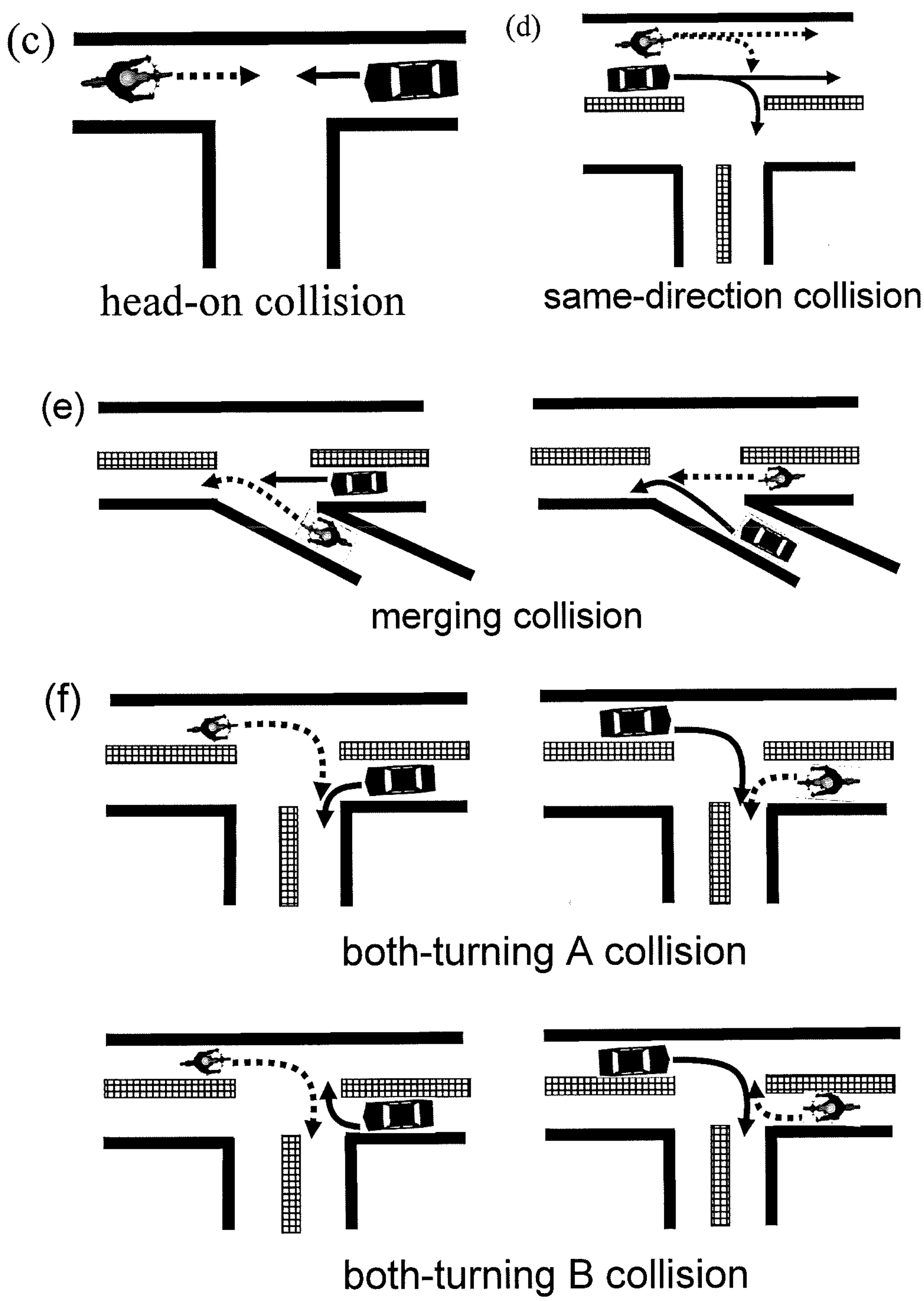


Figure 4.4: Schematic diagram of various crash configurations at T-junctions. (c) head-on crash (d) same-direction crash (e) merging crash (f) both-turning A crash and both-turning B crash. Note: pecked line represents the intended/actual path of a motorcycle and solid line represents the path of a car.

4.3.1 Crashes that Involve Gap Acceptance

Crashes that involve gap acceptance include angle crash and approach-turn crash, as shown in Figure 4.3(a) and Figure 4.3(b) respectively.

An angle crash is defined as a crash in which a right-/left-turn motorcycle/car from the minor road needs to make use of proper gaps amongst the conflicting traffic to cross/merge into the traffic stream. A traffic conflict, which is termed as an angle crash, arises from incorrect gap acceptance by right-/left-turn motorcycle/car. An angle crash is further divided into two sub-crashes: angle A and angle B crash. An angle A crash takes place when one right-turn motorcycle/car from the minor road collides with a travelling-straight motorcycle/car (right-hand side traffic) or collides with a right-turn motorcycle/car (left-hand side traffic) on the main road (such crash is assumed to have a perpendicular crash angle). An angle B crash is defined as a collision in which a right-/left-turn car/motorcycle from the minor road collides with a travelling-straight motorcycle/car (such crash is assumed to have an oblique crash angle). The data of whether the involved vehicles were on the main road or minor road are provided by the variable "2.9a Vehicle Location at Time of Accident" in the Stats19. Note here that a turning-right vehicle/motorcycle may simply make a U-turn.

An approach-turn collision is defined as a collision where a right-turn car/motorcycle from the major road needs to make use of proper gaps among the conflicting traffic to cross or merge into the traffic stream (such car/motorcycle is in a need to either turn right from the major road into the minor road or simply make a U-turn). A traffic conflict (i.e., an approach-turn crash) arises from incorrect gap acceptance by a right-turn car/motorcycle. An approach-turn crash is subdivided into two crash configurations: approach-turn A and approach-turn B, depending on whether the turning vehicle is a motorcycle or a car. An approach-turn A crash takes place when one right-turn motorcycle collides with an oncoming car and such motorcycle turns right into the path of such car; and an approach-turn B crash occurs when one right-turn car collides with an approaching motorcycle and such car turns right into the path of such motorcycle

It merits mention here that the data of whether a turning motorcycle/car is turning right or turning left are provided in the variable "2.7 Manoeuvres" in the Stats19 (see category code 07, 08, 09, and 10 in Table 4.3 and Table 4.4).

4.3.2 Head-on Crash

A head-on crash, as illustrated in Figure 4.4(c), is defined as a crash where one motorcycle and one car originally travelling from opposite directions collided with each other. An example of a head-on crash is that a motorcycle travelling eastwards collides with a car travelling westwards and both are travelling straight instead of making a turn.

4.3.3 Same-direction Crash

As shown in Figure 4.4(d), a same-direction collision is defined as a collision where one motorcycle and one car travelling from same direction collided with each other. This can be a sideswipe or rear-end collision that occurs either on the minor road or major road. The involved car and motorcycle may make any kind of manoeuvres (e.g., travelling straight, overtaking, lane changing, or turning).

4.3.4 Other Crash Configurations

Other crash configurations include a merging collision and a both-turning collision, as presented in Figure 4.4(e) and Figure 4.4(f) respectively.

A merging collision is defined as a crash in which one left-turn car/motorcycle on the minor road collided with a travelling-straight motorcycle/car on the major road.

A both-turning collision is defined as a collision where one right-/left-turn car/motorcycle on the major road collides with a right-/left-turn motorcycle/car on the major road and both are from opposite directions. Note here that a right-turn car/motorcycle may simply make a U-turn. A both-turning collision is further categorised into two crashes: a both-turning A collision where the car and the motorcycle have an oblique crash angle (e.g., both are travelling southwards); and a both-turning B collision the car and the motorcycle have a perpendicular collision angle.

The categories of the variable "crash configurations", together with its frequency, are presented in Table 4.5.

Table 4.5: The categories of the crash configurations.

Crash configuration	Total
Angle A crash	33676 (33.1%)
Angle B crash	8357 (8.2%)
Approach-turn A crash	1061 (1.0%)
Approach-turn B crash	16653 (16.4%)
Head-on crash	3741 (3.7%)
Same-direction crash	34806 (34.2%)
Merging crash	3294 (3.2%)
Both-turning A crash	143 (0.1%)
Both-turning B crash	110 (0.1%)
Total	**101841 (100%)**

It should be noted here that there is no "unknown" category in this variable "crash configurations". That is, the crash configurations that could not be identified by using the variables "Vehicle Movement Compass Point" and "Manoeuvres" were removed. The exclusion is because that missing data (i.e., the data that were left blank) for "Vehicle Movement Compass Point" or "Manoeuvres" were found to result in a large fraction of data in other variables. For instance, there are a number of missing data for motorcycle engine size following missing data for "Vehicle Movement Compass Point" and "Manoeuvres". These data have been considered to be unreliable and were therefore removed.

4.4 Investigation Boundaries

The present study aims to analyse multi-vehicle accidents (i.e., motorcycle-car accidents) instead of single-motorcycle accidents. In addition, the investigation is limited to nationwide scale rather than regional patterns of accidents. The investigation boundaries are justified in the following sections.

4.4.1 Exclusion of Single-motorcycle Crash

It is worth noting here that single-motorcycle crash (i.e., an accident where the motorcycle collided no other motorised vehicle but may either have collided with on-/off-roadway objects or capsized) was excluded from the classification here. This is because a majority of KSI casualties were from multi-vehicle accidents - 63% of all KSI motorcyclist casualties were as a result of collisions with other motorised vehicles (see also Figure 1.1). Therefore, motorcycle-car accidents instead of single-motorcycle crash were the main focus of the present study. Another reason for the exclusion is that previous empirical studies (see, for example, Shankar and Mannering, 1996; Savolainen, Mannering, 2007b) tended to analyse single-motorcycle crashes and motorcycle-car accidents separately because of the substantially different casualty mechanisms and factors involved in these two crash types. For example, Shankar and Mannering (1996) suggested that rider attributes such as rider gender/age or speeding, as well geometric factors such as the presence of bend may significantly affect accident consequence in single-motorcycle crashes on undivided roadways while the characteristics of the involved automobile such as type of vehicle may significantly influence the overall accident severity in multi-vehicle accidents. Further research may attempt to analyse single-motorcycle accidents at T-junctions and on undivided road sections by applying the methodology applied in the present study.

4.4.2 Exclusion of Regional Patterns of Accidents

It should be noted here that the present study focuses on motorcycle-car accidents at nationwide level. Regional patterns of accidents such as geographic spread of accidents (or accidents that result in KSIs) were not investigated. A study investigating regional patterns of accidents may have the potential to obtain additional geometric factors (e.g., grade or road alignment/layout) that are not readily available in the Stats19. Attempts were made at early stage of the present research to locate accidents by using the variable "Grid Reference". However, due to a large fraction of missing grid reference data, the data could be fairly unreliable in order to locate the accidents. The large fraction of missing grid reference data may be because the police attending the accident scene may not capture the final location of a motorcycle in the event of an accident. That is, smaller motorbike than a standard automobile makes it hard for the police to accurately locate the involved motorbike, resulting in the missing data for the final digit of the grid reference that references 1-metre square.

4.5 Limitations of the Stats19 Data

It should be justified here that the only accident database analysed in this research is the Stats19 data. There are a few intrinsic research limitations in the current study while analysing the Stats19 data. These limitations include issues such as underreporting data, reliability of the crash configurations classified, reliability of the injury severity levels recorded, and variables that are not available from the Stats19. These limitations are justified in the following sections, whilst a full discussion of the limitations of the Stats19 data is provided in Chapter 9.

4.5.1 Underreporting Data

Traffic accident data can be regarded as outcome-based samples with unknown population shares of the injury severities. An outcome-based sample is overrepresented by accidents of higher severities. That is, accidents that resulted in no injury or slight injury might not be reported to police. There is concern about underreporting data when analysing police accident report (see the study by Yamamoto et al., in press for a full discussion of underreporting data). In terms of the bias that arises from underreporting, underreporting might be a more serious issue for a study that analyses motorist injury severity than a study that analyses motorcyclist injury severity. This is because of the fact that motorcyclists in generally are more vulnerable than motorists given that an accident has occurred. That is, an accident that involves motorist only (e.g., a car-car crash) is less likely to be reported to police as automobile provides more protection to its occupants. On the other hand, an accident that involves motorcyclist is more likely to be reported to police as motorcycles are not as crashworthy as automobiles do. Statistics from DfT (DfT, 2006a, b) also suggested that motorcyclists' relative risk of being KSI per kilometre travelled is almost 50 time that for car occupants. It is recognised in this present study that underreporting may bias the estimated results. However, it is felt that using police data for more vulnerable road users such as motorcyclists is less problematic than for automobile-motorists.

4.5.2 Reliability of the Crash Configurations Classified

Since there is no variable in the Stats19 that explicitly indicates the crash configurations, motorcycle-car accidents were classified in the present study into several crash configurations by using other variables that are available in the Stats19 (i.e., the manoeuvres and first collision points of the involved car and motorcycle, as shown in Section 4.3). While the crash type data are not readily available in the Stats19, police reporting datasets such as NASS (National Automotive Sampling System) in the U.S. explicitly indicate the crash types where the accidents are reported to the police (see, for instance, the study of Ulfarsson et al., 2006 that relied on NASS to analyse car-car accidents). However, the reliability of such crash type data could be somewhat questionable. This is in part because police attending the accident scenes may have obtained the crash type data from the involved victims or witnesses, which may be fairly subjective due to postcrash shock or denial of responsibility. It is beyond the scope of this current study to either examine the reliability of the crash configurations classified in this present study or identify whether a certain dataset is more reliable than another one.

4.5.3 Reliability of the Injury Severity Levels

While police crash data are perhaps the most valuable source of multiple factors that affect accident occurrence/consequence, the injury severity levels recorded can be inaccurate (Rosman and Knuiman, 1994). Rosman and Knuiman noted that injury severity scale may primarily rely on police officers' judgment at the accident scene. Past studies (e.g., Barancik and Fife, 1985) have shown discrepancies between police judgments and medical records. Life-threatening injuries, such as internal brain trauma, could be identified as slight injury if they are not evident to the police officers. However, this may be an innocuous research limitation since a fatal/serious injury is classified in the Stats19 by the observation of a casualty requiring detention in hospital for up to 30 days, rather than by police officers' judgment at the accident scene alone.

4.5.4 Variables that Are Not Available from the Stats19

Perhaps the most obvious limitation stems from the use of the Stats19 data. While the Stats19 provides a detailed source of accident features, several other important factors were not readily available. These factors include the causes to the accident (e.g., violation, speeding etc.), helmet use, speed, other geometric factors such as vertical bends (i.e., grade) rather than horizontal bends, and alcohol use. Exposure data such as traffic flow for the traffic stream at the time of accident, riding/driving experience, and other aspects of risk exposure were also not available. The data that were not available from the Stats19 can be expensive to obtain and thus analyses of these unavailable data are beyond the scope of this thesis. Nonetheless, these factors should not be overlooked in future research.

4.6 Econometric Framework

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 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 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 3, the unordered multinomial logit (MNL) or nested logit models have been widely adopted in literature to determine the factors that affect injury severities sustained by various road users. These models, while accounting for categorical nature of the dependent variable, treat ordinal dependent variables as if they are interval (Borooah, 2001; Long, 1997). Which 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 do not have the restriction of the IIA (the independence of irrelevant alternatives) as a MNL model does (Borooah, 2001; Long, 1997). The ordered response models are introduced in more detail in the subsequent section.

4.6.1 The Ordered Response Model

The 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:

$$y_i = m \qquad \text{if } \mu_{m-1} < y_i^* \le \mu_m \qquad \text{for } m = 1 \text{ to } J \qquad [4.1]$$

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

In order to illustrate the measurement equation (Equation 4.1), consider the dependent variable used in this current study. The data of motorcyclist casualties resulting from motorcycle-car accidents at T-junctions were drawn from the Stats19 for a 14-year period between 1991 and 2004. Motorcyclist injury severity resulting from these motorcycle-car accidents is classified into three levels: no injury, slight injury, and KSI. Assume that this ordered variable is related to a continuous, latent variable $y*$. The ordered response models are usually motivated in a latent (i.e., unobserved) variables framework. The general specification of each single-equation model is

$$y_i* = \beta' x_i + \varepsilon_i \quad [4.2]$$

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. disturbance term is assumed to be heteroskedastic, representing that all individuals have the same variance, and unit variance).

According to the measurement model (Equation 4.1), the observed and coded discrete injury severity, y_i, is determined from the model as follows:

$$y_i = \begin{cases} 1 \text{ if } -\infty < y_i* \leq \mu_1 \text{ (no injury)} \\ 2 \text{ if } \mu_1 < y_i* \leq \mu_2 \text{ (slight injury)} \\ 3 \text{ if } \mu_2 < y_i* < +\infty \text{ (KSI)} \end{cases} \quad [4.3]$$

where the threshold values μ_1 and μ_2 are unknown parameters to be estimated. Figure 4.5 illustrates the correspondence between the latent, continuous underlying injury variable, y_i*, and the observed injury severity class, y_i.

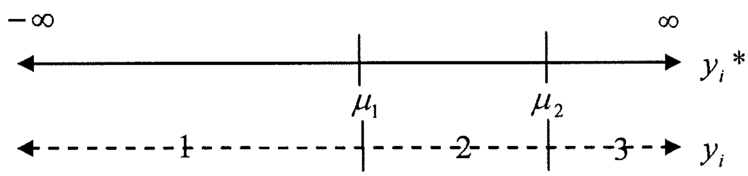


Figure 4.5: Relationship between latent and coded injury variables.

As shown in Figure 4.5, the solid line represents the latent variable y_i*. The cutpoints 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 motorcycle user 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:

$$P(y_i = 1|x_i) = P(\mu_0 < y_i* \le \mu_1 \mid x_i) \quad [4.4]$$

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

$$P(y_i = 1|x_i) = P(\mu_0 < \beta' x_i + \varepsilon_i \le \mu_1 \mid x_i) \quad [4.5]$$

Subtracting $\beta' x_i$ within the inequality,

$$P(y_i = 1|x_i) = P(\mu_0 - \beta' x_i < \varepsilon_i \le \mu_1 - \beta' x_i \mid x_i) \quad [4.6]$$

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

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

[4.7]

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

$$P(y_i = 1|x_i) = \Phi(\mu_1 - \beta' x_i)$$
$$P(y_i = 2|x_i) = \Phi(\mu_2 - \beta' x_i) - \Phi(\mu_1 - \beta' x_i) \qquad [4.8]$$
$$P(y_i = 3|x_i) = 1 - \Phi(\mu_2 - \beta' x_i)$$

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 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:

$$\Phi(\varepsilon) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\varepsilon} \exp(-\frac{t^2}{2})dt \qquad [4.9]$$

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:

$$\Lambda(\varepsilon) = \frac{\exp(\varepsilon)}{1 + \exp(\varepsilon)} \qquad [4.10]$$

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

$$\rho^2 = 1 - [\ln(L_b)/\ln(L_0)] \qquad [4.11]$$

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 of the OP models are estimated and reported in this present study (see Chapter 6 and Chapter 7). It also merits mention that two categories (i.e., KSI v.s. non KSI) can be considered as the dependent variable and the appropriate statistical model for this would be binary logistic regression model, as discussed in Chapter 3. It was found that the estimation results by adopting the binary logistic regression were fundamentally consistent with those by the OP models adopted in this study (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 variable, 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 which can be provided by using the ordered response models) is also supported by several researchers (e.g., Elure and Bhat, 2007).

4.6.2 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 the estimators to be biased, inefficient, or inconsistent, and does not affect the forecasting performance of the model, it might make coefficients less significant (Ramanathan, 1995).

Multicollinearity could be identified by high value for correlation coefficients between variables. A correlation value that is 0.5 or above between two variables may result in 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 multicollinearity problem (see the work of Ramanathan, 1995 for a complete discussion of multicollinearity problem that arises from two variables with a correlation value of 0.5 or above). In this current study, correlation matrix is systematically examined among the variables before they are incorporated into the models (see Chapter 6 and Chapter 7). The symptom of multicollinearity (e.g., wildly changing coefficients when an additional variable is included/removed or unreasonable coefficient magnitudes) are also examined by observing whether the coefficients of the estimated models have meaningful signs and magnitudes. These approaches to avoid multicollinearity have been adopted by several researchers (e.g., Jones and Jørgensen, 2003; Pai and Saleh, in press).

4.6.3 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 section 4.1, an aggregate model by motorcycle-car accidents in whole is firstly estimated in this study. Several disaggregate models by various crash configurations are subsequently estimated. The estimation results for these models will be reported in Chapter 6 and Chapter 7. Two tables are prepared to report the estimation results of each crash model. This is fully described below.

First table reports the general estimation results, which include, for example, categories of the independent/dependent variables, frequency of each variable, the estimated coefficients, significant value for each variable, and model fitting information. Model fitting information includes a pseudo-R^2 measure and classification accuracy, which is explained further below.

A pseudo-R^2 (goodness-of-fit) (Eq. 4.11) measure is presented even though there is no universally accepted goodness-of-fit measure for the ordered response models (Long, 1997; Kennedy, 1993). A pseudo-R^2 measure which has the 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 the linear regression model, where the coefficients are chosen to maximise pseudo-R^2, in ordered response models the coefficient estimates do not maximise any goodness-of-fit measure. Thus, assessing the 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 a pseudo-R^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. The model prediction accuracy is reported in first table for each crash model. The interpretation of CA should proceed with caution since while analysing imbalanced dataset, the less frequent outcome tends to be predicted very poorly (Cramer, 1999).

Second table for each crash model provides information on the probabilities of the three injury-severity levels. Research (e.g., Long, 1997; Eluru et al., in press) has 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 (see Eq. 4.8) allows a better understanding of the relative effectiveness of the independent variables on the probabilities of the three injury-severity levels in this present study.

4.6.4 Benchmark Victim

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. Such accident victim is termed as a "benchmark victim" in the current research. A benchmark case is derived when variables in the models take the value of zero, thereby remaining the reference cases in the model. See also section 4.2.2 for the assignment of a reference case and see Table 4.2 in which the final category is assigned as the reference case for each variable. As an example of the model of motorcycle-car accident in whole (see Chapter 6), such benchmark victim has the following characteristics:

(a) was a female
(b) was aged 20 to 59
(c) was involved in a collision in which the involved motorist was female
(d) the age of the involved motorist was 20 to 59
(e) was riding a motorcycle with engine size up to 125cc
(f) was involved in a collision in which the crash partner was a car
(g) was involved in a two-vehicle collision
(h) was riding on the straight roadway (not on the bend)
(i) her crash partner was riding on the straight roadway (not on the bend)
(j) was involved in a crash where automatic signals were the control measure
(k) was involved in a crash when it was daylight
(l) was involved in a crash in autumn/winter month
(m) was involved in a crash when the weather was adverse
(n) was involved in a crash during non rush hours
(o) was involved in a crash on weekday
(p) was involved in a crash on the built-up road
(q) was involved in a same-direction collision

Estimates of the probabilities that the benchmark victim sustains three levels of injury in the motorcycle-car crash are reported in the first row of the second table for each crash model. Estimates of the injury probabilities are subsequently presented. The changes in the probability levels of the dependent variables are also estimated, which are measured relative to the benchmark victim. 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 victim" approach adopted in this current research to discuss injury probabilities has also been employed by previous researchers (e.g., O'Donnell, and Connor, 1996; Pai and Saleh, 2007b) and are applied in each crash model (see Chapter 6 and Chapter 7).

4.6.5 An Example of the Derivation of the Injury Severity Probabilities

An example of how the injury severity probabilities are derived is given here. Suppose that, for this present study, a male rider (i.e., x_i=1) was involved in an accident with three injury severity outcomes: no injury, slight injury, and KSI. Recall the Eq.(4.8), the predicted probabilities of the three coded injury-severity levels by a victim i, for given x_i are:

$$
\begin{aligned}
P(y_i = 1|x_i) &= \Phi(\mu_1 - \beta' x_i) \\
P(y_i = 2|x_i) &= \Phi(\mu_2 - \beta' x_i) - \Phi(\mu_1 - \beta' x_i) \\
P(y_i = 3|x_i) &= 1 - \Phi(\mu_2 - \beta' x_i)
\end{aligned}
\qquad [4.8]
$$

The unknown parameters μ_1, μ_2, and β' are derived using the statistical software SPSS. If $\mu_1 = -1.5$, $\mu_2 = 1.4$, and β'=0.07 then for x_i=1 (for a male rider, relative to a female rider). The formulas for the injury severity probabilities that derive from the Eq.(4.8) are:

$$
\begin{aligned}
P(y_i &= \text{no injury}|\ \text{male rider}) = \Phi(-1.5 - 0.07 * 1) \\
P(y_i &= \text{slight injury}|\ \text{male rider}) = \Phi(1.4 - 0.07 * 1) - \Phi(-1.5 - 0.07 * 1) \\
P(y_i &= \text{KSI}|\ \text{male rider}) = 1 - \Phi(1.4 - 0.07 * 1)
\end{aligned}
\qquad [4.12]
$$

Thus,

$$P(y_i = \text{no injury} \mid \text{male rider}) = \Phi(-1.57)$$
$$P(y_i = \text{slight injury} \mid \text{male rider}) = \Phi(1.33) - \Phi(-1.57) \quad [4.13]$$
$$P(y_i = \text{KSI} \mid \text{male rider}) = 1 - \Phi(1.33)$$

Recalled the Eq.(4.9), the tabulated quantity is

$$P(U \geq u) = \frac{1}{\sqrt{2\pi}} \int_u^\infty \exp(-\frac{t^2}{2})dt = 1 - \Phi(u) \quad [4.14]$$

Where $\Phi(u)$ is the cdf of the standard normal distribution for the OP model. The cumulative standard normal probabilities are appended in Appendix B: The normal probability integral $1-\Phi(-u)$. For example,

$$1 - \Phi(0.11) = 0.45620 \quad [4.15]$$

Entries in bold type (see Appendix B) take the same decimal prefix as entries in the following row. For example,

$$1 - \Phi(2.36) = 0.0091375 \quad [4.16]$$

The table in Appendix B gives values of $1-\Phi(u)$ for $u \geq 0$. For negative values of u, use the relation

$$\Phi(u) = 1 - \Phi(-u) \quad [4.17]$$

For instance,

$$\Phi(-2.36) = 1 - \Phi(2.36) = 0.0091375 \quad [4.18]$$

Thus, from the table in Appendix B, the probabilities of three injury severity levels are:

$$P(y_i = \text{no injury} \mid \text{male rider}) = 0.058208 \cong 5.82\%$$
$$P(y_i = \text{slight injury} \mid \text{male rider}) = 0.908241 - 0.058208 = 0.8500 \cong 85\% \quad [4.19]$$
$$P(y_i = \text{KSI} \mid \text{male rider}) = 1 - \Phi(1.33) = 0.091759 \cong 9.18\%$$

The probabilities of no injury, slight injury, and KSI sustained by a male rider in an accident are 5.82%, 85%, and 9.17% respectively. The derivation of the probabilities, however, is not calculated in SPSS. The injury severity probabilities were externally calculated using the Microsoft Visual Basic given the derived parameters μ_1, μ_2, and β', as well as the normal probability integral $1-\Phi(-u)$ (see Appendix B).

4.7 Summary

This chapter described the methodology used in this current research to examine motorcyclist injury severity in motorcycle-car accidents at T-junctions. The proposed methodological approach that achieves this comprises the following steps:

- Investigation of the motorcycle-car accident data from the Stats19.
- Identification of a comprehensive set of contributing factors from the Stats19 to explain motorcyclist injury severity at T-junctions, including rider, motorist, vehicle, roadway, environmental, and crash characteristics.
- Development of motorcycle-car accident typology.
- Estimations of the appropriate econometric models to evaluate the determinants of motorcyclist injury severity.
  - an aggregate model by car-motorcycle accidents in whole is estimated first to uncover a general picture of the determinants of motorcyclist injury severity.
  - additional models by different crash configurations are subsequently calibrated to identify whether the identified variables affect motorcyclist injury severities in different crash configurations differently.

- Interpretation of the modelling estimation results.
- Conclusions and recommendations for further research to be drawn.

As previously mentioned, the main objective in this thesis is to identify the factors that affect motorcyclist injury severity at T-junctions. To achieve this, the investigations are divided into three parts: part one, part two, and part three. The investigations part one, two, and three are and explained further below.

Investigation part one – descriptive analysis

Investigation part one represents a descriptive analysis of the variables that are associated with motorcyclist casualties resulting from motorcycle-car accidents at T-junctions, which is reported in Chapter 5. The descriptive analysis provides a general picture of the univariate relationship between motorcyclist injury severity and the independent variables.

Investigation part two – a multivariate examination of the determinants of motorcyclist injury severity

In addition to the investigation of the univariate relationship between motorcyclist injury severity and the independent variables (Chapter 5), investigation part two represents a multivariate examination of the determinants of motorcyclist injury severity (i.e., controlling for all factors that influence motorcyclist injury severity) at aggregate level and at disaggregate level. This study firstly estimates an aggregate model by accidents in whole. This aggregate model is useful for isolating a variety of factors (i.e., human, vehicle, environmental, weather, or geometric factors) that significantly affect motorcyclist injury severity at T-junctions. The variable of interest is "crash configurations" that is incorporated into the model calibration. The primary aim of the aggregate model by motorcycle-car accidents in whole is to identify whether a certain crash configuration is more severe to motorcyclists than other crash configurations, while controlling for other variables.

The second stage of investigation part two is the estimations of the disaggregate models by various crash configurations. The aim of these disaggregate models by different crash configurations are to identify the factors that affect motorcyclist injury severity resulting from specific crash configurations. For example, one might expect an automatic signal to cause different collision-impact to those in angle crashes than those in same-direction crashes. Such information may be obscured by the estimation of the overall model that incorporates the variable "crash configurations" into the model.

Investigations part two will be organised into Chapter 6 and Chapter 7. Chapter 6 presents the estimation results of the econometric model by accidents in whole, while Chapter 7 reports the estimation results of the disaggregate models by various crash configurations.

Investigation part three – further examination of the considered variables amongst various crash configurations that led to KSIs

Investigation part three represents a summary of the findings obtained from the disaggregate models by various crash configurations, as well as a further examination of the considered variables amongst various crash configurations that led to KSIs. The summary of the estimation results of the disaggregate models by various crash configurations provides evidence that the considered variables affect motorcyclist injury severity in various crash configurations differently. The examination of the considered variables amongst various crash configurations leads to insights into whether a certain crash type is more likely than any other crash type to occur under a specific circumstance. Investigation part three will be reported in Chapter 8.

The next chapter (Chapter 5) will provide the results of the investigation part one.

INVERTIGATION PART ONE - DESCRIPTIVE ANALYSIS
CHAPTER 5
DESCRIPTIVE ANALYSIS

5.1 Introduction

This chapter presents the preliminary analysis – descriptive analysis of the considered variables that are associated with motorcyclist casualties resulting from motorcycle-car accidents at T-junctions. In addition to the multivariate analysis by estimating statistical models that will be reported in Chapter 6 and Chapter 7, the descriptive analysis may provide a general understanding of the univariate relationship between motorcyclist injury severity and the independent variables.

This chapter firstly reports on the sample which is used in this research (section 5.2). Sample formation and description are then reported. This is followed by the descriptive analysis of the Stats19 data, with focuses on the distribution of motorcyclist injury severity by variables (section 5.3). The descriptive analysis on the distribution of motorcyclist injury severity by crash configurations is presented separately in section 5.4, as this is the main focus of this current research. A brief summary of the descriptive analysis is finally provided (section 5.5).

5.2 Sample Formation and Description

The motorcycle-car accident data analysed in this current research were drawn from a 14-year period between 1991 and 2004. Accidents considered for the analyses in this study had to satisfy the following two criteria:

- Criteria One: an accident must have been a crash that involves more than two vehicles, and
  - An accident considered includes either a two-vehicle crash (i.e., a motorcycle collides with a car) or a multi-vehicle crash that involves more than three vehicles (i.e., a motorcycle collides with a car, and a second vehicle is not able to avoid the crash ahead so that it collides with such

motorcycle or car). Excluded is a single-motorcycle accident where the motorcycle collided with on-/off-roadway objects, or ran out of roadway.

- Criteria Two: In a motorcycle-car accident considered in the analysis, the first vehicle with which the motorcycle collided must have been an automobile (including private car, bus/coach, and HGV). A motorcycle-motorcycle accident is not considered in this current research because this present study only focuses on motorcycle-car accidents. In a case of an accident that involves more than three vehicles, the second (or the third, forth, etc.) vehicle can be either an automobile or a motorcycle/bicycle.

These two criteria are illustrated in Figure 5.1. As shown in Figure 5.1, in a case of a two-vehicle accident or a multi-vehicle accident that involves more than three vehicles, Vehicle 1 must be a motorcycle, while Vehicle 2 must be an automobile. In a case of a multi-vehicle accident that involves more than three vehicles, Vehicle 3 might be an automobile, a motorcycle, or a bicycle.

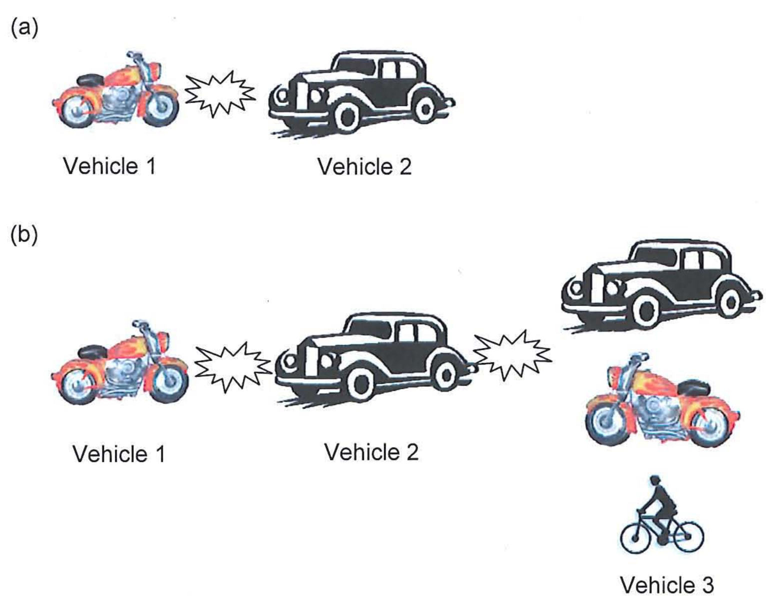


Figure 5.1: A schematic example of a motorcycle-car accident considered in the analysis. (a) a two-vehicle crash that involves one motorcycle (Vehicle 1) and one automobile (Vehicle 2) only; (b) a multi-vehicle crash that involves three vehicles or above (Vehicle 1: a motorcycle; Vehicle 2: an automobile, Vehicle 3: an automobile, a motorcycle, or a bicycle).

In this current study, only accidents that resulted in injuries to motorcyclists (including riders and pillion passengers) are considered. Which is, injuries sustained by pedestrians/bicyclists or motorists in other motorised vehicles that had collided with motorcycles are not considered. It should be noted here that in an accident where one car-occupant is injured but the motorcycle user is not injured, such accident is still recorded in the Stats19. Such motorcyclist that is uninjured is included in this current study and the injury sustained by such motorcyclist is termed as "no injury".

Missing and unrelated data were examined and removed from the sample. Missing data include the data that were left blank. Unrelated data include, for example, the variable "2.7 Manoeuvres" contains the data "Reversing" and "Parked", as discussed in section 4.2.2. The data for "Reversing" and "Parked" were removed because they are not relevant to the classification of the crash configurations in this present study. After missing/unrelated data were removed, a total of 101841 motorcyclist casualties resulting from the motorcycle-car accidents that took place at T-junctions were extracted. Of these motorcyclist casualties that were involved in car-motorcycle accidents at T-junctions, 24.3% are classified as KSI (24709 observations), 74.4% are classified as slight injury (75783 observations), and 1.3% are classified as no injury (1349 observations).

The distribution of motorcyclist injury severity by each year is presented in Table 5.1. It should be noted that, in this table, the injury-severity categories of fatal injury and serious injury are combined into a single category "KSI" (killed or seriously injured) and such combination will be applied for the analysis in the rest of this study. This combination is for the consistency with the dependent variables that contain multiple injury-severity categories for modelling calibration. It was found that the combination of fatal injury and serious injury as one single KSI category resulted in more accurate prediction capability than fatal injury and serious injury respectively. The modelling results will be fully presented in Chapter 6 and Chapter 7.

The descriptive statistics in Table 5.1 indicate that total motorcyclist casualties have decreased from 8857 in 1991 to 6573 in 2004, although there has been a slight increase between 2000 and 2003. In general, the injury-severity level of motorcyclist casualties shows a slight downward trend.

Table 5.1: Distribution of motorcyclist injury severity by year.

Year	No injury	Slight injury	KSI	Total
1991	91 (1.0%)	6343 (71.6%)	2423 (27.4%)	8857 (8.7%)
1992	99 (1.3%)	5757 (73.0%)	2033 (25.8%)	7889 (7.7%)
1993	93 (1.3%)	5298 (73.4%)	1831 (25.4%)	7222 (7.1%)
1994	94 (1.2%)	5254 (73.4%)	1812 (25.3%)	7160 (7.0%)
1995	88 (1.3%)	4971 (73.2%)	1736 (25.5%)	6795 (6.7%)
1996	95 (1.5%)	4829 (73.8%)	1618 (24.7%)	6542 (6.4%)
1997	90 (1.3%)	5172 (74.8%)	1648 (23.8%)	6910 (6.8%)
1998	99 (1.4%)	5138 (74.7%)	1641 (23.9%)	6878 (6.8%)
1999	109 (1.6%)	5256 (75.9%)	1564 (22.6%)	6929 (6.8%)
2000	102 (1.4%)	5666 (75.1%)	1775 (23.5%)	7543 (7.4%)
2001	91 (1.2%)	5889 (77.1%)	1656 (21.7%)	7636 (7.5%)
2002	96 (1.3%)	5612 (75.4%)	1735 (23.3%)	7443 (7.3%)
2003	111 (1.5%)	5655 (75.8%)	1698 (22.7%)	7464 (7.3%)
2004	91 (1.4%)	4943 (75.2%)	1539 (23.4%)	6573 (6.5%)
Total	**1349 (1.3%)**	**75783 (74.4%)**	**24709 (24.3%)**	**101841 (100%)**

5.3 Distribution of Motorcyclist Injury Severity by Variables

Table 5.2 provides information on the distribution of motorcyclist injury severity by the variables considered in the analysis. The overview of these descriptive statistics is organised into several parts: rider/motorist characteristics, vehicle attributes, roadway/geometric characteristics, weather factors, temporal factors, and crash characteristics.

Table 5.2: Distribution of motorcyclist injury severity by variables.

Variables		No injury	Slight injury	KSI	Frequency (%)
Gender of rider	1. male	1246 (1.3%)	69265 (73.9%)	**23156 (24.7%)**	93667 (92.0%)
	2. female	103 (1.3%)	6518 (79.7%)	1553 (19.0%)	8174 (8.0%)
Age of rider	1. 60 above	46 (1.9%)	1703 (69.0%)	**720 (29.2%)**	2469 (2.4%)
	2. up to 19	252 (1.1%)	16917 (77.0%)	4801 (21.9%)	21970 (21.6%)
	3. 20~59	1051 (1.4%)	57163 (73.9%)	19188 (24.8%)	77402 (76.0%)
Gender of collision partner	1. untraced	11 (0.2%)	3855 (85.1%)	662 (14.6%)	4528 (4.4%)
	2. male	825 (1.2%)	49625 (73.6%)	**16984 (25.2%)**	67434 (66.2%)
	3. female	513 (1.7%)	22303 (74.6%)	7063 (23.6%)	9879 (29.3%)
Age of collision partner	1. untraced	24 (0.3%)	8121 (86.4%)	1258 (13.4%)	9403 (9.2%)
	2. 60 above	106 (1.0%)	7253 (69.7%)	**3053 (29.3%)**	10412 (10.2%)
	3. up to 19	113 (2.0%)	3872 (69.7%)	1572 (28.3%)	5557 (5.5%)
	4. 20~59	1106 (1.4%)	56537 (73.9%)	18826 (24.6%)	76469 (75.1%)
Engine size	1. motorcycle over 125cc	944 (1.3%)	52619 (72.3%)	**19178 (26.4%)**	72741 (71.4%)
	2. motorcycle 125 cc or under	405 (1.4%)	23164 (79.6%)	5531 (19.0%)	29100 (28.6%)
Collision partner	1. heavy good vehicle	62 (0.8%)	5254 (70.2%)	**2167 (29.0%)**	7483 (7.3%)
	2. bus/coach	28 (2.1%)	949 (69.8%)	382 (28.1%)	1359 (1.3%)
	3. car	1259 (1.4%)	69580 (74.8%)	22160 (23.8%)	92999 (91.3%)
No. of vehicle involved	1. >=3	258 (3.8%)	4304 (63.6%)	**2208 (32.6%)**	6770 (6.6%)
	2. two vehicles only	1091 (1.1%)	71479 (75.2%)	22501 (23.7%)	95071 (93.4%)
Bend for motorcycle	1. bend	65 (1.3%)	3213 (65.1%)	**1657 (33.6%)**	4935 (4.8%)
	2. non bend	1284 (1.3%)	72570 (74.9%)	23052 (23.8%)	96906 (95.2%)
Bend for car	1. bend	44 (2.1%)	1264 (60.0%)	**799 (37.9%)**	2107 (2.1%)
	2. non bend	1305 (1.3%)	74519 (74.7%)	23910 (24.0%)	99734 (97.9%)

Table 5.2 (Continued)

Variables		No injury	Slight injury	KSI	Frequency (%)
Junction control	1. uncontrolled	217 (1.7%)	9239 (74.3%)	2984 (24.0%)	12440 (12.2%)
	2. stop, give-way sign or markings	1018 (1.2%)	61967 (74.0%)	**20727 (24.8%)**	83712 (82.2%)
	3. automatic traffic signals	114 (2.0%)	4577 (80.5%)	998 (17.5%)	5689 (5.6%)
Light conditions	1. darkness: street lights unknown	11 (1.1%)	708 (73.9%)	239 (24.9%)	958 (0.9%)
	2. darkness: street lights lit	282 (1.2%)	17452 (73.2%)	6111 (25.6%)	23845 (23.4%)
	3. darkness: street lights unlit	31 (1.4%)	1337 (60.8%)	**830 (37.8%)**	2198 (2.2%)
	4. daylight	1025 (1.4%)	56286 (75.2%)	17529 (23.4%)	74840 (73.5%)
Accident month	1. spring/summer (Mar~Aug)	735 (1.4%)	38482 (73.6%)	**13069 (25.0%)**	52286 (51.3%)
	2. autumn/winter (Sep~Feb)	614 (1.2%)	37301 (75.3%)	11640 (23.5%)	49555 (48.7%)
Weather conditions	1. other or unknown	28 (1.4%)	1619 (79.4%)	392 (19.2%)	2039 (2.0%)
	2. fine weather	1170 (1.3%)	64767 (73.8%)	**21767 (24.8%)**	87704 (86.1%)
	3. bad weather	151 (1.2%)	9397 (77.7%)	2550 (21.1%)	12098 (11.9%)
Accident time	1. evening (1800~2359)	342 (1.2%)	20053 (72.1%)	7412 (26.7%)	27807 (27.3%)
	2. midnight; early morning (0000~0659)	46 (1.5%)	2149 (68.5%)	**943 (30.1%)**	3138 (3.1%)
	3. rush hours (0700~0859; 1600~1759)	418(1.2%)	25723 (75.7%)	7836 (23.1%)	33977 (33.4%)
	4. non rush hours (0900~1559)	543(1.5%)	27858 (75.5%)	8518 (23.1%)	36919 (36.3%)
Accident day of week	1. weekend (Sat~Sun)	346 (1.6%)	15320 (70.6%)	**6030 (27.8%)**	21696 (21.3%)
	2. weekday (Mon~Fri)	1003 (1.3%)	60463 (75.4%)	18679 (23.3%)	80145 (78.7%)
Speed limit	1. non built-up roads (>40mph)	156 (1.3%)	6642 (55.2%)	**5224 (43.5%)**	12022 (11.8%)
	2. built-up roads (<=40mph)	1193 (1.3%)	69141 (77.0%)	19485 (21.7%)	89819 (88.2%)
Total		**1349 (1.3%)**	**75783 (74.4%)**	**24709 (24.3%)**	**101841 (100%)**

5.3.1 Rider/Motorist Characteristics

For the gender of riders, Table 5.2 shows that there are about twelve times more male casualties than female casualties. A similar pattern of motorcyclist casualties was observed by Hancock et al. (2005) in the United States. Hancock et al. noted that this was probably because motorcycle riding remains a predominantly male activity. Table 5.2 also indicates that the percentage of male motorcyclists sustaining KSIs (24.7%) was higher than that of female riders sustaining KSIs (19.0%).

For gender of motorist, the statistics indicate that as much as 66.2% of all motorcyclist casualties were in collisions with male motorists. In addition, the percentage of those sustaining KSIs in collisions with male motorists was slightly higher than that of those with female drivers (25.2% versus 23.6%).

Regarding age of rider, motorcyclists aged 60 or above were more likely to be KSI (29.2% of the injuries were KSIs) than other riders of age groups (21.9% for those aged up to 19; 24.8% for those aged between 20-59), as shown in Table 5.2. Previous studies (e.g., Evans, 1988) suggested that this was probably because younger individuals can tolerate crashes of any specific severity more successfully than their older peers. With respect to motorist age, riders were more injury-prone in collisions with motorists aged 60 or above (29.3% of the injuries were KSIs) than when they were in collisions with motorists of other age groups (28.3% of the injuries were KSIs for those colliding with teenaged motorists; 24.6% of the injuries were KSIs for those colliding with motorists aged between 20-59).

5.3.2 Vehicle Attributes

Statistics show that, for motorcycle engine size, 71.4% of all casualties were users of motorcycles with engine size over 125cc. This may be a reflection of the fact that there might be much more active riders of larger motorcycles in the UK (Broughton, 2005). In addition, there has been a large increase in numbers of licensed stock for motorcycles with engine sizes over 500cc (see DfT, 2006b for detailed statistics on licensed stock by engine size). The data in Table 5.2 also indicate that 26.4% of those using heavier motorbikes sustained KSIs, which is more than those of smaller bikes sustaining KSIs (19.0% of the injuries were KSIs).

For motorcycle's crash partner, the data show that it was most frequently a car (with 91.3% of all casualties were in collisions with cars). However, collisions with cars tended to result in less severe injury outcome than those with HGVs or buses/coaches (23.8% for collisions with cars, 29.0% for collisions with HGVs, and 28.1% for collisions with buses/coaches).

5.3.3 Roadway/Geometric Factors

Roadway/geometric variables include the presence of bend for motorcycle/car, junction control measures, light conditions, and speed limits.

As shown in Table 5.2, there appeared far more motorcyclist casualties when there was no bend for motorcycles (95.2%) or for cars (97.9%) than when there were bends for motorcycles (4.8%) or for cars (2.1%). However, among those involved in accidents on bends, injuries were much more severe. Which is, 33.6% and 37.9% of the injuries were KSIs when there were bends for motorcycles or for cars.

With respect to junction control measures, as much as 82.2% of all casualties were as a result of accidents that occurred at stop/give-way controlled junctions. This is probably in part because there is a comparatively large number of T-junctions that are controlled by stop, give way signs or markings in the UK. Stop, give-way signs or marking also appeared to predispose riders to a great risk of KSIs (as much as 24.8% of casualties sustained KSIs), followed by uncontrolled junctions (24.0%).

For street light conditions, daytime accidents resulted in 73.5% of all motorcyclist casualties. This may suggest that motorcyclists tend to have greater discretion about travelling during daytime. However, the proportion of those having KSIs on unlit streets (37.8%) was much higher than that of those on lit streets (25.6%) or in daylight condition (23.4%).

Motorcyclist casualties on built-up roadways appeared to outnumber those on non built-up roadways by nearly 8-to-1 (88.2% versus 11.8%). Nonetheless, riders in accidents on non built-up roadways were about two times more likely than those in accidents on non built-up roadways to be KSI (43.5% versus 21.7%).

5.3.4 Weather/Temporal Factors

The data for the weather factor show that about six-sevenths of all casualties were as a result of accidents that occurred under fine weather (86.1%). This may suggest riders' greater willingness to travel when the weather is fine. The percentage of KSIs under fine weather appeared to be higher than that of KSIs under adverse weather (24.8% versus 21.1%). This may be a reflection of more cautious road behaviours under adverse weather.

Regarding seasonal variation, accidents that occurred in spring/summer months resulted in slightly more casualties than those that occurred in autumn/winter months (51.3% versus 48.7%). This is likely because motorcycling travel is more active in spring/summer months. In addition, riders having accidents in spring/summer months were slightly more likely than those having accidents in autumn/winter months to be KSI (25.0% versus 23.5%).

With regard to time of accident, 33.4% of all casualties were as a result of accidents that took place during 4-hour rush hours (7 a.m. to 08:59 and 4 p.m. to 17:59). This may be a consequence of the fact that there is more traffic during rush hours. The data also show that there are much fewer accidents that occurred during midnight/early morning hours, with only 3.1% of all casualties resulting from accidents during this period. Nevertheless, injuries in accidents that occurred during this period were greatest, with 30.1% of motorcyclists sustaining KSIs.

For accident day of week, 78.7% of all casualties had accidents on weekdays, which is more than the number of casualties on weekends. This may be a reflection of the way in which many people use motorcycles regularly to get to and from work during weekdays (DfT, 2006b). However, injuries in accidents on weekends were more severe than those on weekdays (27.8% versus 23.3%).

5.3.5 Crash Characteristics

Crash characteristics include two variables: "number of vehicle involved" and "crash types". The descriptive statistics show that over 93% of all casualties were in two-vehicle collisions, which outnumber those in accidents involving more than three vehicles by approximately 14-to-1 (see also Figure 5.1 for a schematic example of a two-vehicle accident and a multi-vehicle accident that involves more than three vehicles). However, there is an increase in injury severity to those in accidents that involved three vehicles or above (32.6% of the injuries were KSIs). This may be a reflection of a greater collision-impact imposed by more vehicles involved in accidents.

The descriptive analysis for the variable "crash configurations" is reported in the subsequent section.

5.4 Distribution of Motorcyclist Injury Severity by Crash Configurations

Table 5.3 provides information on the distribution of motorcyclist injury severity by crash configurations. It should be noted that collisions that have small number of occurrences are combined with other crashes that have greater occurrences (see also Table 4.4 in section 4.3.4 for original categories of crash configurations) so that variability caused by random effects when statistical models are applied can be reduced. As shown in Table 4.4 in section 4.3.4, this includes the combination of "both-turning A collision" (0.1% of all casualties resulted from both-turning A crashes) and "merging collision" (3.2% of all casualties resulted from merging crashes) with "angle B collision" as these three types of crashes are assumed to have an oblique collision angle. Moreover, "both-turning B collision" (0.1% of all casualties resulted from both-turning B crashes) is combined with "angle A collision" as these two crashes are assumed to have a perpendicular collision angle. These combinations result in a total of six crash configurations for the analysis (see Table 5.3), including angle A crash, angle B crash, approach-turn A crash, approach-turn B crash, head-on crash, and same-direction crash.

Table 5.3: Distribution of motorcyclist injury severity by crash configurations.

Crash configuration	No injury	Slight injury	KSI	Total
Angle A crash	377 (1.1%)	25888 (72.7%)	9338 (26.2%)	**35603 (38%)**
Angle B crash	106 (1.1%)	7698 (77.2%)	2173 (21.8%)	9977 (9.8%)
Approach-turn A crash	34 (3.2%)	771 (72.7%)	256 (24.1%)	1061 (1.0%)
Approach-turn B crash	130 (0.8%)	11233 (67.5%)	**5290 (31.8%)**	16653 (16.4%)
Head-on crash	60 (1.6%)	2429 (64.9%)	**1252 (33.5%)**	3741 (3.7%)
Same-direction crash	642 (1.7%)	27764 (79.6%)	6400 (18.4%)	**34806 (31.3%)**
Total	**1349 (1.3%)**	**75783 (74.4%)**	**24709 (24.3%)**	**101841 (100%)**

The data in Table 5.3 show that there is the relatively high number of casualties that resulted from angle A crashes and same-direction crashes (38% and 31.3% respectively). The statistics in Table 5.3 also indicate a substantially higher percentage of those sustaining KSIs in approach-turn B crashes and in head-on crashes (31.8% and 33.5% respectively) than those sustaining KSIs in other crash configurations. However, head-on crashes only represent 3.8% of all casualties. Same-direction crashes appeared to predispose the riders to the least risk of KSIs (18.7% of the injuries were KSIs).

5.5 Summary

This chapter presented the investigation part one – the descriptive analysis of the Stats19 data for 14 years (1991-2004) which are associated with motorcyclist casualties resulting from motorcycle-car accidents at T-junctions. The descriptive statistics presented in this chapter provided a general understanding of the univariate relationship between motorcyclist injury severity and the independent variables.

The subsequent chapters (Chapter 6 and Chapter 7) present the investigation part two: a multivariate examination of the determinants of motorcyclist injury severity (i.e., controlling for all factors that influence motorcyclist injury severity) at an aggregate level (an econometric model by motorcycle-car accidents in whole) and at a disaggregate level (separate econometric models by various crash configurations).

INVESTIGATION PART TWO – MULTIVARIATE ANALYSIS
CHAPTER 6
MODELLING MOTORCYCLIST INJURY SEVERITY BY ACCIDENTS IN WHOLE

6.1 Introduction

Chapter 5 presented the investigation part one – descriptive analysis of the considered variables that are associated with motorcyclist injury severity resulting from motorcycle-car accidents at T-junctions. The descriptive data that were shown in Chapter 5 provided a general examination of the univariate relationship between motorcyclist injury severity and the considered variables. This chapter presents the first stage of the investigation part two – a multivariate examination of the determinants of motorcyclist injury severity (i.e., controlling for all factors that influence motorcyclist injury severity) by motorcycle-car accidents in whole. The second stage of the investigation part two, a multivariate examination of the determinants of motorcyclist injury severity (i.e., controlling for all factors that influence motorcyclist injury severity) by various crash configurations, will be reported in the subsequent chapter.

This chapter firstly presents the estimation results of the OP model by motorcycle-car accidents in whole. The variable of particular interest is "crash configurations" that is incorporated into the model calibration. The primary aim of the estimation of the aggregate crash model is to examine whether a certain crash configuration is more severe than other crash configurations, while controlling for other variables.

6.2 Model Specification

The detailed derivation of the OP models has been given in Chapter 4 (Section 4.6 Econometric Framework). Therefore it is not repeated here. The first model presented here is the model of motorcyclist injury severity by motorcycle-car accidents in whole. A preliminary analysis (i.e., descriptive analysis) of these variables has been conducted in Chapter 5. These variables include rider/motorist attributes, vehicle characteristics, roadway/geometric factors, weather/temporal factors, and crash characteristics, as shown in Chapter 4 and Chapter 5. The crash configurations examined in the model include accidents involving gap acceptance (angle A crash, angle B crash, approach-turn A crash, approach-turn B crash), head-on crash, and same-direction crash (see section 4.3 for the classification of these crash configurations).

A correlation matrix among the variables was reported in Table 6.1 to assess the presence of multicollinearity. No variable was found to be correlated to each other (i.e., correlation that is over 0.5 can cause multicollinearity but it was not observed). Therefore there is no need to concern about multicollinearity in the model. The highest correlation values found were two values that were close to 0.5. For instance, the correlation value that was 0.434 was observed for the variables "Bend for motorcycle" and "Bend for Car". Another correlation value that was 0.384 was observed for the variables "Street light conditions" and "Accident time". The explanation of the higher correlation value for the variables "Bend for motorcycle" and "Bend for Car" is probably because there is the relatively high number of casualties that resulted from same-direction crashes (see Table 5.3 in section 5.3) in which the motorcycle and the car originally travelling from the same direction collided with each other. The correlation value that was 0.384 for the variables "Street light conditions" and "Accident time" was thought to be reasonable and acceptable because whether street lights are lit or unlit depends on the time of day.

Additional efforts have been made to observe the symptom of multicollinearity where the models were calibrated (e.g., wildly changing coefficients when an additional variable of these four variables is included/removed or unreasonable coefficient magnitudes). The symptom of multicollinearity was not observed and therefore these four variables (i.e., Bend for motorcycle, Bend for Car, Street light conditions, Accident time) were all retained in the model.

Table 6.1: Correlation matrix between the variables in the model of motorcycle-car accidents in whole.

variables	engine size	bend for motorcycle	bend for car	crash type	crash partner	rider gender	rider age	motorist gender	motorist age	number of vehicle involved	month	week day	time of day	speed limit	control measure	light	weather
engine size	1	0.031	0.008	-0.019	0.020	0.171	-0.223	0.001	-0.022	0.032	0.069	0.041	-0.051	0.114	-0.016	-0.077	0.044
bend for motorcycle		1	**0.434**	0.090	0.022	0.020	0.004	-0.011	-0.010	0.007	0.045	0.046	-0.007	0.153	0.052	-0.043	0.008
bend for car			1	0.031	0.018	0.009	0.023	0.005	-0.013	0.020	0.039	0.040	-0.004	0.124	0.043	-0.035	0.004
crash type				1	-0.071	0.016	0.036	-0.085	-0.015	-0.046	-0.045	-0.022	0.045	0.037	0.037	0.050	-0.030
crash partner					1	0.002	-0.024	0.149	-0.036	0.006	0.012	-0.064	-0.079	0.032	-0.014	-0.065	0.002
rider gender						1	-0.008	0.008	-0.021	0.016	0.026	0.039	0.031	0.024	0.005	0.020	0.019
rider age							1	-0.023	-0.005	-0.005	-0.031	0.004	0.033	-0.044	0.054	0.039	-0.015
motorist gender								1	0.294	-0.009	0.007	0.014	0.053	-0.019	-0.036	0.052	0.002
motorist age									1	-0.028	-0.002	0.002	0.001	-0.012	-0.037	0.019	0.016
number of vehicle involved										1	0.020	0.027	-0.022	0.063	0.007	-0.032	0.001
month											1	0.055	-0.020	0.061	0.008	-0.289	0.077
week day												1	-0.057	0.090	0.026	-0.029	0.033
time of day													1	-0.042	-0.014	**0.384**	-0.034
speed limit														1	0.064	-0.092	0.027
control measure															1	-0.029	0.007
light conditions																1	-0.087
weather																	1

6.3 Estimation Results

The estimation results of the aggregate crash model are reported in Table 6.2. A total of 101841 motorcyclist casualties resulting from the motorcycle-car accidents that took place at T-junctions were extracted. Of these motorcyclist casualties that were involved in car-motorcycle accidents at T-junctions, 24.3% are classified as KSI (24709 observations), 74.4% are classified as slight injury (75783 observations), and 1.3% are classified as no injury (1349 observations). The model has a pseudo-R^2 measure of 0.093. As for predicting each injury-severity category, the classification accuracy for KSI, slight injury, and no injury was 4.7%, 99.0%, and 0%.

A benchmark case (see section 4.4.3 for a discussion of a benchmark case) was generated in order to discuss probabilities of three injury levels, which is derived by holding all dummy variables to 0 (see Table 6.3). Such benchmark victim has the following characteristics:

(a) was a female
(b) was aged between 20-59
(c) was involved in a collision in which the involved motorist was female
(d) was involved in a collision in which the age of the involved motorist was between 20-59
(e) was riding a motorcycle with engine size up to 125cc
(f) was involved in a collision in which the crash partner was a car
(g) was involved in a two-vehicle collision
(h) was riding on the straight roadway (not on the bend)
(i) her crash partner was riding on the straight roadway (not on the bend)
(j) was involved in a crash where automatic signals were the control measure
(k) was involved in a crash when it was daylight
(l) was involved in a crash in autumn/winter month
(m) was involved in a crash when the weather was adverse
(n) was involved in a crash during non rush hours
(o) was involved in a crash on weekday
(p) was involved in a crash on the built-up road
(q) was involved in a same-direction collision

Table 6.2: Statistics summary and estimation results of the aggregate model by motorcycle-car accidents in whole.

Variable	Categories of each variable	Frequency (%)	Coefficients (p-value)
Gender of rider	1. male	93667 (92.0%)	**0.075 (<0.001)**
	2. female	8174 (8.0%)	Reference case
Age of rider	1. 60 or above	2469 (2.4%)	**0.158 (<0.001)**
	2. up to 19	21970 (21.6%)	-0.004 (0.937)
	3. 20~59	77402 (76.0%)	Reference case
Gender of collision partner	1. untraced	4528 (4.4%)	0.043 (0.108)
	2. male	67434 (66.2%)	**0.041 (<0.001)**
	3. female	9879 (29.3%)	Reference case
Age of collision partner	1. untraced	9403 (9.2%)	-0.219 (<0.001)
	2. 60 above	10412 (10.2%)	**0.073 (<0.001)**
	3. up to 19	5557 (5.5%)	0.041 (0.025)
	4. 20~59	76469 (75.1%)	Reference case
Engine size	1. motorcycle over 125cc	72741 (71.4%)	**0.164 (<0.001)**
	2. motorcycle 125 cc or under	29100 (28.6%)	Reference case
Collision partner	1. heavy good vehicle	7483 (7.3%)	**0.187 (<0.001)**
	2. bus/coach	1359 (1.3%)	0.122 (0.001)
	3. car	92999 (91.3%)	Reference case
No. of vehicle involved	1. >=3	6770 (6.6%)	0.097 (<0.001)
	2. two vehicles only	95071 (93.4%)	Reference case
Bend for motorcycle	1. bend	4935 (4.8%)	**0.024 (0.260)**
	2. non bend	96906 (95.2%)	Reference case
Bend for car	1. bend	2107 (2.1%)	**0.101 (0.002)**
	2. non bend	99734 (97.9%)	Reference case
Junction control	1. uncontrolled	12440 (12.2%)	0.098 (<0.001)
	2. stop, give-way sign or markings	83712 (82.2%)	**0.156 (<0.001)**
	3. automatic traffic signals	5689 (5.6%)	Reference case
Light conditions	1. darkness: street lights unknown	958 (0.9%)	0.054 (0.211)
	2. darkness: street lights lit	23845 (23.4%)	0.066 (<0.001)
	3. darkness: street lights unlit	2198 (2.2%)	**0.093 (0.001)**
	4. daylight	74840 (73.5%)	Reference case
Accident month	1. spring/summer (Mar~Aug)	52286 (51.3%)	**0.019 (0.031)**
	2. autumn/winter (Sep~Feb)	49555 (48.7%)	Reference case
Weather conditions	1. other or unknown	2039 (2.0%)	-0.064 (0.047)
	2. fine weather	87704 (86.1%)	0.087 (<0.001)
	3. bad weather	12098 (11.9%)	Reference case
Accident time	1. evening (1800~2359)	27807 (27.3%)	0.094 (<0.001)
	2. midnight; early morning (0000~0659)	3138 (3.1%)	**0.188 (<0.001)**
	3. rush hours (0700~0859; 1600~1759)	33977 (33.4%)	0.021 (0.048)
	4. non rush hours (0900~1559)	36919 (36.3%)	Reference case
Accident day of week	1. weekend (Sat~Sun)	21696 (21.3%)	**0.068 (<0.001)**
	2. weekday (Mon~Fri)	80145 (78.7%)	Reference case
Speed limit	1. non built-up roads (>40mph)	12022 (11.8%)	**0.510 (<0.001)**
	2. built-up roads (<=40mph)	89819 (88.2%)	Reference case
Crash configuration	1. angle A	37114 (38%)	0.227 (<0.001)
	2. angle B	8467 (8.7%)	0.116 (<0.001)
	3. approach-turn A	1061 (1.1%)	0.129 (0.002)
	4. approach-turn B	16653 (17.1%)	**0.404 (<0.001)**
	5. head-on	3741 (3.8%)	0.334 (<0.001)
	6. same-direction	30538 (31.3%)	Reference case
	μ_1	-1.527 (<0.001)	
	μ_2	1.484 (<0.001)	

Summary Statistics
-2 Log-likelihood at zero = 53660.859
-2 Log-likelihood at convergence = 48677.559
Log-likelihood ratio index (ρ^2) = 0.093
The number of KSI that was correctly predicted: 1159 (4.7%)
The number of slight injury that was correctly predicted: 75028 (99.0%)
The number of no injury that was correctly predicted: 0 (0%)
Observations = 101841 (KSI: 24.3%; slight injury: 74.4%; no injury: 1.3%)

Table 6.3: Motorcyclist injury severity probabilities in motorcycle-accident accidents in whole.

Variable		Estimated probability			Percent change relative to benchmark case (%)		
		No injury	Slight	KSI	No injury	Slight	KSI
Benchmark case		0.0634	0.8677	0.0689			
Gender of rider	1. male	0.0546	0.866	**0.0794**	-13.88	-0.20	**15.24**
Age of rider	1. 60 above	0.046	0.8616	**0.0924**	-27.44	-0.70	**34.11**
	2. up to 19	0.0639	0.8677	0.0684	0.79	0.00	-0.73
Gender of collision partner	1. untraced	0.0582	0.867	0.0748	-8.20	-0.08	8.56
	2. male	0.0584	0.867	**0.0745**	-7.89	-0.08	**8.13**
Age of collision partner	1. untraced	0.0954	0.8603	0.0443	50.47	-0.85	-35.70
	2. 60 above	0.0548	0.8661	**0.0791**	-13.56	-0.18	**14.80**
	3. up to 19	0.0584	0.867	0.0748	-7.89	-0.08	8.56
Engine size	1. motorcycle over 125cc	0.0454	0.8612	**0.0934**	-28.39	-0.75	**35.56**
Crash partner	1. heavy goods vehicle	0.0433	0.8594	**0.0973**	-31.70	-0.96	**41.22**
	2. bus/coach	0.0496	0.8638	0.0866	-21.77	-0.45	25.69
No. of vehicle involved	1. >= 3	0.0522	0.8651	**0.0827**	-17.67	-0.30	**20.03**
Bend for motorcycle	1. bend	0.065	0.8674	**0.0721**	2.52	-0.03	**4.64**
Bend for car	1. bend	0.0518	0.8649	**0.0833**	-18.30	-0.32	**20.90**
Junction control	1. uncontrolled	0.0521	0.865	0.0829	-17.82	-0.31	20.32
	2. stop, give way sign or markings	0.0462	0.8617	**0.0921**	-27.13	-0.69	**33.67**
Light condition	1. darkness: street lights unknown	0.0569	0.8667	0.0764	-10.25	-0.12	10.89
	2. darkness: street lights lit	0.0556	0.8663	0.0781	-12.30	-0.16	13.35
	3. darkness: street lights unlit	0.0526	0.8653	**0.0821**	-17.03	-0.28	**19.16**
Accident month	1. spring/summer (Mar~Aug)	0.0611	0.8675	0.0715	-3.63	-0.02	**3.77**
Weather Conditions	1. other or unknown	0.0717	0.8675	0.0608	13.09	-0.02	-11.76
	2. fine weather	0.0533	0.8655	**0.0812**	-15.93	-0.25	**17.85**
Accident time	1. evening (1800~2359)	0.0525	0.8652	0.0823	-17.19	-0.29	19.45
	2. midnight; early morning (0000~0659)	0.0432	0.8593	**0.0975**	-31.86	-0.97	**41.51**
	3. rush hours (0700~0859; 1600~1759)	0.0608	0.8675	0.0717	-4.10	-0.02	4.06
Accident day of week	1. weekend (Sat~Sun)	0.0554	0.8665	**0.0784**	-12.62	-0.14	**13.79**
Speed limit	1. non built-up roads	0.0208	0.8141	**0.165**	-67.19	-6.18	**139.48**
Crash Configuration	1. angle A	0.0397	0.8559	0.1044	-37.38	-1.36	51.52
	2. angle B	0.0502	0.8642	0.0857	-20.82	-0.40	24.38
	3. approach-turn A	0.0489	0.8634	0.0877	-22.87	-0.50	27.29
	4. approach-turn B	0.0267	0.8332	**0.1401**	-57.89	-3.98	**103.34**
	5. head-on	0.0314	0.8436	0.1251	-50.47	-2.78	81.57

Note: The reference case for each variable is not shown as it is taken as the benchmark victim.

As shown in Table 6.3, estimates of the probabilities that the benchmark victim sustains three injury-severity levels are reported in the first row of the second table. Estimates of the injury probabilities are subsequently presented. The changes in the probabilities of three injury-severity levels are calculated relative to this benchmark case. This allows one to interpret changes in the probabilities of the injury-severity levels for a change in a given parameter, relative to the benchmark victim.

An example of the derivation of the injury severity probabilities (see also Table 6.3) is given here. Given the estimated cutpoints $\mu_1 = -1.527$ and $\mu_2 = 1.484$ (see Table 6.2), the probabilities of no injury, slight injury, and KSI sustained by, for instance, a rider involved in an approach-turn B crash (β'=0.404) are:

$$P(y_i = \text{no injury} \mid \text{male rider}) = \Phi(-1.527 - 0.404 * 1)$$
$$P(y_i = \text{slight injury} \mid \text{male rider}) = \Phi(1.484 - 0.404 * 1) - \Phi(-1.527 - 0.404 * 1) \quad [6.1]$$
$$P(y_i = \text{KSI} \mid \text{male rider}) = 1 - \Phi(1.484 - 0.404 * 1)$$

Thus,

$$P(y_i = \text{no injury} \mid \text{male rider}) = \Phi(-1.931)$$
$$P(y_i = \text{slight injury} \mid \text{male rider}) = \Phi(1.08) - \Phi(-1.931) \quad [6.2]$$
$$P(y_i = \text{KSI} \mid \text{male rider}) = 1 - \Phi(1.08)$$

According to the table in Appendix B, the probabilities of three injury severity levels are (see also Section 4.6.4 for guidance on the use of the table in Appendix B):

$$P(y_i = \text{no injury} \mid \text{male rider}) = 0.0267 \cong 2.67\%$$
$$P(y_i = \text{slight injury} \mid \text{male rider}) = 0.8332 \cong 83.32\% \quad [6.3]$$
$$P(y_i = \text{KSI} \mid \text{male rider}) = 0.1401 \cong 14.01\%$$

6.3.1 Rider/Motorist Characteristics

The effects of rider/motorist attributes on motorcyclist injury severity were examined. Motorcyclists were most likely to be severely injured while they were aged 60 or above (a 34.11% increased probability to sustain KSIs than mid-aged riders), they were males (a 15.24% increased probability to sustain KSIs than females), or while they were involved in accidents with male drivers (an 8.13% increased probability to sustain KSIs than females) or elderly drivers (a 14.80% increased probability to sustain KSIs than mid-aged riders).

6.3.2 Vehicle Attributes

Vehicle factors include motorcycle's engine sizes and the type of motorcycle's collision partner. In terms of the effect motorcycles engine size has on motorcyclist injury severity, motorcycles with engine capacity over 125cc (relative to engine size up to 125cc) have a positive coefficient (0.164) and about a 36% increase in the probability of a KSI. There are at least two possible explanations for this: first, larger motorcycles tend to be ridden on roadways with higher speed limits; and second, drinkers are more likely to be on bigger motorcycles (Broughton, 1988, 2005). An intoxicated motorcyclist's ability to react may be impaired, which might influence the injury outcome as a result of lesser evasive reaction. In addition, higher speed by heavier motorcycles on high-speed roadways may act synergistically with the influence of alcohol to increase injury severity.

With regard to the effect of motorcycle's collision partner, injuries sustained by riders appeared to be greatest in collisions with HGVs (heavy good vehicles), with a positive coefficient of 0.187. The probabilities of KSIs sustained by riders in collisions with HGVs are 41.22% higher, relative to collisions with cars. Similar effect was found in previous research by Maki et al. (2003) who analysed accidents involving vulnerable road users (i.e., pedestrians and bicyclists) and cars. They suggested that there were at least two explanations for this effect. First, the collision-impact resulting from exteriors of a HGV can be much greater to human than those of a passenger car; and second, a HGV is more likely to run the victim over due to their higher position of compartment than a passenger car. Such explanations may also be applied to the effect found here.

6.3.3 Roadway/Geometric Factors

Roadway/geometric variables include the presence of bend for motorcycle/car, junction control measures, light conditions, and speed limits.

Regarding the effect of the bend on motorcyclist injury severity, bends (relative to non bend) either for motorcycles or cars appeared to result in more severe injuries (though only at a 70% level of confidence for accidents where there were bends for motorcycles). That is, there is a 4.64% and 20.90% increase in KSIs in accidents where there were bends for motorcycles or for cars. The results here for motorcycle-car accidents are generally consistent with those of previous studies by, for example, Hurt et al. (1981, 1984) and Clarke et al. (2007). These researchers reported that riders in single-motorcycle accidents on bends experienced a higher likelihood of sustaining more severe injuries.

With regard to the effect of junction control measures, T-junctions controlled by stop, give-way signs or markings appeared to give motorcyclists the deadliest risks, accounting for an approximately 34% increased probability of KSI relative to those controlled by automatic signals.

Unlit streets in darkness were found to be a deadly factor to motorcyclists, with a 19.16% increased probability of KSI relative to daylight conditions. Motorcyclists riding on non built-up roadways (speed limits over 40mph) experienced about a 140% increased probability of KSI relative to built-up roadways (speed limits up to 40mph). Such effect is in line with the findings in literature (e.g., Hancock et al., 2005; Clarke et al., 2007) that the majority of fatal motorcycle accidents occurred in rural areas where there tend to be more non built-up roadways. This may be also partly as a result of the additional time needed for emergency-vehicle response in rural areas, which cuts directly into the golden hours of survival after a crash (Hancock et al., 2005; Noland and Quddus, 2004).

6.3.4 Weather/Temporal Factors

Weather/temporal effects examined in the model include weather conditions, time of day, day of week, and month of year of the accident occurrence. Riding under fine weather increases the injury severity, with a positive coefficient of 0.087. The probability of KSIs relative to bad weather increases by 17.85%. A likely explanation is that motorcycle/car travel speed may be higher under fine weather (Padget et al., 2001).

Seasonable effects were measured based on six-month range (spring/summer month versus autumn/winter month). Spring/summer months have a coefficient value of 0.019, with only a minor increase in KSIs (3.77%), relative to autumn/winter months.

With respect to time-of-day effect, those riding in mid-night and early morning (i.e., 0000~0659) appeared to have the most tendencies in sustaining KSIs. Early morning KSI probabilities are 41.51% higher. Riding on the weekends (relative to weekdays) have a positive coefficient of 0.068 and about a 14% increase in KSIs. The results that riding during early morning and on weekends resulted in more severe injuries is perhaps reasonable, as it is likely that speeding and alcohol use are greater during midnight/early morning hours and there are more recreational and social activities on weekends (Broughton, 2005; Kasantikul et al., 2005; Shankar, 2001, 2003; Kim et al., 2000).

6.3.5 Crash Characteristics

Crash characteristics include two variables: "number of vehicles involved" and "crash configurations". The effect of number of vehicle involved is measured relative to a two-vehicle accident. The results show a positive coefficient for accidents involving three vehicles or above. This indicates that riders in accidents that involved three vehicles or above were more injurious than those involved in two-vehicle accidents. In the probability estimates derived in Table 6.3, an accident that involved three vehicles or above, relative to the reference case of a two-vehicle accident, results in a 20.03% increase in the probability of a KSI. Such effect is not surprising as more impact loads from two vehicles may be directed onto a motorcyclist victim. For example, an ejecting motorcyclist after being struck by the first car may be run over by a second car nearby).

The crash configurations that occurred were estimated relative to same-direction collisions. Injuries to motorcyclists were greatest when riders were involved in approach-turn B collisions (coefficient=0.404; p-value<0.001). This crash type has the greatest increase in the probability of a KSI of 103.34% relative to same-direction crashes. The second deadliest crash configuration to motorcyclists was a head-on crash, with an about 82% increase in the probability of a KSI relative to a same-direction crash.

The results in Table 6.2 (see the frequency data) also show that the total number of motorcyclist causalities in approach-turn B crashes were about seventeen-times more than those in approach-turn A crashes. The difference in approach-turn A crash and approach-turn B crash is that an approach-turn A crash is defined as a crash when the turning vehicle is a motorcycle. An approach-turn B crash is defined as a crash when the turning vehicle is a car (see Figure 4.3(b) in section 4.3.3 for a schematic diagram of approach-turn A/B crash). The findings regarding the effects of approach-turn collisions are generally consistent with those of previous studies (e.g., Hurt et al., 1981; Hancock et al., 2005; Peek-Asa and Kraus, 1996a) that specifically analysed motorcycle-car approach-turn collisions at intersections. These researchers reported that approximately 70% of approach-turn collisions took place when an approaching motorcycle crashed into the side of a turning car (i.e., a turning car violated the right-of-way of an oncoming motorcycle). In addition, Peek-Asa and Kraus further indicated that such crash type was usually followed by the ejection of the motorcyclist from the machine, resulting in devastating injury outcome.

6.4 Summary

The estimation results of the aggregate model by motorcycle-car accidents in whole were presented in this chapter. One of the noteworthy findings was that approach-turn B crashes were more severe to motorcyclists than other crash configurations. Some other factors found to be significantly associated with more severe injuries include male or elderly riders/motorists (as crash partners), larger engine capacity of motorcycle, the presence of bends for motorcycles or cars, riding in mid-night/early morning, on weekends, in spring/summer months, under fine weather, and on non built-up roads, riding in unlit darkness and at stop-controlled junctions, and HGV or bus/coach as crash partners.

Although the aggregate crash model has successfully identified the determinants of motorcyclist injury severity, a specific picture of the factors that affect motorcyclist injury severity resulting from different crash configurations is obscured by the estimation of the aggregate model. For example, the aggregate crash model shows that approach-turn B crashes were more severe to motorcyclists than other crash configurations but the factors that affect injury severity resulting from such crash type are still unknown. As pointed out in past studies (e.g., Hurt et al., 1981; Pai and Saleh, 2008), the principal factors for the occurrence of an approach-turn crash lies with turning drivers failing to recognise, adapt to, and avoid motorcyclists. There has been evidence in literature (e.g., Horswill et al., 2005) that right-turn motorists infringing upon motorcycles' right-of-way by accepting smaller gap in front of motorcycles was one of the important reasons for the occurrence of such crash type. Additional research is clearly needed to examine whether drivers' failure to yield also play a part in affecting motorcyclist injury severity resulting from accidents that involve gap acceptance.

A disaggregate picture of the determinants of injury severity resulting from other crash configurations (e.g., head-on crash, sideswipe crash) is also obscured by the estimation of the aggregate crash model. Research has indicated that, for example, the severity of car-car head-on crashes was associated with nighttime hours (Deng et al., 2006); and lane-changing manoeuvres were associated with the occurrences of car-car sideswipe crashes (Pande and Abdel-Aty, 2006). Whether these factors contribute to the increased motorcyclist injury severity in head-on/sideswipe collisions deserve further research.

To do this, investigations are directed toward the estimation of additional models by different crash configurations, with additional variables being incorporated into these separate models (e.g., the variable "drivers' failure to yield" for approach-turn crash model). The subsequent chapter (Chapter 7) represents the second stage of the investigation part two - the disaggregate models by different crash configurations.

CHAPTER 7
MODELLING MOTORCYCLIST INJURY SEVERITY BY VARIOUS CRASH CONFIGURATIONS

7.1 Introduction

Chapter 5 presented the descriptive analysis of the Stats19 data which have been used in this current research. Chapter 6 reported the estimation results of the aggregate model by motorcycle-car accidents in whole. The aggregate model has successfully identified the determinants of motorcyclist injury severity at T-junctions.

To obtain a clearer understanding of the impacts of different factors on motorcyclist injury severity in various crash configurations, additional models of motorcyclist injury severity by different crash configurations are needed. The estimation of the additional models is preferable to employing one aggregate model as the impacts human, vehicle, and environmental factors have on injury levels are expected to vary across different crash configurations. For example, one would expect an automatic junction signal to have a different impact on injury-severity levels in rear-end collisions than it would in the cases of head-on crashes. Such information was obscured in the aggregate crash model that examined the variable "crash configurations" as one of the independent variables (see Chapter 6). The estimation of the separate injury severity models can be more useful for gaining an understanding of the different effects of predictor variables on injury severities in different crash configurations. As a result, appropriate countermeasures may be suggested to deal with different crash configurations. From a statistical standpoint, such separate models may also avoid the complicated interpretations resulting from several interaction terms (e.g., interaction effects of various crash configurations and other variables) that have to be incorporated into one aggregate model.

The disaggregate models are estimated by different crash configurations. These crash configurations include accidents that involve gap acceptance (i.e., approach-turn crash, angle crash), head-on crashes, and same-direction crashes (see also Figure 4.3 and Figure 4.4 in section 4.3.3 for a schematic diagram of various crash configurations at

T-junctions). The modelling results are presented in the subsequent sections, with the above order of crash type. This chapter ends with a general summary of the research findings.

7.2 Approach-turn Crash and Angle Crash

7.2.1 Introduction

The aggregate model (see Table 6.2 and Table 6.3 in section 6.3) shows that motorcyclists involved in approach-turn B crashes were most likely of all crash configurations to be KSI, with about 103% increase in the probability of a KSI relative to same-direction collisions (although such crash type only represents about 17% of all casualties).

The aggregate model also revealed that angle A crashes were among the most frequently occurring collision types, and ranked third in terms of injury severity (with a coefficient value of 0.227), following approach-turn B crashes (with a coefficient value of 0.404) and head-on crashes (with a coefficient value of 0.334). Several researchers (e.g., Hurt et al., 1981; Peek-Asa and Kraus, 1996a; Pai and Saleh, 2008) have suggested that one of the typical mechanisms behind the occurrences of approach-turn B crashes and angle A crashes was that motorists were observed to adopt smaller safety margins when pulling out in front of motorcycles compared with cars (also see section 2.4.1 for a review of past studies discussing gap acceptance problem for accidents involving motorists and motorcyclists).

This section provides an in-depth multivariate analysis that explores the determinants of motorcyclist injury severity in motorcycle-car accidents that involve gap acceptance, with a focus on the effects of motorists' failure to yield to motorcyclists. This section begins with a description of model specification, followed by the modelling results. Finally, a brief summary of the estimation results is provided.

7.2.2 Crash Classification and Model Specification

Given that research (e.g., Kim et al., 1994; Preusser et al., 1995) has suggested that automatic signals with improved signal timing could be a potential countermeasure for reducing approach-turn/angle crashes, junction control measures is the variable of interest for the analyses of approach-turn A/B crashes in this section. Table 7.1 shows the distribution of motorcyclist injury severity by the interaction of junction control measures and approach-turn A/B crashes. The descriptive statistics in Table 7.1 show that, for approach-turn A crashes, injures were greatest to motorcyclists in accidents at signalised junctions (i.e., as much as 28% of the injuries were KSIs). For approach-turn B crashes, injuries were greatest in accidents that occurred at stop-/give-way controlled junctions (i.e., as much as 32.5% of the injuries were KSIs).

Table 7.1: Distribution of motorcyclist injury severity by the interaction of junction control measures and approach-turn A/B crashes.

Crash type	Control measure	No injury	Slight injury	KSI	Total
Approach-turn A	uncontrolled	3 (2.9%)	75 (71.4%)	27 (25.7%)	105 (9.9%)
	stop, give way sighs or markings	29 (3.8%)	562 (73.3%)	176 (22.9%)	767 (72.3%)
	automatic signals	2 (1.1%)	134 (70.9%)	**53 (28.0%)**	189 (17.8%)
	Total	34 (3.2%)	771 (72.2%)	256 (24.1%)	1061 (100%)
Approach-turn B	uncontrolled	15 (0.7%)	1501 (69.2%)	652 (30.1%)	2168 (13.0%)
	stop, give way signs or markings	99 (0.7%)	8864 (66.8%)	**4307 (32.5%)**	13270 (79.7%)
	automatic signals	16 (1.3%)	868 (71.4%)	331 (27.2%)	1215 (7.3%)
	Total	130 (0.8%)	11233 (67.5%)	5290 (31.8%)	16653 (100%)
Total		**164 (0.9%)**	**12004 (67.8%)**	**5546 (31.3%)**	**17714 (100%)**

While approach-turn crashes were classified into approach-turn A and approach-turn B crashes depending on whether it was the car or motorcycle that turned right (as shown in Figure 4.3(b) in section 4.3), angle A/B collisions (as shown in Figure 4.3(a) in section 4.3) are further categorised into five crash patterns based on the manoeuvres of motorcycles and cars prior to the crashes. These five crash patterns are: (a) angle A collision: both turning; (b) angle A collision: car travelling straight and motorcycle turning; (c) angle A collision: car turning and motorcycle travelling straight; (d) angle B collision: car travelling straight and motorcycle turning; and (e) angle B collision: car turning and motorcycle travelling straight. These five crash patterns are illustrated in Figure 7.1.

The reason for classifying angle collisions into several sub-crashes was because it is hypothesised in this study that injury-severity levels may be associated with different pre-crash manoeuvres that motorcycles and cars were making in different ways. For instance, the crash impact of a crash pattern (b) (see Figure 7.1) in which a right-turn motorcycle collides with a travelling-straight car may be different from that of a crash pattern (c) (see Figure 7.1) in which a travelling-straight motorcycle collides with a turn-right car. Note here that a turning manoeuvre used for the classification of an angle crash includes a U-turn manoeuvre by motorcycles or cars. For example, for crash pattern (c), a right-turn car may have attempted to make a U-turn and subsequently collided with a travelling-straight motorcycle on the major road.

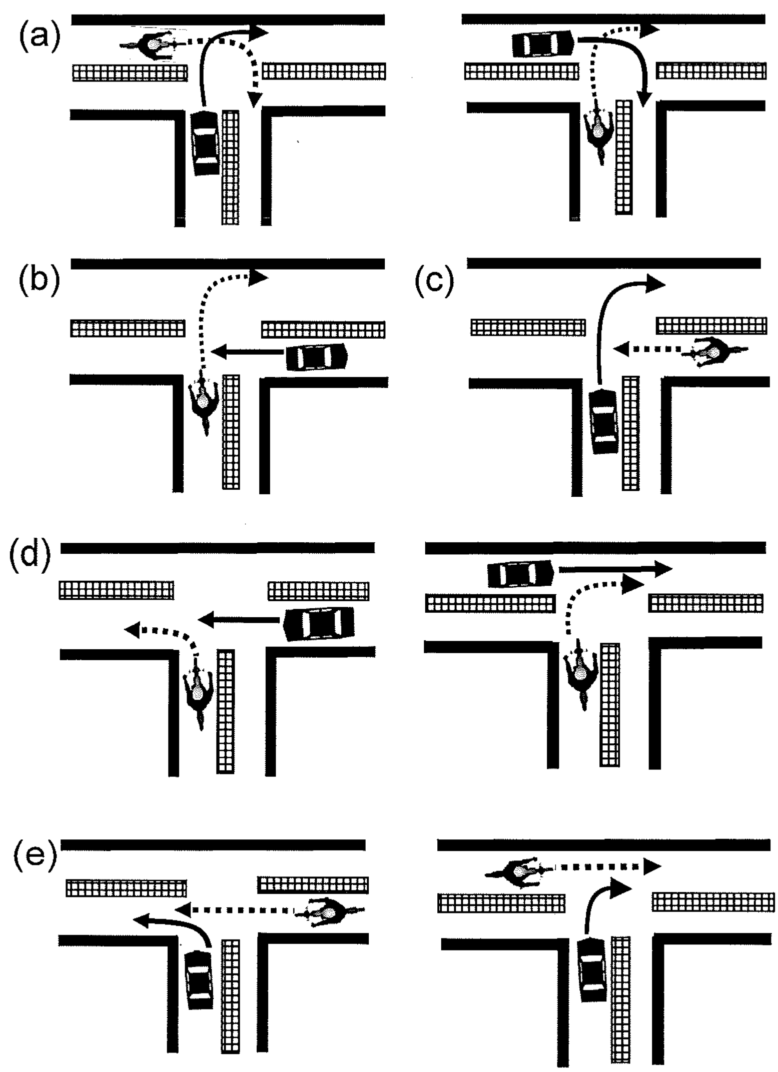


Figure 7.1: Schematic diagram of angle collisions at T-junctions. (a) angle A collision: both turning; (b) angle A collision: car travelling straight and motorcycle turning; (c) angle A collision: car turning and motorcycle travelling straight; (d) angle B collision: car travelling straight and motorcycle turning; and (e) angle B collision: car turning and motorcycle travelling straight. (Note: pecked line represents the intended path of a motorcycle; solid line represents the intended path of a car).

The categories of the variable "crash patterns in angle A/B crashes", together with its frequency, are presented in Table 7.2. As shown in Table 7.2, the most frequently occurring crash pattern is an angle A crash in which a turning car collides with a travelling motorcycle (see Figure 7.1(c)). Such crash pattern represents 60% of all casualties. It is worthwhile to note that some crash patterns could not be fit into the five crash patterns identified here and these were classified as unidentified crash pattern, which accounted for 12.1% of all casualties. These unidentified crash patterns include, for example, a situation when a car from the minor road did not make a right-/left-turn at all. Rather, this car travelled straight to the kerb of the major road (i.e., the top of the T-junction) and collided with an oncoming motorcycle. This may be a car attempting to park on the kerb of the major road for business purposes. These unidentified crash patterns were thought to be irrelevant to this current research and therefore were not considered in the analysis in this chapter. However, these unidentified crash patterns may deserve future research as they still accounted for 12.1% of all casualties.

Table 7.2: The categories of five crash manners in angle A/B crashes.

Crash patterns in angle A/B crashes	Total
Unidentified	5527 (12.1%)
angle A collision: both turning	1202 (2.6%)
angle A collision: car travelling straight and motorcycle turning	2402 (5.3%)
angle A collision: car turning and motorcycle travelling straight	27359 (60.0%)
angle B collision: car travelling straight and motorcycle turning	1025 (2.2%)
angle B collision: car turning and motorcycle travelling straight	8065 (17.7%)
Total	**45580 (100%)**

Table 7.3 and Table 7.4 provide the information on the distribution of injury severity by the interaction of junction control measures and different crash patterns for angle A and B collisions respectively. As reported in Table 7.3 and Table 7.4, two combined effects (i.e., a travelling-straight motorcycle collided with a right-/left-turn car at stop-controlled junctions, as shown in Figure 7.1(c) and (e)) represented the deadliest risks of KSIs to motorcyclists (i.e., as much as 27.1% and 22.8% of the injuries were KSIs).

The detailed derivation of the OP models has been given in Chapter 4 (Section 4.6 Econometric Framework). Therefore it is not repeated here.

Table 7.3: Distribution of motorcyclist injury severity by the interaction of junction control measures and pre-crash manoeuvres for angle A collisions.

Manoeuvres * control measures	Injury severity			Total
	No Injury	Slight	KSI	
both turning * uncontrolled	0(0%)	109(80.1%)	27(19.9%)	136(0.44%)
both turning * stop, give-way sign or markings	16(1.6%)	821(80.6%)	181(17.8%)	1018(3.29%)
both turning * automatic signal	1(2.1%)	35(72.9%)	12(25%)	48(0.16%)
car straight, motorcycle turning * uncontrolled	11(4%)	203(73.8%)	61(22.2%)	275(0.89%)
car straight, motorcycle turning * stop, give-way sign or markings	58(2.9%)	1423(70.8%)	530(26.4%)	2011(6.49%)
car straight, motorcycle turning * automatic signal	3(2.6%)	87(75.0%)	26(22.4%)	116(0.37%)
car turning, motorcycle straight * uncontrolled	30(1.1%)	2020(74.9%)	646(24.0%)	2696(8.71%)
car turning, motorcycle straight * stop, give-way sign or markings	182(0.7%)	17513(72.1%)	**6579(27.1%)**	**24274(78.40%)**
car turning, motorcycle straight * automatic signal	8(2.1%)	280(72.0%)	101(26.0%)	389(1.26%)
Total	**309(1%)**	**22491(72.6%)**	**8163(26.4%)**	**30963(100%)**

Table 7.4: Distribution of injury severity by the interaction of junction control measures and pre-crash manoeuvres for angle B collisions.

Manoeuvres * control measures	Injury severity			Total
	No Injury	Slight	KSI	
car straight, motorcycle turning * uncontrolled	5(4.8%)	82(78.1%)	18(17.1%)	105(1.6%)
car straight, motorcycle turning * stop, give-way sign or markings	21(2.6%)	621(75.5%)	180(21.9%)	822(9.11%)
car straight, motorcycle turning * automatic signal	5(5.1%)	86(87.8%)	7(7.1%)	98(1.09%)
car turning, motorcycle straight * uncontrolled	8(0.9%)	702(78.0%)	190(21.1%)	900(9.98%)
car turning, motorcycle straight * stop, give-way sign or markings	50(0.7%)	5352(76.5%)	**1591(22.8%)**	**6993(77.51%)**
car turning, motorcycle straight * automatic signal	1(0.6%)	140(81.4%)	31(18.0%)	172(1.91%)
Total	**90(1%)**	**6983(76.8%)**	**2017(22.2%)**	**9090(100%)**

7.2.3 Modelling Results for Approach-turn Crashes

As shown in Table 7.1, a total of 17714 motorcyclist casualties resulting from motorcycle-car approach-turn crashes that took place at T-junctions were extracted from the Stats19. Of these motorcyclist casualties, 31.3% are classified as KSI, 67.8%

are classified as slight injury, and 0.9% are classified as no injury. Automatic signals and stop, give-way signs and marks tended to predispose riders to a greater risk of KSIs in approach-turn A crashes and approach-turn B crashes respectively (as much as 28% and 32.5% of the injuries were KSIs).

In order to gain a further understanding of the factors that affect motorcyclist injury severity resulting from these deadliest combinations (i.e., approach-turn A crashes that occurred at signalised junctions; approach-turn B crashes that occurred at stop/give-way controlled junctions), the separate OP models by these deadliest combinations are estimated. For approach-turn A crashes that occurred at signalised junctions, most of the variables were found to be insignificant in explaining injury severity. This is possibly due to comparatively few observations of casualties resulting from such crashes (N=189). The estimation results of this model are therefore not reported. Only the estimation results of the approach-turn B crash model are provided (see Table 7.8 and Table 7.9 in section 7.2.3.2 below).

7.2.3.1 Variables considered

The variables examined in the aggregate model (see Table 6.2 in section 6.3) are incorporated into the disaggregate model of approach-turn B crashes that occurred at stop-controlled junctions. In addition to these variables, two more variables are incorporated into the approach-turn B crash model. These two variables are "motorist's right-of-way violation" and "motorcycle's manoeuvre", which are explained in more details below.

The inclusion of the variable "right-of-way violation" in the approach-turn B crash model is because research (e.g., Hurt et al., 1981; Peek-Asa and Kraus, 1996a; Pai and Saleh, 2008) has suggested that one of the typical mechanisms behind the occurrences of approach-turn B crashes was that motorists were observed to adopt smaller safety margins when pulling out in front of motorcycles compared with cars. This is typically termed as "motorist's failure to give way". For this current research, the variable "right-of-way violation" is incorporated into the approach-turn B crash model to examine its effect on motorcyclist injury severity. There are three categorises for this variable: right-of-way violation, non right-of-way violation, and unknown, as illustrated in Figure 7.2. The definition of right-of-way violation and non right-of-way violation is provided below.

The information on right-of-way violation is not explicitly provided in the Stats19. Instead, the variable "First Point of Impact" that is readily available in the Stats19 is used to assign motorist's right-of-way violation. The variable "First Point of Impact" provides the information on the first crash point of the involved car and motorcycle (see Figure 7.3 for an illustration of the variable "First Point of Impact" that is readily available in the Stats19).

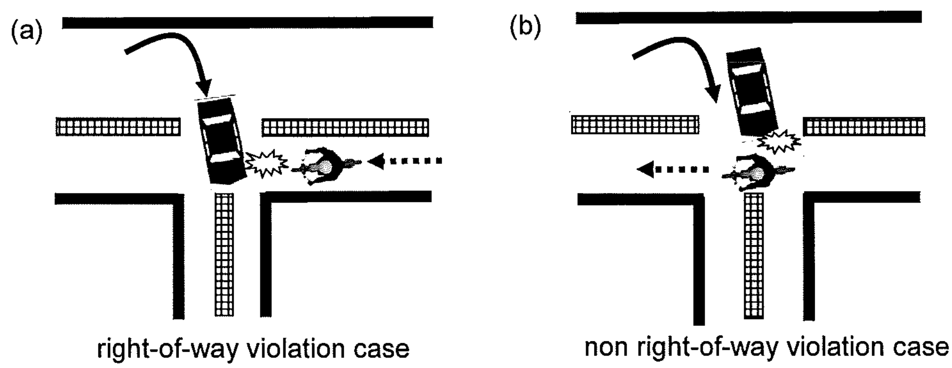


Figure 7.2: Schematic diagram of (a) a right-of-way violation case and (b) a non right-of-way violation case in an approach-turn B collision at T-junctions (Note: pecked line represents the intended/actual path of a motorcycle and solid line represents the path of a car).

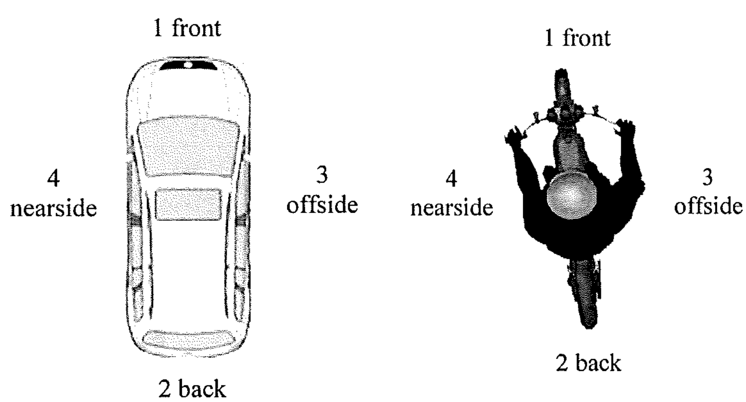


Figure 7.3: Illustration of the variable "First Point of Impact" in the Stats19 that is used to create the variable "Right-of-way violation".

A common definition in most of the right-of-way violation studies has been that a turning automobile adopts smaller safety margins when pulling out in front of a motorcycle (see, for example, Hurt et al., 1981; Peek-Asa and Kraus, 1996a; Horswill et al., 2005; Pai and Saleh, 2008). In this present study, an approach-turn B crash that involves right-of-way violation (see Figure 7.2(a)) is defined as a crash where the right-turn car was assumed to have entered the junction earlier than the approaching motorcycle and such motorcycle crashed into the car.

It was assumed that such right-turn car had been in the path of the oncoming motorcycle to which it should have yielded the right of way. The variable "First Point of Impact" has been used to identify the right-of-way violation cases. Which is, a right-of-way violation case is defined as a crash in which the front of an oncoming motorcycle crashed into the nearside of the car (i.e., front versus nearside). Note here that the front of the motorcycle does not necessarily have to be the first collision point with which the nearside of the car collides. The first crash point can be the nearside/offside/back of the motorcycle with which the car collides due to the fact that motorcycles are more capable of swerving prior to the crash (Obenski et al., 2007). A crash in which the front of a right-turn car was the first crash point with which the front of an approaching motorcycle collides was also identified as a crash that involves right-of-way violation. This is because such turn-right car was assumed to have entered the junction as soon as the bike has entered the junction so that its front had struck the front of a motorcycle.

A non right-of-way-violation crash (see Figure 7.2(b)) is defined as a crash in which an oncoming motorcycle was assumed to be the first vehicle that had entered the junction and the front of a right-turn car crashed into the offside of an oncoming motorcycle. It should be noted here that there are some cases that could not be identified as a right-of-way case or a non right-of-way case. Examples of these unidentified cases include the collisions where the rear of a motorcycle struck the rear of a car. These collisions that could not be fit into a right-of-way case or a non right-of-way case are categorised as "unknown" in the variable "right-of-way violation".

Table 7.5 reports the information on the distribution of motorcyclist injury severity by right-of-way violation. The descriptive statistics in Table 7.5 indicate that motorcyclist casualties resulting from right-of-way violation cases outnumber those resulting from non right-of-way violation cases by nearly 10-to-1 (86.8% versus 9.1%). In addition, riders involved in right-of-way violation cases were more likely to be KSI (33.2% of the injuries were KSIs).

Table 7.5: Distribution of motorcyclist injury severity by right-of-way violation in approach-turn B crashes.

Right-of-way violation	No injury	Slight injury	KSI	Total
Right-of-way violation	85 (0.7%)	7615 (66.1%)	**3822 (33.2%)**	**11522 (86.8%)**
Not right-of-way violation	5 (0.4%)	844 (69.7%)	362 (29.9%)	1211 (9.1%)
Unknown	9 (1.7%)	405 (75.4%)	1123 (22.9%)	537 (4.0%)
Total	**99 (0.7%)**	**8864(66.8%)**	**4307 (32.5%)**	**13270 (100%)**

In addition to the variable "right-of-way violation", another variable "motorcycle's pre-crash manoeuvre" is incorporated into the model, given that research (e.g., Preusser et al., 1995) has suggested that there was a potential risk for approach-turn crashes in which the smaller motorcycle may remain blocked behind larger cars and suddenly become visible by its overtaking manoeuvres from behind. The variable contains three types of manoeuvres: travelling straight, changing lane, and overtaking, which are available from the variable "2.7 Manoeuvres" in the Stats19 (see also Table 4.3 and Table 4.4 in section 4.3 for an example of these manoeuvres that have been used to classify crash configurations).

Table 7.6 reports the information on the distribution of motorcyclist injury severity by motorcycle's pre-crash manoeuvre. The data in Table 7.6 show that motorcyclists were more likely to be KSI when they were travelling straight than when their pre-crash manoeuvres were changing lane and overtaking (33.2% versus 28.6% and 23.7%).

Table 7.6: Distribution of motorcyclist injury severity by motorcycle's pre-crash manoeuvre in approach-turn B crashes.

Pre-crash manoeuvre	No injury	Slight injury	KSI	Total
travelling straight	90 (0.7%)	8158 (66.1%)	**4085 (33.2%)**	**12333 (92.9%)**
changing lane	0 (0%)	5 (71.4%)	2 (28.6%)	7 (0.1%)
overtaking	9 (1.0%)	701 (75.4%)	220 (23.7%)	930 (7.0%)
Total	**99 (0.7%)**	**8864(66.8%)**	**4307 (32.5%)**	**13270 (100%)**

A correlation matrix among the variables was reported (see Table 7.7) to assess the presence of multicollinearity. Multicollinearity was found to exist between the variable "street light condition" and "time of accident", with a correlation value of 0.622. For these two variables that are highly correlated with each other, only the most significant variable, which is "time of accident", is retained in the analysis.

7.2.3.2 Estimation results

Table 7.8 presents the estimation results for approach-turn B crash model, conditioned on the accidents having occurred at stop-controlled junctions. Of 13270 motorcyclist casualties that were involved in approach-turn B crashes at stop-/give-way controlled T-junctions, 32.5% are classified as KSI (4307 observations), 66.8% are classified as slight injury (8864 observations), and 0.7% are classified as no injury (99 observations). The model has a pseudo-R^2 measure of 0.084. As for predicting each injury-severity category, the classification accuracy for KSI, slight injury, and no injury was 14.8%, 95.0%, and 0%.

Table 7.7: Correlation matrix between the variables in the approach-turn B crash model.

variables	engine size	motorcycle's manoeuvre	bend for motorcycle	violation	crash partner	rider gender	rider age	motorist gender	motorist age	number of vehicle involved	month	week day	time of day	speed limit	light	weather
engine size	1	0.020	0.029	0.047	0.033	0.162	-0.288	-0.008	-0.008	0.038	0.082	0.033	-0.081	0.125	-0.122	0.052
motorcycle's manoeuvre		1	0.050	0.012	-0.016	0.020	0.002	0.006	0.054	-0.099	-0.009	0.047	0.077	0.039	0.076	0.005
bend for motorcycle			1	0.008	0.011	-0.002	0.006	-0.024	-0.006	-0.020	0.025	0.030	-0.047	0.159	-0.070	0.010
violation				1	-0.013	0.024	0.021	-0.043	-0.036	0.037	0.011	0.025	0.009	0.068	0.002	-0.002
crash partner					1	-0.001	-0.016	0.135	-0.033	-0.006	0.008	-0.036	-0.083	0.049	-0.073	-0.006
rider gender						1	-0.013	0.020	-0.001	0.005	0.020	0.035	0.016	0.039	-0.004	0.031
rider age							1	-0.011	0.002	0.005	-0.032	0.006	0.060	-0.064	0.068	-0.013
motorist gender								1	0.237	-0.012	0.002	0.022	0.054	-0.023	0.054	0.016
motorist age									1	0.001	-0.015	0.015	-0.030	0.014	-0.002	0.021
number of vehicle involved										1	0.022	0.037	-0.030	0.083	-0.032	-0.004
month											1	0.051	-0.065	0.075	-0.230	0.094
week day												1	-0.038	0.065	-0.033	0.032
time of day													1	-0.073	**0.622**	-0.031
speed limit														1	-0.130	0.031
light conditions															1	-0.079
weather																1

Table 7.8: Statistics summary and estimation results of the approach-turn B crash model (limited to those that occurred at stop-controlled junctions).

Variable	Categories of each variable	Frequency (%)	Coefficients (p-value)
Gender of rider	1. male	12429 (93.7%)	**0.088 (0.059)**
	2. female	841 (6.3%)	Reference case
Age of rider	1. 60 above	258 (1.9%)	**0.185 (0.021)**
	2. up to 19	2631 (19.8%)	0.003 (0.914)
	3. 20~59	10381 (78.2%)	Reference case
Gender of collision partner	1. untraced	439 (3.3%)	0.139 (0.097)
	2. male	9003 (67.8%)	**0.045 (0.075)**
	3. female	3828 (28.8%)	Reference case
Age of collision partner	1. untraced	919 (6.9%)	-0.360 (<0.001)
	2. 60 above	1875 (14.1%)	0.057 (0.079)
	3. up to 19	869 (6.5%)	**0.074 (0.093)**
	4. 20~59	9607 (72.4%)	Reference case
Engine size	1. engine size over 125cc	9588 (72.3%)	**0.138 (<0.001)**
	2. engine size up to 125cc	3682 (27.7%)	Reference case
Number of vehicle involved	1. >=3	706 (5.3%)	**0.250 (<0.001)**
	2. two-vehicle crash	12564 (94.7%)	Reference case
Bend for motorcycle	1. bend	426 (3.2%)	-0.160 (0.013)
	2. non bend	12844 (96.8%)	**Reference case**
Collision partner	1. heavy good vehicle (HGV)	811 (6.1%)	0.157 (0.001)
	2. bus/coach	127 (1.0%)	**0.246 (0.029)**
	3. car	12332 (92.9%)	Reference case
Accident month	1. spring/summer (Mar~Aug)	6384 (48.1%)	-0.023 (0.319)
	2. autumn/winter (Sep~Feb)	6886 (51.9%)	**Reference case**
Weather condition	1. other or unknown	238 (1.8%)	0.092 (0.307)
	2. fine weather	11605 (87.5%)	**0.126 (0.001)**
	3. bad weather	1427 (10.8%)	Reference case
Accident time	1. evening (1800~2359)	4662 (35.1%)	0.168 (<0.001)
	2. midnight; early morning (0000~0659)	416 (3.1%)	**0.215 (0.001)**
	3. rush hours (0700~0859; 1600~1759)	4126 (31.1%)	0.033 (0.249)
	4. non rush hours (0900~1559)	4066 (30.6%)	Reference case
Accident day of week	1. weekend (Sat~Sun)	2674 (20.2%)	**0.066 (0.019)**
	2. weekday (Mon~Fri)	10596 (79.8%)	Reference case
Speed limit	1. non built-up roads (>40mph)	1257 (9.5%)	**0.623 (<0.001)**
	2. built-up roads (<=40mph)	12013 (90.5%)	Reference case
Motorcycle's manoeuvre	1. going straight	12333 (92.9%)	**0.232 (<0.001)**
	2. traversing	937 (7.1%)	Reference case
Right-of-way violation	1. violation case	11522 (86.8%)	**0.197 (0.001)**
	2. not violation case	1211 (9.1%)	0.169 (0.013)
	3. unknown	5377 (4.0%)	Reference case
	μ_1	-1.612 (<0.001)	
	μ_2	1.349 (<0.001)	

Summary Statistics
-2 Log-likelihood at zero = 7090.671
-2 Log-likelihood at convergence = 6492.716
Log-likelihood ratio index (ρ^2) = 0.084
The number of KSI that was correctly predicted: 639 (14.8%)
The number of slight injury that was correctly predicted: 8420 (95.0%)
The number of no injury that was correctly predicted: 0 (0%)
Observations = 13270 (KSI: 32.5%; slight injury: 66.8%; no injury: 0.7%)

A benchmark case (see section 4.3.3 for a discussion of a benchmark case) was generated in order to discuss probabilities of three injury levels, which is derived by holding all dummy variables to 0 (see Table 7.9). Such benchmark victim has the following characteristics:

(a) was a female
(b) was aged between 20-59
(c) was involved in a collision in which the involved motorist was female
(d) was involved in a collision in which the age of the involved motorist was aged between 20-59
(e) was riding a motorcycle with engine size up to 125cc
(f) was involved in a collision in which the crash partner was a car
(g) was involved in a two-vehicle collision
(h) was riding on the straight roadway (not on the bend)
(i) was involved in a crash in autumn/winter month
(j) was involved in a crash when the weather was adverse
(k) was involved in a crash during non rush hours
(l) was involved in a crash on weekday
(m) was involved in a crash on the built-up road
(n) was having traversing manoeuvre
(o) was involved in a crash in which the status of right-of-way violation was unknown

Table 7.9: Motorcyclist injury severity probabilities in approach-turn B crashes.

Variable		Estimated probability			Percent change relative to benchmark case (%)		
		No injury	Slight	KSI	No injury	Slight	KSI
Benchmark case		0.0535	0.8578	0.0887			
Gender of rider	1. male	0.0446	0.8518	**0.1037**	-16.64	-0.70	**16.91**
Age of rider	1. 60 above	0.0362	0.8416	**0.1222**	-32.34	-1.89	**37.77**
	2. up to 19	0.0532	0.8577	0.0892	-0.56	-0.01	0.56
Gender of collision partner	1. untraced	0.04	0.8469	0.1131	-25.23	-1.27	27.51
	2. male	0.0488	0.8551	**0.0961**	-8.79	-0.31	**8.34**
Age of collision partner	1. untraced	0.1053	0.851	0.0437	96.82	-0.79	-50.73
	2. 60 above	0.0476	0.8543	0.0982	-11.03	-0.41	10.71
	3. up to 19	0.0459	0.8529	**0.1012**	-14.21	-0.57	**14.09**
Engine size	1. motorcycle over 125cc	0.0401	0.847	**0.1129**	-25.05	-1.26	**27.28**
No. of vehicle involved	1. >= 3	0.0313	0.8328	**0.1359**	-41.50	-2.91	**53.21**
Bend for motorcycle	1. bend	0.0733	0.8611	0.0657	37.01	0.38	-25.93
Crash partner	1. heavy goods vehicle	0.0384	0.8449	0.1166	-28.22	-1.50	31.45
	2. bus/coach	0.0316	0.8334	**0.135**	-40.93	-2.84	**52.20**
Accident month	1. spring/summer (Mar~Aug)	0.056	0.8589	0.085	4.67	0.13	-4.17
Weather Conditions	1. other or unknown	0.0442	0.8514	0.1044	-17.38	-0.75	17.70
	2. fine weather	0.0411	0.8482	**0.1107**	-23.18	-1.12	**24.80**
Accident time	1. evening (1800~2359)	0.0375	0.8437	0.1188	-29.91	-1.64	33.93
	2. midnight; early morning (0000~0659)	0.0339	0.8377	**0.1284**	-36.64	-2.34	**44.76**
	3. rush hours (0700~0859; 1600~1759)	0.05	0.8559	0.0941	-6.54	-0.22	6.09
Accident day of week	1. weekend (Sat~Sun)	0.0467	0.8536	**0.0997**	-12.71	-0.49	**12.40**
Speed limit	1. non built-up roads	0.0127	0.7534	**0.2339**	-76.26	-12.17	**163.70**
Motorcycle's manoeuvre	1. going straight	0.0326	0.8354	**0.132**	-39.07	-2.61	**48.82**
Right-of-way violation	1. violation case	0.0352	0.8401	**0.1247**	-34.21	-2.06	**40.59**
	2. not violation case	0.0375	0.8435	0.119	-29.91	-1.67	34.16

Note: The reference case for each variable is not shown as it is taken as the benchmark victim.

An example of the derivation of the injury severity probabilities (see also Table 7.9) is given here. Given the estimated cutpoints $\mu_1 = -1.612$ and $\mu_2 = 1.349$ (see Table 7.8), the probabilities of no injury, slight injury, and KSI sustained by, for instance, a rider of a motorcycle with engine size over 125cc (β'=0.138) are:

$$P(y_i = \text{no injury} \mid \text{male rider}) = \Phi(-1.612 - 0.138 * 1)$$
$$P(y_i = \text{slight injury} \mid \text{male rider}) = \Phi(1.349 - 0.138 * 1) - \Phi(-1.612 - 0.138 * 1) \quad [7.1]$$
$$P(y_i = \text{KSI} \mid \text{male rider}) = 1 - \Phi(1.349 - 0.138 * 1)$$

Thus,

$$P(y_i = \text{no injury} \mid \text{male rider}) = \Phi(-1.75)$$
$$P(y_i = \text{slight injury} \mid \text{male rider}) = \Phi(1.211) - \Phi(-1.75) \quad [7.2]$$
$$P(y_i = \text{KSI} \mid \text{male rider}) = 1 - \Phi(1.211)$$

According to the table in Appendix B, the probabilities of three injury severity levels are (see also Section 4.6.4 for guidance on the use of the table in Appendix B):

$$P(y_i = \text{no injury} \mid \text{male rider}) = 0.0401 \cong 4.01\%$$
$$P(y_i = \text{slight injury} \mid \text{male rider}) = 0.8470 \cong 84.70\% \quad [7.3]$$
$$P(y_i = \text{KSI} \mid \text{male rider}) = 0.1129 \cong 11.29\%$$

The estimation results of the approach-turn B model (Table 7.8) reveal that riders involved in right-of-way violation cases appeared to be more injury-prone, with a positive coefficient value of 0.197 relative to "unknown" features. The probability of a KSI increases by 40.59% for a right-of-way violation case (Table 7.9). A study by Peek-Asa and Kraus (1996a) explained why such violation cases were severe to motorcyclists. They noted that head and chest injuries, which normally result in severe or fatal consequence, were found to be the main injured human-body regions for those involved in accidents where a right-turn motorist failed to give way to an approaching motorcycle.

With regard to the effect of motorcycle's pre-crash manoeuvre, manoeuvres such as overtaking and changing lane (see the original categories in Table 7.6) are combined into one single manoeuvre category (i.e., traversing) as this combination was found to lead to more statistically significant result than treating them as two separate manoeuvres. The estimation results (Table 7.8) show that motorcyclists that were travelling straight were more injurious, with a positive coefficient value of 0.232 and about a 49% (Table 7.9) increased probability of a KSI relative to "traversing manoeuvres". This is likely attributable to the higher speed of a travelling-straight motorcycle than that of a traversing motorcycle, thereby resulting in greater collision-impact.

Other modelling results support those results that were observed from the aggregate crash model (see Table 6.2 and Table 6.3 in section 6.3), except for the effects of motorist age and the presence of bend for motorcycle. The aggregate model by motorcycle-car accidents in whole revealed that elderly motorists appeared to predispose riders to a greater risk of KSIs. However, the approach-turn B crash model (Table 7.8) shows that injuries to motorcyclists were greatest in collisions with teenaged motorists, with a coefficient value of 0.074 relative to mid-aged motorists. This may be due to the fact that young motorists' inexperience, inattention, or risky driving behaviours were often cited as reasons for crash involvement (Garber and Srinivasan, 1991; Dissanayake et al., 1999; Kim et al., 2007). However, whether these factors contribute to the increased motorcyclist injury severity in approach-turn B crashes is unknown and can not be ascertained in this study because behavioural factors are not readily available from the Stats19. A better understanding of a comparison of the crossing behaviours among motorists in different age groups when intersecting with oncoming motorcyclists could be a fruitful area for future research.

With regard to the effect of curved roadway on motorcyclist injury severity, the aggregate model by motorcycle-car accidents in whole revealed that riders were more injurious where there were bends either for cars or for motorbikes. However, it was found from the approach-turn B crash model that those riding on the bends were less injurious (Table 7.8), with about a 26% decreased probability of a KSI relative to "non bend" (Table 7.9). Possible explanations for this could be that an approaching motorcycle on the major roadway may speed down while riding on the bends, thereby reducing collision-impact once they have collided with a turning car.

Some of the similar effects between the aggregate model and the disaggregate model of approach-turn B crashes need further discussions. For example, the disaggregate model of approach-turn B crashes (Table 7.8) indicates that injuries were greatest during mid-night/early morning hours. Approach-turn B crashes that occurred during mid-night/early morning hours have a 44.76% increase in the probability of a KSI (Table 7.9), relative to non rush hours.

Alcohol use and higher speeds during these mid-night/early morning hours have been commonly documented in past studies as one of the reasons behind the severe accident consequence (see, for example, Kasantikul et al., 2005). Peek-Asa and Kraus (1996a) further reported that approach-turn crashes were more likely than other crash configurations to occur in diminished lighting conditions. They argued that motorcycle's poor conspicuity as a result of its small frontal surface and single head lamp can be exacerbated during these hours. Street light condition was not examined in the model as this variable is correlated with the variable "time of accident", as shown in Table 7.7. The results here (Table 7.8 and Table 7.9) suggest that riding during mid-night/early morning hours, which is in diminished lighting conditions, resulted in more severe injuries. Supplemental results from the estimated model (see Table 7.8 and Table 7.9), coupled with those of Peek-Asa and Kraus (1996a), underscore the role motorcycle's poor conspicuity may play in affecting both accident occurrence and injury severity.

7.2.4 Modelling Results for Angle Crashes

As reported in Table 7.3 and Table 7.4, two combined effects (i.e., a travelling-straight motorcycle collided with a right-/left-turn car at stop-controlled junctions, as shown in Figure 7.1(c) and (e)) represented the deadliest risks of KSIs to motorcyclists (i.e., as much as 27.1% and 22.8% of the injuries were KSIs). A similar crash pattern (i.e., a travelling-straight motorcycle collided with a right-turn car) was also identified by Pickering et al. (1986) and Stone and Broughton (2002) as particular source of car-car and bicycle-car accidents at T-junctions.

In order to gain a further understanding of the factors contributing to more severe injuries resulting from these two deadly combinations, two separate OP models are estimated and the results are reported (see Table 7.16 and Table 7.17 in section 7.2.4.2). It should be noted here that an additional model was also estimated for another hazardous combination (i.e., angle A collision in which a travelling-straight car collided with a right-turn motorcycle at stop-controlled junctions, as shown in Figure 7.1(b)). It was observed from Table 7.3 that 26.4% of the injuries were KSIs that resulted from such crash pattern (Figure 7.1(b)). However, a vast majority of the variables that are incorporated into the model by such crash pattern appeared to be insignificant in explaining injury severity. Again, this is possibly due to relatively few observations of casualties resulting from such crashes (N=2011). The estimation results of this model are therefore not reported. Only the estimation results of the models by the two deadliest combinations (i.e., a travelling-straight motorcycle collided with a right-/left-turn car at stop-controlled junctions) are provided (Table 7.16 and Table 7.17 in section 7.2.4.2).

7.2.4.1 Variables considered

The variables examined in the disaggregate model by approach-turn B crashes (see Table 7.8 in section 7.2.3.2) are incorporated into the disaggregate models of two deadliest combinations in angle A and angle B crashes respectively. Two variables of particular interest include "motorist's right-of-way violation" and "motorcycle's manoeuvre". The inclusion of the variable "right-of-way violation" in the analysis here is because angle A and angle B crashes, similar to approach-turn collisions, are accidents that involve gap acceptance (see a discussion of motorcycle-car accidents that involve gap acceptance in Chapter 2). Previous studies (see, for example Hurt et al., 1981; Peek-Asa and Kraus, 1996a; Pai and Saleh, 2008) have suggested that more than 70% of approach-turn collisions occurred as a result of a turning car's failure to give way to an oncoming motorcycle (see also Figure 7.2(a)). It is hypothesised in this current study that "motorist's fail to give way" may have some influence on motorcyclist injury severity in angle A/B crashes.

Similar to the variable "right-of-way violation" that was incorporated in the model of approach-turn B crashes (Table 7.8 in section 7.2.3.2), there are three categorises for this variable that is incorporated into the models of angle A and angle B crashes. These categories include right-of-way violation, non right-of-way violation, and unknown, as illustrated in Figure 7.4. The definition of right-of-way violation and non right-of-way violation has been provided in section 7.2.3.2. Thus it is not repeated here.

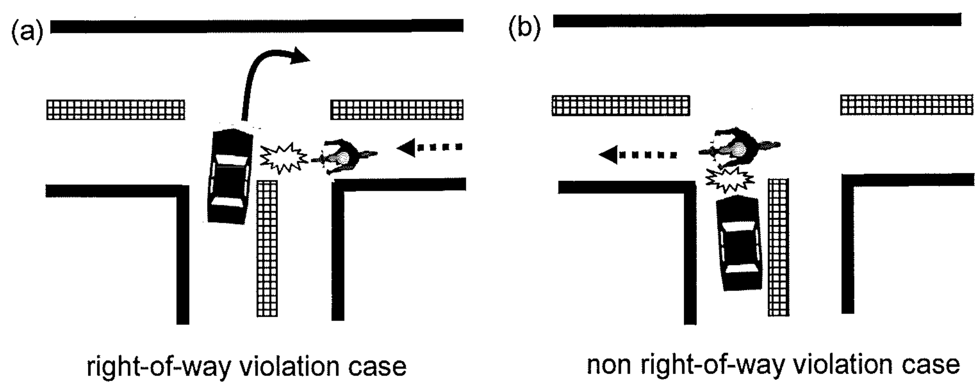


Figure 7.4: Schematic diagram of (a) a right-of-way violation case and (b) a non right-of-way violation case in an angle A/B collision at T-junctions (Note: pecked line represents the intended/actual path of a motorcycle and solid line represents the path of a car).

Table 7.10 and Table 7.11 reports the information on the distribution of motorcyclist injury severity by right-of-way violation in angle A and angle B crashes respectively (i.e., under stop, give-way signs or markings, an angle A/B collision in which a turning car from the minor road collided with an oncoming motorcycle from the major road). The descriptive statistics in Table 7.10 and 7.11 indicate that motorcyclist casualties resulting from right-of-way violation cases outnumber those resulting from non right-of-way violation cases by nearly 5-to-1 (79.3% versus 17.3% for angle A crashes; 78.5% versus 16.5% for angle B crashes). In addition, riders involved in right-of-way violation cases were more likely to be KSI (28.3% of the injuries were KSIs in angle A crashes; 24.1% of the injuries were KSIs in angle B crashes).

Table 7.10: Distribution of motorcyclist injury severity by right-of-way violation in angle A crashes.

Right-of-way violation	No injury	Slight injury	KSI	Total
Right-of-way violation	148 (0.8%)	1336 (71.0%)	**5439 (28.3%)**	**19248 (79.3%)**
Not right-of-way violation	32 (0.8%)	3165 (75.2%)	1014 (24.1%)	4211 (17.3%)
Unknown	2 (0.2%)	687 (84.3%)	126 (15.5%)	815 (3.4%)
Total	**182 (0.7%)**	**17513 (72.1%)**	**6579 (27.1%)**	**24274 (100%)**

Table 7.11: Distribution of motorcyclist injury severity by right-of-way violation in angle B crashes.

Right-of-way violation	No injury	Slight injury	KSI	Total
Right-of-way violation	41 (0.7%)	4129 (75.2%)	**1322 (24.1%)**	**5492 (78.5%)**
Not right-of-way violation	8 (0.7%)	919 (80.7%)	212 (18.6%)	1139 (16.3%)
Unknown	1 (0.3%)	304 (84.0%)	57 (15.7%)	362 (5.2%)
Total	**50 (0.7%)**	**5352 (76.5%)**	**1591 (22.8%)**	**6993 (100%)**

Similar to the variable "motorcycle's pre-crash manoeuvre" that was incorporated in the model of approach-turn B crashes (see Table 7.8 in section 7.2.3.2), there are three categories for this variable that is incorporated into the models of angle A and angle B crashes. These categories include travelling straight, changing lane, and overtaking.

Table 7.12 and Table 7.13 report the information on the distribution of motorcyclist injury severity by motorcycle's pre-crash manoeuvre. The data in Table 7.12 show that injuries resulting from angle A crashes were more severe when motorcyclists were travelling straight or changing lane (27.8% of the injuries were KSIs for both manoeuvres). Note here that "changing lane" manoeuvre only represents 0.1% of all motorcyclist casualties (18 observations). For angle B crashes examined in Table 7.13, motorcyclists were more likely to be KSI when they were travelling straight than when their pre-crash manoeuvres were changing lane or overtaking (23.0% versus 14.3% and 21.0%).

Table 7.12: Distribution of motorcyclist injury severity by motorcycle's pre-crash manoeuvre in angle A crashes.

Pre-crash manoeuvre	No injury	Slight injury	KSI	Total
travelling straight	154 (0.8%)	14513 (71.4%)	**5648 (27.8%)**	20315 (83.7%)
changing lane	0 (0%)	13 (71.4%)	**5 (27.8%)**	18 (0.1%)
overtaking	28 (0.7%)	2987 (75.8%)	926 (23.5%)	3941 (16.2%)
Total	**182 (0.7%)**	**17513(72.1%)**	**6579 (27.1%)**	**24274 (100%)**

Table 7.13: Distribution of motorcyclist injury severity by motorcycle's pre-crash manoeuvre in angle B crashes.

Pre-crash manoeuvre	No injury	Slight injury	KSI	Total
travelling straight	48 (0.8%)	4818 (76.3%)	**1450 (23.0%)**	6316 (90.3%)
changing lane	0 (0%)	12 (85.7%)	2 (14.3%)	14 (0.2%)
overtaking	2 (0.3%)	522 (78.7%)	139 (21.0%)	663 (9.5%)
Total	**50 (0.7%)**	**5352 (76.5%)**	**1591 (22.8%)**	**6993 (100%)**

Before the variables are incorporated into the models, correlation among the variables is examined (see Table 7.14 and Table 7.15). Multicollinearity was found to exist between the variable "street light condition" and "time of accident", with a correlation value of 0.572 and 0.574. For these two variables that are highly correlated with each other, only the most significant variable, which is "time of accident", is retained in the analysis.

7.2.4.2 Estimation results

Table 7.16 and Table 7.17 present the estimation results for angle A crash and angle B crash models (i.e., crash pattern (c) and crash pattern (e), as shown in Figure 7.1), conditioned on the accidents having occurred at stop-controlled junctions. Of 24274 motorcyclist casualties that were involved in angle A crashes at stop-/give-way controlled T-junctions (Table 7.16), 27.1% are classified as KSI (6579 observations), 72.1% are classified as slight injury (17513 observations), and 0.7% are classified as no injury (182 observations). Of 6993 casualties that were involved in angle B crashes at stop-/give-way controlled T-junctions (Table 7.17), 22.8% are classified as KSI (1591 observations), 76.5% are classified as slight injury (5352 observations), and 0.7% are classified as no injury (50 observations).

The angle A crash model has a pseudo-R^2 measure of 0.076. As for predicting each injury-severity category, the classification accuracy for KSI, slight injury, and no injury was 4.4%, 98.9%, and 0% (Table 7.16). The angle B crash model has a pseudo-R^2 measure of 0.057. As for predicting each injury-severity category, the classification accuracy for KSI, slight injury, and no injury was 0.5%, 99.9%, and 0% (Table 7.17).

Table 7.14: Correlation matrix between the variables in the angle A crash model.

variables	engine size	motorcycle's manoeuvre	bend for motorcycle	violation	crash partner	rider gender	rider age	motorist gender	motorist age	number of vehicle involved	month	week day	time of day	speed limit	light	weather
engine size	1	0.005	0.030	0.038	0.014	0.171	-0.309	0.005	-0.012	0.039	0.078	0.050	-0.045	0.125	0.082	0.060
motorcycle's manoeuvre		1	0.110	0.065	-0.001	0.001	0.001	0.018	0.078	-0.152	-0.015	0.073	0.113	0.070	0.121	-0.008
bend for motorcycle			1	0.028	0.042	0.024	0.002	-0.008	-0.001	-0.012	0.051	0.037	-0.002	0.124	-0.042	0.020
violation				1	0.010	0.037	0.010	-0.017	-0.040	0.010	0.005	0.021	0.036	0.068	0.030	0.013
crash partner					1	0.003	-0.025	0.140	-0.046	-0.002	0.018	-0.046	-0.055	0.027	-0.048	-0.001
rider gender						1	-0.013	0.003	-0.020	0.009	0.028	0.040	0.025	0.038	0.013	0.022
rider age							1	-0.018	0.005	0.002	-0.050	-0.010	0.027	-0.057	0.050	-0.023
motorist gender								1	0.242	-0.011	-0.007	0.019	0.062	-0.004	0.051	0.009
motorist age									1	-0.006	0.016	0.034	-0.018	0.031	-0.004	0.018
number of vehicle involved										1	0.024	0.004	-0.032	0.036	-0.054	0.019
month											1	0.067	-0.032	0.047	-0.308	0.074
week day												1	-0.057	0.078	-0.031	0.041
time of day													1	-0.007	**0.572**	-0.037
speed limit														1	-0.053	0.037
light conditions															1	-0.098
weather																1

Table 7.15: Correlation matrix between the variables in the angle B crash model.

variables	engine size	motorcycle's manoeuvre	bend for motorcycle	violation	crash partner	rider gender	rider age	motorist gender	motorist age	number of vehicle involved	month	week day	time of day	speed limit	light	weather
engine size	1	0.016	0.020	0.055	0.011	0.191	-0.301	-0.019	-0.030	0.038	0.073	0.053	-0.041	0.133	-0.074	0.066
motorcycle's manoeuvre		1	0.071	0.016	0.001	-0.037	0.001	0.031	0.073	-0.102	0.004	0.040	0.081	0.031	0.079	0.010
bend for motorcycle			1	0.017	0.036	0.013	-0.008	-0.006	0.009	0.009	0.019	0.019	0.006	0.077	-0.013	0.001
violation				1	0.007	0.018	0.007	-0.069	-0.129	0.056	-0.011	0.033	0.002	0.099	0.022	0.003
crash partner					1	-0.001	-0.014	0.144	-0.038	-0.004	0.012	-0.036	-0.071	0.035	-0.051	0.006
rider gender						1	-0.028	-0.001	-0.005	0.030	0.025	0.033	0.032	0.035	0.005	0.034
rider age							1	0.008	0.012	-0.011	-0.026	0.009	0.048	-0.075	0.049	0.002
motorist gender								1	0.327	-0.023	0.019	0.034	0.079	-0.036	0.086	-0.006
motorist age									1	-0.045	0.010	0.020	-0.007	-0.013	0.015	0.018
number of vehicle involved										1	-0.001	0.011	-0.016	0.040	-0.011	-0.016
month											1	0.039	-0.044	0.062	-0.321	0.080
week day												1	-0.058	0.097	-0.011	0.035
time of day													1	-0.021	**0.574**	-0.022
speed limit														1	-0.058	0.041
light conditions															1	-0.084
weather																1

Table 7.16: Statistics summary and estimation results of the angle A crash model (limited to a collision where a turning car collided with a travelling-straight motorcycle at stop-controlled junctions).

Variable	Categories of each variable	Frequency (%)	Coefficients (p-value)
Gender of rider	1. male	22319 (91.9%)	0.030 (0.346)
	2. female	1955 (8.1%)	Reference case
Age of rider	1. over 60	619 (2.6%)	**0.183 (0.001)**
	2. up to 19	4951 (20.4%)	-0.015 (0.509)
	3. 20-59	18704 (77.1%)	Reference case
Gender of collision partner driver	1. untraced	665 (2.7%)	0.057 (0.390)
	2. male	15096 (62.2%)	**0.031 (0.085)**
	3. female	8513 (35.1%)	Reference case
Age of collision partner driver	1. untraced	1478 (6.1%)	-0.243 (<0.001)
	2. over 60	2915 (12.0%)	**0.049 (0.063)**
	3. up to 19	1458 (6.0%)	0.044 (0.215)
	4. 20-59	18423 (75.9%)	Reference case
Engine size	1. engine size over 125cc	17625 (72.6%)	0.160 (<0.001)
	2. engine size up to 125cc	6649 (27.4%)	Reference case
Collision partner	1. HGV (heavy good vehicle)	1268 (5.2%)	0.128 (0.001)
	2. bus/coach	184 (0.8%)	**0.177 (0.062)**
	3. car	22822 (94.0%)	Reference case
Number of vehicle involved	1. >=3	1306 (5.4%)	**0.210 (<0.001)**
	2. two-vehicle crash	22968 (94.6%)	Reference case
Bend for motorcycle	1. bends	1420 (5.8%)	0.022 (0.545)
	2. non bends	22854 (94.2%)	Reference case
Weather condition	1. other or unknown	509 (2.1%)	0.037 (0.556)
	2. fine weather	20411 (84.1%)	**0.078 (0.002)**
	3. bad weather	3354 (13.8%)	Reference case
Accident time	2. evening (1800~2359)	6510 (26.8%)	0.152 (<0.001)
	1. midnight/early morning (0000~0659)	728 (3.0%)	**0.300 (<0.001)**
	4. rush hours (0700~0859; 1600~1759)	9130 (37.6%)	0.032 (0.126)
	3. non rush hours (0900~1559)	7906 (32.6%)	Reference case
Accident month	1. spring/summer (Mar~Aug)	11611 (47.8%)	-0.008 (0.641)
	2. autumn/winter (Sep~Feb)	12663 (52.2%)	Reference case
Accident day of week	1. weekend (Sat~Sun)	4696 (19.3%)	**0.054 (0.012)**
	2. weekday (Mon~Fri)	19578 (80.7%)	Reference case
Motorcycle's manoeuvre	1. going straight	20315 (83.7%)	**0.065 (0.007)**
	2. traversing	3959 (16.3%)	Reference case
Speed limit	1. non built-up roads (>40mph)	3172 (13.1%)	**0.499 (<0.001)**
	2. built-up roads (<=40mph)	21102 (86.9%)	Reference case
Right-of-way violation	1. violation case	19248 (79.3%)	**0.232 (<0.001)**
	2. non violation case	4211 (17.3%)	0.151 (0.004)
	3. untraced	815 (3.4%)	Reference case
	μ_1	-1.833 (<0.001)	
	μ_2	1.272 (<0.001)	

Summary Statistics
-2 Log-likelihood at zero = 11888.956
-2 Log-likelihood at convergence = 10989.033
Log-likelihood ratio index (ρ^2) = 0.076
The number of KSI that was correctly predicted: 294 (4.4%)
The number of slight injury that was correctly predicted: 17312 (98.9%)
The number of no injury that was correctly predicted: 0 (0%)
Observations = 24274 (KSI: 27.1%; slight injury: 72.1%; no injury: 0.7%)

Table 7.17: Statistics summary and estimation results of the angle B crash model (limited to a collision where a turning car collided with a travelling-straight motorcycle at stop-controlled junctions).

Variable	Categories of each variable	Frequency (%)	Coefficients (p-value)
Gender of rider	1. male	6338 (90.6%)	0.046 (0.432)
	2. female	655 (9.4%)	Reference case
Age of rider	1. over 60	191 (2.7%)	**0.228 (0.020)**
	2. up to 19	1256 (17.9%)	-0.046 (0.318)
	3. 20-59	5546 (79.3%)	Reference case
Gender of collision partner driver	1. untraced	409 (5.8%)	0.040 (0.672)
	2. male	4309 (61.6%)	-0.005 (0.884)
	3. female	2275 (32.5%)	Reference case
Age of collision partner driver	1. untraced	817 (11.7%)	-0.256 (<0.001)
	2. over 60	936 (13.4%)	**0.110 (0.023)**
	3. up to 19	394 (5.6%)	-0.006 (0.933)
	4. 20-59	4846 (69.3%)	Reference case
Engine size	1. engine size over 125cc	5068 (72.5%)	**0.218 (<0.001)**
	2. engine size up to 125cc	1925 (27.5%)	Reference case
Collision partner	1. HGV (heavy good vehicle)	431 (6.2%)	**0.179 (0.008)**
	2. bus/coach	89 (1.3%)	-0.201 (0.184)
	3. car	6473 (92.6%)	Reference case
Number of vehicle involved	1. >=3	423 (6.0%)	**0.234 (<0.001)**
	2. two-vehicle crash	6570 (94.0%)	Reference case
Bend for motorcycle	1. bend	313 (4.5%)	-0.114 (0.152)
	2. non bend	6680 (95.5%)	Reference case
Weather condition	1. other or unknown	164 (2.3%)	-0.218 (0.069)
	2. fine weather	5829 (83.4%)	**0.067 (0.157)**
	3. bad weather	1000 (14.3%)	Reference case
Accident time	1. evening (1800~2359)	1839 (26.3%)	0.141 (0.001)
	2. midnight/early morning (0000~0659)	197 (2.8%)	**0.171 (0.090)**
	3. rush hours (0700~0859; 1600~1759)	2581 (34.0%)	0.047 (0.236)
	4. non rush hours (0900~1559)	2376 (33.9%)	Reference case
Accident month	1. spring/summer (Mar~Aug)	3353 (47.9%)	**0.044 (0.183)**
	2. autumn/winter (Sep~Feb)	3640 (52.1%)	Reference case
Accident day of week	1. weekend (Sat~Sun)	1348 (19.3%)	**0.124 (0.003)**
	2. weekday (Mon~Fri)	5645 (80.7%)	Reference case
Motorcycle's manoeuvre	1. going straight	6316 (90.3%)	0.030 (0.594)
	2. traversing	677 (9.8%)	Reference case
Speed limit	1. non built-up roads (>40mph)	893 (12.8%)	**0.381 (<0.001)**
	2. built-up roads (<=40mph)	6100 (87.2%)	Reference case
Right-of-way violation	1. violation cases	5492 (78.5%)	**0.111 (0.154)**
	2. non violation cases	1139 (16.3%)	-0.001 (0.993)
	3. untraced	362 (5.2%)	Reference case
	μ_1	-1.995 (<0.001)	
	μ_2	1.287 (<0.001)	

Summary Statistics
-2 Log-likelihood at zero = 4424.803
-2 Log-likelihood at convergence = 4175.050
Log-likelihood ratio index (ρ^2) = 0.057
The number of KSI that was correctly predicted: 8 (0.5%)
The number of slight injury that was correctly predicted: 5346 (99.9%)
The number of no injury that was correctly predicted: 0 (0%)
Observations = 6993 (KSI: 22.8%; slight injury: 76.5%; no injury: 0.7%)

Similar to the approach-turn B crash model, a benchmark case was generated in order to discuss probabilities of three injury-severity levels in angle A/B crashes. The probabilities of a benchmark sustaining three injury-severity levels are derived by holding all dummy variables to 0 (see Table 7.18 and Table 7.19). Such benchmark victim has the following characteristics:

(a) was a female
(b) was aged between 20-59
(c) was involved in a collision in which the involved motorist was female
(d) was involved in a collision in which the age of the involved motorist was aged between 20-59
(e) was riding a motorcycle with engine size up to 125cc
(f) was involved in a collision in which the crash partner was a car
(g) was involved in a two-vehicle collision
(h) was riding on the straight roadway (not on the bend)
(i) was involved in a crash in autumn/winter month
(j) was involved in a crash when the weather was adverse
(k) was involved in a crash during non rush hours
(l) was involved in a crash on weekday
(m) was involved in a crash on the built-up road
(n) was having traversing manoeuvre
(o) was involved in a crash in which the status of right-of-way violation was unknown

Table 7.18: Motorcyclist injury severity probabilities in angle A crashes.

Variable		Estimated probability			Percent change relative to benchmark case (%)		
		No injury	Slight	KSI	No injury	Slight	KSI
Benchmark case		0.0334	0.8649	0.1017			
Gender of rider	1. male	0.0312	0.8616	0.1071	-6.59	-0.38	**5.31**
Age of rider	1. 60 above	0.0219	0.84	0.1381	-34.43	-2.88	**35.79**
	2. up to 19	0.0345	0.8664	0.099	3.29	0.17	-2.65
Gender of collision partner	1. untraced	0.0294	0.8584	0.1122	-11.98	-0.75	10.32
	2. male	0.0312	0.8615	0.1073	-6.59	-0.39	**5.51**
Age of collision partner	1. untraced	0.0559	0.8792	0.0649	67.37	1.65	-36.18
	2. 60 above	0.0299	0.8594	0.1107	-10.48	-0.64	**8.85**
	3. up to 19	0.0303	0.86	0.1097	-9.28	-0.57	7.87
Engine size	1. motorcycle over 125cc	0.0231	0.8438	0.1331	-30.84	-2.44	**30.88**
No. of vehicle involved	1. >= 3	0.0205	0.8354	0.1441	-38.62	-3.41	41.69
Bend for motorcycle	1. bend	0.0318	0.8626	0.1057	-4.79	-0.27	3.93
Crash partner	1. heavy goods vehicle	0.0249	0.8487	0.1263	-25.45	-1.87	24.19
	2. bus/coach	0.0222	0.841	0.1368	-33.53	-2.76	**34.51**
Accident month	1. spring/summer (Mar~Aug)	0.034	0.8657	0.1003	1.80	0.09	-1.38
Weather Conditions	1. other or unknown	0.0307	0.8608	0.1084	-8.08	-0.47	6.59
	2. fine weather	0.028	0.8558	0.1162	-16.17	-1.05	**14.26**
Accident time	1. evening (1800~2359)	0.0236	0.8451	0.1314	-29.34	-2.29	29.20
	2. midnight; early morning (0000~0659)	0.0165	0.818	0.1655	-50.60	-5.42	**62.73**
	3. rush hours (0700~0859; 1600~1759)	0.0311	0.8614	0.1075	-6.89	-0.40	5.70
Accident day of week	1. weekend (Sat~Sun)	0.0296	0.8588	0.1116	-11.38	-0.71	**9.73**
Speed limit	1. non built-up roads	0.0099	0.7704	0.2198	-70.36	-10.93	**116.13**
Motorcycle's manoeuvre	1. going straight	0.0289	0.8574	0.1137	-13.47	-0.87	**11.80**
Right-of-way violation	1. violation case	0.0195	0.8314	0.1492	-41.62	-3.87	**46.71**
	2. not violation case	0.0236	0.8452	0.1311	-55.89	-2.28	28.91

Note: The reference case for each variable is not shown as it is taken as the benchmark victim.

Table 7.19: Motorcyclist injury severity probabilities in angle B crashes.

Variable		Estimated probability			Percent change relative to benchmark case (%)		
		No injury	Slight	KSI	No injury	Slight	KSI
Benchmark case		0.023	0.8779	0.099			
Gender of rider	1. male	0.0206	0.8721	0.1073	-10.43	-0.66	**8.38**
Age of rider	1. 60 above	0.0131	0.8421	0.1448	-43.04	-4.08	**46.26**
	2. up to 19	0.0257	0.8831	0.0913	11.74	0.59	-7.78
Gender of collision partner	1. untraced	0.0209	0.8729	0.1062	-9.13	-0.57	7.27
	2. male	0.0233	0.8785	0.0982	1.30	0.07	-0.81
Age of collision partner	1. untraced	0.041	0.8976	0.0614	78.26	2.24	-37.98
	2. 60 above	0.0176	0.8628	0.1196	-23.48	-1.72	**20.81**
	3. up to 19	0.0234	0.8786	0.098	1.74	0.08	-1.01
Engine size	1. motorcycle over 125cc	0.0135	0.844	0.1425	-41.30	-3.86	**43.94**
No. of vehicle involved	1. >= 3	0.0129	0.8409	0.1462	-43.91	-4.21	**47.68**
Bend for motorcycle	1. bend	0.03	0.8894	0.0806	30.43	1.31	-18.59
Crash partner	1. heavy goods vehicle	0.0149	0.8512	0.1339	-35.22	-3.04	**35.25**
	2. bus/coach	0.0364	0.9636	0.0684	58.26	9.76	-30.91
Accident month	1. spring/summer (Mar~Aug)	0.0207	0.8723	0.1069	-10.00	-0.64	7.98
Weather Conditions	1. other or unknown	0.0378	0.8961	0.0662	64.35	2.07	-33.13
	2. fine weather	0.0196	0.8692	0.1112	-14.78	-0.99	**12.32**
Accident time	1. evening (1800~2359)	0.0163	0.8578	0.1259	-29.13	-2.29	27.17
	2. midnight; early morning (0000~0659)	0.0152	0.8526	0.1322	-33.91	-2.88	**33.54**
	3. rush hours (0700~0859; 1600~1759)	0.0206	0.8719	0.1075	-10.43	-0.68	8.59
Accident day of week	1. weekend (Sat~Sun)	0.017	0.8605	0.1224	-26.09	-1.98	23.64
Speed limit	1. non built-up roads	0.0086	0.8073	0.1841	-62.61	-8.04	**85.96**
Motorcycle's manoeuvre	1. going straight	0.0214	0.8742	0.1044	-6.96	-0.42	**5.45**
Right-of-way violation	1. violation case	0.0176	0.8626	0.1198	-23.48	-1.74	**21.01**
	2. not violation case	0.0231	0.878	0.0989	0.43	0.01	-0.10

Note: The reference case for each variable is not shown as it is taken as the benchmark victim.

Consistent results were observed between the angle A crash model and the angle B crash model with regard to the effect of motorist's failure to yield. As shown in Table 7.18 and Table 7.19, right-of-way violation has a positive coefficient of 0.232 and 0.111 for both angle A and angle B crashes (though only at an 80% level of confidence for angle B crashes). There is a 46.71% and 21.01% increased probability of a KSI for both crash configurations relative to unknown cases (Table 7.18 and Table 7.19).

With regard to the effect of motorcycle's pre-crash manoeuvre, manoeuvres such as overtaking and changing lane (see the original categories in Table 7.12 and Table 7.13) are combined into one single manoeuvre category (i.e., traversing). This is because the combination was found to result in more statistically significant result. The estimation results (Table 7.16 and Table 7.17) show that motorcyclists that had "travelling straight" as the pre-crash manoeuvres were more injury-prone, with a positive coefficient value of 0.065 and 0.030 (with lack of statistical significance). Those travelling straight have about a 5.45% and 11.80% higher probability of KSIs in angle A and angle B crashes, relative to traversing manoeuvres (Table 7.18 and Table 7.19).

Some consistent results are observed between the angle A crash model and the angle B crash model. For example, factors found to be most significantly associated with the increased motorcyclist injury severity include elderly riders, elderly motorists, heavier motorcycles, accidents that involved three vehicles or above, and accidents that occurred during mid-night/early morning hours or on the weekends. Similar factors were also found to be correlated with the increased motorcyclist injury severity in the approach-turn B crash model (see Table 7.8 and Table 7.9).

A difference is observed for the effect of bus/coach on motorcyclist injury severity in angle A and angle B crashes. As reported in Table 7.18, an angle A crash involving a bus/coach has the greatest increase in the probability of a KSI of 34.51% (relative to a car). However, as shown in Table 7.17, an angle B crash involving a bus/coach has a negative coefficient value (though only at an 80% level of confidence for angle B crashes), with a decreased probability of 30.91% of a KSI relative to a car (Table 7.19). The cause of these contradictory findings cannot be determined with any reasonable certainty. This may be due to the difference in the crossing behaviour of a bus/coach between an angle A crash (with a need to cross-through the conflicting traffic) and an angle B crash (with a need to merge with the conflicting traffic). Further research may attempt to examine the crossing behaviour among different types of automobiles when they are in a need to cross through or merge with the conflicting traffic (particularly motorcycle).

7.2.5 Right-of-way Violation

In the course of the investigation of the factors that affect motorcyclist injury severity, it became clear that another problem, that of a right-turn motorist's failure to yield to motorcyclists, needs to be further examined. The binary logistic models are estimated to evaluate the likelihood of motorist's right-of-way violation over non right-of-way violation as a function of human, vehicle, weather/temporal, and environment factors. The theoretical framework of the binary logistic model including the model specification and method of evaluation is briefly discussed in the subsequent section. Detailed derivation of this model is provided in several studies (e.g., Long, 1997; Hosmer and Lemeshow, 2000).

The analyses here are limited to angle A crashes and approach-turn B crashes that occurred at stop-controlled junctions where a right-turn car collided with an oncoming motorcycle (see also Figure 7.2 and Figure 7.4). Estimation results of the binary logistic model for angle B crashes are found to be relatively comparable to those of the binary logistic model for angle A crashes. Thus the modelling results of angel B crashes are not reported here.

It merits mention here that the analysis is limited to the occurrences of violation and non violation cases in accidents rather than motorcyclist casualties in accidents. It is thought that analyses of motorcyclist casualties in accidents rather than the number of accidents may lead to imprecise results as one individual violation case may result in more than one motorcyclist casualty (i.e., a rider and a pillion passenger, as discussed in section 4.2.1). The accidents analysed here are also limited to those that resulted in injured motorcyclists (i.e., cases that resulted in KSIs or slight injuries). Accidents that resulted in noninjured motorcyclists are not included in the analyses. A total of

12184 approach-turn B accidents and 22447 angle A accidents are included in the analysis.

7.2.5.1 General specification of the binary logistic model

The binary logistic models are widely used if the dependent variable is dichotomous (right-of-way violation versus non right-of-way violation in this current study) in the regression equation. This model has many advantages over ordinary least-squares regression models while the dependent variable violates the assumptions of continuous or normal distribution. The logistic regression allows one to predict a binary outcome from a set of explanatory variables that may be continuous, categorical, or a mixture of the two. All explanatory variables are treated as categorical variables in this current research (see also section 4.2.2 for a discussion of the variables considered in the analysis).

In the logistic regression model, a latent variable is formulated by the following expression:

$$g(x) = \beta_0 + \beta_1 \chi_1 + \beta_2 \chi_2 + ... + \beta_j \chi_j + ... \beta_p \chi_p \quad [7.1]$$

where χ_j is the value of the j th independent variable; and β_j as the corresponding coefficient, for j =1, 2, 3... p , and is the number of independent variables.

With this latent variable, the conditional probability of a positive outcome is determined by

$$\pi(\chi) = \frac{\exp(g(\chi))}{1 + \exp(g(x))} \quad [7.2]$$

The maximum likelihood (ML) method (see the work of McCullagh, 1980, or Amemiya, 1985, for a complete discussion of ML estimation in the context of statistical and econometric models) is employed to measure the associations by constructing the likelihood function as follows:

$$l(\beta) = \prod_{i=1}^{n} \pi(\chi_i)^{y_i} (1 - \pi(\chi_i))^{1-y_i} \qquad [7.3]$$

where y_i denotes the i th observed outcome, with the value of either 0 or 1, and i =1, 2, 3,..., n, where n is the number of observations. The best estimate of β could be obtained by maximising the log likelihood expression as:

$$LL(\beta) = \ln(l(\beta)) = \sum_{i=1}^{n} \{y_i \ln(\pi(\chi_i)) + (1 - y_i)\ln(1 - \pi(\chi_i))\} \qquad [7.4]$$

The effect of attribute k on right-of-way violation could be revealed by the odds ratio (OR):

$$\text{OR}=\exp(\beta_j) \qquad [7.5]$$

An odds ratio that is greater than 1 indicates that the concerned attribute leads to a higher probability of right-of-way violation, and vice versa. Odds ratios of 1 or close to 1 suggest a neutral or weak effect. To assess the goodness-of-fit of the logistic regression model, the change in deviance can be determined by comparing the log likelihood functions between the unrestricted model and the restricted model with the following expression:

$$G = -2(LL(c) - LL(\theta)) \qquad [7.6]$$

where $LL(c)$ is the log likelihood function of the restricted model and $LL(\theta)$ is the log likelihood function of the unrestricted model. Under the null hypothesis that there are no effects of the variables included in the model, G is likelihood ratio χ^2 with p degrees of freedom (DF), where p is the number of variables considered. If G is significant at the 5% level, the null hypothesis could be rejected, and one could conclude that the proposed model generally fits well with the observed outcome.

7.2.5.2 Likelihood of right-of-way violation

The variables considered in the analysis here are those that have been included in the disaggregate OP models by approach-turn B crashes and angle A crashes (see Table 7.8 and Table 7.16). The variable "Number of vehicle involved" is not included in the analysis here because it is considered to be a postcrash event that may not have influence on the likelihood of right-of-way violation. The variable "Street light condition" is excluded from the analysis in the logistic models as it is correlated with the variable "Accident time" (see Table 7.7 and Table 7.14).

Table 7.20 and Table 7.21 report the estimation results of the binary logistic models for approach-turn B crashes and angle A crashes. For ease of interpretation, the coefficients, the p-value, and odds ratios are provided. Of 12184 approach-turn B crashes, there are 11020 observations for right-of-way violation cases (90.4%) and 1164 observations for non right-of-way violation cases (9.3%). Of 22447 observations for angle A crashes, there are 18437 observations for right-of-way violation cases (82.1%) and 4010 observations for non right-of-way violation cases (17.9%). The likelihood ratio χ^2 measures of these two models reveal that null hypothesis that there are no effects of the variables included in the models could be rejected. As for predicting each violation/non violation category, all violation cases were predicted correctly in two models, with none of non violation cases being correctly predicted.

Table 7.20: The binary logistic model of the likelihood of motorist's right-of-way violations over non right-of-way violation for approach-turn B crashes at stop-controlled junctions.

Variable		Coefficient (p-value)	Odds Ratio (OR)
Intercept		1.583 (<0.001)	
Gender of rider	1. male	0.386 (<0.001)	1.474
	2. female	Reference case	Reference case
Age of rider	1. 60 above	-0.400 (0.034)	0.670
	2. up to 19	0.108 (0.193)	1.115
	3. 20~59	Reference case	Reference case
Gender of crash partner	1. untraced	0.127 (0.567)	1.136
	2. male	0.130 (0.062)	1.141
	2. female	Reference case	Reference case
Age of crash partner	1. untraced	-0.165 (0.264)	0.848
	2. 60 above	-0.049 (0.583)	0.952
	2. up to 19	0.228 (0.098)	1.256
	3. 20~59	Reference case	Reference case
Bend for motorcycle	1. bend	-0.435 (0.006)	0.647
	2. non bend	Reference case	Reference case
Engine size	1. engine size > 125cc	0.085 (0.246)	1.088
	2. engine size up to 125cc	Reference case	Reference case
Collision partner	1. heavy good vehicle	0.057 (0.675)	1.059
	2. bus/coach	-0.108 (0.726)	0.879
	3. car	Reference case	Reference case
Accident month	1. spring/summer (Mar-Aug)	0.109 (0.085)	1.115
	2. autumn/winter (Sep-Feb)	Reference case	Reference case
Weather condition	1. other/unknown	-0.073 (0.755)	0.929
	2. fine weather	-0.016 (0.870)	0.984
	3. bad weather	Reference case	Reference case
Accident time	1. evening (1800-2359)	0.125 (0.114)	1.133
	2. midnight; early morning (0000-0659)	0.001 (0.995)	1.001
	3. rush hours (0700-0859; 1600-1759)	0.029 (0.711)	1.030
	4. non rush hours (0900-1559)	Reference case	Reference case
Accident day of week	1. weekend (Saturday~Sunday)	0.053 (0.507)	1.055
	2. weekday (Monday~Friday)	Reference case	Reference case
Speed limit	1. non built-up roads (>40mph)	0.526 (<0.001)	1.693
	2. built-up roads (<=40mph)	Reference case	Reference case
Motorcycle's manoeuvre	1. going straight	0.029 (0.811)	1.029
	2. traversing	Reference case	Reference case

Summary statistics
-2 restricted log likelihood = 2720.012
-2 unrestricted log likelihood = 2654.209
Likelihood ratio χ^2 = 65.803 (with 21 D.F., p<0.001)
The number of right-of-way violation cases that was correctly predicted: 11020 (100%)
The number of non right-of-way violation cases that was correctly predicted: 0 (0%)
Observations: 12184 (11020 observations for violation cases; 1164 observations for non violation cases)

Table 7.21: The binary logistic model of the likelihood of motorist's right-of-way violations over non right-of-way violation for angle A crashes at stop-controlled junctions.

Variable		Coefficient (p-value)	Odds Ratio (OR)
Intercept		0.851 (<0.001)	
Gender of rider	1. male	0.328 (<0.001)	1.389
	2. female	Reference case	Reference case
Age of rider	1. 60 above	-0.315 (0.002)	0.730
	2. up to 19	0.070 (0.136)	1.072
	3. 20~59	Reference case	Reference case
Gender of crash partner	1. untraced	-0.325 (0.011)	0.722
	2. male	0.074 (0.050)	1.076
	2. female	Reference case	Reference case
Age of crash partner	1. untraced	-0.031 (0.726)	0.969
	2. 60 above	0.071 (0.210)	1.074
	2. up to 19	0.018 (0.816)	1.018
	3. 20~59	Reference case	Reference case
Bend for motorcycle	1. bend	0.050 (0.529)	1.051
	2. non bend	Reference case	Reference case
Engine size	1. engine size > 125cc	0.034 (0.419)	1.035
	2. engine size up to 125cc	Reference case	Reference case
Collision partner	1. heavy good vehicle	0.263 (0.002)	1.301
	2. bus/coach	0.327 (0.148)	1.387
	3. car	Reference case	Reference case
Accident month	1. spring/summer (Mar-Aug)	0.079 (0.026)	1.083
	2. autumn/winter (Sep-Feb)	Reference case	Reference case
Weather condition	1. other/unknown	0.152 (0.261)	1.164
	2. fine weather	-0.076 (0.142)	0.927
	3. bad weather	Reference case	Reference case
Accident time	1. evening (1800-2359)	0.223 (<0.001)	1.250
	2. midnight; early morning (0000-0659)	0.292 (0.010)	1.340
	3. rush hours (0700-0859; 1600-1759)	0.021 (0.612)	1.022
	4. non rush hours (0900-1559)	Reference case	Reference case
Accident day of week	1. weekend (Saturday~Sunday)	0.092 (0.053)	1.096
	2. weekday (Monday~Friday)	Reference case	Reference case
Speed limit	1. non built-up roads (>40mph)	0.292 (<0.001)	1.339
	2. built-up roads (<=40mph)	Reference case	Reference case
Motorcycle's manoeuvre	1. going straight	0.224 (<0.001)	1.252
	2. traversing	Reference case	Reference case

Summary statistics
-2 restricted log likelihood = 6042.978
-2 unrestricted log likelihood = 5840.598
Likelihood ratio χ^2 = 202.380 (with 21 D.F., p<0.001)
The number of right-of-way violation cases that was correctly predicted: 18437 (100%)
The number of non right-of-way violation cases that was correctly predicted: 0 (0%)
Observations: 22447 (18437 observations for violation cases; 4010 observations for non violation cases)

The estimation results revealed that for both crash configurations, male riders (OR=1.474, p<0.001; OR=1.389, p<0.001) were more likely to experience a violation case than female riders; and younger riders (OR=1.115, p=0.193; OR=1.072, p=0.148) were more prone to experience a violation case than mid-aged motorcyclists, as shown in Table 7.20 and Table 7.21. Younger motorists in approach-turn B crashes were 1.256 times more likely to violate motorcycle's right-of-way than mid-aged motorists (Table 7.20), whilst such effect was not significant for angle A crashes (Table 7.21). Elderly motorists in angle A crashes were most likely of all age groups to infringe upon motorcycle's right-of-way (OR=1.074, p=0.210) (Table 7.21). Male motorists were 1.141 and 1.076 times more prone than female motorists to commit right-of-way violations in both approach-turn B crashes and angle A crashes (Table 7.20 and Table 7.21).

In addition to gender-/age-specific determinants of motorist's failure to yield, other factors such as temporal factors, roadway factors were examined. An approach-turn B crash that occurred during evening hours has the greatest increase in the probability of a violation case of 13% (OR=1.133, p=0.114) relative to no rush hours (Table 7.20). An angle A collision that occurred during midnight/early morning hours has the greatest increase in the probability of a violation case of 34% (OR=1.340, p=0.010) relative to no rush hours (Table 7.21).

With regard to the effect of motorcycle's collision partner, professional motorists (i.e., HGV or bus/coach driver) were about 1.30 times (OR=1.301, p=0.002 for HGV; OR=1.387, p=0.148 for bus/coach) more likely than passenger car drivers to fail to yield in angle A crashes (Table 7.21), although such effect was not significant for approach-turn B crashes (Table 7.20).

Regarding the effect of speed limit, riding on non built-up roadways were 1.693 times (for approach-turn B crashes, as reported in Table 7.20) and 1.339 times (for angle A crashes, as reported in Table 7.21) more likely than riding on built-up roadways to experience right-of-way violations.

With regard to the effect of motorcycle's pre-crash manoeuvre, a travelling-straight motorcycle was 1.252 times (OR=1.252, p<0.001) more likely than a traversing motorcycle to experience a violation case in angle A crashes (Table 7.21). Such effect was not significant for approach-turn B crashes (Table 7.20).

The estimation results of two binary models could be used to enhance enforcement efforts as well as public information and safety education programmes to curb motorists' failure to yield. For instance, safety education programmes may be directed toward certain drivers such as male motorists and young motorists, or drivers of heavier vehicles. Enforcement efforts may need to be directed towards certain times and locations where right-of-way violations are more likely to occur (e.g., during evening/nighttime and on non built-up roads). Several studies have reported that enforcement by police near a junction makes turning motorists more cautious (e.g., Cooper and McDowell, 1977; Storr et al., 1980). It is clear here such temporal factors (i.e., evening/midnight/early morning) and location factors (non built-up roads) need to be taken into consideration in the implementation of police-enforcement strategies meant to curb motorcycle-car crashes that result from right-of-way violations.

The result that motorists on non built-up roads were more likely than those on built-up roads to violate motorcycle's right of way may deserve further discussions. This may be a consequence of higher motorcycle speed on non built-up roadways. The following studies may lend support for the reasoning here:

Statistics from DfT (2006b) has revealed several phenomenons about the speed distributions by motorcycles and automobiles – it was found that average motorcycle speeds are generally slightly higher than average automobile speed on the same types of road. Specifically, about a quarter of motorcyclists exceed the speed limit by more than 10mph on motorways and dual carriageways, while around one in ten exceed the limit by more than 10mph on other roads. In a study by Brenac et al. (2006), the mean speed of the motorcycle involved in conspicuity-related accidents was found to be significantly higher than that in non conspicuity-related collisions. Brenac et al., together with Kim and Boski (2001), suggested that motorcycle's poor conspicuity may be exacerbated with higher speed, which may decrease their detectability from a turning motorist's perspective. Peek-Asa and Kraus (1996a) specifically discussed speeding effect on the occurrences of approach-turn crashes. They found that for approach-turn crashes, a motorcycle striking a turning car (i.e., a right-of-way violation case) was more prone to be speeding than a motorcycle struck by a turning car (i.e., a non right-way-way violation case). They pointed out that the turning motorist might have not been able to correctly judge the speed of the approaching motorcycle and might have not been able to clear the junction in time to avoid a crash. They suggested that controlling motorcycle speed may decrease the number of such crash type.

Motorists' higher speeds arising from higher speed limits may also result in themselves failing to yield to motorcycles. This hypothesis may be supported by Summala and his colleagues (see, for example, Räsänen and Summala, 2000; Summala et al., 1996) who analysed automobile-bicycle accidents at roundabouts. They reported that higher vehicle approach speed contributed to motorists not looking to their right or not giving way to bicyclists at roundabouts. They further pointed out that speed-reducing countermeasures may enable a turning driver to have more time in searching a bicyclist travelling from the right. The findings of Summala and his colleagues were specific to automobile-bicycle accidents at roundabouts rather than motorcycle-car accidents at T-junctions. Nonetheless, their findings may provide additional insight into the possibility that motorists' higher speeds that arise from higher speed limits may also result in themselves failing to yield to motorcycles.

7.2.6 Summary

This chapter firstly attempted to investigate the distribution of motorcyclist injury severity by the interaction of approach-turn crashes/angle crashes and junction control measures. Angle crashes were further classified into five crash patterns depending on the pre-crash manoeuvres of the involved motorcycles and cars. Injuries to motorcyclists appeared to be greatest in approach-turn A crashes at signalised junctions and in approach-turn B crashes at stop-controlled junctions (Table 7.1). For approach-turn B crashes, the most severe crash pattern identified was a crash in which a right-turn car pulled out into the path of an approaching motorcycle. Such a right-turn car was assumed to have violated the motorcycle's right-of-way. In addition, right-of-way violations by right-turn motorists were found to lead to the most motorcycle-car approach-turn B crashes and predispose riders to a greater risk of KSIs (Table 7.8 and Table 7.9).

Similar effects were observed for those involved in angle A/B crashes. Injuries to motorcyclists appeared to be greatest in angle A crashes and angle B crashes in which a turning car from the minor road collided with an oncoming motorcycle from the major road (while stop, give-way signs and markings were present at accident locations) (Table 7.3 and Table 7.4). A right-/left-turn motorist (from minor road) intending to cross-through/merge with the conflicting traffic was found to frequently fail to yield to an approaching motorcyclist (Table 7.16 and Table 7.17). Motorcyclists appeared to be more injurious in such right-of-way-violation cases than those in non right-of-way violation cases (see Table 7.16 to Table 7.19).

The binary logistic models were subsequently estimated to explain the likelihood of motorists' failure to yield as a function of human, weather, roadway and vehicle factors. Specific human features such as gender and age of the motorists, and temporal factors such as time of accidents, were found to be significant in explaining the likelihoods of right-of-way violations. Noteworthy findings for both approach-turn B crashes and angle A crashes include that violation cases were more likely to occur on non built-up roadways, and during evening/midnight/early morning hours (Table 7.20 and Table 7.21).

The next section presents an analysis of the factors that affect motorcyclist injury severity resulting from motorcycle-car head-on crashes.

7.3 Head-on Crash

7.3.1 Introduction

The aggregate model (see Table 6.2 in section 6.3) has revealed that riders in head-on crashes were more likely to be KSI than riders in other crashes except for approach-turn B crashes. There has been a great deal of research (see Chapter 2 for a review of relevant studies) analysing car-car head-on crashes, of which much has focused on examining what factors were correlated with the occurrences of or consequences of such crash type that occurred either on undivided roadways (e.g., Deng et al., 2006) or intersections (e.g., Ulfarsson et al., 2006). Explorations of the factors affecting motorcyclist injury severity resulting from head-on crashes, however, have been fairly limited in literature. This section attempts to identify the determinants of motorcyclist injury severity resulting from head-on crashes that occurred at T-junctions.

The remainder of this section proceeds with a description of motorcycle-car head-on crashes. The descriptive analysis is then conducted to examine the distribution of motorcyclist injury severity by the variables of primary interest. This is followed by a multivariate examination of the determinants of motorcyclist injury severity in head-on crashes. The section ends with a summary of the research findings.

7.3.2 Model Specification

A motorcycle-car head-on crash is defined as a crash in which a motorcycle and car originally travelling from opposite directions collided with each other (e.g., a motorcycle travelling eastwards collided with a car travelling westwards), as illustrated in Figure 4.4(c). It is worth mentioning here that the analyses are not limited to the collisions where the front of the motorcycle was the first collision point. Instead, other combinations of the first crash point such as the front of a car and the nearside of a motorcycle are also included in the analyses. This is because motorcycles that are capable of swerving prior to the crash may have other crash parts (e.g., nearside, offside instead of front) as first crash point (Obenski et al., 2007). Data that were removed include missing data and unreliable data. Examples of unreliable data include a crash in which either the car or motorcycle did not impact at all.

There is evidence in the literature (e.g., Mizuno and Kajzer, 1999; Ulfarsson et al., 2006) that unintended/intended lane changing manoeuvres on curved roads were linked with a strong increase in the probability of head-on crashes. The presence of curves on the roadways and the pre-crash manoeuvres of motorcycles and cars are therefore the variables of particular interest.

The descriptive analysis is firstly conducted to examine the distribution of motorcyclist injury severity by the presence of bend, as well as the manoeuvres of motorcycles and cars. Table 7.22 and Table 7.23 report the distribution of motorcyclist injury severity by the presence of bend for motorcycle/car. The statistics in Table 7.22 and Table 7.23 show that riders were more likely to be KSI when there were bends for motorcycles or for cars (42.3% and 44.3%).

Table 7.22: Distribution of motorcyclist injury severity by the presence of bend for motorcycles in head-on crashes.

The presence of bend	No injury	Slight injury	KSI	Total (% of total)
Bend	7 (0.9%)	447 (56.8%)	**333 (42.3%)**	787 (21%)
Non bend	53 (1.8%)	1982 (67.1%)	919 (31.1%)	2954 (79.0%)
Total	**60 (1.6%)**	**2429 (64.9%)**	**1252 (33.5%)**	**3741 (100%)**

Table 7.23: Distribution of motorcyclist injury severity by the presence of bend for cars in head-on crashes.

The presence of bend	No injury	Slight injury	KSI	Total (% of total)
Bend	8 (1.2%)	364 (54.5%)	**296 (44.3%)**	668 (17.9%)
Non bend	52 (1.7%)	2065 (67.2%)	956 (31.1%)	3073 (82.1%)
Total	**60 (1.6%)**	**2429 (64.9%)**	**1252 (33.5%)**	**3741 (100%)**

Table 7.24 reports the distribution of motorcyclist injury severity by the interaction of the presence of bend for motorcycles and cars. The descriptive data in Table 7.24 reveal that riders in general were least likely to be KSI when there was absence of bend for motorcycles and cars (30.6% of the injuries were KSIs for accidents where there was no bend for motorcycles and cars). It was found that injuries were greatest in head-on collisions in which motorcycles travelling on non bends collided with cars travelling on bends (as much as 47.3% of the injuries were KSIs).

Table 7.24: Distribution of motorcyclist injury severity by the interaction of the presence of bend for motorcycles and cars in head-on crashes.

Interaction of the presence of bend for motorcycles and cars	No injury	Slight injury	KSI	Total (% of total)
Bend * bend	6 (1.0%)	317 (55.1%)	252 (43.8%)	575 (15.4%)
Bend * non bend	1 (0.5%)	130 (61.3%)	81 (38.2%)	212 (5.7%)
Non bend * bend	2 (2.2%)	47 (50.5%)	**44 (47.3%)**	93 (2.5%)
Non bend * non bend	51 (1.8%)	1935 (67.6%)	875 (30.6%)	2861 (76.5%)
Total	**60 (1.6%)**	**2429 (64.9%)**	**1252 (33.5%)**	**3741 (100%)**

Table 7.25 and Table 7.26 present the distribution of motorcyclist injury severity by motorcycle's manoeuvre and car's manoeuvre respectively. The manoeuvres examined include changing lane, overtaking, and travelling straight. The statistics show that injuries were greatest when motorcyclists were overtakers (34.6% of the injuries were KSIs, as shown in Table 7.25), and when cars were travelling straight (34.1% of the injuries were KSIs, as shown in Table 7.26). This may be as a result of motorbikes being at acceleration modes while overtaking other vehicles.

Table 7.25: Distribution of motorcyclist injury severity by motorcycle's manoeuvre.

Manoeuvre	No injury	Slight injury	KSI	Total (% of total)
Changing lane	1 (1.7%)	25 (69.4%)	10 (27.8%)	36 (1.0%)
Overtaking	9 (1.7%)	346 (63.7%)	**188 (34.6%)**	543 (14.5%)
Travelling straight	50 (1.6%)	2058 (65.1%)	1054 (33.3%)	3162 (84.5%)
Total	**60 (1.6%)**	**2429 (64.9%)**	**1252 (33.5%)**	**3741 (100%)**

Table 7.26: Distribution of motorcyclist injury severity by car's manoeuvre.

Manoeuvre	No injury	Slight injury	KSI	Total (% of total)
Changing lane	1 (0.9%)	86 (73.5%)	30 (25.6%)	117 (3.1%)
Overtaking	3 (0.9%)	222 (69.4%)	95 (29.7%)	320 (8.6%)
Travelling straight	56 (1.7%)	2121 (64.2%)	**1127 (34.1%)**	3304 (88.1%)
Total	**60 (1.6%)**	**2429 (64.9%)**	**1252 (33.5%)**	**3741 (100%)**

Table 7.27 reports the distribution of motorcyclist injury severity by the interaction of the manoeuvres of motorcycles and cars prior to accidents. It should be noted here that in Table 7.27, the manoeuvres "changing lane" and "overtaking" were merged into one single manoeuvre "traversing manoeuvre". This is because in the multivariate analysis through the use of the OP model of motorcyclist injury severity, changing lane and overtaking were found to yield less statistically significant results than grouping lane changing and overtaking together into one category. As a result, the two manoeuvre groups (traversing and travelling straight) were considered to be more appropriate than three manoeuvre groups (overtaking, changing lane, and travelling straight). The descriptive statistics in Table 7.27 show that injuries to motorcyclists were greatest in head-on collisions in which a traversing motorcycle collided with a travelling-straight car (35.2% of the injuries were KSIs).

Table 7.27: Distribution of motorcyclist injury severity by the interaction of the manoeuvres of motorcycles and cars in head-on crashes.

Interaction of the manoeuvres of motorcycles and cars	No injury	Slight injury	KSI	Total (% of total)
Traversing * traversing	1 (1.5%)	49 (72.1%)	18 (26.5%)	68 (1.8%)
Traversing * straight	9 (1.8%)	322 (63.0%)	**180 (35.2%)**	511 (13.7%)
Straight * traversing	3 (0.8%)	259 (70.2%)	107 (29.0%)	369 (9.9%)
Straight * straight	47 (1.8%)	1799 (64.4%)	947 (33.9%)	2793 (74.7%)
Total	**60 (1.6%)**	**2429 (64.9%)**	**1252 (33.5%)**	**3741 (100%)**

In addition to the variables of interest (i.e., the presence of bend, pre-crash manoeuvres), the variables examined in the aggregate model (see Table 6.2 in section 6.3) are incorporated into the disaggregate model of head-on crashes. These variables include rider/motorist factors, vehicle factors, weather/temporal factors, and roadway/geometric characteristics.

A correlation matrix among the variables was reported (see Table 7.28) to assess the presence of multicollinearity. Similar to the models of approach-turn B crashes, and angle A/B crashes (see Table 7.7, Table 7.14, and Table 7.15), multicollinearity was found to exist between the variable "street light condition" and "time of accident", with a correlation value of 0.572. For each of these two variables that are highly correlated with each other, a model run was calibrated and the most significant variable, which is "time of accident", is retained in the analysis.

Table 7.28: Correlation matrix between the variables in the head-on crash model.

variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1. engine size	1	0.001	0.074	-0.039	0.072	0.056	0.167	-0.368	0.015	-0.045	0.068	0.072	0.036	-0.058	0.158	-0.037	-0.071	0.035
2. motorcycle manoeuvre		1	-0.214	0.003	-0.121	-0.006	0.002	-0.012	-0.019	-0.038	0.069	0.001	-0.025	-0.020	-0.044	-0.029	-0.015	-0.014
3. bend for motorcycle			1	-0.117	**0.744**	0.035	0.035	-0.011	-0.043	-0.050	-0.081	0.112	0.099	-0.039	0.330	0.130	-0.134	0.036
4. car manoeuvre				1	-0.159	-0.015	-0.031	-0.012	0.043	0.011	0.006	-0.021	-0.054	0.063	-0.086	-0.001	0.078	0.004
5. bend for car					1	0.041	0.023	0.008	-0.047	-0.045	-0.062	0.092	0.074	-0.029	0.343	0.112	-0.104	0.021
6. crash partner						1	0.027	-0.009	0.155	-0.043	0.024	0.012	-0.091	-0.088	0.056	-0.010	-0.075	-0.005
7. rider gender							1	-0.012	-0.023	-0.013	0.015	0.029	0.031	-0.004	0.023	-0.028	-0.011	0.023
8. rider age								1	-0.020	0.001	-0.045	-0.016	0.022	0.019	-0.080	0.079	-0.008	-0.023
9. motorist gender									1	0.324	-0.009	-0.027	-0.048	0.054	-0.001	-0.050	0.079	-0.032
10. motorist age										1	-0.048	-0.023	-0.042	0.054	-0.030	-0.013	0.078	0.004
11. number of vehicle involved											1	-0.019	0.016	-0.008	0.043	-0.025	-0.010	-0.006
12. month												1	0.066	-0.002	0.109	0.040	-0.271	0.088
13. week day													1	-0.101	0.110	0.044	-0.087	0.036
14. time of day														1	-0.068	-0.011	**0.572**	-0.014
15. speed limit															1	0.101	-0.162	0.023
16. control measure																1	-0.066	0.025
17. light condition																	1	-0.090
18. weather																		1

The variable "bend for motorcycle" was also correlated with the variable "bend for car", with a correlation value of 0.744 (Table 7.28). For each of these two variables that are highly correlated with each other, similarly a model run was calibrated and the most significant variable, which is "Bend for car", is retained in the analysis.

The subsequent section presents a multivariate examination of the determinants of motorcyclist injury severity in head-on crashes (i.e., controlling for all factors that influence motorcyclist injury severity) using the OP model.

7.3.3 Estimation Results

Table 7.29 reports the estimation results of the head-on crash model. A total of 3741 motorcyclist casualties resulting from head-on collisions at T-junctions were extracted from the Stats19 over the period of years 1991-2004. Of 3741 motorcyclist casualties, 33.5% are classified as KSI, 64.9% are classified as slight injury, and 1.6% are classified as no injury. The model has a pseudo-R^2 measure of 0.061. As for predicting each injury-severity category, the classification accuracy for KSI, slight injury, and no injury was 20.4%, 93.4%, and 0%.

Table 7.29: Statistics summary and estimation results of the head-on crash model.

Variables	Categories	Frequency (%)	Coefficient (p-value)
Gender of rider	1. male	3524 (94.2%)	0.060 (0.505)
	2. female	217 (5.8%)	Reference case
Age of rider	1. 60 above	63 (1.7%)	-0.017 (0.915)
	2. up to 19	944 (25.2%)	-0.101 (0.054)
	3. 20~59	2734 (73.1%)	**Reference case**
Gender of collision partner	1. untraced	185 (4.9%)	-0.070 (0.610)
	2. male	2608 (69.7%)	**0.113 (0.020)**
	3. female	948 (25.3%)	Reference case
Age of collision partner	1. untraced	319 (8.5%)	-0.199 (0.051)
	2. 60 above	338 (9.0%)	-0.026 (0.717)
	3. up to 19	198 (5.3%)	-0.117 (0.209)
	4. 20~59	2886 (77.1%)	**Reference case**
Bend for car	1. bend	668 (15.4%)	**0.172 (0.003)**
	2. non bend	3073 (82.1%)	Reference case
Engine size	1. engine size > 125cc	2763 (73.9%)	**0.092 (0.081)**
	2. engine size up to 125cc	978 (26.1%)	Reference case
Number of vehicle involved	1. >=3	711 (19.0%)	**0.164 (0.002)**
	2. two-vehicle crash	3030 (81.0%)	Reference case
Collision partner	1. heavy goods vehicle	311 (8.3%)	**0.264 (<0.001)**
	2. bus/coach	109 (2.9%)	0.132 (0.281)
	3. car	3321 (88.8%)	Reference case
Accident month	1. spring/summer (Mar~Aug)	2094 (56.0%)	-0.029 (0.497)
	2. autumn/winter (Sep~Feb)	1647 (44.0%)	Reference case
Junction control measure	1. uncontrolled	684 (18.3%)	0.332 (0.024)
	2. stop, give-way signs or marking	2970 (79.4%)	**0.427 (0.002)**
	3. automatic signal	87 (2.3%)	Reference case
Weather condition	1. other/unknown	67 (1.8%)	-0.040 (0.806)
	2. fine weather	3198 (85.5%)	**0.110 (0.077)**
	3. bad weather	476 (12.7%)	Reference case
Accident time	1. evening (1800~2359)	1111 (29.7%)	0.192 (<0.001)
	2. midnight; early morning (0000~0659)	136 (3.6%)	**0.490 (<0.001)**
	3. rush hours (0700~0859; 1600~1759)	1055 (28.2%)	0.010 (0.840)
	4. non rush hours (0900~1559)	1439 (38.5%)	Reference case
Accident day of week	1. weekend (Saturday~Sunday)	1074 (28.7%)	**0.079 (0.088)**
	2. weekday (Monday~Friday)	2667 (71.3%)	Reference case
Speed limit	1. non built-up roads (>40mph)	667 (17.8%)	**0.483 (<0.001)**
	2. built-up roads (<=40mph)	3074 (82.2%)	Reference case
Interaction effect of motorcycle's and vehicle's manoeuvres	1. traversing * traversing	68 (1.8%)	-0.110 (0.480)
	2. traversing * straight	511 (13.7%)	**0.081 (0.183)**
	3. straight * traversing	369 (9.9%)	0.006 (0.935)
	4. straight * straight	2793 (74.7%)	Reference case
	μ_1	-1.312 (<0.001)	
	μ_2	1.355 (<0.001)	

Summary Statistics
-2 Log-likelihood at zero = 3967.295
-2 Log-likelihood at convergence = 3727.382
Log-likelihood ratio index (ρ^2) = 0.061
The number of KSI that was correctly predicted: 255 (20.4%)
The number of slight injury that was correctly predicted: 2268 (93.4%)
The number of no injury that was correctly predicted: 0 (0%)
Observations = 3741 (KSI: 33.5%; slight injury: 64.9%; no injury: 1.6%)

Similar to the models that have been calibrated in previous sections (see the models of motorcycle-car accidents in whole, approach-turn B crashes, and angle A crashes in section 6.3, section 7.2.3.2, and section 7.2.4.2), a benchmark case was generated in order to discuss probabilities of three injury-severity levels in head-on crashes. The probabilities of a benchmark sustaining three injury-severity levels are derived by holding all dummy variables to 0 (see Table 7.30). Such benchmark victim has the following characteristics:

(a) was a female
(b) was aged between 20-59
(c) was involved in a collision in which the involved motorist was female
(d) was involved in a collision in which the age of the involved motorist was aged between 20-59
(e) was riding a motorcycle with engine size up to 125cc
(f) was involved in a collision in which the crash partner was a car
(g) was involved in a two-vehicle collision
(h) was involved in a collision where her collision partner was travelling on the straight road (not on the bend)
(i) was involved in a crash in autumn/winter month
(j) was involved in a crash when the weather was adverse
(k) was involved in a crash during non rush hours
(l) was involved in a crash on weekday
(m) was involved in a crash on the built-up road
(n) was involved in a crash in which she was travelling straight and her crash partner was travelling straight at the same time

Table 7.30: Motorcyclist injury severity probabilities in head-on crashes.

Variable		Estimated probability			Percent change relative to benchmark case (%)		
		No injury	Slight	KSI	No injury	Slight	KSI
Benchmark case		0.0948	0.8175	0.0877			
Gender of rider	1. male	0.085	0.8173	0.0977	-10.34	-0.02	11.40
Age of rider	1. 60 above	0.0977	0.8173	0.085	3.06	-0.02	-3.08
	2. up to 19	0.1129	0.8144	0.0727	19.09	-0.38	-17.10
Gender of collision partner	1. untraced	0.1071	0.8158	0.0771	12.97	-0.21	-12.09
	2. male	0.0771	0.8158	0.1071	-18.67	-0.21	**22.12**
Age of collision partner	1. untraced	0.1329	0.807	0.0604	40.19	-1.28	-31.13
	2. 60 above	0.0992	0.8171	0.0836	4.64	-0.05	-4.68
	3. up to 19	0.116	0.8134	0.0705	22.36	-0.50	-19.61
Engine size	1. motorcycle over 125cc	0.0802	0.8165	0.1033	-15.40	-0.12	**17.79**
No. of vehicle involved	1. >= 3	0.07	0.8132	0.1168	-26.16	-0.53	**33.18**
Bend for car	1. bend	0.0689	0.8127	0.1184	-27.32	-0.59	**35.01**
Crash partner	1. heavy goods vehicle	0.0575	0.4048	0.1376	-39.35	-50.48	**56.90**
	2. bus/coach	0.0743	0.815	0.1107	-21.62	-0.31	26.23
Accident month	1. spring/summer (Mar~Aug)	0.0997	0.8171	0.0832	5.17	-0.05	-5.13
Control measure	1. uncontrolled	0.0501	0.7968	0.1532	-47.15	-2.53	74.69
	2. stop, give-way signs or marking	0.041	0.7828	0.1767	-56.75	-4.24	**101.48**
Weather conditions	1. other or unknown	0.1017	0.8168	0.0815	7.28	-0.09	-7.07
	2. fine weather	0.0775	0.8159	0.1066	-18.25	-0.20	21.55
Accident time	1. evening (1800~2359)	0.0663	0.8113	0.1224	-30.06	-0.76	39.57
	2. midnight; early morning (0000~0659)	0.0358	0.7707	0.1935	-62.24	-5.72	**120.64**
	3. rush hours (0700~0859; 1600~1759)	0.0931	0.8176	0.0893	-1.79	0.01	1.82
Accident day of week	1. weekend (Sat~Sun)	0.0821	0.8169	0.101	-13.40	-0.07	**15.17**
Speed limit	1. non built-up roads	0.0363	0.7721	0.1916	-61.71	-5.55	**118.47**
Interaction of motorcycle's and car's manoeuvres	1. traversing * traversing	0.1169	0.8139	0.0715	23.31	-0.44	-18.47
	2. traversing * straight	0.1818	0.8169	0.1013	91.77	-0.07	**15.51**
	3. straight * traversing	0.0938	0.8176	0.0887	-1.05	0.01	1.14

Note: The reference case for each variable is not shown as it is taken as the benchmark victim.

The effects human factors have on motorcyclist injury severity were estimated. Fairly different results regarding the effects of human factors, while compared with those of the aggregate model for accidents in whole (Table 6.2 and Table 6.3 in section 6.3), were observed. For example, mid-aged motorcyclists in head-on crashes tended to be more injurious than other age groups that have negative coefficient values (Table 7.29). Riders were most likely to be KSI while they collided with mid-aged motorists (see the negative coefficient values for other age groups in Table 7.29). With regard to the effect of rider/motorist gender, no variation was found for rider gender due to its lack of statistical significance. However, male motorists have a positive coefficient of 0.113 (Table 7.29). The probability of a KSI in a collision with a male motorist is 22.12% higher (Table 7.30).

The effects of other explanatory variables appeared to be fairly similar to those of the aggregate model (see Table 6.2 and Table 6.3 in section 6.3). As reported in Table 7.29, factors that were most significantly associated with the increased motorcyclist injury severity include heavier motorcycle engine size (coefficient value=0.092, p-value=0.081), HGVs as collision partners (coefficient value=0.264, p-value<0.001), accidents that occurred at stop-controlled junctions (coefficient value=0.427, p-value=0.002), riding on non built-up roads (coefficient value=0.483, p-value<0.001), and during mid-night/early morning hours (coefficient value=0.490, p-value<0.001). These results are not surprising. For instance, HGVs that have higher compartment may run over the riders involved in head-on collisions, resulting in more severe injuries to riders than a car. For mid-night/early morning riding conditions, there might be much more alcohol use and speeding during this period (Broughton, 2005; Pai and Saleh, 2007b). Collision impact that arises from opposite directions (e.g., a car travelling eastwards collided with a motorcycle travelling westwards) can thus be higher.

The bend effect is measured relative to roadways without bend. Only the variable “bend for car” was included in the analysis as the variable “bend for motorcycle” was found to be correlated with the variable “bend for car”. As shown in Table 7.29, motorcyclists tended to be more injurious when there were bends for cars, with a coefficient of 0.172. The presence of bend for a car has a 35.01% increase in the probability of a KSI, relative to the absence of bend for a car (Table 7.30). The likely explanation for this effect is that bends on roadways may overtax either riders or motorists in following the curving alignment, thereby reducing the sight distance and the ability of riders and/or motorists to detect the oncoming traffic travelling along the curve. This is also likely to be the consequence of either the car or motorcycle that travels beyond the centreline in order to reduce the centrifugal force, as shown in Figure 7.5. A collision that results from an unintended/intended movement into the oncoming traffic may therefore be unexpected and severe.

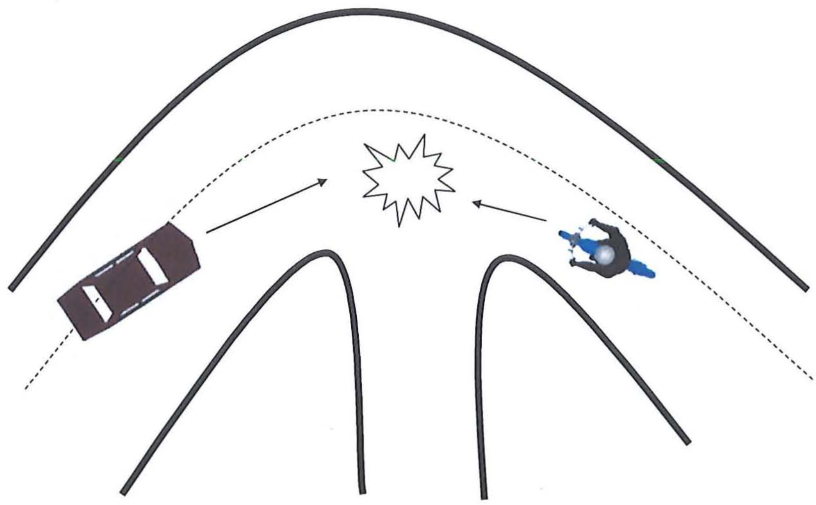


Figure 7.5: Schematic diagram of a head-on crash in which a car travelling beyond the centreline (in order to reduce the centrifugal force) collided with an oncoming motorcycle.

The interaction effects of the pre-crash manoeuvres of motorcycles and cars on motorcyclist injury severity were investigated. As reported in Table 7.29, injuries to riders were greatest in a head-on crash in which a traversing motorcycle collided with a travelling-straight car, though only at an 80% confidence level. The probability of a KSI increases by 15.51% under such circumstance relative to a crash in which a travelling-straight motorcycle collided with a travelling-straight car (Table 7.30). Speed might be one of the likely explanations for this effect. Which is, higher speed of a travelling-straight car (relative to a traversing car) may act synergistically with the sudden appearance of a traversing motorcycle (that may originally be blocked by other traffic) to increase motorcyclist injury severity.

7.3.4 Summary

This section presented the estimation results of the motorcycle-car head-on crash model. The factors that affected motorcyclist injury severity resulting from head-on crashes have been successfully identified. Specifically, the modelling results revealed some combined effects that predisposed riders to a greater risk of KSIs. For instance, there is evidence that riders were more injury-prone when curves were present for cars than when there was no curvature at all for cars. In addition, injuries were greatest in a head-on crash in which a traversing motorcycle collided with a travelling-straight car (see Table 7.29 and Table 7.30).

The next section presents an analysis of the factors that influence motorcyclist injury severity resulting from same-direction crashes.

7.4 Same-direction crash

7.4.1 Introduction

Although the descriptive analysis (Table 5.3 in section 5.4) and the aggregate crash model (Table 6.2 in section 6.3) showed that riders in same-direction crashes were the least likely of all crash configurations to be KSI (18.4% of the injuries were KSIs), such crash configuration accounted for one-third of all motorcycle-car accidents at T-junctions (31.3% of all casualties were as a result of same-direction collisions). See Figure 4.4(d) in section 4.3 for a schematic diagram of a same-direction crash. Therefore it is worth identifying the hazardous factors that are most significantly associated with the increased motorcyclist injury severity in this crash configuration.

In this section, motorcycle-car same-direction crashes are subdivided into sideswipe crashes and rear-end crashes. This section attempts to identify the determinants of motorcyclist injury severity resulting from motorcycle-car same-direction crashes, focusing on the effects of the pre-crash manoeuvres by motorcycles and cars, as well as different junction control measures. These factors (i.e., pre-crash manoeuvres and junction control measures) have been found to contribute to the occurrences of car-car sideswipe crashes (e.g., Chovan et al., 1994; Li and Kim, 2000) or car-car rear-end crashes (e.g., Abdel-Aty and Abdelwahab, 2003, 2004; Wang and Abdel-Aty, 2006). It is hypothesised in this current study that these factors may play a part in affecting motorcyclist injury severity resulting from these two crash configurations.

The remainder of this section proceeds with a description of the crash typology for sideswipe and rear-end collisions. The descriptive analysis is then conducted to examine the distribution of motorcyclist injury severity by the variables of interest (e.g., pre-crash manoeuvres and junction control measures). This is followed by a multivariate examination of the determinants of motorcyclist injury severity in sideswipe crashes and rear-end crashes. The modelling results by sideswipe and rear-end crashes are provided separately. The section ends with a summary of the research findings.

7.4.2 Classification of Same-Direction Crashes

A same-direction collision is classified into six crash manners, depending on the first point of impact of the motorcycle and car. The variable "First Point of Impact" that is readily available in the Stats19 provides the information on the first crash point of the involved car and motorcycle (see Figure 7.6). A schematic diagram of six crash manners that are classified from same-direction collisions is provided in Table 7.31. The classification of these six crash manners that are based on the first point of impact is also explained in Table 7.31, with the frequency of each crash manner.

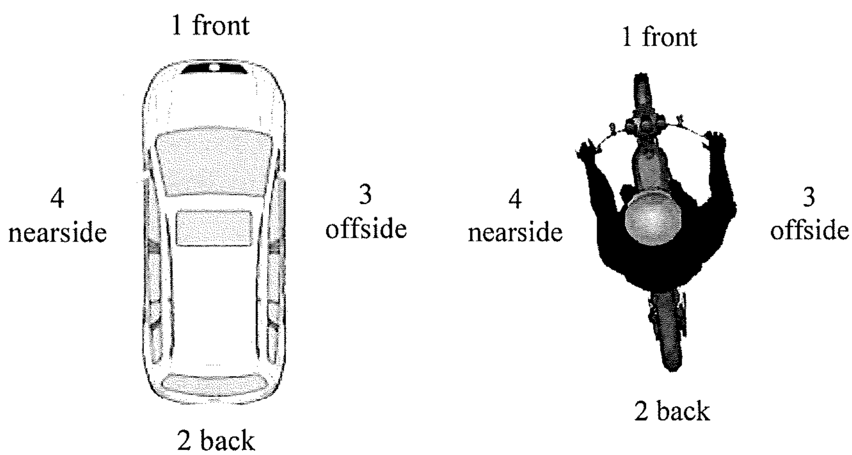
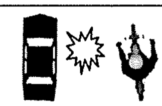
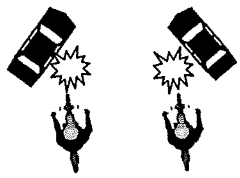
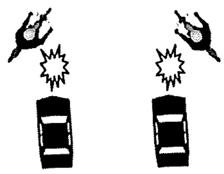
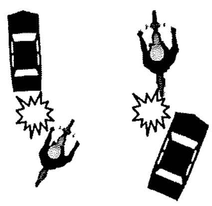


Figure 7.6: Illustration of the first crash point of car and motorcycle in the Stats19 for the classification of sideswipe and rear-end crash.

Table 7.31: The classification of the six crash manners that are based on the first points of impact of the involved motorcycle and car in same-direction crashes.

Crash manner	First point of impact of a motorcycle	First point of impact of a car	Frequency (%)
a. 	nearside/offside	nearside/offside	6261 (18.0%)
b. 	front	nearside/offside	11056 (31.8)
c. 	nearside/offside	front	1483 (4.3%)
d. 	back/ nearside/offside	nearside/offside/ back	643 (1.85%)
e. 	front	back	7087 (20.4%)
f. 	back	front	3614 (10.4%)
g. other	other combinations of first point of impact		4662 (13.4%)
Total			34806 (100%)

As reported in Table 7.31, a same-direction crash is classified into six crash manners (from (a) to (f)), with an "other" category (g). The details of these six crash manners are provided below:

(a) a car collides with a motorcycle at a parallel crash-angle (the side of a motorcycle strikes the side of a car)
  - the first point of impact of a motorcycle and a car can be "offside versus offside" or "nearside versus nearside"

(b) a motorcycle head-to-sides a car (the front of a motorcycle crashes into the side of a car)
  - the first point of impact of a motorcycle and a car can be "motorcycle's front versus car's offside/nearside"

(c) a car head-to-sides a motorcycle (the front of a car crashes into the side of a motorcycle)
  - the first point of impact of a motorcycle and a car can be "car's front versus motorcycle's offside/nearside"

(d) a motorcycle/car crashes into the back of a car/motorcycle with its nearside/offside
  - the first points of impact of a motorcycle and a car can be "nearside/offside of a motorcycle versus back of a car" or "nearside/offside of a car versus back of a motorcycle"

(e) a motorcycle crashes into the back of a car ahead with its front (the front of a motorcycle crashes into the back of a car)
  - the front of a motorcycle is exactly the first point of impact and the back of a car is exactly the first point of impact

(f) a car crashes into the back of a motorcycle ahead with its front (the front of a car crashes into the back of a motorcycle)
  - the front of a car is exactly the first point of impact and the back of a motorcycle is exactly the first point of impact

(g) other crash manners, including those collisions that could not be fit into the six crash manners above.

In this section, crash manners (a) to (d) are termed as "sideswipe crash" as these crash manners take place while the nearside/offside of a motorcycle/car is the first point of impact. Crash manner (d) is termed as a "rear-end McCar crash" which represents a crash in which a following motorcycle crashes into a leading car. Crash manner (e) is termed as a "rear-end CarMc crash" which represents a crash in which a following car crashes into a leading motorcycle.

The main reason for the classification of these crash patterns was that injury-severity levels may be associated with struck or striking role that motorcyclists play in different ways. For instance, motorcyclists that are rear-ended by cars may be more likely to eject and consequently to be run over by other automobiles nearby, while there might be different collision-impact for a motorcyclist that crashes into a leading car ahead. Several researchers (e.g., Duncan et al., 1998; Khattak, 2001) have revealed differences in the injury-severity levels among occupants in the striking and struck cars in car-car rear-end collisions. Duncan et al. and Khattak have similarly found that occupants in the struck cars to the rear appeared to be more severely injured than those in the cars striking another car ahead (section 2.4.3.3 provides the details of literature on car-car sideswipe and rear-end collisions).

Table 7.32 provides the information on the distribution of motorcyclist injury severity by these crash manners in motorcycle-car same-direction crashes. The statistics in Table 7.32 revealed that for sideswipe crashes, a motorcycle crashing into a car (i.e., a motorcycle head-to-sides a car) is the deadliest crash manner (22.0% of the injuries were KSIs). Such crash manner was the most frequently occurring crash type, which accounts for 31.8% of all casualties. For rear-end crashes, injures to motorcyclists were more severe when it was a McCar crash (20.6% of the injuries were KSIs) than when it was a CarMc crash (9.3% of the injuries were KSIs).

Table 7.32: Distribution of motorcyclist injury severity by crash manner in same-direction collisions.

Crash manner	No injury	Slight injury	KSI	Total (% of total)
(a) sideswipe: side to side	53 (0.8%)	5205 (83.1%)	1003 (16.0%)	6261 (18.0%)
(b) sideswipe: motorcycle head-to-sides car	1446 (1.3%)	8477 (76.7%)	**2435 (22.0%)**	**11056 (31.8%)**
(c) sideswipe: car head-to-sides motorcycle	16 (1.5%)	809 (78.0%)	212 (20.4%)	1037 (5.2%)
(d) sideswipe: car/motorcycle crashes into motorcycle/car (side versus back)	9 (1.4%)	501 (77.9%)	133 (20.7%)	643 (1.8%)
(e) rear-end: McCar (motorcycle crashes into car)	212 (3.0%)	5418 (76.4%)	**1457 (20.6%)**	**7087 (20.4%)**
(f) rear-end: CarMc (car crashes into motorcycle)	62 (1.7%)	3216 (89.0%)	336 (9.3%)	3614 (10.4%)
(g) unknown	125 (2.7%)	3767 (78.0%)	770 (16.5%)	4662 (13.4%)
Total	**250 (1.3%)**	**15672 (79.0%)**	**3916 (19.7%)**	**19838 (100%)**

In order to gain an understanding of the factors that affect motorcyclist injury severity resulting from the two deadliest combinations (i.e., crash manner (b) and (e), as illustrated in Table 7.31), two separate OP models by these two crash manners are estimated.

7.4.3 Model Specification

The variables examined in the aggregate model (see Table 6.2 in section 6.3) are incorporated into the disaggregate models of a sideswipe "motorcycle head-to-sides car" crash (i.e., crash manner (b)) and rear-end McCar crash (i.e., crash manner (e)). Among these variables, the variable "junction control measures" is the variable of particular interest. This is because research has reported that at signalised junctions, rear-end crashes were frequently the predominant collision type involving two cars (Wang and Abdel-Aty, 2006). Such crash type arises from the combination a leading car's deceleration under the influence of the automatic signals and the ineffective response of a following car to this deceleration (Wang and Abdel-Aty, 2006). It is hypothesised in this current study that junction control measures would play a part in affecting motorcyclist injury severity in sideswipe "head-to-side" crashes and in rear-end McCar crashes.

In addition to these variables abovementioned, the variable "manoeuvres" is incorporated into the models. This is because there is evidence in the literature documenting the increased risk of involving in car-car sideswipe/rear-end crash due to improper manoeuvres (e.g., overtaking, lane-changing, shunting, or tailgating) (see, for example, Clarke et al., 1998; Abdel-Aty and Abdelwahab, 2003, 2004).

The descriptive analysis is conducted to examine the distribution of motorcyclist injury severity by the variables of primary interest. The variables of interest include junction control measures, and the pre-crash manoeuvres of motorcycle and car.

Table 7.33 and Table 7.34 report the information on the distribution of motorcyclist injury severity by junction control measure in sideswipe "motorcycle head-to-sides car" crashes and rear-end McCar crashes respectively. The data in Table 7.33 and Table 7.34 show that both crash manners that occurred at uncontrolled junctions predispose riders to a greater risk of KSIs (23.5% and 21.3% of the injuries were KSIs). The second deadliest junction control measure is stop/give-way controlled junctions (22.4% and 20.9% of the injuries were KSIs). These data imply that riders involved in accidents at signalised junctions were the least likely of all junction control measures to be KSI in both crash manners.

Table 7.33: Distribution of motorcyclist injury severity by junction control measure in sideswipe "motorcycle head-to-sides car" collisions.

Control measure	No injury	Slight injury	KSI	Total (% of total)
uncontrolled	31 (1.9%)	1196 (74.6%)	**377 (23.5%)**	1604 (14.5%)
stop, give-way signs or markings	110 (1.2%)	6745 (76.3%)	1982 (22.4%)	8837 (79.9%)
automatic signals	3 (0.5%)	536 (87.2%)	76 (12.4%)	615 (5.6%)
Total	**144 (1.3%)**	**15672 (76.7%)**	**2435 (22.0%)**	**11056 (100%)**

Table 7.34: Distribution of motorcyclist injury severity by junction control measure in rear-end McCar collisions.

Control measure	No injury	Slight injury	KSI	Total (% of total)
uncontrolled	44 (4.2%)	772 (74.4%)	**221 (21.3%)**	1039 (14.6%)
stop, give-way signs or markings	136 (2.5%)	4201 (76.6%)	1744 (20.9%)	5481 (77.3%)
automatic signals	32 (5.6%)	445 (78.2%)	92 (16.2%)	569 (8.0%)
Total	**212 (3.0%)**	**5418 (76.4%)**	**1457 (20.6%)**	**7087 (100%)**

Table 7.35 and Table 7.36 report the distribution of motorcyclist injury severity by pre-crash manoeuvre of motorcycle and car in sideswipe "motorcycle head-to-sides car" collisions. The statistics in Table 7.35 and Table 7.36 show that riders were more likely to be KSI when they were overtaking (24.5% of the injuries were KSIs), or when cars were making a turn (23.3% of the injuries were KSIs).

Table 7.35: Distribution of motorcyclist injury severity by motorcycle's manoeuvre in sideswipe "motorcycle head-to-sides car" collisions.

Manoeuvre	No injury	Slight injury	KSI	Total (% of total)
Overtaking	81 (1.3%)	4535 (74.2%)	**1495 (24.5%)**	6110 (55.3%)
Turning	4 (1.3%)	258 (83.0%)	49 (15.8%)	311 (2.8%)
Changing lane	0 (0%)	56 (84.8%)	10 (15.2%)	66 (0.6%)
Travelling straight	59 (1.3%)	3629 (79.4%)	881 (16.9%)	4569 (41.3%)
Total	**144 (1.3%)**	**8477 (76.7%)**	**2435 (22.0%)**	**11056 (100%)**

Table 7.36: Distribution of motorcyclist injury severity by car's manoeuvre in sideswipe "motorcycle head-to-sides car" collisions.

Manoeuvre	No injury	Slight injury	KSI	Total (% of total)
Overtaking	0 (0%)	138 (84.7%)	25 (15.3%)	163 (1.5%)
Turning	120 (1.3%)	6883 (75.4%)	**2123 (23.3%)**	9126 (82.5%)
Changing lane	5 (0.9%)	489 (86.3%)	74 (12.8%)	577 (5.2%)
Travelling straight	19 (1.6%)	958 (80.5%)	213 (17.9%)	1190 (10.8%)
Total	**144 (1.3%)**	**8477 (76.7%)**	**2435 (22.0%)**	**11056 (100%)**

Table 7.37 and Table 7.38 report the distribution of motorcyclist injury severity by pre-crash manoeuvre of motorcycle and car in rear-end McCar collisions. Similar to the data in Table 7.35 and Table 7.36, the descriptive data in Table 7.37 and Table 7.38 reveal that injuries were greatest when motorcycles were overtaking (25.3% of the injuries were KSIs), or when cars were making a turn (23.6% of the injuries were KSIs).

Table 7.37: Distribution of motorcyclist injury severity by motorcycle's manoeuvre in rear-end McCar collisions.

Manoeuvre	No injury	Slight injury	KSI	Total (% of total)
Overtaking	7 (0.8%)	646 (73.9%)	**221 (25.3%)**	847 (12.3%)
Turning	7 (4.8%)	119 (81.5%)	20 (13.7%)	146 (2.1%)
Changing lane	0 (0%)	40 (87.0%)	6 (13.0%)	46 (0.6%)
Travelling straight	198 (3.3%)	4613 (7.6%)	1210 (20.1%)	6021 (85.0%)
Total	**212 (3.0%)**	**5418 (76.4%)**	**1457 (20.6%)**	**7087 (100%)**

Table 7.38: Distribution of motorcyclist injury severity by car's manoeuvre in rear-end McCar collisions.

Manoeuvre	No injury	Slight injury	KSI	Total (% of total)
Overtaking	2 (2.2%)	70 (76.1%)	20 (21.7%)	92 (1.3%)
Turning	80 (2.7%)	2214 (73.7%)	**709 (23.6%)**	3003 (42.4%)
Changing lane	0 (0%)	169 (81.3%)	39 (18.8%)	208 (2.9%)
Travelling straight	130 (3.4%)	2965 (78.4%)	689 (18.2%)	3784 (53.4%)
Total	**212 (3.0%)**	**5418 (76.4%)**	**1457 (20.6%)**	**7087 (100%)**

The descriptive data in Table 7.33 to Table 7.38 provided a general picture of the univariate relationship between motorcyclist injury severity and the variables of interest. The subsequent section presents a multivariate examination of the determinants of motorcyclist injury severity in sideswipe "motorcycle head-to-sides car" crashes and rear-end McCar crashes (i.e., controlling for all factors that influence motorcyclist injury severity) using the OP model.

A correlation matrix among the variables was reported (see Table 7.39 for sideswipe crash and Table 7.40 for rear-end crash) to assess the presence of multicollinearity. Similar to the models of approach-turn B crashes, angle A/B crashes, and head-on crashes (see Table 7.7, Table 7.14, Table 7.15, and Table 7.28), multicollinearity was found to exist between the variable "street light condition" and "time of accident", with a correlation value of 0.582 and 0.554 (see Table 7.39 and Table 7.40). For these two variables that are highly correlated with each other, only the most significant variable, which is "time of accident", is retained in the analysis.

Table 7.39: Correlation matrix between the variables in the sideswipe "motorcycle head-to-sides car" crash model.

variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1. engine size	1	0.011	-0.010	0.020	0.004	0.030	0.138	-0.317	0.015	-0.024	0.021	0.059	0.018	-0.063	0.136	-0.007	-0.072	0.041
2. motorcycle manoeuvre		1	-0.122	0.175	-0.031	0.001	0.040	0.047	-0.093	-0.114	0.014	0.028	0.037	-0.051	0.109	0.091	-0.078	0.025
3. bend for motorcycle			1	-0.032	**0.517**	-0.013	-0.001	0.016	0.012	0.012	0.007	0.024	0.015	0.027	0.067	0.019	0.001	-0.009
4. car manoeuvre				1	-0.147	0.006	0.037	0.016	-0.047	-0.039	-0.123	0.028	0.022	-0.003	0.066	0.101	-0.022	0.003
5. bend for car					1	0.012	-0.001	0.004	0.001	-0.002	0.003	0.007	0.005	0.018	0.003	0.011	0.010	0.003
6. crash partner						1	0.012	-0.041	0.163	-0.021	0.003	0.010	-0.100	-0.085	0.024	-0.011	-0.060	-0.001
7. rider gender							1	0.021	-0.005	-0.037	0.027	0.029	0.043	0.010	0.018	0.015	0.007	0.014
8. rider age								1	-0.068	-0.007	-0.001	-0.041	0.022	0.060	-0.065	0.050	0.053	-0.021
9. motorist gender									1	0.268	0.001	0.006	-0.007	0.040	-0.029	-0.051	0.053	-0.016
10. motorist age										1	-0.025	0.012	-0.010	0.007	-0.028	-0.059	0.024	0.014
11. number of vehicle involved											1	0.037	0.046	-0.004	0.042	0.010	-0.010	0.008
12. month												1	0.041	0.008	0.078	0.003	-0.242	0.054
13. week day													1	-0.073	0.128	0.042	-0.017	0.017
14. time of day														1	-0.065	-0.003	**0.582**	-0.030
15. speed limit															1	0.087	-0.103	0.021
16. control measure																1	-0.011	-0.013
17. light condition																	1	-0.079
18. weather																		1

Table 7.40: Correlation matrix between the variables in the rear-end McCar crash model.

variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1. engine size	1	0.104	0.042	0.074	0.019	0.020	0.178	-0.378	0.041	0.017	0.064	0.087	0.087	-0.030	0.169	0.004	-0.052	0.046
2. motorcycle manoeuvre		1	-0.067	0.266	-0.026	0.015	0.052	-0.079	0.011	-0.024	-0.012	0.035	0.055	0.015	0.135	0.056	-0.019	0.051
3. bend for motorcycle			1	-0.029	**0.538**	0.013	0.016	-0.010	-0.006	-0.010	0.061	0.049	0.031	-0.002	0.116	0.041	-0.021	0.017
4. car manoeuvre				1	-0.071	-0.014	0.063	-0.037	-0.030	-0.005	-0.109	0.047	0.070	0.009	0.133	0.144	-0.032	0.053
5. bend for car					1	0.007	-0.002	-0.005	0.004	0.016	0.048	0.020	0.002	0.010	0.013	0.036	-0.004	0.008
6. crash partner						1	-0.008	0.021	0.010	0.038	0.028	0.065	0.037	0.038	0.008	0.031	-0.039	0.039
7. rider gender							1	-0.008	0.021	0.010	0.038	0.028	0.065	0.037	0.038	0.008	0.031	0.039
8. rider age								1	-0.052	-0.042	-0.030	-0.083	-0.041	0.031	-0.109	0.037	0.040	-0.037
9. motorist gender									1	0.284	-0.005	0.013	0.017	0.045	-0.010	-0.053	0.053	-0.002
10. motorist age										1	-0.055	-0.002	0.001	-0.001	-0.018	-0.041	0.018	0.021
11. number of vehicle involved											1	0.009	0.056	-0.017	0.109	0.009	-0.035	0.023
12. month												1	0.054	0.023	0.060	0.027	-0.240	0.083
13. week day													1	-0.082	0.128	0.030	-0.033	0.053
14. time of day														1	-0.080	-0.016	**0.554**	-0.038
15. speed limit															1	0.082	-0.129	0.045
16. control measure																1	-0.038	0.028
17. light condition																	1	-0.080
18. weather																		1

Similar to the model of head-on crash (see Table 7.28 in section 7.3.2), a high correlation was observed between the variables "bend for motorcycle" and "bend for car", with a value of 0.517 and 0.538 (see Table 7.39 and Table 7.40). For these two variables that are highly correlated with each other, only the most significant variable is retained in the models. It should be noted here that for the model of sideswipe "motorcycle head-to-sides car" crash, the variable "bend for motorcycle" is found to be more significant than the variable "bend for car". However, for the model of rear-end McCar crash, the variable "bend for car" is found to be more significant than the variable "bend for motorcycle". As a result, the variable "bend for motorcycle" is retained in the sideswipe "motorcycle head-to-sides car" crash model, while the variable "bend for car" is retained in the rear-end McCar crash model.

7.4.4 Estimation Results for Sideswipe "Motorcycle Head-to-Sides Car" Collisions

Table 7.41 reports the estimation results of the sideswipe crash model. After removing unreliable/missing data, a total of 11056 motorcyclist casualties resulting from sideswipe "motorcycle head-to-sides car" collisions at T-junctions were extracted from the Stats19. Of 11056 motorcyclist casualties, 22.0% are classified as KSI, 76.7% are classified as slight injury, and 1.3% are classified as no injury. The model has a pseudo-R^2 measure of 0.078. As for predicting each injury-severity category, the classification accuracy for KSI, slight injury, and no injury was 4.8%, 98.7%, and 0%.

Similar to the models that have been calibrated in previous sections (see, for example, the models of motorcycle-car accidents in whole, approach-turn B crashes, and angle A crashes in section 6.3, section 7.2.3.2, and section 7.2.4.2), a benchmark case was generated in order to discuss probabilities of three injury-severity levels in sideswipe "motorcycle head-to-sides car" crashes. The probabilities of a benchmark sustaining three injury-severity levels are derived by holding all dummy variables to 0 (see Table 7.42). Such benchmark victim has the following characteristics:

(a) was a female
(b) was aged between 20-59
(c) was involved in a collision in which the involved motorist was female

(d) was involved in a collision in which the age of the involved motorist was aged between 20-59

(e) was riding a motorcycle with engine size up to 125cc

(f) was involved in a collision in which the crash partner was a car

(g) was involved in a two-vehicle collision

(h) was travelling on the straight road (not on the bend)

(i) was involved in a crash in autumn/winter month

(j) was involved in a crash when the weather was adverse

(k) was involved in a crash during non rush hours

(l) was involved in a crash on weekday

(m) was involved in a crash on the built-up road

(n) was involved in a crash when her pre-crash manoeuvre was "travelling straight"

(o) was involved in a crash when the pre-crash manoeuvre of her crash pattern was "travelling straight"

Table 7.41: Statistics summary and estimation results of the sideswipe "motorcycle head-to-sides car" model.

Variables	Categories of each variable	Frequency (%)	Coefficient (p-value)
Gender of rider	1. male	10436 (94.4%)	0.025 (0.659)
	2. female	620 (5.6%)	Reference case
Age of rider	1. 60 above	162 (1.5%)	**0.240 (0.022)**
	2. up to 19	2200 (19.9%)	-0.010 (0.769)
	3. 20~59	8694 (78.6%)	Reference case
Gender of collision partner	1. untraced	388 (3.5%)	0.051 (0.572)
	2. male	7888 (71.3%)	**0.059 (0.054)**
	3. female	2780 (25.1%)	Reference case
Age of collision partner	1. untraced	968 (8.8%)	-0.134 (0.018)
	2. 60 above	702 (6.3%)	**0.073 (0.161)**
	3. up to 19	538 (4.9%)	0.066 (0.262)
	4. 20~59	8848 (80.0%)	Reference case
Bend for motorcycle	1. bend	118 (1.1%)	**0.181 (0.140)**
	2. non bend	10938 (98.9%)	Reference case
Engine size	1. engine size > 125cc	8419 (76.1%)	**0.220 (<0.001)**
	2. engine size up to 125cc	2637 (23.9%)	Reference case
Number of vehicle involved	1. >=3	509 (4.6%)	**0.273 (<0.001)**
	2. two-vehicle crash	10547 (95.4%)	Reference case
Collision partner	1. heavy good vehicle	1155 (10.4%)	**0.178 (<0.001)**
	2. bus/coach	166 (1.5%)	0.116 (0.263)
	3. car	9735 (88.1%)	Reference case
Accident month	1. spring/summer (Mar~Aug)	6124 (55.4%)	0.006 (0.812)
	2. autumn/winter (Sep~Feb)	4932 (44.6%)	Reference case
Junction control measure	1. uncontrolled	1604 (14.5%)	0.110 (0.099)
	2. stop, give-way signs or marking	8837 (79.9%)	**0.153 (0.010)**
	3. automatic signal	615 (5.6%)	Reference case
Weather condition	1. other/unknown	187 (1.7%)	-0.024 (0.827)
	2. fine weather	9863 (89.2%)	**0.112 (0.014)**
	3. bad weather	1006 (9.1%)	Reference case
Accident time	1. evening (1800~2359)	2654 (24.0%)	0.118 (<0.001)
	2. midnight; early morning (0000~0659)	294 (2.7%)	**0.244 (0.002)**
	3. rush hours (0700~0859; 1600~1759)	3553 (32.1%)	-0.001 (0.986)
	4. non rush hours (0900~1559)	4555 (41.2%)	Reference case
Accident day of week	1. weekend (Sat~Sun)	2505 (22.7%)	**0.085 (0.007)**
	2. weekday (Mon~Fri)	8551 (77.3%)	Reference case
Speed limit	1. non built-up roads (>40mph)	1120 (10.1%)	**0.632 (<0.001)**
	2. built-up roads (<=40mph)	9936 (89.9%)	Reference case
Motorcycle's manoeuvre	1. overtaking	6110 (55.3%)	**0.080 (0.004)**
	2. turning	311 (2.8%)	-0.067 (0.418)
	3. changing lane	66 (0.6%)	-0.027 (0.877)
	4. going straight	4569 (41.3%)	Reference case
Car's manoeuvre	1. overtaking	163 (1.5%)	0.002 (0.986)
	2. turning	9126 (82.5%)	**0.115 (0.009)**
	3. changing lane	577 (5.2%)	-0.098 (0.167)
	4. going straight	1190 (10.8%)	Reference case
	μ_1	-1.534 (<0.001)	
	μ_2	1.560 (<0.001)	

Summary Statistics
-2 Log-likelihood at zero = 7061.156
-2 Log-likelihood at convergence = 6514.299
Log-likelihood ratio index (ρ^2) = 0.078
The number of KSI that was correctly predicted: 117 (4.8%)
The number of slight injury that was correctly predicted: 8383 (98.9%)
The number of no injury that was correctly predicted: 0 (0%)
Observations = 11056 (KSI: 22.0%; slight injury: 76.7%; no injury: 1.3%)

Table 7.42: Motorcyclist injury severity probabilities in sideswipe "motorcycle head-to-sides car" crashes.

Variable		Estimated probability			Percent change relative to benchmark case (%)		
		No injury	Slight	KSI	No injury	Slight	KSI
Benchmark case		0.0625	0.8781	0.0594			
Gender of rider	1. male	0.0595	0.8781	0.0624	-4.80	0.00	**5.05**
Age of rider	1. 60 above	0.038	0.8685	0.0934	-39.20	-1.09	**57.24**
	2. up to 19	0.0638	0.878	0.0582	2.08	-0.01	-2.02
Gender of collision partner	1. untraced	0.0565	0.8779	0.0657	-9.60	-0.02	10.61
	2. male	0.0556	0.8778	0.0667	-11.04	-0.03	**12.29**
Age of collision partner	1. untraced	0.0808	0.8741	0.0451	29.28	-0.46	-24.07
	2. 60 above	0.054	0.8775	0.0685	-13.60	-0.07	**15.32**
	3. up to 19	0.0548	0.8776	0.0676	-12.32	-0.06	13.80
Bend for car	1. bend	0.0432	0.8729	0.0839	-30.88	-0.59	**41.25**
Engine size	1. motorcycle over 125cc	0.0397	0.8702	0.0902	-36.48	-0.90	**51.85**
No. of vehicle involved	1. >= 3	0.0354	0.8656	0.099	-43.36	-1.42	**66.67**
Crash partner	1. heavy goods vehicle	0.0435	0.8731	0.0835	-30.40	-0.57	**40.57**
	2. bus/coach	0.0495	0.8762	0.0744	-20.80	-0.22	25.25
Accident month	1. spring/summer (Mar~Aug)	0.0618	0.8781	0.0601	-1.12	0.00	1.18
Control measure	1. uncontrolled	0.0501	0.8764	0.0735	-19.84	-0.19	23.74
	2. stop, give-way signs or marking	0.0458	0.8745	0.0797	-26.72	-0.41	**34.18**
Weather conditions	1. other or unknown	0.0655	0.8779	0.0566	4.80	-0.02	-4.71
	2. fine weather	0.0499	0.8763	0.0738	-20.16	-0.20	**24.24**
Accident time	1. evening (1800~2359)	0.0493	0.8761	0.0747	-21.12	-0.23	25.76
	2. midnight; early morning (0000~0659)	0.0377	0.8682	0.0941	-39.68	-1.13	**58.42**
	3. rush hours (0700~0859; 1600~1759)	0.0626	0.8781	0.0593	0.16	0.00	-0.17
Accident day of week	1. weekend (Sat~Sun)	0.0527	0.8772	0.0701	-15.68	-0.10	**18.01**
Speed limit	1. non built-up roads	0.0152	0.8081	0.1767	-75.68	-7.97	**197.47**
Motorcycle's manoeuvre	1. overtaking	0.0533	0.8773	0.0694	-14.72	-0.09	**16.84**
	2. turning	0.0712	0.8769	0.0519	13.92	-0.14	-12.63
	3. changing lane	0.0659	0.8778	0.0563	5.44	-0.03	-5.22
Car's manoeuvre	1. overtaking	0.0623	0.8781	0.0596	-0.32	0.00	0.34
	2. turning	0.0496	0.8762	0.0742	-20.64	-0.22	**24.92**
	3. changing lane	0.0755	0.8758	0.0487	20.80	-0.26	-18.01

Note: The reference case for each variable is not shown as it is taken as the benchmark victim.

As reported in Table 7.41, relatively comparable modelling results were observed from the sideswipe "motorcycle head-to-sides car" crash model compared with those of the aggregate model that was estimated in section 6.3 (Table 6.2 and Table 6.3). For example, factors that were most significantly associated with the increased motorcyclist injury severity include elderly riders (coefficient=0.240, p-value=0.022), male motorists (coefficient=0.059), collisions with HGVs (coefficient=0.178, p-value<0.001), larger motorcycle engine capacity (coefficient=0.220, p-value<0.001), and accidents that involved more than three vehicles (coefficient=0.273, p-value<0.001), under fine weather (coefficient=0.112, p-value=0.014), during midnight/early morning hours (coefficient=0.244, p-value=0.002), and on non built-up roads (coefficient=0.632, p-value<0.001). One of the noteworthy results here is that accidents that occurred on non built-up roads have a 197.47% increase in the probability of a KSI, relative to built-up roads (Table 7.42).

The variable of particular interest for the sideswipe "motorcycle head-to-sides car" crash model is the effects of the pre-crash manoeuvres of motorcycle or car and junction control measures. The modelling results (Table 7.41 and Table 7.42) show that accidents that occurred at stop-controlled junctions have the greatest increase in the probability of a KSI of 34.18% (relative to automatic signals). This is followed by accidents that occurred at uncontrolled junctions, with about a 23.74% increased probability of a KSI (Table 7.42). Likely explanations for these results are that an uncontrolled or stop-controlled junction may normally be located in rural areas with higher speed limits. Accident outcome may therefore be more severe once an accident occurred.

With regard to the effect of pre-crash manoeuvre, the deadliest combination of manoeuvres found in "motorcycle head-to-sides car" crash manner was an overtaking motorcycle colliding with a turning car. It should be noted here that the interaction effect of the pre-crash manoeuvres of motorcycle and car is not examined in the model. This is because the two manoeuvre variables that were incorporated into the model have explicitly captured the interaction effect of the pre-crash manoeuvres in such crash manner (i.e., a motorcycle head-to-sides a car ahead).

Instead of examining the interaction effects of the pre-crash manoeuvres, the distribution of motorcyclist casualties sustaining KSIs by the combined manoeuvres was examined (see Figure 7.7). The deadliest combination of manoeuvres (i.e., an overtaking motorcycle collided with a turning car ahead) were found to be overrepresented in such crash manner, accounting for approximately 57% of all motorcyclist casualties that had KSIs.

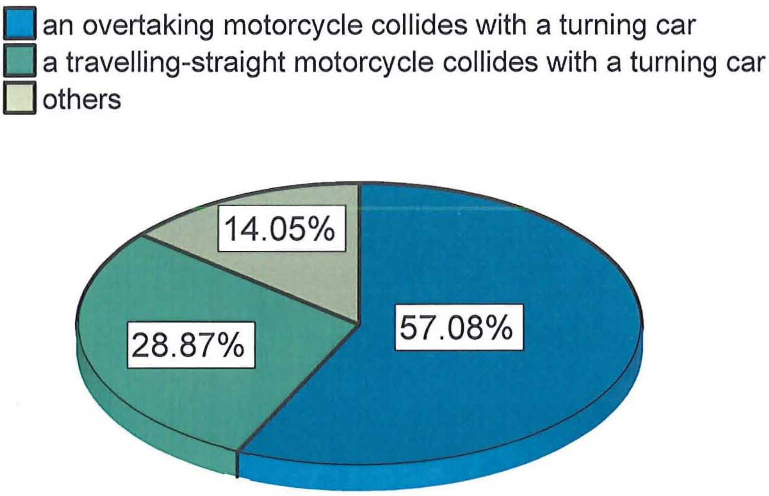


Figure 7.7: Distribution of the manoeuvres by motorcycles and cars prior to sideswipe "motorcycle head-to-sides car" collisions that led to KSIs (N=2435).

Similar results regarding the effects of pre-crash manoeuvres were found in previous studies of car-car accidents (Clarke et al., 1998) and motorcycle-car accidents (Crundall et al., in press). Clarke et al. reported that the most common accidents for overtakers were crashes in which a motorist made an error by overtaking a leading automobile that was turning. Crundall et al. noted that typical motorcycle-car same-direction crashes involved an overtaking or turning motorist in slow moving traffic without checking for filtering motorcycles that were making overtaking manoeuvres between two lanes of stationary/slow moving traffic. The result derived in this study (see Figure 7.7) is in line with the findings of Crundall et al. that a typical motorcycle-car same-direction crash takes place when a turning car collides with a filtering motorcycle that intends to have overtaking manoeuvres.

7.4.5 Estimation Results For Rear-End Collisions

Table 7.43 reports the estimation results of the rear-end McCar crash model. A total of 7087 motorcyclist casualties resulting from rear-end McCar collisions at T-junctions were extracted from the Stats19. Of these 7087 motorcyclist casualties, 20.6% are classified as KSI, 76.4% are classified as slight injury, and 3.0% are classified as no injury. The model has a pseudo-R^2 measure of 0.050. As for predicting each injury-severity category, the classification accuracy for KSI, slight injury, and no injury was 0.4%, 76.5%, and 0%.

Similar to the previous models in previous sections (see, for example, the models of head-on crash section 7.3.3, and sideswipe "motorcycle head-to-sides car" crash in section 7.4.3), a benchmark case was generated in order to discuss probabilities of three injury-severity levels in rear-end McCar crashes. The probabilities of a benchmark sustaining three injury-severity levels are derived by holding all dummy variables to 0 (see Table 7.44). Such benchmark victim has the following characteristics:

(a) was a female
(b) was aged between 20-59
(c) was involved in a collision in which the involved motorist was female
(d) was involved in a collision in which the age of the involved motorist was aged between 20-59
(e) was riding a motorcycle with engine size up to 125cc
(f) was involved in a collision in which the crash partner was a car
(g) was involved in a two-vehicle collision
(h) her collision partner was travelling on the straight road (not on the bend)
(i) was involved in a crash in autumn/winter month
(j) was involved in a crash when the weather was adverse
(k) was involved in a crash during non rush hours
(l) was involved in a crash on weekday
(m) was involved in a crash on the built-up road
(n) was involved in a crash when she was travelling straight and her collision partner was travelling straight at the same time

Table 7.43: Statistics summary and estimation results of the rear-end McCar crash model.

Explanatory variable	Categories of each variable	Frequency (%)	Coefficients (p-value)
Gender of rider	1. male	6464 (91.2%)	**0.072 (0.200)**
	2. female	623 (8.8%)	Reference case
Age of rider	1. over 60	109 (1.5%)	**0.203 (0.104)**
	2. up to 19	2031 (28.7%)	0.052 (0.169)
	3. 20~59	4947 (69.8%)	Reference case
Gender of collision partner	1. untraced	244 (3.4%)	0.072 (0.527)
	2. male	4727 (66.7%)	**0.125 (<0.001)**
	3. female	2116 (29.9%)	Reference case
Age of collision partner	1. untraced	494 (7.0%)	-0.051 (0.523)
	2. over 60	571 (8.1%)	0.063 (0.267)
	3. up to 19	275 (3.9%)	0.069 (0.384)
	4. 20~59	5747 (81.1%)	Reference case
Engine size	1. engine size over 125cc	4931 (69.6%)	**0.169 (<0.001)**
	2. engine size up to 125cc	2156 (30.4%)	Reference case
Bend for car	1. bend	42 (0.6%)	0.014 (0.356)
	2. non bend	7045 (99.4%)	Reference case
Collision partner	1. HGV	558 (7.9%)	**0.210 (<0.001)**
	2. bus/coach	77 (1.1%)	-0.002 (0.988)
	3. car	6542 (91.0%)	Reference case
Number of vehicle involved	1. >= 3	704 (9.9%)	0.058 (0.265)
	2. two vehicles only	6383 (90.1%)	Reference case
Accident month	1. spring/summer (Mar-Aug)	3982 (56.2%)	-0.009 (0.781)
	2. autumn/winter (Sep-Feb)	3105 (43.8%)	Reference case
Weather condition	1. other or unknown	138 (1.9%)	-0.161 (0.182)
	2. fine weather	6044 (85.3%)	**0.093 (0.048)**
	3. bad weather	905 (12.8%)	Reference case
Accident time	1. evening (1800~2359)	1619 (22.8%)	**0.094 (0.020)**
	2. midnight/early morning (0000~0659)	165 (2.3%)	0.010 (0.926)
	3. rush hours (0700~0859; 1600~1759)	2206 (31.1%)	0.044 (0.229)
	4. non rush hours (0900~1559)	3097 (43.7%)	Reference case
Accident day of week	1. weekend (Sat~Sun)	1764 (24.9%)	**0.067 (0.068)**
	2. weekday (Mon~Fri)	5323 (75.1%)	Reference case
Speed limit	1. non built-up roads (>40mph)	1100 (15.5%)	**0.486 (<0.001)**
	2. built-up roads (<=40mph)	5987 (84.5%)	Reference case
Junction control	1. uncontrolled	1037 (14.6%)	0.081 (0.248)
	2. stop, give-way sign or markings	5481 (77.3%)	**0.152 (0.010)**
	3. automatic signal measure	569 (8.0%)	Reference case
Interaction of MC's and Car's manoeuvre	1. traversing * traversing	818 (11.5%)	**0.110 (0.033)**
	2. traversing * travelling straight	248 (3.5%)	0.031 (0.718)
	3. travelling straight * traversing	2485 (35.1%)	0.100 (0.004)
	4. travelling straight * travelling straight	3536 (49.9%)	Reference case
	μ_1	-1.242 (<0.001)	
	μ_2	1.540 (<0.001)	

Summary Statistics
-2 Log-likelihood at zero = 5885.316
-2 Log-likelihood at convergence = 5593.342
Log-likelihood ratio index (ρ^2) = 0.050
The number of KSI that was correctly predicted: 6 (0.4%)
The number of slight injury that was correctly predicted: 5416 (76.5%)
The number of no injury that was correctly predicted: 0 (0%)
Observations = 7087 (KSI: 20.6%; slight injury: 76.4%; no injury: 3.0%)

Table 7.44: Motorcyclist injury severity probabilities in rear-end McCar crashes.

Variable		Estimated probability			Percent change relative to benchmark case (%)		
		No injury	Slight	KSI	No injury	Slight	KSI
Benchmark case		0.1071	0.8311	0.0618			
Gender of rider	1. male	0.0944	0.8345	0.0711	-11.86	0.41	**15.05**
Age of rider	1. 60 above	0.0742	0.8352	0.0906	-30.72	0.49	**46.60**
	2. up to 19	0.0978	0.8338	0.0684	-8.68	0.32	10.68
Gender of collision partner	1. untraced	0.0944	0.8345	0.0711	-11.86	0.41	15.05
	2. male	0.0858	0.8356	0.0785	-19.89	0.54	**27.02**
Age of collision partner	1. untraced	0.1168	0.8274	0.0558	9.06	-0.45	-9.71
	2. 60 above	0.0959	0.8342	0.0698	-10.46	0.37	12.94
	3. up to 19	0.0949	0.8344	0.0706	-11.39	0.40	**14.24**
Engine size	1. motorcycle over 125cc	0.0791	0.8357	0.0852	-26.14	0.55	**37.86**
Bend for car	1. bend	0.1046	0.8319	0.0635	-2.33	0.10	**2.75**
Crash partner	1. heavy goods vehicle	0.0733	0.835	0.0918	-31.56	0.47	**48.54**
	2. bus/coach	0.1075	0.8334	0.0591	0.37	0.28	-4.37
No. of vehicle involved	1. >=3	0.0968	0.834	0.0692	-9.62	0.35	**11.97**
Accident month	1. spring/summer (Mar~Aug)	0.1088	0.8305	0.0607	1.59	-0.07	-1.78
Weather conditions	1. other or unknown	0.1398	0.8157	0.0445	30.53	-1.85	-27.99
	2. fine weather	0.0909	0.8351	0.074	-15.13	0.48	**19.74**
Accident time	1. evening (1800~2359)	0.0908	0.8351	0.0741	-15.22	0.48	**19.90**
	2. midnight; early morning (0000~0659)	0.1053	0.8317	0.063	-1.68	0.07	1.94
	3. rush hours (0700~0859; 1600~1759)	0.0999	0.8333	0.0668	-6.72	0.26	8.09
Accident day of week	1. weekend (Sat~Sun)	0.0953	0.8344	0.0704	-11.02	0.40	**13.92**
Speed limit	1. non built-up roads	0.042	0.8121	0.1459	-60.78	-2.29	**136.08**
Control measure	1. uncontrolled	0.0929	0.8348	0.0723	-13.26	0.45	16.99
	2. stop, give-way signs or marking	0.0817	0.8358	0.0826	-23.72	0.57	**33.66**
Interaction of motorcycle's and car's manoeuvres	1. traversing * traversing	0.0882	0.8355	0.0764	-17.65	0.53	**23.62**
	2. traversing * straight	0.1015	0.8328	0.0657	-5.23	0.20	6.31
	3. straight * traversing	0.0898	0.8353	0.0749	-16.15	0.51	21.20

Note: The reference case for each variable is not shown as it is taken as the benchmark victim.

As reported in Table 7.43, relatively comparable modelling results were observed from the rear-end McCar model compared with those of the aggregate model that was estimated in section 6.3 (Table 6.2 and Table 6.3). For example, factors found to be most significantly associated with the increased motorcyclist injury severity include elderly riders (though only at an 85% confidence interval, with a coefficient value of 0.203, relative to mid-aged riders), male riders (though only at an 80% confidence interval, relative to mid-aged riders), male motorists (coefficient=0.125, p-value<0.001), collisions with HGVs (coefficient=0.210, p-value<0.001), larger motorcycle engine capacity (coefficient=0.169, p-value<0.001), and accidents that occurred under fine weather (coefficient=0.093), during evening hours (coefficient=0.094), on the weekends (coefficient=0.067, p-value=0.048), and on non built-up roadways (coefficient=0.486, p-value<0.001). Similar to the sideswipe "motorcycle head-to-sides car" crash model (see Table 7.41 and Table 7.42), one noteworthy result in the rear-end McCar model is that accidents that occurred on non built-up roads have a 136.08% increase in the probability of a KSI, relative to built-up roads (Table 7.44).

The variables of primary interest in the rear-end McCar crash model include junction control measures and pre-crash manoeuvres. Regarding the effect of junction control measures, rear-end McCar crashes that occurred at stop-controlled junctions have the greatest increase in the probability of a KSI of 33.66% (relative to automatic signals) (Table 7.44). This is followed by accidents that occurred at uncontrolled junctions, with about a 17% increased probability of a KSI (Table 7.44). Possible explanations for these results are that an uncontrolled or stop-controlled junction may normally be located in rural areas with higher speed limits. Accident outcome may therefore be more severe once an accident occurred.

With respect to the pre-crash manoeuvres, manoeuvres such as overtaking, lane changing, and turning (see Table 7.35 to Table 7.38 for original manoeuvre categories) were combined together as one single category "traversing manoeuvres". This is because it was found that one single category "traversing manoeuvres" appeared to result in more statistically significant results than assessing three manoeuvre categories alone in the estimated model. In addition, the variable "interaction of motorcycle's and car's manoeuvres" was incorporated into the model, instead of the two variables "motorcycle's manoeuvres" and "car manoeuvres". This is because the examination of the interaction of the pre-crash manoeuvres was found to result in more statistically significant results than assessing motorcycle's manoeuvres and car's manoeuvres separately. The variable "interaction of motorcycle's and car's manoeuvres" was also incorporated into the model of head-on crashes (see Table 7.29 and Table 7.30 in section 7.3.3).

The modelling results (see Table 7.43) show that riders were more injury-prone as a result of the combinations a traversing motorist colliding with another traversing/travelling-straight motorcyclist, with coefficient values of 0.110 and 0.100. There is a 23.62% increased probability of a KSI and a 21.20% increase in the probability of a KSI for these two combinations (see Table 7.44).

7.4.5 Summary

In this section, a motorcycle-car same-direction crash was firstly subdivided into six crash manners (see Table 7.31). Two deadliest crash manners identified were a sideswipe "motorcycle head-to-sides car" crash and a rear-end McCar crash (see Table 7.32). Two OP models of motorcyclist injury severity by these two deadliest crash manners were estimated. The estimation results of the sideswipe "motorcycle head-to-sides car" crash model revealed that the deadliest pre-crash manoeuvres in such crash pattern were an overtaking motorcycle crashing into a turning car (see Table 7.41 and Table 7.42). For rear-end McCar crashes, traversing manoeuvres by both the motorcycle and car have the highest probability of a KSI (see Table 7.43 and Table 7.44). Another noteworthy result was that injuries were greatest to riders that were involved in both sideswipe "motorcycle head-to-sides car" crashes and rear-end McCar crashes at stop-controlled junctions.

7.5 Summary

This chapter presented the second stage of the investigation part two – the estimation results of the disaggregate models of motorcyclist injury severity by various crash configurations. The disaggregate models by different crash configurations showed that the considered variables affect motorcyclist injury severity in various crash configurations differently, which is clearly obscured by the estimation of the aggregate crash model. Additional variables were also incorporated into the disaggregate crash models and these variables were found to be significantly associated with the increased motorcyclist injury severity in specific crash configurations.

The subsequent chapter (Chapter 8) provides a summary of the findings obtained from the disaggregate models by various crash configurations. Chapter 8 also reports the investigation part three – a further examination of the considered variables amongst various crash configurations that led to KSIs.

INVETIGATION PART THREE - FURTHER EXAMINATION OF THE CONSIDERED VARIABLES

CHAPTER 8

FURTHER EXAMINATION OF THE CONSIDERED VARIABLES AMONGST CRASH CONFIGURATIONS THAT LED TO KSIS

8.1 Introduction

A multivariate examination of the determinants of motorcyclist injury severity, the investigation part two, has been conducted in Chapter 6 and Chapter 7. The results of the first stage of the investigation part two (see Table 6.2 and Table 6.3 in section 6.3) showed that approach-turn B crashes and head-on crashes were the deadliest crash configurations to riders. Chapter 7, the second stage of the investigation part two, has presented the estimation results of the disaggregate models of motorcyclist injury severity by various crash configurations that occurred at T-junctions.

The investigation part three is reported in this chapter that firstly reports a summary of the findings obtained from the disaggregate crash models by various crash configurations. This is followed by a further examination of the considered variables (i.e., the explanatory variables that have been incorporated into the aggregate model by accidents in whole, as can be seen in Table 6.2 in section 6.3) amongst various crash configurations that led to KSIs.

The further examination in this chapter is limited to the accidents that led to KSIs as this is the main focus of this current research. Such examination can be useful for obtaining insights into whether a certain crash configuration is more likely than any other crash configuration to occur under a specific circumstance. For instance, a head-on crash might be more likely than other crash configurations to occur on the curved road since bends on roadways may overtax either riders or motorists in following the curving alignment and drifting into oncoming traffic.

8.2 General Comment and Summary

Following Chapter 6 that investigated motorcyclist injury severity resulting from motorcycle-car accidents in whole, Chapter 7 reported the estimation results of the disaggregate OP models by various crash configurations. Additional variables that were of interest in this present study were incorporated into the disaggregate crash models of various crash configurations. For example, the effects of motorists' failure to yield right-of-way to motorcyclists were incorporated into approach-turn B crash and angle A crash models (section 7.2.3 and section 7.2.4); and the effects of pre-crash manoeuvres of motorcycles and cars were specifically examined in the models of head-on crashes (section 7.3.3), sideswipe "motorcycle head-to-sides car" crashes, and rear-end McCar crash (section 7.4.3 and section 7.4.4).

8.2.1 General Findings

In Chapter 7, it appears that the disaggregate models of motorcyclist injury severity by crash configurations provided valuable insights (that may not be uncovered by an aggregate model) into some of the pre-crash conditions that influence motorcyclist injury severity in these crash configurations differently. Table 8.1 provides a summary of the variables that were incorporated into the disaggregate crash models. Arrows in Table 8.1 show increase (up) or decrease (down) in the probability of a KSI, relative to the reference case of each variable, and shading indicates the most severe category (if there are more than three categories).

Table 8.1: A summary of the variables that affect motorcyclist injury severity in the disaggregate crash models.

Variables		Crash configuration					
		1	2	3	4	5	6
Rider sex	1. male	⇧	n.s.	n.s.	n.s.	n.s.	⇧
Rider age	1. over 60	⬆	⬆	⬆	n.s.	⬆	⬆
	2. up to 19	n.s.	n.s.	n.s.	⇩	n.s.	⇧
Motorist sex	1. unknown	⬆	n.s.	n.s.	n.s.	n.s.	n.s.
	2. male	⇧	⬆	n.s.	⇧	⬆	⬆
Motorist age	1. unknown	⇩	⇩	n.s.	⇩	⇩	n.s.
	2. over 60	⇧	⬆	⬆	n.s.	⬆	n.s.
	3. up to 19	⬆	n.s.	n.s.	n.s.	n.s.	n.s.
Engine size	1. engine size over 125cc	⇧	⇧	⇧	⇧	⇧	⇧
Bend for motorcycle	1. bend	⇩	n.s.	⇩		⇧	
Bend for car	1. bend				⇧		n.s.
Crash partner	1. HGV	⇧	⇧	⬆	⬆	⬆	⬆
	2. Bus/coach	⬆	⬆	⇩	⇧	n.s.	n.s.
No. of vehicle involved	1. >=3	⇧	⇧	⇧	⇧	⇧	n.s.
Accident month	1. spring/summer	n.s.	n.s.	⇧	n.s.	n.s.	n.s.
Weather conditions	1. other or unknown	n.s.	n.s.	⇩	n.s.	n.s.	⇩
	2. fine weather	⬆	⬆	⬆	⬆	⬆	⬆
Accident time	1. evening	⇧	⇧	⇧	⇧	⇧	⬆
	2. midnight/early morning	⬆	⬆	⬆	⬆	⬆	n.s.
	3. rush hours	n.s.	⇧	n.s.	n.s.	n.s.	n.s.
Day of week	1. weekend	⇧	⇧	⇧	⇧	⇧	⇧
Control measure	1. uncontrolled				⇧	⇧	n.s.
	2. stop, give-way sign or markings				⬆	⬆	⬆
Speed limit	1. non built-up roads	⇧	⇧	⇧	⇧	⇧	⇧
Right-of-way violation	1. violation case	⬆	⬆	⬆			
	2. non violation case	⇧	⇧	n.s.			
Motorcycle's manoeuvre	1. travelling straight	⇧	⇧	n.s.			
Interaction effect of motorcycle's and vehicle's manoeuvres	1. traversing * traversing				n.s.		⬆
	2. traversing * straight				⬆		n.s.
	3. straight * traversing				n.s.		⇧
Motorcycle's manoeuvre	1. overtaking					⬆	
	2. turning					n.s.	
	3. changing lane					n.s.	
Car's manoeuvre	1. overtaking					n.s.	
	2. turning					⬆	
	3. changing lane					⇩	

Note:

(a) crash configurations 1-6 represent the disaggregate crash models (1) the approach-turn B crash model, (2) the angle A crash model, (3) the angle B crash model, (4) head-on crash model, (5) the sideswipe "motorcycle head-to-sides car" crash model, and (6) the rear-end McCar crash model.

(b) Arrows "⇧" and "⇩" show increase (up) or decrease (down) in KSI, relative to the reference case of each variable, and shading "⬆" indicates the most severe category (if there are more than three categories).

(c) n.s. stands for non statistically significant relative to the reference case at 80% level of confidence.

As reported in Table 8.1, the estimation results of the disaggregate crash models suggest that the effects of some variables on injury-severity levels vary across different crash configurations. Several observations may be made from Table 8.1:

1. male riders did not show a significant difference in the probability of sustaining KSIs in all crash configurations, except for approach-turn B crashes and rear-end McCar crashes;
2. elderly riders were most likely of all age groups to be KSI in all crash configurations, except for head-on crashes;
3. riders generally experienced a higher probability of a KSI in collisions with male motorists than female motorists (but such effect is not significant for angle B crashes);
4. riders had a higher probability of a KSI in collisions with elderly motorists in angle A/B crashes and sideswipe "motorcycle head-to-sides car" crashes, but teenaged motorists predisposed riders to a greater risk of KSIs in approach-turn B crashes;
5. riders were more injurious in all crash configurations when they were riding heavier motorbikes;
6. there were inconsistent results for the effects of the presence of bend for motorcycle or for car;
7. buses/coaches appear to be the deadliest collision partner to those involved in accidents that involve gap acceptance (approach-turn B crash and angle A crash), whilst HGVs tend to be most hazardous to those involved in other crash configurations;
8. all crash configurations that involved three vehicles or above resulted in more severe injuries (but such effect was not significant in rear-end McCar collisions);
9. accident month appears not to be a predictor of motorcyclist injury severity in most of crash configurations;
10. motorcyclists were more injury-prone in all crash configurations when riding under fine weather than riding under adverse weather;
11. mid-night/early morning hours appear to be the deadliest period in all crash configurations, whilst injuries were greatest to riders in rear-end McCar collisions that occurred during evening hours;

12. weekend riding tended to be more hazardous than weekday riding in all crash configurations;
13. stop, give-way signs or markings appeared to be the deadliest junction control measure in all crash configurations; and
14. riding on non built-up roadways tended to predispose riders to a greater risk of KSIs in all crash configurations.

8.2.2 Specific Findings

For approach-turn B crashes and angle A crashes, right-of-way violations by right-turn motorists were found to outnumber non violation cases. Moreover, riders appeared to be more severely/fatally injured when involved in right-of-way violation cases than no right-of-way violation cases. Results also showed that the effect of right-of-way violation on motorcyclist injury severity was more pronounced at stop-controlled junctions (see section 7.2.3 and section 7.2.4).

The right-of-way violation problem in approach-turn B crashes and angle A crashes was further examined by estimating the binary logistic models. Specific findings include that violations on non built-up roadways were more likely to occur than those on built-up roadways; and violations in daytime were less likely than those during evening/midnight/early morning hours to occur (see section 7.2.5).

For head-on crashes, results indicated that injuries tended to be greatest in collisions where curves were present for motorcycles, and a traversing motorcycle colliding with a travelling-straight car predisposed motorcyclists to a greater risk of KSIs (see section 7.3.3).

For motorcycle-car same-direction collisions, the deadliest crash manner identified was when a motorcycle crashed into the side of a car ahead. Such crash manner was termed as a sideswipe "motorcycle head-to-sides car" crash. The second deadliest crash manner identified was when a motorcycle as a following vehicle crashed into the back of a leading car. Such crash manner was termed as a rear-end McCar crash. For sideswipe "motorcycle head-to-sides car" crashes, the most hazardous pre-crash manoeuvres identified were the combination that an overtaking motorcycle crashed into a turning car. For rear-end McCar crashes, injuries tended to be greatest when motorcycles were making traversing manoeuvres and cars were making traversing manoeuvres at the same time. Another noteworthy result was that injuries were greatest to riders that were involved in both sideswipe “motorcycle head-to-sides car” crashes and rear-end McCar crashes at stop-controlled junctions (see section 7.4.3 and section 7.4.4).

8.3 Examination Results

The considered variables are further examined amongst different crash configurations that led to KSIs, as shown in Table 8.2. The crash configurations include approach-turn A crash, approach-turn B crash (see Figure 4.3(b) in section 4.3), angle A and angle B (see Figure 7.1(c) and (e) in section 7.2.2), head-on crash (see Figure 4.3(c) in section 4.3), sideswipe “side-to-side” crash (see Table 7.31(a) in section 7.4.2), sideswipe “motorcycle head-to-sides car” crash (see Table 7.31(b) in section 7.4.2), rear-end McCar crash (see Table 7.31(d) in section 7.4.2), and rear-end CarMc crash (see Table 7.31(e) in section 7.4.2).

It should be noted here that only the variables that have been incorporated into the aggregate model (see Table 6.2 in section 6.3) are further examined here. Specific variables for certain disaggregate models are not examined. These specific variables include, for instance, right-of-way violation for the models of approach-turn B crashes and angle A crashes.

Table 8.2: The examination of the considered variables amongst various crash configurations that led to KSIs.

		Crash configuration									
		Approach -turn A	**Approach -turn B**	**Angle A**	**Angle B**	**Head-on**	**Sideswipe: side to side**	**Sideswipe: head-to-side**	**Rear-end McCar**	**Rear-end CarMc**	**Average**
Total number of casualties		256	**5290**	**7326**	1812	1252	1003	**2435**	1457	336	2351.89
Rider gender	male	90.2	**95.0**	**93.2**	92.1	**95.0**	92.2	**95.9**	**93.6**	90.5	93.08
	female	**9.8**	5.0	6.8	**7.9**	5.0	**7.8**	4.1	6.4	**9.5**	6.92
Rider age	over 60	**4.3**	2.3	**3.0**	**3.3**	1.8	**3.9**	1.8	1.9	**4.5**	2.98
	up to 19	**22.7**	18.0	18.1	15.0	**20.6**	17.7	17.2	**24.2**	**19.3**	19.20
	20~59	68.0	**79.7**	**78.8**	**81.8**	**77.6**	**78.8**	**80.9**	74.0	76.2	77.31
Motorist gender	unknown	2.0	2.2	1.8	3.9	2.8	**5.4**	2.2	2.1	**13.7**	4.01
	male	**70.3**	**70.3**	64.7	64.5	**74.3**	**71.6**	**73.2**	**70.2**	64.3	69.27
	female	**27.7**	**27.5**	**33.4**	**31.6**	22.9	23.0	24.6	**27.7**	22.0	26.71
Motorist age	unknown	3.1	3.9	3.6	6.7	5.0	**11.0**	5.3	4.5	**20.8**	7.10
	over 60	7.0	**15.4**	**13.7**	**16.9**	9.3	6.0	7.6	9.1	4.8	9.98
	up to 19	5.1	**7.4**	**6.9**	**6.2**	5.3	4.6	5.7	4.6	**6.3**	5.79
	20~59	**84.8**	73.3	75.7	70.1	**80.4**	**78.5**	**81.4**	**81.8**	68.2	77.13
Bend for motorcycle	bend	0	3.5	**7.1**	4.8	**26.6**	1.2	1.4	3.8	1.8	5.58
	non bend	**100**	**96.5**	92.9	**95.2**	73.3	**98.8**	**98.6**	**96.2**	**98.2**	94.41
Bend for car	bend	**5.1**	0	0	0	**23.6**	1.3	0.4	1.0	**4.2**	3.96
	non bend	94.9	**100**	**100**	**100**	76.4	**98.7**	**99.6**	**99.0**	95.8	96.04
Engine size	engine size over 125cc	64.5	**77.4**	**78.5**	**80.2**	**79.8**	76.2	**84.2**	**78.6**	67.3	76.30
	up to 125cc	**35.5**	22.6	21.5	19.8	20.2	**23.8**	15.8	21.4	**32.7**	23.70
Number of vehicle involved	>=3	3.9	7.1	7.2	8.8	**24.0**	9.6	7.0	**13.5**	**11.0**	10.23
	two-vehicle crash	96.1	92.9	92.8	91.2	76.0	90.4	2265	86.5	89.0	331.10
Collision partner	heavy good vehicle	7.0	7.4	6.2	7.3	**10.9**	**16.3**	**12.6**	**10.6**	**10.7**	9.89
	bus/coach	**2.3**	1.2	1.0	1.0	**3.8**	**3.0**	**1.8**	1.0	0.3	1.71
	car	**90.6**	**91.4**	**92.9**	**91.7**	85.3	80.8	85.6	**88.4**	**89.0**	88.41
Control measure	uncontrolled	10.5	12.3	8.8	10.5	**17.6**	**14.7**	**15.85**	**15.2**	**14.0**	13.27
	stop, give-way sign or markings	68.8	**81.4**	**89.8**	**87.8**	**81.2**	76.2	**81.4**	78.5	69.9	79.44
	automatic signals	**20.7**	6.3	1.4	1.7	1.3	**9.2**	3.1	6.3	**16.1**	7.34

continued

		Crash configuration									
		Approach -turn A	**Approach -turn B**	**Angle A**	**Angle B**	**Head-on**	**Sideswipe: side to side**	**Sideswipe: head-to-side**	**Rear-end McCar**	**Rear-end CarMc**	**Total**
Total number of casualties		256	**5290**	**7326**	1812	1252	**1003**	**2435**	1457	336	2351.89
Street light condition	lighting unknown	0.8	**1.2**	**0.9**	**1.2**	**1.1**	**0.9**	0.7	0.5	0.6	0.88
	darkness: street light lit	**30.5**	**35.2**	**25.8**	**23.8**	22.0	14.4	18.4	14.4	21.4	22.88
	darkness: street light unlit	**4.7**	2.9	**4.4**	3.0	**4.3**	1.8	2.1	1.7	**3.6**	3.17
	daylight	64.1	60.7	68.9	72.0	72.5	**83.0**	**78.7**	**83.3**	**74.4**	73.07
Accident month	spring/summer	**55.9**	49.2	49.0	50.7	**57.7**	**56.4**	**58.9**	**58.5**	52.4	54.30
	autumn/winter	44.1	**50.8**	**51.0**	**49.3**	42.3	43.6	41.1	41.5	**47.6**	45.70
Weather conditions	other or unknown	0.4	**1.8**	**2.0**	**1.4**	**1.4**	0.7	**1.2**	**1.2**	0.3	1.16
	fine weather	**91.8**	**89.1**	86.0	86.2	81.2	**91.6**	**91.5**	**88.9**	**88.7**	88.33
	bad weather	8.2	**9.2**	**12.0**	**12.5**	1.3	7.7	7.2	**9.9**	**11.0**	8.78
Accident time	evening	**31.1**	**37.5**	**29.8**	**28.0**	**31.5**	22.0	25.3	23.7	26.5	28.38
	midnight/early morning	**5.5**	**4.1**	**3.9**	3.0	**5.0**	2.7	3.3	2.2	**4.8**	3.83
	rush hours	**31.6**	**29.2**	**35.3**	**35.0**	26.4	**31.8**	**29.9**	**31.3**	26.5	30.78
	non rush hours	31.6	29.2	31.0	33.9	**37.1**	**43.5**	**41.5**	**43.0**	**42.3**	37.01
Day of week	weekend	22.3	22.9	21.7	23.2	**32.1**	23.5	**27.7**	**29.1**	24.1	25.18
	weekday	**77.7**	**77.1**	**78.3**	**76.8**	67.9	**76.5**	72.3	70.9	**75.9**	74.82
Speed limit	non built-up roads	**22.3**	15.9	**22.2**	20.8	**28.0**	16.5	21.0	**28.1**	18.5	21.48
	built-up roads	77.7	**84.1**	77.8	**79.2**	72.0	**83.5**	**79.0**	71.9	**81.5**	78.52

The values in Table 8.2 represent the percentage of KSIs resulting from the variable. For instance, for approach-turn A crashes, there was a total of 256 casualties sustaining KSIs. Among these casualties, 90.2% were males, and 9.8% were females. The average of the percentage of each variable among various crash configurations is reported in the final column. The number that is bold represents that it is higher than the average percentage. For instance, the average percentage of male casualties is 93.08. The percentage of male casualties in several crash configurations (i.e., approach-turn A crash, angle A crash, head-on crash, sideswipe "motorcycle head-to-sides car" crash, and rear-end McCar crash) is higher than the average percentage. The examination results are organised by type of factors: rider/motorist factors, roadway/geometric factors, vehicle factors, and crash factors.

8.3.1 Rider/Motorist Factors

As reported from Table 8.2, the percentage of male casualties from sideswipe "motorcycle head-to-sides car" crashes is the highest (95.9%). In addition, female casualties were overrepresented in approach-turn A crashes (9.8%). While there is no prior studies examining these effects, possible explanations for these effects could be that male motorcyclists could be more aggressive in filtering out from traffic than when they were having other traffic tasks (e.g., when intersecting with the conflicting traffic). Turning to female casualties in approach-turn A crashes, this may be a reflection of the possibility that female riders could not execute a turn as safely as they could in other situations.

It was found that 33.4% of casualties in angle A collisions and 31.6% of casualties in angle B crashes were as a result of the collisions with female motorists, which was the highest among all crash configurations. Elderly motorists appeared to be overrepresented in accidents where a turning car collided with an approaching motorcycle (i.e., 15.4% for approach-turn B crashes, 13.7% for angle A crashes, and 16.9% for angle B crashes). This implies that elderly motorists intending to make a turn may have more difficulties in intersecting with oncoming motorcycles than when they are executing other traffic tasks (e.g., when they intersect with motorcycles travelling from same directions). Similar conclusions were drawn by several researchers (e.g., Clarke et al., 2007; Keskinen et al., 1998) who reported that elderly motorists tended to cross into and merge with the traffic stream more slowly and have problems detecting approaching motorcycles. Numerous studies of car-car accidents (see, for example, Mayhew et al., 2006; Chipman, 2004) have also noted that elderly motorists were generally found to be overrepresented in right/left turn as well as angle crashes compared with those in other crash configurations.

One noteworthy difference observed from Table 8.2 was that there is far higher percentage of unknown motorist gender and age for rear-end CarMc collisions. Unknown motorist gender and age contribute to 13.7% and 20.8% of the casualties in rear-end CarMc collisions respectively. While the cause of these differences cannot be determined with any certainty, it is likely that the car as a following car that crashed into a leading motorcycle may be more likely to escape from the accident scene than other crash configurations. A work that examines the explanations for these effects could be an interesting future research area.

8.3.2 Roadway/Geometric Characteristics

It was found that head-on crashes were far more likely than other crash configurations to occur when there were bends for motorcycles or for cars. "Bends for motorcycles" represent 26.6% of the casualties in head-on crashes, while "bends for cars" contribute to 23.6% of the casualties in head-on crashes. This result is in accordance with the findings by several researchers (e.g., Mizuno and Kajzer, 1999; Ulfarsson et al., 2006), who pointed out that unintended/intended lane changing manoeuvres on curved roads were linked with a strong increase in the probability of head-on crashes.

With regard to junction control measures, uncontrolled junctions were overrepresented in head-on crashes (17%). This could be because either motorcycles or cars may be more likely to make improper manoeuvres (such as travelling beyond the centreline of the road) that arise from fewer restraints to manoeuvre at uncontrolled junctions.

For stop, give-way signs and markings, angle A/B collisions were more likely than other crash configurations to occur at stop-controlled junctions (89.8% and 87.8% respectively). Head-on and angle A/B collisions were the least likely of all crash configurations to occur at signalised junctions (1.3% for head-on crashes; 1.4% for angle A crashes; 1.7% for angle B crashes), whilst approach-turn A and rear-end CarMc collisions were far more likely than any other crash configuration to take place under automatic signals (20.7% for approach-turn A collisions; 16.1% for rear-end CarMc collisions).

To the knowledge of the author, research investigating the relationship between junction control measures and motorcycle-car crash configurations is scarce in literature, which deserves further research. One exception seems to be the work by Pai and Saleh (2007a) in which similar findings were drawn. Pai and Saleh suggested that for approach-turn A crashes (see the illustration in Figure 4.3(b) in section 4.3), while signalised junctions provide definite right to right-turn motorcyclists and travelling-straight motorists to cross the junctions, the turning riders probably did not compensate as sufficiently as they normally did at signalised junctions (for other travelling tasks such as intersecting with the conflicting traffic on the major roads). If there is any truth to this, automatic signals should be similarly overrepresented in approach-turn B crashes in which an approaching motorcycle collided with a right-turn car. However, statistics in Table 8.2 show that 6.3% of approach-turn B crashes took place at signalised junctions, which appears to be far less often than approach-turn A crashes at signalised junctions. Clearly this deserves to be further researched.

Regarding street light conditions, it was found that daylight conditions contributed to 60.7% of the casualties in approach-turn B crashes, which was less often than other crash configurations. This implies that this crash configuration was more likely than other crash configurations to occur in darkness, irrespective of the street lighting conditions.

For speed limit effect, approach-turn B crashes were most likely of all crash configurations to take place on built-up roads (84.1%). Several researchers (e.g., Hole et al., 1996; Clarke et al., 2007) similarly found that the majority of right-of-way violation accidents took place at urban intersections. Head-on and rear-end McCar crashes were most likely of all crash configurations to occur on non built-up roads (about 28.0% for both head-on crashes and rear-end McCar crashes).

8.3.3 Vehicle Factors

With regard to the effect of motorcycle engine size, it was found that the highest percentage of casualties that were users of heavier motorcycles was for sideswipe "motorcycle head-to-sides car" crashes (84.2%). The lowest percentage of casualties that were users of heavier motorcycles was for approach-turn A crashes (64.5%). Possible explanations for these effects could be as a result of different road behaviours of these heavier-bike users such as their overconfidence in overtaking manoeuvres for sideswipe "motorcycle head-to-sides car" crashes (also see the estimation results in Table 7.41 and Table 7.42 regarding overtaking manoeuvres in the model of sideswipe "motorcycle head-to-sides car" crashes), and more cautious crossing behaviours for approach-turn A crashes.

As reported in Table 8.2, it appears that the percentage of HGVs in same-direction collisions (i.e., sideswipe "side to side" crash, rear-end McCar crash, rear-end CarMc crash) is higher than accidents that involve gap acceptance (i.e., approach-turn A/B crash, angle A/B crash). The highest percentage of HGVs is for sideswipe "side to side" crash (16.3%). These results are probably because HGVs which have higher passenger compartment may exacerbate the problem that motorcycles are often in motorists' blind spots (particularly a filtering motorcycle from behind or on the adjacent lane). On the other hand, it could be easier for HGVs that have higher passenger compartment to detect an oncoming motorcycle due to their less obstructed sight distance. However, there are 10.9% of the causalities in head-on collisions with HGVs in which the HGVs with higher compartment might have less obstructed sight distance to detect oncoming motorcycles. Other factors such as the presence of bend for motorcycle or car may play a part in such effect. It might be interesting for future research that attempts to examine HGVs' road behaviours on the roadways with bends.

Head-on crashes are found to be far more likely than other crash configurations to involve the third vehicle or above (24% of the casualties were involved in head-on crashes that involved more than three vehicles). Rear-end McCar and CarMc collisions were second most likely to involve the third vehicle or above (13.5% and 11.0% respectively). To the knowledge of the author, there seems to be a lack of research examining why motorcycle-car head-on crashes/rear-end crashes were more likely than other crash configurations to involve more than three vehicles or above. Estimation results of head-on crash model also showed that riders were more injurious in head-on crashes that involved more than three vehicles than in two-vehicle head-on crashes (see Table 7.45 in section 7.5.1). Such effect was not significant in explaining motorcyclist injury severity in rear-end McCar crashes (see Table 7.45 in section 7.5.1). The examination results here, coupled with the findings in the model of head-on crashes, may lend support for future work that examines the characteristics of these crash configurations involving more than three vehicles.

8.3.4 Weather/Temporal Factors

For weather conditions, it was observed from Table 8.2 that adverse weather is overrepresented in angle A and angle B collisions (12.0% and 12.5%). Such effect may be explained by the possibility that adverse weather is more likely to exacerbate the sight distance of a turning car that is in a need to intersect with an oncoming motorcycle.

With respect to temporal factors, 37.5% of approach-turn B collisions took place during evening hours, which was the highest than all other crash configurations. This finding concurs with the conclusions drawn by Peek-Asa and Kraus (1996a) who suggested that approach-turn collisions were more likely than other multiple vehicle crashes to occur in dusk lighting conditions. The examination results for street light conditions also reveal that approach-turn B crashes were more likely than other crash configurations to occur in darkness, irrespective of the street lighting conditions (see section 8.3.2 above). The findings here, coupled with those of Peek-Asa and Kraus, underscore the importance of improving motorcycle's conspicuity especially during evening/nighttime hours.

For weekday effect, head-on collisions appeared more likely than any other crash configuration to occur on weekends (32.1%). This may be a reflection of more relaxing or aggressive driving/riding behaviours on the weekend, thereby resulting in riders/motorists more frequently drifting into oncoming traffic.

8.4 Summary

This chapter firstly provided a summary of the findings obtained from the disaggregate models by various crash configurations. The summary, as shown in Table 8.1, suggested that the effects of some variables on injury-severity levels vary across different crash configurations.

Following the summary of the estimation results of the disaggregate crash models, the considered variables amongst various crash configurations that led to KSIs were further examined. The examination results showed that there were differences in the considered variables amongst various crash configurations that led to KSIs. The examination results provided insights into whether a specific crash configuration leading to KSIs was most likely of all crash configurations to occur in a certain situation. Noteworthy examination results include, for instance, elderly motorists were disproportionately represented in accidents where turning cars collided with approaching motorcycles (i.e., approach-turn B and angle A/B crashes); head-on crashes were far more likely than any other crash configuration to take place on the curved roadway and on the weekend; and approach-turn B crashes were more likely than other crash configurations to occur in darkness, regardless of the street light conditions, and during evening hours.

The next chapter will provide a discussion of the research findings obtained in this present study.

CHAPTER 9
DISCUSSIONS AND RESEARCH LIMITATIONS

9.1 Introduction

The implications of the findings obtained from this research are discussed in this chapter, with particular emphasis being placed on the potential countermeasures that could be applied to prevent the hazards from occurring. The discussions are organised by the crash configurations, followed by a general discussion for possible prevention strategies that may be beneficial for all crash configurations. The constraints and research limitations that exist in this current study are also described. This chapter ends with a brief summary.

9.2 Discussions and Potential Countermeasures

9.2.1 Approach-Turn and Angle Crash

9.2.1.1 Right-of-way violation

The results in this research showed that, for approach-turn B crashes and angle A crashes, motorists' failure to give way appeared to be a deadly factor to motorcyclists. The contributory factors documented in literature that result in motorists failing to yield include motorcycles' poorer conspicuity (Hurt et al., 1981; Preusser et al., 1995), motorcycle's speed being difficult to determine, size-arrival effect (Horswill et al., 2005; Caird and Hancock, 1994), elderly motorists' difficulties in detecting motorcycles (Hole et al., 1996; Clarke et al., 2007), and some other cognitive/attitudinal factors (Hancock et al., 1990). These contributory factors were not examined in this research due to the absence of this type of data in the Stats19. However, this research has uncovered other factors determining the likelihood of motorists' failure to yield. These factors include gender-/age-specific factors, as well as other factors such as temporal, roadway, and vehicle factors. Countermeasures aimed to improve motorcycle safety may first attempt to curb motorists' failure to yield through enforcement efforts as well as public information and safety education programmes. For instance, safety education programmes may be directed towards certain groups of motorists such as the elderly/teenage motorists, or professional motorists of larger motor vehicles that appeared to be more likely to violate motorcyclists' right of way. Enforcement efforts such as police patrol near junctions (Cooper and McDowell, 1977; Storr et al., 1980) may need to be directed towards certain times and locations such as nighttime/weekend and non built-up roads where violations were more likely to occur.

In this research the relationship between actual pre-crash speed of car and motorcycle and right-of-way violation was not examined because such data was not available from the Stats19. "Speed limit" was examined as a surrogate variable for vehicle crash speed (see Table 7.20 and Table 7.21 in section 7.2.5.1). The estimation results of the binary logistic models (see Table 7.20 and Table 7.21) suggested that violation cases were more likely to occur on non built-up roads than those on built-up roadways. Controlling traffic speed by reducing speed limit may be an intervention measure to curb right-of-way violations.

Past studies of car-car angle crashes at T-junctions (e.g., Cooper and McDowell, 1977; Storr et al., 1980; Darzentas, 1980a, b) and motorcycle-car approach-turn collisions at four-legged junctions (e.g., Peek-Asa and Kraus, 1996a; Brenac et al., 2006), as well as car-bicycle accidents at roundabouts (Räsänen and Summala, 2000; Summala et al., 1996), may lend support for the proposed countermeasure here. Research analysing car-car angle collisions at T-junctions (Cooper and McDowell, 1977; Storr et al., 1980; Darzentas, 1980a, b) argued that when the traffic on the major road was slower and more uniform in speed, turning drivers tended to make fewer perceptual errors and collisions were reduced. Studies of car-motorcycle approach-turn/angle crashes (Peek-Asa and Kraus, 1996a; Brenac et al., 2006) reported that a high speed (or speeding) motorcycle may affect the motorcycle's detectability and may be a determining crash factor. Summala and his colleagues (Räsänen and Summala, 2000; Summala et al., 1996), in analyses of car-bicycle accidents, pointed out that higher motor vehicle approach speed contributed to motorists not looking to their right or to not giving way to bicyclists at roundabouts. The conclusions drawn by these researchers, coupled with the findings in this current research, underscore the importance of controlling traffic speed by reducing speed limit to assist the detectablity and identification of motorcycles in traffic. The number of right-of-way violations may therefore be reduced.

Evidence in literature (e.g., Hurt et al., 1981) showed that motorists violating motorcycles' right-of-way often claimed not to have seen them at all or not to have seen them in time to avoid the crash. Whether motorcycles being less conspicuous resulted in motorists' failure to yield was not directly examined in the thesis due to the lack of data. Rather, the effect of accident time was investigated (Table 7.20 and Table 7.21 in section 7.2.5.1). The estimation results of the binary logistic models (see Table 7.20 and Table 7.21) revealed that evening and mid-night/early morning hours (relative to non rush hours) were associated with more right-of-way violations. The finding that evening and mid-night/early morning hours were correlated with more right-of-way violations may point to the need to enhance motorcycle's conspicuity particularly during these hours. This is because motorcycles' poor conspicuity may be exacerbated during evening and mid-night/early morning hours (Peek-Asa and Kraus, 1996a), thereby decreasing their detectability from right-turn motorists' perspective.

There is a lengthy literature investigating whether some measures would effectively improve motorcycle/motorcyclist conspicuity. The measures examined include running the headlight during the daytime (Janoff and Cassel, 1971; Fulton et al., 1980; Umar et al., 1996), additional running lights in varying patterns during nighttime (Hancock et al., 2005), fairings that increase the frontal surface area (Williams and Hoffmann, 1979a), and the wearing of fluorescent garments/helmets/leg shields (Donne and Fulton, 1985; Donne et al., 1990; Olson et al., 1981; Hancock et al., 2005). Relatively consistent conclusions drawn in these studies include that, through the use of these measures, motorists were more likely to notice and pause for the oncoming motorcycles. Being able to virtually detect a motorcycle may prevent motorists from making a turn recklessly, or at least, help to allow more chances to brake abruptly before a collision (Peek-Asa and Kraus, 1996a). This current study did not attempt to evaluate the role of improved motorcycle's conspicuity in either curbing right-of-way violations or reducing motorcyclist injury severity conditioned on an accident having occurred. However, the results suggested (see Table 8.2 in section 8.3) that approach-turn B collisions were the least likely of all crash configurations to occur in daylight conditions (60.7% of approach-turn B crashes took place in daylight conditions which is about 13% below the overall average for this variable, as shown in Table 8.2). This implies that approach-turn B collisions were most likely of all crash configurations to occur during evening/midnight/early morning hours. For evening/midnight/early morning riding conditions, there may be value in adopting these measures proposed in past studies, which may in turn reduce the turning motorists' perceptual errors when intersecting with motorcyclists.

The conspicuity problem that motorcycles have may also arise from the fact that motorcycles being much smaller than other motor vehicles (particularly when viewed from the front of machine) are more likely to be blocked in traffic streams (Olson, 1989). Blockages such as a larger motor vehicle nearby or a nature obstruction (e.g., tree or curved roadway) may cause motorists' failure to see the oncoming motorcycle or see it in time to avoid the crash (Hurt et al., 1981; Williams and Hoffman, 1979a). There has been considerable agreement among these researchers – blockages of direct visibility may play a significant role in approximately half of motorcycle-car crashes that involved right-of-way violations. Other researchers (e.g., Preusser et al., 1995; Clarke, 1999; Kim and Boski, 2001) suspected that motorcycles' improper overtaking manoeuvres would reduce their visibility because they generally popped out in traffic streams.

In this current research, the effects of these two factors (i.e., the presence of bend and motorcycles' traversing manoeuvres, as abovementioned) on the likelihood of motorists' right-of-way violations were examined (see Table 7.20 and Table 7.21 in section 7.2.5.1). It was found that the presence of bend was not significant in explaining the likelihood of motorists' failure to yield. Moreover, for angle A crashes, right-of-way violations were more likely to occur to a travelling-straight motorcycle than a traversing motorcycle (such effect was insignificant for cases in approach-turn B crashes). Such results may be somewhat inconsistent with those of the abovementioned studies. Possible explanations for the first result could be that the bend data of the Stats19 were thought to be fairly unreliable – none of traversing manoeuvres (i.e., overtaking or lane changing) was recorded to have occurred on curved roads. The second result could be attributable to the possibility that a travelling-straight motorcycle may travel faster than a traversing motorcycle, allowing less time for a turning motorist to clear the junction in time. It could also be a consequence of an overtaking manoeuvre by a motorcycle that represents the presence of other motorised vehicles nearby, which may act as a visual deterrent to reckless crossing by a turning motorist.

Junction control could be important in controlling the occurrence of approach-turn crashes (see conclusions drawn by Peek-Asa and Kraus, 1996a; Kim et al., 1994; Preusser et al., 1995). Junction control measures may be a starting intervention point to help eliminate the needs of a right-turn motorist to detect an oncoming motorcycle, thereby reducing the number of right-of-way violations. Priority signal measures such as priority phases with arrows that direct turning motor vehicles to proceed in their desired directions, as well as a longer duration of green phase for either motorcycles or motor vehicles, could be beneficial at junctions where there are high traffic volume of motorcycle and motor vehicle.

9.2.1.2 Injury severity

The countermeasures mentioned above, which aim to prevent the crash from occurring by curbing right-of-way violations, were termed as primary prevention strategies by Peek-Asa and Kraus (1996a). Secondary prevention strategies, which aim to reduce the number/severity of injuries resulting from accidents, were also discussed by Peek-Asa and Kraus. Typical secondary prevention strategies include the use of energy-absorbing structures such as engine guards, air bags, leg protectors, and helmets that decrease the energy of the crash, direct the impact energy away from the rider, or dissipate energy away from the motorcyclist.

Defining the patterns of injuries sustained in various crash configurations, which indicated where the energy of the impact is absorbed by the motorcyclists, helped Peek-Asa and Kraus identify potential secondary prevention measures. For example, they reported that the odds of lower extremity injuries among injured motorcyclists in approach-turn crashes was more than twice that of injured riders in single-motorcycle crashes. Approach-turn crashes were further disaggregated into two crash configurations – crashes in which motorcycle turned left and car turned left. Among approach-turn crashes in which the car was left turning, lower extremity injuries (i.e., limb fracture) were more common when the approaching motorcycle was struck by the left-turn car due to the entrapment with the car. Injuries of the lower extremities often resulted in infection, required longer hospital stays and costly medical treatment including complicated surgery, skin and bone grafts, total joint replacement, and amputation (Mackay, 1986). They argued that, for such injury pattern, several different types of devices to protect legs of the injured riders including crash bars, or energy absorbing leg protectors with cage-like structures (Haddon, 1973; Harms, 1989) may be beneficial in reducing the severity of limb injuries. Other findings drawn by Peek-Asa and Kraus include that, in approach-turn crashes in which car was left turning, injuries to motorcyclists were generally more severe when the motorcycle struck the car than when motorcycle was struck by the car. The striking riders appeared to be more prone than the struck riders to sustain head, chest, spine, and upper extremity injuries. Part of their findings generally concurs with the finding in this current research that motorists infringing upon motorcyclists' right of way predisposed riders to a greater risk of KSIs.

The abovementioned findings by Peek-Asa and Kraus with respect to the injured regions of human body cannot be ascertained in this current research due to the lack of data on medical diagnoses records. Therefore no secondary prevention measures that target injuries resulting from specific crash configurations can be identified. However, the current research may provide some important preliminary evidence for the development of countermeasures that can be applied to prevent the hazards from occurring, or reduce injury severity once an accident has occurred. For example, the examination of temporal factors in this current study (see Table 7.8 and Table 7.9 in section 7.3.2) point to the conclusion that more alcohol use and speeding during particular hours or days of week (e.g., evening, mid-night/early morning hours, weekends) may be associated with the increased motorcyclist injury severity (Kasantikul et al., 2005). Evidence in literature (e.g., Kasantikul et al., 2005) revealed that alcohol-involved motorcycle accidents were more frequent on weekends and during evening/nighttime hours. Whether riders/motorists were more likely to be speeding on weekends and during evening/nighttime hours seem not to be thoroughly researched. Clearly, further research examining the relationship between injury severity, alcohol use, speeding, and temporal factors (e.g., nighttime/weekend riding) may confirm the conjecture here. If the relationship between motorcyclist injury severity and these factors can be confirmed, educating riders about the risks that they face while drink-riding particularly during evening/nighttime/early morning hours and on the weekends, as well as police enforcements meant to curb drink-riding and speeding, are likely to bring more immediate benefits.

9.2.2 Head-on Crash

It was found that riders in head-on crashes were more injurious when there was a bend for car than when there was no bend for car at all (see Table 7.29 and Table 7.30 in section 7.3.3). Head-on collisions leading to KSIs also appeared to be far more likely than other crash configurations to occur on the curved roadways (see Table 8.2 in section 8.3). Past studies analysing the accident occurrences concluded that a curved road was linked with a strong increase in the probability of car-car head-on crashes (e.g., Ulfarsson et al., 2006; Zhang and Ivan, 2005). Zhang and Ivan attributed this to the possibility that drivers may be more likely to drift into the oncoming traffic following the curvature. Ulfarsson et al. further pointed out that reducing the degree of the horizontal curves may be effective for reducing most car-car head-on crashes. It is recognised in this present study that making the geometric changes would not be a cost-effective measure. Instead of curves strengthening, a mirror that is erected on the kerb and reflects the presence of the oncoming traffic has been widely used in Asian countries. Such countermeasure may have the potential in increasing the ability of the motorist/rider to detect the approaching traffic on curved roads, thereby preventing the hazards from happening.

Riding during mid-night hours/early morning hours and on the weekend appeared to predispose motorcyclists to a greater risk of KSIs (see Table 7.29 and Table 7.30 in section 7.3.3). Similar to the features of approach-turn and angle crashes examined in this research, speeding and more alcohol use during these hours may play a part. Peek-Asa and Kraus (1996a) specifically comparing the characteristics of head-on crashes with those of other crash configurations reported that the motorist was drinking most often in head-on crashes, and the motorcyclist was drinking the second most often in such collisions followed by single-motorcycle crashes. Peek-Asa and Kraus further noted that riders in head-on crashes were most likely of all crash configurations except for single-motorcycle collisions to be speeding. Although the effect of speeding and alcohol use was not examined in this research, the modelling results that riders were more injury-prone during mid-night hours/early morning hours point to the conclusion that enforcement that prohibits speeding or drink riding/driving should be directed towards mid-night and early morning hours.

Injuries tended to be greatest in head-on collisions in which a traversing motorcycle collided with a travelling-straight car (see Table 7.29 and Table 7.30 in section 7.3.3). In order to prevent such hazard from occurring, traversing manoeuvres should be prohibited at T-junctions.

9.2.3 Sideswipe and Rear-end Crash

While traversing manoeuvres were found to increase car-car sideswipe crashes in extant literature (e.g., Chovan et al., 1994; Li and Kim, 2000), it was found in this research that the deadliest pre-crash manoeuvres in sideswipe "motorcycle head-to-sides car" crashes were an overtaking motorcycle crashing into a turning car (see Table 7.41 and Table 7.42 in section 7.4.3). For rear-end McCar crashes, traversing manoeuvres by both the motorcycle and car have the highest probability of a KSI (see Table 7.43 and Table 7.44 in section 7.4.4).

Prevention strategies for these deadly combinations include engineering measures such as motorcycle segregation that precludes motorcyclists and motorists from sharing the same pavement on high-speed roadways, and/or on roads with a significant fraction of heavy motor vehicles. Such engineering measure may be beneficial in reducing the risks of traversing-related (e.g., overtaking, lane changing) accidents on undivided roadways in general and at junctions in particular. Motorcycle segregation from other motor vehicle traffic has been adopted in highly motorcycled countries in Asia such as Taiwan and Malaysia (Radin Umar et al., 2000; Harnen et al., 2003).

Similar to approach-turn and angle collisions, it is suspected in this study that motorcycles' poor conspicuity may play a part in determining motorcyclist injury severity in sideswipe and rear-end crashes. Which is, motorists may not be able to detect a filtering motorcycle from behind or a motorcycle on the adjacent lane in time until the crash takes place. Researchers (e.g., Freedman, 1982; Freedman and Davit, 1984; Tang, 2003; Tang et al., 2006) have suggested that manipulations that can increase the detectability of a motorcycle through the improved conspicuity to the sides and rear of motorcycles may have an impact on reducing rear-end/sideswipe crashes. These researchers observed the significant differences between various side and rear conspiuity-enhancing treatments such as a twin/triple tail-lamp and flashing turn signals in their laboratory/field studies that simulated motorcycle's appearance in day and night, urban and rural conditions. The reaction time to rear conspituity-enhancing treatments was found to be significantly reduced particularly during nighttime, and the side reflectorisation aids may improve side conspicuity.

Manipulations that may increase detection frequency through improvements in car conspicuity were also discussed in past studies of car-car accidents. Many of these efforts such as collision warning/avoidance measures are directed towards specific crash configurations. The crash configuration that has received most attention is probably the rear-end/sideswipe collision. For instance, McIntyre (2008) noted that yellow tail-lamp resulted in faster reaction times and fewer errors than current red tail-lamp; and the centre high-mounted stoplight (CHMSL) equipped with the leading car may lead to an decreased injury severity level of the motorist in the following car (Khattak, 2001). Evidence in literature also revealed that intelligent transportation system (ITS) technologies such as side blind zone alert (SBZA) systems had the potential to reduce lane changing-/overtaking-related crashes in which "did not see other vehicle" was a principal causal factor (Kiefer and Hankey, 2008).

The effects of these abovementioned measures on motorcycle safety are uncertain, and there seems to be a lack of research into this area. However, they may have the potential in preventing several crash configurations (e.g., head-on crashes, rear-end crashes) from occurring. The results in this current study revealed that crash configurations such as head-on crashes and rear-end crashes were more likely than other crash configurations to involve three vehicles or above (see Table 8.2 in section 8.3). These findings may underscore the need for the countermeasures (e.g., collision warning/avoidance measures) to prevent the third vehicle from being involved in head-on crashes and rear-end crashes.

9.2.4 General Discussions

There is evidence in past studies documenting elderly motorists' over-involvement in angle crashes (Garber and Srinivasan, 1991; McKelvey and Stamatiadis, 1989; Abdel-Aty et al., 1999), sideswipe crashes, and head-on crashes (Garber and Srinivasan, 1991). Researchers have attributed these phenomena to the possibility that the elderly motorist was more likely to be cited for failure to yield right of way (Garber and Srinivasan, 1991; McKelvey and Stamatiadis, 1989; Stamatiadis et al., 1991), and more prone to disregard traffic signal, make improper turns, and have improper lane usage (Garber and Srinivasan, 1991). Similar results were observed in this current research – elderly motorists were found to be overrepresented in approach-turn B crashes, angle A crashes, and angle B crashes (see Table 8.2 in section 8.3). In addition, riders aged 60 or above were generally found to be more injurious than those of younger age groups across all crash configurations (see Table 7.45 in section 7.5.1). Researchers analysing car-car accidents (e.g., Evans, 1988) attributed this discrepancy to the possibility that younger individuals may tolerate crashes of any specific severity more successfully than their older peers. Research into motorcycle accidents (e.g., Shankar and Mannering, 1996; Quddus et al., 2002) noted that the elderly that were frailer to accident injuries may be due to physiological factors associated with advanced age.

In this current research, male motorcyclists were generally more injury-prone than females, which is consistent with the findings of several researchers (e.g., Keng, 2005; Lapparent, 2006; Chang and Yeh, 2006), but inconsistent with that of Quddus et al. (2002). Such result is likely to be as a result of some other exogenous factors that were not assessed in this research. For example, male riders were found to be more likely to drink and ride than females (Kasantikul et al., 2005), which could be an explanation for the gender differences found in this research.

The estimation results also showed that injuries tended to be greatest to elderly riders both in accidents in whole and in different crash configurations. Efforts such as training programmes or license restrictions to prevent crashes or reduce injuries (in an event of a crash) in the elderly will be increasingly important particularly in an ageing society.

Riding in mid-night and early morning was found to predispose motorcyclists to a greater risk of KSIs in almost all crash configurations. As mentioned previously in this thesis, speeding and alcohol use might be a contributory factor to this effect. While this conjecture cannot be confirmed in this current research as a result of the absence of such data in the Stats19, several published studies have suggested that drink riding was overrepresented in fatal accidents that occurred during these hours. For example, Hancock et al. (2005) reported that motorcyclists killed at nights were nearly four times as likely to be intoxicated as those killed during daytime hours. Efforts meant to curb drink driving/riding such as education programmes and police enforcement during these hours may constitute effective countermeasures in areas with a significant fraction of motor vehicles/motorcycles.

ITS technologies that are capable of helping drivers avoid crashes (or mitigate the impact of crashes) under some conditions are emerging into the marketplace or are under development. The effects of emerging intelligent transport system technologies on the consequence/occurrence of car-car accidents have been regularly researched in literature (see, for example, Khattak, 2001; Kiefer and Hankey, 2008). ITS measures that help motorists detect and track walking pedestrians have also been developed (see for example, Pai et al., 2004). Compared with the widespread development and applications of ITS measures for car-car/car-pedestrian accidents, there is little attention currently given to car-motorcycle accidents (Hancock, 1995; Hancock et al., 2005). Future research may attempt to identify whether the ITS measures such as collision warning/avoidance systems currently used for the prevention of car-car/car-pedestrian accidents may also be applied for car-motorcycle accidents. Collision warning/avoidance systems may have the potential to help turning motorists detect an approaching motorcycle (for angle and approach-turn B crashes) or a filtering motorcycle nearby or from behind (for sideswipe "motorcycle head-to-sides car" crash/rear-end McCar crash).

9.3 Research Limitations

There are a few intrinsic research limitations in the current research. These limitations are described below.

9.3.1 Underreporting Issue

The ideal study population for this current research would include all motorcyclists involved in accidents, irrespective of injury severity. This research was limited to motorcycle-car accidents that resulted in either motorcyclists or motorists being injured and that were reported to the police. It was recognised at the outset of this current research that the underreporting motorcycle-car accidents would be a serious concern, with direct implications for the analyses. That is, the police-reported crashes can skew injury severity levels towards more severe crashes. This current study therefore may not be generalisable to the entire spectrum of motorcycle crash injuries. However, this underreporting issue can be compensated for in two ways. First, a 14-year database was analysed. By extracting data of additional years, additional motorcycle accidents were analysed. Second, it is believed that a large proportion of motorcycle crashes involving severely injured motorcyclists that required medical treatments were reported to police. Underreporting accidents that resulted in slight injuries or no injury at all to motorcyclists may not be properly reported to police (the slightly injured/uninjured motorcyclist may have left the accident scene) but such cases have not been the focus of this current research. Rather, the main focus of this current study has been on the KSIs sustained by motorcyclists.

9.3.2 Classification of Crash Configuration

Another limitation of this current work is that the method of classifying actual/intended paths of motorcycle and car may interact synergistically with the complexity of motorcycle collision kinematics to undermine the validity of the crash typology developed in this study. This is, for example, classifying an angle crash into angle A crash (perpendicular collision-angle) and angle B crash (oblique collision-angle) on the basis of car/motorcycle actual/intended paths can be somewhat problematic.

Take something as simple as a motorcycle and car on perpendicular paths (i.e., the collisions in which a right-turn car on the slip road collided with an oncoming motorcycle travelling on the major road, as illustrated in Figure 7.1(c) in section 7.2.2). If the motorcycle hits the side of the car (i.e., such motorcycle's intended path is perpendicularly conflicting with the car's intended path), it is a perpendicular collision; if such motorcycle plows across the front end of the car (this may happen as the motorcycle may swerve before crash), the contact surface is parallel/oblique. In a crash with perpendicular collision-angle, crash-impact/injuries can be affected by where the rider hits. For instance, the occupant compartment of a HGV or SUV will stop a rider's forward motion, which would result in "above-the-knee" injuries. Hitting the bonnet or the boot area of a passenger car can result in the rider ejecting and tumbling (Obenski et al., 2007), which would generate secondary contacts between the motorcyclist and the car and motorcyclist and ground. Furthermore, crash-impact in a perpendicular collision, if a car is the striking vehicle, is also affected by car speed or car type – if the speed is high enough, it can cause the motorcycle to yaw during impact; and higher compartment of the involved automobile, if it is a truck, may run over the rider or cause the entrapment of the rider.

Efforts have also been made to capture the abovementioned variability (i.e., the effects of striking/struck role and types of collision partner) that may undermine the validity of the crash typology developed in this present study. It is recognised in this current research that there might be some other sources of variability that may be overlooked. The crash typology developed in this study, however, was the best the author can do with police report data.

9.3.3 Definition of Right-of-way Violation

While the data on right-of-way violation are not explicitly provided in the Stats19, the variable "First Point of Impact" that is available in the Stats19 has been used to assign motorist's right-of-way violation (see section 7.2.3.1 for a detailed discussion of how motorist's right-of-way violation was assigned). Although extensive research (e.g., Hurt et al., 1981; Hancock et al., 1991; Peek-Asa and Kraus, 1996a; Pai and Saleh, 2008) has adopted the similar approach used in this present study in assigning right-of-way violation, one may argue that assuming right-of-way violation by "First Point of Impact" can be somewhat subjective. For instance, a right-turn car crashing into the offside of an approaching motorcycle could be classified as a right-of-way violation case rather than a non violation case (see Figure 7.2 in section 7.2.3.1 for a schematic diagram of a right-of way violation case and a non right-of-way violation case). This is because such right-turn motorist may be too impatient to wait for the oncoming motorbike to clear the junction (or simply misjudge the time such motorbike needs to clear the junction), thereby deliberately infringing upon such motorcycle's right-of-way and crashing into its offside. However, it is beyond the scope of this current research to examine whether the approach adopted in previous studies and in this research is robust without any bias.

9.3.4 Data Availability

Perhaps the most obvious limitation stems from the use of the Stats19 data. While the Stats19 provides a detailed source of accident features, several other important factors were not readily available. These factors include the causes to the accident (e.g., violation, speeding etc.), helmet use, speed, other geometric factors such as vertical bends (i.e., grade) rather than horizontal bends, and alcohol use. Exposure data such as traffic flow for the traffic stream at the time of accident, riding/driving experience, and other aspects of risk exposure were also not available. The data that were not available from the Stats19 can be expensive to obtain and thus analyses of these unavailable data are beyond the scope of this thesis. Nonetheless these factors should not be overlooked in further research.

Speed of the involved motorcycle and car could be one of the most important factors that affect injury outcome or likelihood of motorists' failure to give way. Most of published works relying on police reports to conduct their studies have encountered the same problem as this current research has, which is, the lack of data on speed. For some studies examining the effect of speed factor that was available from some database, the reliability of such speed data could be rather questionable. This is in part because police attending the accident scenes may have obtained the speed data from the involved victims or witnesses, which may be fairly subjective due to postcrash shock or denial of responsibility.

9.3.5 Inclusion of Data and Reliability Issue

While the problems that arise from analysing police crash report data were addressed in section 8.3.1 and section 8.3.4 in this chapter, several shortcomings of the Stats19 regarding the reliability of the data are reported below.

First, while this thesis has been completed, the Stats19 data for years 2005 and 2006 have been readily available. The author decided not to include the data of 2005 and

2006 in the analyses of the data for years 1991-2004 because the modification of the categories in the variable "Junction control measures" makes it inappropriate to combine the data of 2005 and 2006 with those of previous years. This is, the category "Give way sign or marking" is merged with the category "Uncontrolled" for the data of years 2005 and 2006. It is considered here to be an inappropriate modification as a significant difference in the injury severity was observed in this current study for several crash configurations (e.g., head-on crashes, sideswipe "motorcycle head-to-sides car" crashes) that occurred at uncontrolled junctions and stop-controlled junctions (see Table 7.45 in section 7.5.1). It is also worthwhile to note that the data for years 1985-1990 were initially deposited by the DfT and became available while this thesis was being finalised. It was decided not to include the 1985-1990 data in the analyses as the inclusion of the 1985-1990 data in the original analyses is very time-consuming. Further research may extend the work conducted in this current study by including the 2005 and 2006 data, as well as the 1985-1990 data.

Second, while police crash data are perhaps the most valuable source of multiple factors that affect accident occurrence/consequence, the injury severity levels recorded can be inaccurate (Rosman and Knuiman, 1994). This is largely because injury severity scale may primarily rely on police officers' judgment at the accident scene. Past studies (e.g., Barancik and Fife, 1985) have shown discrepancies between police judgments and medical records. Life-threatening injuries, such as internal brain trauma, could be identified as slight injury if they are not evident to the police officers. However, this may be an innocuous research limitation since a fatal/serious injury is classified in the Stats19 by the observation of a casualty requiring detention in hospital for up to 30 days, rather than by police officers' judgment at the accident scene alone.

Finally, it should be pointed out here that the bend data of the Stats19 are thought to be somewhat inaccurate/unreliable. In the Stats19, the variable "2.7 Manoeuvres" is the only variable that provides the information on the presence of bend. Which is, the categories "Going ahead left hand bend" and "Going ahead right hand bend" in the variable "2.7 Manoeuvres" represent the presence of bend. It is recognised in this present research that this may be a misleading recording system which results in none of traversing manoeuvres (i.e., overtaking or lane changing) being recorded to have occurred on curved roads. In spite of the bend data that are thought to be somewhat inaccurate/unreliable, the bend data were still included in the analysis as previous studies (e.g., Broughton, 2005; Clarke, 2007) suggested that the presence of curvature on the roadway is a serious concern for motorcycle safety. For instance, Broughton pointed out that motorcyclists riding on bends experienced a higher risk in being fatally/severely injured in single-motorcycle accidents. In addition, Clarke noted that the presence of curvature on roadway is one of the significant factors to the occurrence of fatal single-motorcycle crash. Interesting results related to the presence of bend were also found in this current research. For instance, there is about a 35% increased probability of a KSI for a head-on crash that occurred on the roadway with bend for car relative to non bend for car (see Table 7.30 in section 7.3.3). The examination results (see Table 8.2 in section 8.3) also revealed that head-on collisions were most likely of all other crash configurations to occur on the roadways with bends. It appears here that, given that research (e.g., Broughton, 2005) indicating that the presence of curvature on the roadway is a serious concern for single-motorcycle accidents, roadways with bends may also play a part in affecting motorcyclist injury severity in motorcycle-car accidents. It is therefore recommended that for more accurate and reliable bend data, an additional variable be added into the Stats19 recording system.

9.3.6 Cost-Effective Issue

Although several possible countermeasures were proposed in this current research, the author acknowledges that they may not be cost effective due to the fact that the United Kingdom is not a highly motorcycled country. The present study cannot address the question of whether or not these countermeasures are cost effective, nor can it conduct before-and-after studies due to the limited time and fund (see the work of Hauer, 1997, for a complete discussion of the essentials for a before-and-after study). The author recognises that these countermeasures may only be cost effective in areas with heavy automobile and/or motorcycle traffic. However, it is felt that these possible countermeasures may be beneficial in making driving safer for all road users in general and motorcyclists in particular. For instance, police surveillance can be targeted toward nighttime/weekend hours, and on non built-up roads, thereby helping making the right-turn motorists intersect with other motorised vehicles (particularly motorcycles) more cautiously.

9.4 Summary

This chapter discussed the findings in this research, with emphases on the potential countermeasures that can be applied to help curb right-of-way violations and prevent specific hazards from occurring.

The prevention measures that may curb motorists' failure to yield in accidents involving gap acceptance were first discussed. Gender-/age-specific factors, as well as other factors such as temporal, roadway, and vehicle factors were found to be associated with more right-of-way violation cases. These factors should be taken into account for the implementation of the countermeasures. For example, countermeasures such as public information and safety education programmes can be targeted toward certain groups of motorists such as the elderly/teenage motorists, or professional drivers of larger motor vehicles that were found to be more likely to violate motorcycles' right of way. Police patrol near junctions that can be a potential countermeasure may also need to be directed towards certain times and locations such as nighttime/weekend and non built-up roads where violations were more likely to occur.

Evidence in literature has shown that motorcycles' poor conspicuity may be one of the contributory factors to motorists' failure to give way. The relationship between right-of-way violations and motorcycles' poor conspicuity was not directly assessed in this research. However it was found in this research that evening/nighttime/early morning hours riding was associated with more right-of-way violations. It was suggested in this research that improving motorcycles'/motorcyclists' conspcituity through the use of the measures such as the wearing of fluorescent garments/helmets/leg shields may make motorcycling safer during daytime in general and during evening/midnight/early morning hours in particular.

It was also suggested in this research that certain types of junction control measures may have the potential in helping eliminate the needs of a right-turn motorist to detect an approaching motorcycle, thereby reducing the number of right-of-way violations. These measures that could prevent the direct crossing from occurring include priority signal phases and a longer duration of green phases for either motorcycles or motor vehicles

No secondary prevention policy that aims to decrease the number of injuries or lessen injury severity can be proposed based on the findings in this research. Rather, measures that may help prevent the specific hazards from occurring in certain crash configurations are discussed. For example, injuries in head-on crashes were greater when there was presence of bends than there was absence of bends on the roadways. It was suggested in this research that a mirror erected on the kerb could help motorists/motorcyclists detect oncoming traffic that may be blocked by the bends. Moreover, for the finding that traversing manoeuvres such as overtaking or lane changing by motorcycles resulted in the increased injury severity in sideswipe “motorcycle head-to-side” crashes and rear-end McCar crashes, efforts should be made to prevent motorcyclists from filtering in the traffic stream on high-speed roadways. Engineering measures such as motorcycle segregation lane may have the potential in reducing the number of overtaking-/lane changing-related accidents.

The next chapter ends this thesis with conclusions and recommendations for future research.

CHAPTER 10
CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

10.1 Introduction

The primary objective of this current research has been to investigate the factors that were associated with the increased motorcyclist injury severity resulting from various motorcycle-car accidents that occurred at T-junctions. This chapter presents a summary of the main results and conclusions obtained from the research. Furthermore, some recommendations based on the findings of this thesis for future research in the field of motorcycle safety are discussed.

10.2 Conclusions

Using data extracted from the Stats19 accident injury database, the current research estimated the aggregate OP model of motorcyclist injury severity by motorcycle-car accidents in whole. Additional disaggregate models of motorcyclist injury severity by various crash configurations were also conducted. The results obtained in this current research, by exploring a broad range of variables including attributes of riders and motorists, roadway/geometric characteristics, weather/temporal factors, and vehicle characteristics, provide valuable insights into the underlying relationship between risk factors and motorcycle injury severity both at an aggregate level and disaggregate level. The binary logistic models were also built to explain the likelihood of motorists failing to yield to motorcyclists in accidents that involved gap acceptance (i.e., approach-turn and angle crashes). The conclusions of this current research are organised into several sub-sections and presented below.

10.2.1 Right-of-way Violation

This current work has uncovered a significant problem involving the failure of a right-turn motorist to give way to motorcyclists in approach-turn and angle crashes. Right-of-way violation cases appeared to outnumber non right-of-way cases and predispose motorcyclists to a greater risk of KSIs in both approach-turn B collisions and angle A crashes. Significant factors (e.g., demographic, temporal, roadway and vehicle factors) associated with right-of-way violations have emerged. Such findings may facilitate the identification of the possible countermeasures that aim to curb motorists' failure to give way. Gender-/age-specific factors, as well as other factors such as temporal, roadway, and vehicle factors should be taken into consideration in the design and implementation of countermeasures meant to curb right-of-way violations. For instance, prevention strategies such as public information and safety education programmes can be targeted towards certain groups of motorists such as male motorists, young/elderly motorists, or professional motorists that were found to be more prone to infringe upon motorcyclists' right of way. Police patrol near junctions as a countermeasure may also need to be directed towards certain times and locations such as nighttime/weekend and non built-up roads where violations were more likely to occur.

10.2.2 Other Important Empirical Findings

There are some other important empirical findings. First, an important result is that injuries were generally greatest to riders in almost all crash configurations that occurred at stop-controlled junctions. One exception is for approach-turn A crashes where riders were more injury-prone under automatic signals. Second, the presence of the curvature for car resulted in the increased motorcyclist injury severity in head-on crashes. Third, overtaking manoeuvres by motorcycles appeared to be the deadliest manoeuvre to motorcyclists in sideswipe "motorcycle head-to-sides car" crashes. Fourth, injuries to riders were greatest in rear-end McCar collisions in which a traversing motorcycle collided with a traversing car ahead. With reference to past studies on motorcyclist injury severity which have focused primarily on estimating aggregate models by accidents in whole, there have been very few, if any, studies that resulted in similar significant findings.

Other factors found to generally increase motorcyclist injury severity in all crash configurations include elderly rider, motorcycle with engine size over 125cc, elderly motorist as motorcycle's crash partner, accidents that involved three vehicles or above, and accidents that occurred on non built-up roadways, during midnight/early morning hours, and on the weekend.

10.2.3 Possible Countermeasures

The results obtained in this current research have important implications for education programmes, traffic regulation and engineering control, and planning of motorcyclist facilities, as discussed in Chapter 9. One of the examples of potential measures based on the findings of this thesis is that engineering measures such as certain types of junction control measures may have the potential in helping eliminate the needs of a right-turn motorist to detect an approaching motorcycle, thereby reducing the number of right-of-way violations. The measures that could prevent motorists' direct crossing include priority signal phases and a longer duration of green phases for either motorcycles or motor vehicles. Another example is that motorcycle segregation that precludes motorcyclists and motorists from sharing the same pavement on high-speed roadways, and/or on roads with a significant fraction of heavy motor vehicle traffic may be beneficial in reducing the risks of overtaking-/lane changing-related accidents on undivided roadways in general and at junctions in particular.

10.3 Recommendations for Future Work

The scope of this current research was limited to the analyses of available data from the Stats19. Due to the restrictions on funding and time, it appeared impossible to extend this current research by analysing data from other datasets or validating the results by conducting a local case study. Therefore, the following issues are recommended for future research and are described further in the subsequent sections:

- Further research for specific crash type with available data in the Stats19
- Improving the model specification by including additional variables
- Improving the predictability of the calibrated models
- Validation of the modelling results

10.3.1 Further Research for Specific Crash Configurations with Available Data in the Stats19

Research is needed for specific crash configurations with available data in the Stats19. This is organised by crash type and explained further in the following sections.

10.3.1.1 Angle A/B crash

In this current research, angle A/B crashes were classified into five crash manners depending on the pre-crash manoeuvres of the involved motorcycle and car (see Figure 7.1 in section 7.2.2). There exist some crash patterns that could not be fit into five crash patterns and these were classified as unidentified crash pattern, which accounted for 12.1% of all casualties (i.e., 5527 observations, as reported in Table 7.2). These unidentified crash patterns include, for example, a situation when a car from the minor road did not make a right-/left-turn at all. Rather, this car travelled straight to the kerb of the major road (i.e., the top of the T-junction) and collided with an oncoming motorcycle. It is suspected that this may have been a car attempting to park on the kerb of the major road for business purpose. These unidentified crash patterns are irrelevant to this current research and therefore were not considered in the analysis. However, further research may attempt to identify whether these unidentified crash patterns resulted from inappropriate roadside parking that led to collisions with motorcycles. Further research may make the use of the variable “Vehicle Movement Compass Point” that provides information on the parking status of an involved vehicle.

10.3.1.2 Approach-turn A crash

As reported in Table 7.1, 28% of the injuries resulting from approach-turn A crashes under automatic signals were KSIs. No disaggregate model was estimated by this deadly combination as there were too few observations of casualties resulting from such crash configuration (N=189) to yield statistically significant modelling results. The examination of the considered variables amongst different crash configurations (see Table 8.2) also revealed that approach-turn A crashes were most likely of all crash configurations to occur under automatic signals. Clearly further research is needed to examine the causality mechanisms and factors involved in this crash configuration. To do so, further research may conduct univariate descriptive analysis (as conducted in Chapter 5 in this thesis), instead of the multivariate modelling approach, through the use of the data available from the Stats19.

10.3.1.3 Head-on crash

It was found from the disaggregate model of head-on crashes that riders were more injurious in head-on crashes that involved three vehicles or above (Table 7.29 and Table 7.30). The examination of the considered variables among different crash configurations (see Table 8.2) also revealed that head-on crashes were far more likely than other crash configurations to involve three vehicles or above. Similar to approach-turn A crashes that occurred at signalised junctions, the total number of casualties resulting from such crash configuration that involved three vehicles or above was too few to yield significant modelling result (N=711). Through the use of the data that is readily available from the Stats19, further research may conduct univariate descriptive analysis (as conducted in Chapter 5 in this thesis), instead of the multivariate modelling approach, to examine the causality mechanisms and factors involved in head-on crash that involves three vehicles or above.

10.3.1.4 Rear-end/sideswipe crash

Regarding rear-end/sideswipe crashes, there are three recommendations for future research:

- further research may attempt to identify whether a motorcycle is the middle vehicle that crashes into the car ahead and subsequently is rear-ended by a car;
- further research may attempt to analyse rear-end crashes with unknown gender/age of motorist; and
- further research may attempt to examine why the percentage of HGVs in same-direction collisions (i.e., sideswipe “side to side” crash, rear-end McCar crash, rear-end CarMc crash) is higher than accidents that involve gap acceptance (i.e., approach-turn A/B crash, angle A/B crash).

These three recommendations are further described below.

Regarding rear-end collisions that involve three vehicles or above, research analysing car-car rear-end crashes (e.g., Khattak, 2001) reported that in rear-end crashes that involved three vehicles or above, injuries to occupants in the middle car tended to be greatest. For motorcycle-car rear-end crashes, one may expect motorcyclist injury severity to be more severe if the motorcyclist victim is in the middle position. For this current research, the author has not been able to identify whether the motorcycle is exactly the middle vehicle that crashes into the car ahead and subsequently is struck by another automobile behind. This is because the variable "First Point of Impact" that has been used to classify rear-end McCar/CarMc collisions (see section 7.4.2 for more discussions on the use of the variable "First Point of Impact") only provides the information on the first point of impact. To identify a motorcycle that crashes into the car ahead and subsequently is struck by another automobile behind, information both on first point of impact (i.e., it must be the front of a motorcycle) and on second point of impact (i.e., it must be the back of a motorcycle) is needed. Unfortunately, information about second point of impact is not available in the Stats19.

Although the author has not been able to extract the abovementioned data from the Stats19, further research may still attempt to identify such crash pattern (i.e., the motorcycle as the middle vehicle that crashes into the car ahead and subsequently is struck by another automobile behind). A possible way to do this is to identify such crash pattern by using the information provided in the variable "2.18 Part(s) Damage". The variable "2.18 Part(s) Damage" provides the information on the multiple parts of damage of one vehicle (e.g., front, back, offside, nearside, roof, underside, all four sides), although it was observed that there is a relatively large fraction of missing data on this variable.

With respect to unknown gender/age of motorist in rear-end collisions, it was found that there is far higher percentage of unknown gender and age of motorist for rear-end CarMc collisions (see Table 8.2). Unknown motorist gender and age contribute to 13.7% and 20.8% of the casualties in rear-end CarMc collisions respectively. While the cause of these differences cannot be determined with any certainty, it is likely that the car as a following vehicle that crashed into a leading motorcycle (i.e., a rear-end

CarMc crash) may be more likely to escape from the accident scene than those in other crash configurations.

The findings related to unknown gender/age of motorist in rear-end CarMc crashes underscore the need for a careful and comprehensive study of "hit-and-run" accidents. Further work may examine whether these rear-end CarMC crashes with unknown gender/age of motorist are "hit-and-run" accidents through the use of the variable "2.24 Hit and Run" in the Stats19. The variable "2.24 Hit and Run" provides the information on whether it is a hit-and-hit accident, although it was observed that there is a relatively large fraction of missing data on this variable.

Turning to the third recommendation, it was found (see Table 8.2) that the percentage of HGVs in same-direction collisions (i.e., sideswipe "side to side" crash, rear-end McCar crash, rear-end CarMc crash) is higher than accidents that involve gap acceptance (i.e., approach-turn A/B crash, angle A/B crash). It is suspected in this present study that HGVs that have higher passenger compartment may exacerbate the problem that motorcycles (particularly a filtering motorcycle from behind or on the adjacent lane) are often in motorists' blind spots. On the other hand, it could be easier for HGVs that have higher passenger compartment to detect an oncoming motorcycle due to their less obstructed sight distance.

Future research may attempt to examine the explanations for these effects. A recommended way for developing such future work is to use the data that is readily available from the Stats19 and conduct univariate descriptive analysis (similar to that conducted in Chapter 5 in this thesis). For instance, further work may discern the relationship between roadway factors and temporal factors (e.g., street light conditions and time of accident that may affect motorcycle's conspicuity) and the occurrences of same-direction collisions.

10.3.2 Improving the Model Specification by Including Additional Variables

The analyses in this current research are limited by the variables that are readily available in the Stats19. Clearly there is room for improving the model specification by incorporating additional variables into the models. These additional variables include, for example, headlight use, alcohol use, detailed roadway geometrics data, medical diagnoses records, or detailed motorcycle factors. Analyses of more detailed data than those obtained from the Stats19 would provide more precise and conclusive estimation results. The importance of these unavailable data is described below.

10.3.2.1 Headlight use

Past studies (e.g., Wells et al., 2004; Hole and Tyrrell, 1995) have suggested that measures such as daytime running lights (DRLs), fluorescent garments, or illuminated leg shields may improve motorcycle's conspicuity, thereby reducing the number of right-of-way violations. However, there has been little convincing evidence that these measures actually increase detectability in real traffic situations (Wulf et al., 1989a, 1989b; Cercarelli et al., 1992). DRLs for motorcycles are compulsory in a number of European countries and several states in the U.S., while several countries have mandated DRLs for all motor vehicles (e.g., Iceland) (Elvik, 1993; Hansen, 1994). Hancock et al. (2005) argued that motorcycles may be more conspicuous to other road users by using DRLs, but such improvement is likely to decrease if other motor vehicles have headlights on at the same time. It would be interesting for future research to identify whether these measures efficiently increase detectability of motorcycles in real traffic circumstance.

10.3.2.2 Geometric factors

Geometrics factors such as grade, shoulder widths, alignment of roadways, or curvature may play a role in motorcycle safety. The Stats19 provides limited data on geometric factors. The only geometric factor available is the presence of curvature but seems to be somewhat unreliable, as discussed in Chapter 9. Research (e.g., Broughton, 2005; Clarke, 2007) has revealed that curved roads both contributed to the occurrence of a single-motorcycle crash and resulted in more severe injuries in such crash type. Interesting results related to the presence of bend were also found in this current research. For example, the presence of bend for car was found to be associated with the increased motorcyclist injury severity in head-on collisions. It was also found that head-on collisions were far more likely than other crash configurations to occur on the roadway with bend. It appears here that roadways with bends may also play a part in affecting motorcyclist injury severity in motorcycle-car accidents. Future research may attempt to extend the work conducted in this current research by obtaining and analysing more accurate and reliable bend data from other data source instead of the Stats19.

Evidence in several studies of motorcycle-car accidents (see, for example, Harnen et al., 2003) has revealed that geometric factors such as number of lanes and shoulder width were significant in explaining car-motorcycle accident occurrences – Harnen et al. considered the possibility that there may have been a reduction of motorcycle-car rear-end/sideswipe crashes as a result of an increase in number of lanes and wider shoulders on the major roads. Further research analysing additional geometric variables that may be obtained from other databases may allow more conclusive results than those in this current research.

10.3.2.3 Alcohol use

The modelling results in this research showed that late evening/mid-night/early morning hours were associated with the increased motorcyclist injury severity. In addition, right-of-way violation was more likely to occur during these hours. Although it was stated in this thesis that this is perhaps a consequence of alcohol during these hours, the real effect of drink riding/driving could not be examined in this current study due to the lack of such data from the Stats19. This is a result that needs more scrutiny in future studies. Past studies (e.g., Kim et al., 2000; Peek-Asa and Kraus, 1996b; Shankar, 2001, 2003; Nakahara et al., 2004; Kasantikul et al., 2005; Broughton, 2005) may confirm the conjecture here – alcohol-related motorcycle accidents during these hours were much frequent than those during other hours. Moreover, drinking riders were less likely to wear a helmet, more likely to lose control, more likely to violate traffic signals, and more likely to be speeding. Future studies may seek to obtain alcohol use data from other database – for instance, Blood Alcohol Content (BAC) data supplied by Coroners and Procurators Fiscal to Transport Research Laboratory (TRL) for those who died in traffic accidents.

10.3.2.4 Medical diagnoses records

Peek-Asa and her colleagues (1994, 1996a) have previously investigated the effects of crash characteristics on the injured body regions among different crash configurations. However, their work has been more than 10 years old and has not been able to control for other important factors such as junction control measures or types of collision partners. Future studies may seek to analyse data for which information from the Stats19 is linked to medical diagnoses records that may include the injured anatomic location. A research programme is warranted that combines the methodology of this current research that has controlled for several important factors and Peek-Asa and her colleagues' works.

10.3.2.5 Detailed motorcycle factors

The only variable that is available for the attributes of motorcycle in the Stats19 is engine size. Other characteristics of motorcycle such as type or more detailed engine size are not readily available, but they may influence use and hence exposure to situations. Which is, powerful motorcycles can travel faster and any high speed collision can result in more severe injury outcome.

Evidence in literature (e.g., Broughton, 2005; Clarke et al., 2007) has revealed that more detailed data on engine size/type of machine may be desired in analysing motorcycle safety. For instance, Broughton suggested that there were almost 9 times as many deaths per large motorcycle (over 500cc) as per moped (0-50cc). Clarke et al. concluded that super-sport motorcycles were overrepresented in accidents that occurred on curved roads, whilst scooters and mopeds were more likely to be involved in rear-end shunt collisions. They also found that super-sport motorcycles had a significantly lower propensity than other types of motorcycles for being involved in right-of-way violation accidents; and super-sport motorcycles appeared significantly overrepresented in overtaking (passing)/filtering accidents.

In this current research, engine size effect was measured with two categories: engine size up to 125cc and engine size over 125cc. Engine size data were extracted from the variable "vehicle type" of the Stats19 that provides three types of engine capacity:

moped, engine size up to 125cc, and engine size over 125cc. "Moped" and "engine size up to 125cc" are merged into one category to improve statistical significance in the calibrated models, as discussed in Chapter 4. Estimation results of the aggregate crash model and disaggregate crash models suggested that bikes with engine size over 125cc predisposed riders to a greater risk of KSIs.

The Stats19 data for the year 2005 onwards subdivide the over 125cc range of engine size, with a total of four engine sizes available: moped, engine size up to 125cc, engine size over 125cc and up to 500cc, and engine size over 500cc. The Stats19 data for the year 2005 upwards were not included in the analysis in this present study (see the reasons and discussions in section 9.3.5). Therefore, the effect of engine size over 500cc on motorcyclist injury severity was not examined in this thesis.

Future research may investigate the effects of more detailed engine size (e.g., the subgroups of engine size examined in the work of Broughton) and machine type (e.g., the machine types examined in the work of Clarke et al.) on motorcyclist injury severity. Data on engine size over 500cc are available from the Stats19 for the year 2005 upwards, as abovementioned. In addition, more detailed engine size data (e.g., engine size over 500cc and up to 1000cc, and engine size over 1000cc) and machine type data (e.g., sports bike) are available from the National Driving and Vehicle Licensing Agency (DVLA) for those vehicles whose Vehicle Registration Marks (VRMs) were recorded by the police in the Stats19. Future research may attempt to augment "Vehicle record data" of the Stats19 with the national DVLA data and adopt the similar research methodology of this current study.

10.3.2.6 The presence of pillion passenger

Past studies of car-car accidents examining the effect of passenger carriage pointed out that carrying passenger was associated with proportionately more at-fault fatal crashes than driving alone for motorists aged 24 or younger (e.g., Preusser et al., 1998; Chen et al., 2000). Preusser et al.'s and Chen et al.'s results indicated that restrictions on carrying passengers should be considered for inclusion in graduated licensing systems for young motorists. Neyens and Boyle (2007, 2008) further noted that passenger distractions at intersections resulted in more angle collisions and rear-end collisions relative to crashes with fixed objects.

There seems to be a lack of research into this area for motorcycle accidents. Two exceptions are the studies by Quddus et al. (2002) and Broughton (2005). Quddus et al. found that carrying passenger resulted in an increased motorcyclist injury severity. Broughton further compared the proportion of passenger fatalities among motorcycles with different engine capacity. He concluded that the proportion of passenger fatalities tended to rise with engine capacity, and one tenth of fatalities on machines over 1000cc capacity were pillion passengers.

The effect of passenger carriage on motorcyclist injury severity is not examined in this current study as the Stats19 does not explicitly provide information on whether a pillion passenger is present or not in an accident. Future research may attempt to identify whether passenger carriage increases motorcyclist injury severity, especially for riders of heavier machines (as discussed by Broughton, 2005). This can be important for experienced motorcyclists who are more likely to use heavier machines that are more suitable than small ones for carrying passengers. With higher speed that larger machines can perform, accidents outcome may be devastating to riders and/or passengers once a crash has occurred.

10.3.3 Improving the Predictability of the Calibrated Models

Overall, the current research contributes to the literature from empirical standpoint. Moreover, the investigations of various crash configurations have not been considered previously in literature for motorcycles at T-junctions. This research presents an investigation of identification of crash configurations at T-junctions for motorcycles, which is a severely under researched area. A number of papers have been prepared based on the results obtained in this present study and published in a number of international journals to report the results.

The ordered response models have been used in this current research to investigate the factors that affect motorcyclist injury severity at an aggregate level (accidents in whole) and disaggregate level (by various crash configurations). It should be noted here that, as discussed in section 3.3, the ordered response models employed in this research suffer from the same problem of previous studies that estimated the ordered response models (see, for example, Abdel-Aty and Abdelwahab, 2004c) – the less frequent categories of the dependent variable tended to be predicted badly. The combination of fatal injury and serious injury as one single KSI category was found to result in more accurate prediction capability than fatal injury and serious injury alone, but the accuracy was still fairly low (see Table 10.1 for a summary of the prediction performance of the calibrated models). As reported in Table 10.1, the classification accuracy (CA) of each calibrated model while predicting the most severe injury (i.e., KSI, which is the focus of this current research) is relatively low. As for predicting the KSIs, the head-on crash model performs the best among the calibrated crash models, with 20.4% of the KSIs being correctly predicted. The angle B crash model and rear-end McCar crash model perform the worst among the calibrated models, with only 0.5% and 0.4% of the KSIs being correctly predicted.

Table 10.1: A summary of classification accuracy (CA) of the calibrated OP models.

Crash model	CA for injury severity (%)			Average CA (%)	Total observations
	No injury	Slight	KSI		
1	0 (0%)	75028 (99.0%)	1159 (4.7%)	74.81%	101841
2	0 (0%)	8450 (95.0%)	639 (14.8%)	68.49%	13270
3	0 (0%)	17312 (98.9%)	294 (4.5%)	72.53%	24274
4	0 (0%)	5346 (99.9%)	**8 (0.5%)**	76.56%	6993
5	0 (0%)	2268 (93.4%)	**255 (20.4%)**	67.44%	3741
6	0 (0%)	8383 (98.9%)	117 (4.8%)	76.88%	11056
7	0 (0%)	5416 (100%)	**6 (0.4%)**	76.51%	7087

Note: Crash model 1-7 represent (1) aggregate crash model by accidents in whole, (2) approach-turn B crash model, (3) angle A crash model, (4) angle B crash model, (5) head-on crash model, (6) sideswipe "motorcycle head-to-sides car" crash model, and (7) rear-end McCar crash model.

Further work may attempt to identify whether the predictability of the OP models estimated in this present study (especially the angle B crash model and rear-end McCar crash model, as reported in Table 10.1) can be improved by estimating some other non-parametric models such as artificial neural networks (see the review of past studies in section 3.3 that developed non-parametric models).

10.3.4 Validation of the Modelling Results

This present research was limited to a sample of motorcyclists sustaining different injury severity levels, which were not true relative risks because they were derived from the Stats19 over years 1991-2004 and may not be generalisable to the entire spectrum of motorcycle crash injuries. The important issue of transferability of the calibrated models to other jurisdictions, as well as validation of the modelling results, were beyond the scope of the research. Addressing these issues in further studies would involve a comparison of model parameters and predictions with those of other calibrated models, and validation with a different database.

REFERENCES

Abdel-Aty, M., Abdelwahab, H., 2003. Configuration analysis of two-vehicle rear-end crashes. *Transportation Research Record*, 1840, 140-147.

Abdel-Aty, M., Abdelwahab, H., 2004a. Modelling rear-end collisions including the role of driver's visibility and light truck vehicles using a nested logit structure. *Accident Analysis and Prevention*, 36(3), 447-456.

Abdel-Aty, M., Abdelwahab, H., 2004b. Analysis and prediction of traffic fatalities resulting from angle collisions including the effect of vehicles' configuration and compatibility. *Accident Analysis and Prevention*, 36(3), 457-469.

Abdel-Aty, M., Abdelwahab, H., 2004c. Predicting injury severity levels in traffic crashes: a modelling comparison. *Journal of Transportation Engineering*, 130(2), 204-210.

Abdel-Aty, M., Keller, J., 2005. Exploring the overall and specific crash severity levels at signalised interactions. *Accident Analysis and Prevention*, 37(3), 417-425.

Abdel-Aty, M., Keller, J., Brady, P., 2005. Analysis of types of crashes at signalised intersections by using complete crash data and tree-based regression. *Transportation Research Record*, 1908 37-45.

Abdelwahab, H., Abdel-Aty, M., 2004. Investigating the effect of light truck vehicle percentages on rear-end fatal traffic crashes. *Journal of Transportation Engineering*, 130(4), 419-428.

Acierno, S., Kaufman, R., Rivara, F., Grossman, D., Mock, C., 2004. Vehicle mismatch: Injury patterns and severity. *Accident Analysis and Prevention*, 36(5), 761-772.

Adebisi, O., Sama, G., 1989. Influence of stopped delay on driver gap acceptance behaviour. *Journal of Transportation Engineering*, 115(3), 305-315.

Agent, K., Deen, R., 1975. Relationship between roadway geometrics and accidents. *Transportation Research Record*, 541, 1-11.

Aldman, B., Cacciola, I., Gustafsson, H., Nygren, A., Wersall, J., 1981. The protective effect of different kinds of protective clothing worn by motorcyclists. *Journal of Traffic Medicine*, 9(4), 57-58.

Alexander, J., Barham, P., Black, I., 2002. Factors influencing the probability of an incident at a junction: Results from an interactive driving simulator. *Accident Analysis and Prevention*, 34(6), 779-792.

Al-Ghamdi, A., 2002. Pedestrian-vehicle crashes and analytical techniques for stratified contingency table. *Accident Analysis and Prevention*, 29(3), 205-214.

Al-Senan, S., Wright, P., 1987. Prediction of head-on accident sites. *Transportation Research Record*, 1122, 79-85.

Amemiya, T., 1985. *Advanced Econometrics*. Cambridge, MA: Harvard University Press.

Ashton, S., 1979. Some factors influencing the injuries sustained by child pedestrians struck by the front of cars. In: Proceedings of the 23rd STAPP Car Crash Conference, STAPP, San Diego, California 17-19 October, 353-380.

Ashton, S., 1982. *Vehicle design and pedestrian injuries*. In: Chapman, A., Wade, F., Foot, H., (Eds), *Pedestrian Accidents*. Wiley, London.

Ashton, S., Pedder, J., Mackay, G., 1978. *Influence of vehicle design on pedestrian leg injuries*. In: Proceedings of the 22nd Conference of American Association for Automotive Medicine, Ann Arbor, Michigan, 10-14 July, 216-236.

Ashworth, R., Bottom, C., 1977. Some observations of driver gap-acceptance behaviour at a priority intersection. *Traffic Engineering and Control*, 18(12), 569-571.

Atkins, R., Turner, W., Duthie, R., Wilde, B., 1988. Injuries to pedestrians in road traffic accidents. *British Medical Journal*, 297(6661), 1431-1434.

Atkinson, J., Hurst, P., 1983. Collisions between cyclists and motorists in New Zealand. *Accident Analysis and Prevention*, 15(2), 137-151.

Attwood, D., 1981. The potential of daytime running lights as a vehicle collision countermeasure. Ottawa: Transport Canada, Road Safety Unit, Road and Motor Vehicle Traffic Safety Branch.

Ballesteros, M., Dischinger, P., Langenberg, P., 2004. Pedestrian injuries and vehicle type in Maryland, 1995-1999. *Accident Analysis and Prevention*, 36(1), 73-81.

Barancik, J., Fife, D., 1985. Discrepancies in vehicular crash injury reporting: Northeastern Ohio trauma study IV. *Accident Analysis and Prevention*, 17(2), 147-154.

Ben-Akiva, M., Lerman, S., 1985. *Discrete Choice Analysis*. MIT Press, Cambridge, MA.

Borooah, V.K., 2001. Logit and Probit: *Ordered and Multinomial Models*. Sage University Papers Series on Quantitative Application in the Social Sciences, 07-138. Thousand Oaks, CA: Sage Publications.

Braitman, K., Kirley, B., Ferguson, S., Chaudhary, N., 2007. Factors leading to older drivers' intersection crashes. *Traffic Injury Prevention*, 8(3) 267-274.

Braver, E., Ferguson, S., Greene, M., Lund, A., 1997. Reductions in deaths in frontal crashes among right front passengers in vehicles equipped with passenger air bags. *JAMA: the Journal of the American Medical Association*, 278(17), 1437-1439.

Brenac, T., Clabaux, N., Perrin, C., Van Elslande, P., 2006. Motorcyclist conspicuity-related accidents in urban areas: A speed problem? *Advances in Transportation Studies*, 8(A), 23-29.

Broughton, J., 1988. *The relation between motorcycle size and accident risk*. TRL Report TRL169, Transport Research Laboratory, Crowthorne, England.

Broughton, J., 2005. *Car occupant and motorcyclist deaths, 1994-2002.* TRL Report TRL629, Transport Research Laboratory, Crowthorne, England.

Broughton, J., 2007. *Casualty rates by type of car.* TRL Report PPR203, Transport Research Laboratory, Crowthorne, England.

Brown, I., 2002. A review of the 'look but failed to see' accident causation factor. In: Behavioural Research in Road Safety XI. Department of Transport, Local Government and the Regions, London, UK.

Broyles, J. Clarke, S., Narine, L., Baker, D., 2001. Factors contributing to the amount of vehicular damage resulting from collisions between four-wheel drive vehicles and passenger cars. *Accident Analysis and Prevention*, 33(5), 673-678.

Broyles, J., Narine, L., Clarke, S., Baker, D., 2003. Factors associated with the likelihood of injury resulting from collisions between four-wheel drive vehicles and passenger cars. *Accident Analysis and Prevention*, 35(5), 677-681.

Caird, J., Hancock, P., 1994. The perception of arrival time for different oncoming vehicles at an intersection. *Ecological Psychology*, 6(2), 83-109.

Caird, J., Hancock, P., 2002. *Left-turn and gap acceptance crashes.* In: Dewar, R.E., Olson, P., (Eds.), *Human factors in traffic safety.* Lawyers & Judges Publishing: Tucson, AZ, 613-652.

Cercarelli, L., Arnold, P., Rosman, D., Sleet, D., Thornett, M., 1992. Travel exposure and choice of comparison crashes for examining motorcycle conspicuity by analysis of crash data. *Accident Analysis and Prevention*, 24(4), 363-368.

Chang, H.-L., Yeh, T.-H., 2006. Risk factors to driver fatalities in single-vehicle crashes: comparisons between non-motorcycle drivers and motorcyclists. *Journal of Transportation Engineering*, 132(3), 227-236.

Chang, L.-Y., Mannering, F., 1999. Analysis of injury severity and vehicle occupancy in truck- and non-truck-involved accidents. *Accident Analysis and Prevention*, 31(5), 579-592.

Chang, L.-Y., Wang, H.-W., 2006. Analysis of traffic injury severity: An application of non-parametric classification tree techniques. *Accident Analysis and Prevention*, 38(5), 1019-1027.

Chen, L.-H., Baker, S., Braver, E., Li., G., 2000. Carrying passengers as a risk factor for crashes fatal to 16- and 17-year-old drivers. *JAMA: the Journal of the American Medical Association*, 283(12), 1578-1582.

Chinn, B., Hopes, P., Finnis, M., 1989. Leg protection and its effect on motorcycle rider trajectory. Twelfth International Technical Conference on Experimental Safety Vehicles. Crowthorne, Berkshire, England: Department of Transport.

Chipman, M., 2004. Side impact crashes – factors affecting incidence and severity: review of the literature. *Traffic Injury Prevention*, 5(1), 675-55.

Chovan, J., Tijerina, L., Alexander, G., Hendricks, D., 1994. Examination of lane change crashes and potential IVHS countermeasures. Report DOT-VNTSC-NHTSA-93-2. NHTSA, US Department of Transportation.

Clarke, D., Ward, P., Bartle, C., Truman W., 2007. The role of motorcyclist and other driver behaviour in two types of serious accident in the UK. *Accident Analysis and Prevention*, 39(5), 974-981.

Clarke, D., Ward, P., Jones, J., 1998. Overtaking road-accidents: differences in manoeuvre as a function of driver age. *Accident Analysis and Prevention*, 30(4), 455-467.

Clarke, D., Ward, P., Jones, J., 1999. Processes and countermeasures in overtaking road accidents. *Ergonomics*, 42(6), 846-867.

Clissold, C., 1976. Wet weather injury accidents on New Zealand roads. *Transportation Research Record*, 624 136-140.

Connelly, M., Conaglen, H., Parsonson, B., Isler, R., 1998. Child pedestrians' crossing gap thresholds. *Accident Analysis and Prevention*, 30(4), 443-453.

Cooper, D., McDowell, M., 1977. Police effects on accident risk at T-junctions. *Traffic Engineering and Control*, 18(10), 486-487.

Cooper, D., Smith, W., Broadie, V., 1976. The effect of approach speed on merging gap acceptance. *Traffic Engineering and Control*, 17(6), 256-257.

Cooper, D., Storr, P., Wennell, J., 1977. The effect of speed on gap acceptance and conflict rate. *Traffic Engineering and Control*, 18(3), 110-112.

Cox, A., Cox, D., 1998. Compensatory driving strategy of older people may increase driving risk. *Journal of the American Geriatrics Society*, 46(8), 1058-1059.

Cramer, J., 1999. Predictive performance of the binary logit model in unbalanced samples. *Journal of the Royal Statistical Society*, Series D (The Statistician), 85-94.

Crandall, C., Olson, L., Sklar, D., 2001. Mortality reduction with air bag and seat belt use in head-on passenger car collisions. *American Journal of Epidemiology*, 153(3), 219-214.

Cross, K., Fisher, G., 1977. A study of bicycle/motor vehicle accidents: identification of problem types and countermeasure approaches. National Highway Traffic Safety Administration, Washington, DC.

Crundall, D., Bibby, P., Clarke, D., Ward, P., Bartle, C., in press. Car drivers' attitudes towards motorcyclists: A survey. *Accident Analysis and Prevention*.

Crundall, D., Humphrey, K., Clarke, D., in press. Perception and appraisal of approaching motorcycles at junctions. *Transportation Research Part F: Traffic Psychology Behaviour*.

Darzentas, J., Cooper, D., Storr, P., McDowell, M., 1980a. Simulation of road traffic conflicts at T-junctions. *Simulation*, 34(5), 155-164.

Darzentas, J., McDowell, M., Cooper, D., 1980b. Minimum acceptable gaps and conflict involvement in a simple crossing manoeuvre. *Traffic Engineering and Control*, 21(2), 58-61.

Darzentas, J., McDowell, M., Cooper, D., 1980c. Driver behaviour at a T-junction in daylight and darkness. Traffic *Engineering and Control*, 21(4), 186-189.

Davis, G., Swenson, T., 2004. Field study of gap acceptance by left turning drivers. *Transportation Research Record*, 1899 71-75.

DeLucia, P., 2004. Time-to-contact judgments of an approaching objects that is partially concealed by an occluder. Journal of Experimental Psychology. *Human Perception and Performance*, 30(2), 287-304.

DeLucia, P., Warren, R., 1994. Pictorial and motion-based depth information during active control of self-motion – size arrival effects on collision-avoidance. *Journal of Experimental Psychology. Human perception and performance*, 20(2), 83-109.

Deng, Z, Ivan J., Garder, P. 2006. Analysis of factors affecting the severity of head-on crashes Two-lane rural highways in Connecticut. *Transportation Research Record*, 1953, 137-146.

Department for Transport (DfT), 2004. *Transport Statistics Great Britain*. The Stationery Office, London.

Department for Transport (DfT), 2006a. *Road Casualties Great Britain 2005*. The Stationery Office, London.

Department for Transport (DfT), 2006b. *Transport Statistics Bulletin – Compendium of Motorcycling Statistics*. The Stationery Office, London.

Department of Environment, Transport and the Regions (DETR) Report, 2000. *Tomorrow's road – safer for everyone: The government's road safety strategy and casualty reduction targets for 2010*, HMSO.

Dischinger, P., Cushing, B., Kerns, T., 1993. Injury patterns associated with direction of impact: Drivers admitted to trauma centres. *Journal of Trauma*, 35(3), 454-459.

Dissanayake, S., Lu, J., 2002a. Factors influential in making an injury severity difference to older drivers involved in fixed object-passenger car crashes. *Accident Analysis and Prevention*, 34(5), 609-618.

Dissanayake, S., Lu, J., 2002b. Analysis of severity of young driver crashes – Sequential binary logistic regression modelling. *Transportation Research Record*, 1784, 108-114.

Dissanayake, S., Lu., J., Chu, X., Turner, P., 1999. Evaluation of critical highway safety needs of special population groups. *ITE Journal*, 69(9), 28-35.

Donne, G., 1990. Research into motorcycle conspicuity and its implementation. SAE Technical paper 900749.

Donne, G., Fulton, E., 1985. *The evaluation of aids to the daytime conspicuity of motorcycles* (Laboratory report LR1137). Transport Research Laboratory, Crowthorne, England.

Drew, D., 1967. Gap acceptance characteristics for ramp-freeway surveillance and control. *Highway Research Record*, 157, 108-143.

Duncan, C., Khattak, A., Council, F., 1998. Applying the ordered probit model to injury severity in truck-passenger car rear-end collisions. *Transportation Research Record*, 1635, 63-71.

Durbin, D., Chen, I., Elliott, M., Winston, F., 2004. Factors associated with front row seating of children in motor vehicle crashes. *Epidemiology*, 15(3), 345-349.

Eberts, R., MacMillan, A., 1985. Misperception of small cars. In: Eberts, R., Eberts, C., (Eds.), Trends in Human Factors/Ergonomics II. Elsevier Science Publishers: Amsterdam, 33-39.

Eguakun, G., Wilson, F., 1995. Safety implications of extending some Canadian motor vehicle safety standards to light trucks and vans. *Accident Analysis and Prevention*, 27(2), 225-235.

Elliott, M., Baughan, C., Sexton, B., 2007. Errors and violations in relation to motorcyclists' crash risk. *Accident Analysis and Prevention*, 39(3), 491-499.

Eluru, N., Bhat, C., 2007. A joint econometric analysis of seat belt use and crash-related injury severity. *Accident Analysis and Prevention*, 39(5), 1037-1049.

Eluru, N., Bhat, C., Hensher, D., in press. A mixed generalised ordered response model for examining pedestrian and bicyclist injury severity level in traffic crashes. *Accident Analysis and Prevention.*

Elvik, R., 1993. The effects on accidents of compulsory use of daytime running lights for cars in Norway. *Accident Analysis and Prevention*, 25(4), 383-398.

Evans, L., 1988. Older driver involvement in fatal and severe traffic crashes. *Journal of Gerontology*, 43(6), 186-193.

Evans, L., 2001. Female compared with male fatality risk from similar physical impacts. *Journal of Trauma*, 50(2), 281-288.

Evans, L., Frick, M., 1986. Helmet effectiveness in preventing motorcycle driver and passenger fatalities. (Research Publication GMR-5602). Warren, MI: General Motors Research Laboratories.

Evans, L., Frick, M., 1992. Car size or car mass: which has greater influence on fatality risk. *American Journal of Public Health*, 82(8), 1105-1112.

Evans, L., Wasielewski, P., 1987. Serious or fatal driver injury rate versus car mass in head-on crashes between cars of similar mass. *Accident Analysis and Prevention*, 19(2), 119-131.

Farmer, C., Braver, E., Mitter, E., 1996. Two-vehicle side impact crashes: the relationship of vehicle and crash characteristics to injury severity. *Accident Analysis and Prevention*, 29(3), 399-406.

Federal Highway Administration (FHWA), 1993. Traffic manoeuvre problems of older drivers: Final technical report. FHWA-RD-92-092, US. Department of Transportation, FHWA, Washington, D.C.

Fitzpatrick, K., 1991. Gaps accepted at stop-controlled intersections. *Transportation Research Record*,1303, 103-112.

Freedman, M., 1982. Effectiveness of technologies to improve side and rear conspicuity of motorcycles and mopeds, 26th Proceedings of the American Association for Automotive Medicine. Des Plaines, IL.

Freedman, M., Davit, P., 1984. Improved conspicuity to the sides and rear of motorcycles and mopeds. *Journal of Safety Research*, 15(4), 176-177.

Fulton, E., Kirkby, C., Stroud, P., 1980. *Daytime motorcycle conspicuity*. Supplementary Report 625. Department of the Environment, Department of Transportation. U.K.: Transport Research Laboratory, Crowthorne, England

Gabella, B., Kathy, L., Richard, E., Magdalena, C., Lorann, S., 1995. Relationship of helmet use and head injuries among motorcycle crash victims in El Paso County, Colorado, 1989-1990. *Accident Analysis and Prevention*, 27(3), 363-369.

Garber, N., Srinivasan, R., 1991. Characteristics of accidents involving elderly drivers at intersections. *Transportation Research Record*, 1325, 8-16.

Golob, T., Recker, W., 2004. A method for relating type of crash to traffic flow characteristics on urban freeways. *Transportation Research Part A: Policy and Practice*, 38(1), 53-80.

Grayson, G., Hakkert A., 1987. *Accident analysis and conflict behaviour*. In: Rothengatter, J., de Bruin, R. (Eds.), *Road Users and Traffic Safety*. Van Gorcum, Assen, Netherlands.

Greene, W., 2003. *Econometric Analysis*. 5^{th} ed. Prentice Hall.

Haddon, W., 1973. Energy damage and the ten countermeasure strategies. *Journal of Trauma*, 13(4), 321-331.

Haland, Y., Lovsund, P., Nygren, A., 1993. Life-threatening and disabling injuries in car-to-car side impacts – implications for development of protective systems. *Accident Analysis and Prevention*, 25(2), 199-206.

Hamed, M., Easa, S., Batayneh, R., 1997. Disaggregate gap-acceptance model for unsignalised T-intersection. *Journal of Transportation Engineering*, 123(1), 36-42.

Hancock, P., 1995. Motorcycles in intelligent transport systems. Technical Report for the Motorcycle Safety Foundation, Irvine, CA.

Hancock, P., Caird, J., 1993. Factors influencing older drivers' left-turn decisions. Technical Report, Transportation Research Board, National Research Council, Washington, DC.

Hancock, P., Caird, J., Shekhar, S., Vercruyssen, M., 1991. Factors influencing drivers' left-turn decisions. Proceedings of the Human Factors Society 35^{th} Annual Meeting, 1139-1143.

Hancock, P., Hurt, H., Ouellet, J., Thom, D., 1986. Failure of driver sustained attention in the epiology of motorcycle-automobile collisions. Proceedings of the Annual Conference of the Human Factors Association of Canada. Vancouver, Canada.

Hancock, P., Oron-Gilad, T., Thom, D., 2005. *Human factors issues in motorcycle collisions.* In: Noy, I., Karwowski, W., (Eds.). *Handbook of human factors in litigation.* Chapter 18: 1-20. CRC Press: Boca Raton, FL.

Hancock, P., Wulf, G., Thom, D., 1990. Driver workload during differing driving manoeuvres. *Accident Analysis and Prevention*, 22(3), 281-290.

Hancock, P., Wulf, G., Thom, D., Fassnacht, P., 1989. Contrasting driver behaviour during turns and straight driving. 33rd Proceedings of the Human Factors Society. Vancouver, Canada. 918-922.

Hansen, L., 1994. Daytime running lights (DRL): experience with compulsory use in Denmark. Danish Council of Road Safety Research, Copenhagen, Denmark.

Harb, R., Radwan, E., Yan, X., Abdel-Aty, M., 2007. Light truck vehicle (LTVs) contribution to rear-end collisions. *Accident Analysis and Prevention*, 39(5), 1026-1036.

Harms, P., 1989. Leg injuries and mechanisms in motorcycling accidents. 12th International Technical Conference on Experimental Safety Vehicles. Crowthorne, Berkshire, Department of Transport.

Harnen, S., Radin Umar, R., Wong, S., Hashim Wan, W., 2003. Predictive model for motorcycle accidents at three-legged priority junctions. *Traffic Injury Prevention*, 4(4), 363-369.

Harrell, F., 2001. *Regression modelling strategies.* New York: Springer.

Hatfield, J., Murphy, S., 2007. The effects of mobile phone use on pedestrian crossing behaviour at signalised and unsignalised intersections. *Accident Analysis and Prevention*, 39(1), 197-205.

Hauer, E., 1997. *Observational before-after studies in road safety: estimating the effect of highway and traffic engineering measures on road safety.* Pergamon, Oxford.

Hauer, E., Ng, J., Lovell, J., 1988. Estimation of safety at signalised intersections. *Transportation Research Record*, 1185, 48-60.

Haworth, J., Mulvihill, C., Wallace, P., Summons, M., Regan, M., 2005. Hazard perception and responding by motorcyclists: Summary of background, literature review and training methods. Report No., 234. Monash University Accident Research Centre.

Henary, B., Ivarsson, J., Crandall, J., 2006. The influence of age on the morbidity and mortality of pedestrian victims. *Traffic Injury Prevention*, 7(2), 182-190.

Herman, R., Weiss, H., 1961. Comment on the highway crossing problem. *Operations Research*, 9(6), 828-840.

Herslund, M.-B., Jørgensen, N., 2003. Looked-but-failed-to-see errors in traffic. *Accident Analysis and Prevention*, 35(6), 885-891.

Highway Capacity Manual: Special Report 209, 1994. Transportation Research Board, Washington, D.C.

Hill, J., Boyle, L., 2006. Assessing the relative risk of severe injury in automotive crashes for older female occupants. *Accident Analysis and Prevention*, 38(1), 148-154.

Holdridge, J., Shankar, V., Ulfarsson, G., 2005. The crash severity impacts of fixed roadside objects. *Journal of Safety Research*, 36(2), 139-147.

Hole, G., Tyrrell, L., 1995. The influence of perceptual set on the detection of motorcyclists using daytime headlights. *Ergonomics*, 38(7), 1326-1341.

Hole, G., Tyrrell, L., Langham, M., 1996. Some factors affecting motorcyclists' conspicuity. *Ergonomics*, 39(7), 946-965.

Holst, L., 1993. Car vs. bike. *Sport Rider*, 1(6), 17-27.

Horswill, M., Helman, S., 2001. A comparative approach to differential accident liability. Final report. EPSRC, Swindon.

Horswill, M., Helman, S., 2003. A behavioural comparison between motorcyclists and a matched group of non-motorcycling car drivers: factors influencing accident risk. *Accident Analysis and Prevention*, 35(4), 589-597.

Horswill, M., Helman, S., Ardiles, P., Wann, J., 2005. Motorcycle accident risk could be inflated by a time to arrival illusion. *Optometry and Vision Science*, 82(8), 740-746.

Hosmer, D., Lemeshow, S., 2000. *Applied Logistic Regression.* Wiley-Interscience, New York, USA.

Huang, H., Chin, H., Heng, A., 2006. Effect of read light cameras on accident risk at intersections. *Transportation Research Record*, 1969, 18-26.

Huang, H., Chin, H., Md. Mazharul., H., 2008. Severity of driver injury and vehicle damage in traffic crashes at intersections: A Bayesian hierarchical analysis. *Accident Analysis and Prevention*, 40(1), 45-54.

Huang, S., Yang, J., Eklund, F., in press. Evaluation of remote pedestrian sensor system based on the analysis of car-pedestrian accident scenarios. *Safety Science*.

Huelke, D., Compton, C., 1992. Analysis of passenger car side impacts – crash location, injuries, AIS and contacts (SAE 920353). Society of Automotive Engineering, Warrendale, PA.

Hurt, H., DePont, C., 1977. Human factors in motorcycle accidents. Society of Automotive Engineers. Booklet 770103.

Hurt, H., Hancock, P., Thom, D. 1984. Motorcycle-automobile collision prevention through increased motorcyclist frontal conspicuity. Proceedings of 28th the Human Factors Society. Vancouver, Canada.

Hurt, H., Ouellet, J., Jennings, G., 1984. Motorcycle crash bar effectiveness: A re-evaluation using AIS-80. Proceedings of 28th Annual Conference of the American Association for Automotive Medicine. 237-246.

Hurt, H., Ouellet, J., Thom, D., 1981. Motorcycle Accident Cause Factors and Identification of Countermeasures, Volume. 1. Technical Report. DOT HS-5-01160. NHTSA, U.S. Department of Transportation.

Islam, S., Mannering, F., 2006. Driver aging and its effect on male and female single-vehicle accident injuries: Some additional evidence. *Journal of Safety Research*, 37(3), 267-276.

Janoff, M., Cassel, A., 1971. Effect of distance and motorcycle headlight condition on motorcycle noticeability. *Highway Research Record*, 377, 53-63.

Jones, A., Jørgensen, S., 2003. The use of multilevel models for the prediction of road accident outcomes. *Accident Analysis and Prevention*, 35(1), 59-69.

Kajzer, J., Yang, J., Mohan, D., 1992. Safer bus fronts for pedestrian impact protection in bus-pedestrian accidents. International IRCOBI Conference on the Biomechanics of Impacts.

Kasantikul, V., Ouellet, J., Smith, T., Sirathranont, J., Panichabhongse, V., 2005. The role of alcohol in Thailand motorcycle crashes. *Accident Analysis and Presentation*, 37(2), 357-366.

Kearney, J., Grechkin, T., Cremer, J., Plamert, J., 2006. Traffic generation for studies of gap acceptance. In: Proceedings of the Driving Simulation Conference DSC 2006, Paris, France, 177-186.

Keng, S., 2005. Helmet use and motorcycle fatalities in Taiwan. *Accident Analysis and Prevention*, 37(2), 349-355.

Kennedy, P., 1993. *A Guide to Econometrics*. The MIT Press, Cambridge, Mass.

Keskinen, E., Ota, H., Katila, A., 1998. Older drivers fail in intersections: speed discrepancies between older and younger male drivers. *Accident Analysis and Prevention*, 30(3), 323-330.

Kettelson, W., Vandehey, M., 1991. Delay effects on driver gap acceptance characteristics at two-way stop-controlled intersections. *Transportation Research Record*, 1320, 154-159.

Khattak, A., 2001. Injury severity in multivehicle rear-end crashes. *Transportation Research Record*, 1746, 59-68.

Khattak, A., Fan, Y., 2008. What exacerbates injury and harm in car-SUV collisions? *Journal of Transportation Engineering*, 134(2), 93-104.

Khattak, A., Kantor, P., Council, F., 1998. Role of adverse weather in key crash types on limited-access roadways: Implication for advanced weather systems. *Transportation Research Record*, 1621, 10-19.

Khattak, A., Knapp, K., 2001. Interstate highway crash injuries during winter snow and nonsnow events. *Transportation Research Record*, 1746, 30-36.

Khattak, A., Pawlovich, M., Souleyrette, R., Hallmark, S., 2002. Factors related to more severe older driver traffic crash injuries. *Journal of Transportation Engineering*, 128(3), 243-249.

Khattak, A., Rocha, M., 2004. Are SUVs "supremely unsafe vehicles"? Analysis of rollovers and injuries with sport utility vehicles. *Transportation Research Record*, 1840, 167-177.

Khattak, A., Targa, F., 2004. Injury severity and total harm in truck-involved work zone crashes. *Transportation Research Record*, 1877, 106-116.

Kiefer, R., Hankey, J., 2008. Lane change behaviour with a side blind zone alert system. *Accident Analysis and Prevention*, 40(2), 683-690.

Kim, D.-G., Lee., Y., Washington, S., Choi, K., 2007. Modelling crash outcome probabilities at rural intersections: Application of hierarchical binomial logistic models. *Accident Analysis and Prevention*, 39(1), 125-134.

Kim, D.-G., Washington, S., Oh, J., 2006. Modelling crash types: new insights into the effects of covariates on crashes at rural intersections. *Journal of Transportation Engineering*, 132(4), 282-292.

Kim, J.-K., Kim, S., Ulfarsson, G., Porrello, L., 2007. Bicyclist injury severities in bicycle-motor vehicle accidents. *Accident Analysis and Prevention*, 39(2), 238-251.

Kim, J.-K., Wang, Y., Ulfarsson, G., 2007. Modelling the probability of freeway rear-end crash occurrence. *Journal of Transportation Engineering*, 133(1), 11-19.

Kim, K., Boski, J., 2001. Finding fault in motorcycle crashes in Hawaii – environmental, temporal, spatial, and human factors. *Transportation Research Record*, 1779, 182-188.

Kim, K., Boski, J., Yamashita, E., 2002. Typology of motorcycle crashes rider characteristics, environmental factors, and spatial patterns. *Transportation Research Record*, 1818, 47-53.

Kim, K., Brunner, I., Yamashita, E., in press. Modelling violation of Hawaii's crosswalk law. *Accident Analysis and Prevention*.

Kim, K., Kim, S., Yamashita, E., 2000. Alcohol-impaired motorcycle crashes in Hawaii, 1986-199: An analysis. *Transportation Research Record*, 1734, 77-85.

Kim, K., Li, L., 1996. Modelling fault among bicyclists and drivers involved in collisions in Hawaii, 1986-1991. *Transportation Research Record*, 1538, 75-80.

Kim, K., Nitz, L., Richardson, J., Li, L., 1994. Analyzing the relationship between crash types and injuries in motor vehicle collisions in Hawaii. *Transportation Research Record*, 1467, 9-13.

Kim, M., Hallmark, S., Wu., H., Pawlovich, M., 2007. Impact of left-turn phasing on older and younger drivers at high-speed signalised intersections. *Journal of Transportation Engineering*, 133(10), 556-563.

Kita, H., 1993. *Effects of merging lane length on the merging behaviour at expressway on-ramps*. In: Daganzo, C., (Eds.). *Transportation and Traffic Theory*. Elsevier Press, Amsterdam, Netherlands, 37-70.

Klop, J., Khattak, A., 1999. Factors influencing bicycle crash severity on two-lane, undivided roadways in North Carolina. *Transportation Research Record*, 1674, 78-85.

Kockelman, K., Kweon, Y.-J., 2002. Driver injury severity: an application of ordered probit models. *Accident Analysis and Prevention*, 34(3), 313-321.

Koustanaï, A., Boloix, E., Elslande, P., Bastien, C., 2008. Statistical analysis of "looked-but-failed-to-see" accidents: Highlighting the involvement of two distinct mechanisms. *Accident Analysis and Prevention*, 40(2), 461-469.

Kraus, J., Peek-Asa, C., McArthur, D., Williams, A., 1994. The effect of the 1992 California motorcycle helmet use law on motorcycle crash fatalities and injuries. *JAMA: the Journal of the American Medical Association*, 272(19), 1506-1511.

Krull, K., Khattak, A., Council, F., 2000. Injury effects of rollovers and events sequence in single-vehicle crashes. *Transportation Research Record*, 1717, 46-54.

Laberge, J., Creaser, J., Rakauskas, M., Ward, N., 2006. Design of an intersection decision support (IDS) interface to reduce crashes at rural stop-controlled intersections. *Transportation Research Part C: Emerging Technology*, 14(1), 39-56.

Lane, P., McClafferty, K., Nowak, E., 1994. Pedestrians in real world collisions. *Journal of Trauma*, 36(2), 231-236.

Lapparent, M., 2006. Empirical Bayesian analysis of accident severity for motorcyclists in large French urban areas. *Accident Analysis and Prevention*, 38(2), 260-268.

Lee, C., Abdel-Aty, M., 2005. Comprehensive analysis of vehicle-pedestrian crashes at intersection in Florida. *Accident Analysis and Prevention*, 37(4), 775-786.

Lee, D., Young, D., McLaughlin, C., 1984. A roadside simulation of road crossing for children. *Ergonomics*, 27(12), 1271-1281.

Lee, J., Mannering, F., 2002. Impact of roadside features on the frequency and severity of run-off-roadway accidents: an empirical analysis. *Accident Analysis and Prevention*, 34(2), 149-161.

Lenguerrand, E., Martin, J., Laumon, B., 2006. Modelling the hierarchical structure of road crash data: Application to severity analysis. *Accident Analysis and Prevention*, 38(1), 43-53.

Li, G., Baker, S., 1994. Alcohol in fatally injured bicyclists. *Accident Analysis and Prevention*, 26(4), 543-548.

Li, L., Kim, K., 2000. Estimating driver crash risks based on the extended Bradley-Terry model: an induced exposure method. *Journal of Royal Statistical Society A (Statistics in Society)*, 163(2), 227-240.

Lin, M.-R., Chang, S.-H., Huang, W., Huang, H.-F., Pai, L., 2003. Factors Associated with Severity of Motorcycle Injuries Among Young Adult Riders, *Annuals of Emergency Medicine*, 41(6), 783-791.

Lobjois, R., Cavallo, V., 2007. Age-related differences in street-crossing decisions: The effects of vehicle speed and time constraints on gap selection in an estimation task. *Accident Analysis and Prevention*, 35(3), 934-943.

Long, J., 1997. *Regression models for categorical and limited dependent variables*. Thousand Oaks, CA: Sage Publications.

Luna, G., Maier, R., Sowder, L., Copass, M., Oreskovich, M., 1984. The influence of ethanol intoxication on the outcome of injured motorcyclists. *Journal of Trauma*, 24(8), 695-700.

Lynam, D., Broughton, J., Minton, R., Tunbridge, R., 2001. *An analysis of police reports of fatal accidents involving motorcycles*. TRL Report 492. Transport Research Laboratory, Berkshire, United Kingdom.

Mackay, G., 1986. Lower limb injuries to riders of motorcycles. *Biomechanics and Medical Aspects of Lower Limb*, 129-135.

Madanat, S., Cassidy, M., Wang, M., 1994. Probabilistic delay model at a stop-controlled intersection. *Journal of Transportation Engineering*, 120(1), 21-36.

Maher, M., Dowse, R., 1983. Estimating parameters in models of gap acceptance by queues. *Traffic Engineering and Control*, 24(5), 252-255.

Mahmassani, H., Sheffi, Y., 1981. Using gap sequences to estimate gap acceptance functions. *Transportation Research Part B: Methodological*, 15(3), 143-148.

Maki, T., Kajzer, J., Mizuno, K., Sekine, Y., 2003. Comparative analysis of vehicle-bicyclist and vehicle-pedestrian accidents in Japan. *Accident Analysis and Prevention*, 35(6), 927-940.

Mannering, F., Grodsky, L., 1995. Statistical analysis of motorcyclists' perceived accident risk. *Accident Analysis and Prevention*, 27(1), 21-31.

Mayhew, D., Simpson, H., Ferguson, S., 2006. Collisions involving senior drivers: high-risk conditions and locations. *Traffic Injury Prevention*, 7(2), 117-124.

Mayrose, J., Jehle, D., 2002.Vehicle weight and fatality risk for sport utility vehicle-versus-passenger car crashes. *Journal of Trauma*, 53(4), 751-753.

McCarthy, M., Gilbert, K., 1996. Cyclist road deaths in London 1985-1992: drivers, vehicles, manoeuvres and injuries. *Accident Analysis and Prevention*, 28(2), 275-279.

McCartt, A., Kyrychenko, S., 2007. Efficacy of side airbags in reducing driver deaths in driver-side car and SUV collisions. *Traffic Injury Prevention*, 8(2), 162-170.

McCullagh, P., 1980. Regression models for ordinal data (with discussion). *Journal of Royal Statistical Society*, 42(2), 109-142.

McFadden, D., Train, K., 2000. Mixed MNL models for discrete response. *Journal of Applied Econometrics*, 15(5), 447-470.

McIntyre, S., 2008. Capturing attention to brake lamps. *Accident Analysis and Prevention*, 40(2), 691-696.

McKelvey, F., Stamatiadis, N., 1989. Highway accident patterns in Michigan related to older drivers. *Transportation Research Record*, 1210, 53-57.

McLellan, B., Rizoli, B., Brenneman, F., Boulanger, B., Sharkey, P., Szalai, J., 1996. Injury pattern and severity in lateral motor vehicle collisions: A Canadian perspective. *Journal of Trauma*, 41(4), 708-713.

Mercier, C., Shelley II M., Adkins, G., Mercier, J., 1999. Age and Gender as predictors of injury severity in broadside and angle vehicular collisions. *Transportation Research Record*. 1693, 50-61.

Mercier, C., Shelley II M., Rimkus, J., Mercier, J., 1997. Age and Gender as predictors of injury severity in head-on highway vehicular collisions. *Transportation Research Record*, 1581, 37-46.

Miles-Doan, R., 1996. Alcohol use among pedestrians and the odds of surviving an injury: Evidence from Florida Law Enforcement Data. *Accident Analysis and Prevention*, 28(1), 23-31.

Milton, J., Shankar, V., Mannering, F., 2008. Highway accident severities and the mixed logit model: An exploratory empirical analysis. *Accident Analysis and Prevention*, 40(1), 260-266.

Mitra, S., Chin, H., Quddus, M., 2002. Study of intersection accidents by manoeuvre type. *Transportation Research Record*, 1784, 43-50.

Mizuno, K., Kajzer, J., 1999. Compatibility problems in frontal, side, single car collisions and car-to-pedestrian accidents in Japan. *Accident Analysis and Prevention*, 31(4), 381-391.

Mortimer, R., Hofmann, E., Poskocil, A., Jorgeson, C., Moore, C., Olson, P., 1974. Studies of automobile and truck rear lighting and signalling systems. Report No. HF-74-25. Highway Safety Research Institute. University of Michigan.

Muller, A., 1984. Daytime headlight operation and motorcyclist fatalities. *Accident Analysis and Prevention*, 16(1), 1-18.

Murphy, D., 2005. Aging matters, strategies for optimal care of the elderly. Elderly drivers: When is it time to take the keys away? *Consultant*, 45(1), 118-122.

Nagayama, Y., 1984. An analysis of accidents involving motorcycles and suggestion for drivers' education. *International Association of Traffic and Safety Sciences (IATSS) Research*, 8(1), 28-39.

Nagayama, Y., Morita, T., Miura, T., Watanabe, J., Murakami, N., 1980. Speed judgement of on-coming motorcycles. Proceedings of International Motorcycle Safety Conference, Linthicum MD, USA. Volume II 955-971.

Nakahara, S., Chadbunchachai, W., Ichikawa, M., Tipsuntornsak, N., Wakai, S., 2005. Temporal distribution of motorcyclist injuries and risk of fatalities in relation to age, helmet use, and riding while intoxicated in Khon Kaen, Thailand. *Accident Analysis and Prevention,* 37(5), 833-842.

Neyens, D., Boyle, L., 2007. The effect of distractions on the crash types of teenage drivers. *Accident Analysis and Prevention,* 39(1), 206-212.

Neyens, D., Boyle, L., 2008. The influence of driver distraction on the severity of injuries sustained by teenage drivers and their passengers. *Accident Analysis and Prevention,* 40(1), 254-259.

Noland, R., Quddus, M., 2004. Analysis of pedestrian and bicycle casualties with regional panel data. *Transportation Research Record,* 1897, 28-33.

O'Donnell, C., Connor, D., 1996. Predicting the severity of motor vehicle accident injuries using models of ordered multiple choice. *Accident Analysis and Prevention,* 28(6), 739-753.

Obeng, K., 2007. Some determinants of possible injuries in crashes at signalised intersections. *Journal of Safety Research,* 38(1), 103-112.

Obenski, K., Hill, P., Shapiro, E., Debes, J., 2007. *Motorcycle accident reconstruction and litigation.* 4th edition. Lawyers & Judges Publishing Co. Tucson, AZ.

Olson, P., 1989. Motorcycle conspicuity revisited. *Human Factors,* 31(2), 141-146.

Olson, P., Halstead-Nussloch, R., Sivak, M., 1981. The effect of improvements in motorcycle/motorcyclist conspicuity on driver behaviour. *Human Factors,* 23(2), 237-248.

Otte, D., Suren, E., Appel, H., Nehmzow, J., 1984. Vehicle parts causing injuries to front-seat car passengers in lateral impact. In Twenty-Eighth Stapp Car Crash Conference Proceedings, 13-24, Society of Automotive Engineering, Warrendale, PA.

Ouellet, 1982. Environmental hazards in motorcycle accidents. 26th Annual Proceedings American Association for Automotive Medicine. 117-129. October 4-6, 1982, Ontario, Canada.

Ouellet, J., Hurt, H., Thom, D., 1987a. Alcohol involvement in motorcycle accidents. Proceedings of 1987 SAE International Congress and Exposition, Detroit, February. SAE Paper 870602.

Ouellet, J., Hurt, H., Thom, D., 1987b. Collision performance of contemporary crash bars and motorcycle rider leg injuries. Proceedings of 1987 SAE International Congress and Exposition, Detroit, February. SAE Paper 870603.

Ouellet, J., Kasantikul, V., 2006. Motorcycle helmet effect on a per-crash basis in Thailand and the United States. *Traffic Injury Prevention*, 7(1), 49-54.

Oxley, J., Fildes, B., Corben, B., Langford, J., 2006. Intersection design for older drivers. *Transportation Research Part F: Traffic Psychology Behaviour*, 9(5), 335-346.

Padget, E., Knapp, K., Thomas, G., 2001. Investigation of winter-weather speed variability in sport utility vehicles, pickup trucks, and passenger cars. *Transportation Research Record*, 1779, 116-124.

Pai, C.-J., Tyan, H.-R., Liang, Y.-M., Liao, H.-Y., Chen, S.-W., 2004. Pedestrian detection and tracking at crossroads. *Pattern Recognition*, 37(5), 1025-1034.

Pai, C.-W., Saleh, W., 2007a. An analysis of motorcyclist injury severity under various traffic control measures at three-legged junctions in the UK. *Safety Science*, 45(8), 832-847.

Pai, C.-W., Saleh, W., 2007b. Exploring motorcyclist injury severity resulting from various crash configurations at T-junctions in the UK – an application of the ordered probit models. *Traffic Injury Prevention*, 8(1), 62-68.

Pai, C.-W., Saleh, W., 2008. Exploring motorcyclist injury severity in approach-turn collision at T-junctions: Focusing on the effects of driver's failure to yield and junction control measures. *Accident Analysis and Prevention*, 40(2), 479-486.

Pai, C.-W., Saleh, W., in press. Modelling motorcyclist injury severity by various crash types at T-junctions in the UK. *Safety Science.*

Pande, A., Abdel-Aty, M., 2006. Assessment of freeway traffic parameters leading to lane-change related collisions. *Accident Analysis and Prevention*, 38(5), 936-948.

Partyka, S., 1991. Light truck side impacts with serious occupant injury. In Proceedings of the 13th International Technical Conference on Experimental Safety Vehicles, 673-683. National Highway Traffic Safety Administration, Washington, DC.

Paulozzi, L., 2005. United States pedestrian fatality rates by vehicle type. *Injury Prevention*, 11(4), 232-236.

Peek-Asa, C., Braver, E., Shen, H., Kraus, J., 1994. Lower extremity injuries from motorcycle crashes: a common cause of preventable injury. *Journal of Trauma*, 37(3), 358-364.

Peek-Asa, C., Kraus, J., 1996a. Injuries sustained by motorcycle riders in the approaching turn crash configuration. *Accident Analysis and Prevention*, 28(5), 561-569.

Peek-Asa, C., Kraus, J., 1996b. Alcohol use, driver, and crash characteristics among injured motorcycle drivers. *Journal of Trauma*, 41(6), 989-993.

Peek-Asa, C., Kraus, J., 1997. Estimates of injury impairment after acute traumatic injury in motorcycle crashes before and after passage of a mandatory helmet use law. *Annals of Emergency Medicine*, 29(5), 630-636.

Peek-Asa, C., McArthur, D., Kraus, J., 1999. The prevalence of non-standard helmet use and head injuries among motorcycle riders. *Accident Analysis and Prevention*, 31(3), 229-233.

Pernia, J., Lu, J., Weng, M., Xie, X., Yu, Z., 2002. Development of models to quantify the impacts of signalization on intersection crashes. FDOT Report.

Persaud, B., Nguyen, T., 1998. Disaggregate safety performance models for signalised intersection on Ontario Provincial roads. *Transportation Research Record*, 1635, 113-120.

Persaud, M., Council, F., Lyon, C., Eccles, K., Griffith, M., 2005. Multijurisdictional safety evaluation of red light cameras. *Transportation Research Record*, 1922, 29-37.

Pickering, D., Hall, R., Grimmer, 1986. *Accidents at rural T-junctions*. TRL Research Report 65, Transport Research Laboratory, Crowthorne, England.

Pictcairn, K., Edlmann, T., 2000. Individual differences in road crossing ability in young children and adults. *British Journal of Psychology*, 91(3), 391-410.

Pitt, R., Guyer, B., Hsieh, C., Malek, M., 1990. The severity of pedestrian injuries in children: an analysis of the pedestrian injury causation study. *Accident Analysis and Prevention*, 22(6), 549-559.

Plumert, J., Kearney, J., Cremer, J., 2004. Children's perception of gap affordance: bicycling across traffic-filled intersections in an immersive virtual environment. *Child Development*, 75(4), 1243-1253.

Poch, M., Mannering, F., 1996. Negative binomial analysis of intersection-accident frequencies. *Journal of Transportation Engineering*, 122(2), 105-113.

Polus, A., 1983. Gap acceptance characteristics at unsignalised urban intersections. *Traffic Engineering and Control*, 24(5), 255-258.

Polus, A., 1985. Driver behaviour and accident records at unsignalised urban intersections. *Accident Analysis and Prevention*, 17(1), 25-32.

Preusser, D., Ferguson, S., Williams, A., 1998. The effect of teenage passengers on the fatal crash risk of teenage drivers. *Accident Analysis and Prevention*, 30(2), 217-222.

Preusser, D., Leaf, W., DeBartolo, K., Blomberg, R., Levy, M., 1982. The effect of right-turn-on-red on pedestrian and bicyclist accidents. *Journal of Safety Research*, 13(2), 44-55.

Preusser, D., Williams, A., Ferguson, S., Ulmer, R., Weinstein, H., 1998. Fatal crash risk for older drivers at intersections. *Accident Analysis and Prevention*, 30(2), 151-159.

Preusser, D., Williams, A., Ulmer, R., 1995. Analysis of fatal motorcycle crashes: crash typing. *Accident Analysis and Prevention*, 27(6), 845-851.

Quddus, M., Noland, R., Chin, H., 2002. An analysis of motorcycle injury and vehicle damage severity using ordered probit models. *Journal of Safety Research*, 33(4), 445-462.

Radin Umar, R., Mackay, M., Hills, B., 2000. Multivariate analysis of motorcycle accidents and the effect of exclusive motorcycle lanes in Malaysia. *Journal of Crash Prevention and Injury Control*, 2(1), 11-17.

Rahimi, M., 1989. A task, behaviour, and environmental analysis for automobile left-turn manoeuvres. 33rd Proceedings of the Human Factors Society. Voncouver, Canada. 905-909.

Ramanathan, R., 1995. *Introductory Econometrics with Applications*. The Dryden Press, Fort Worth, TX.

Räsänen, M., Summala, H., 1998. Attention and expectation problems in bicycle-car collisions: an in-depth study. *Accident Analysis and Prevention*, 30(5), 657-666.

Räsänen, M., Summala, H., 2000. Car drivers' adjustments to cyclists at roundabouts. *Transportation Human Factors*, 2(1), 1-17.

Ray, M., 1999. Impact conditions in side-impact collisions with fixed roadside objects. *Accident Analysis and Prevention*, 31(1), 21-30.

Renski, H., Khattak, A., Council, F., 1999. Effect of speed limit increases on crash injury severity: Analysis of single-vehicle crashes on North Carolina Interstate Highways. *Transportation Research Record*, 1665, 100-108.

Retting, R., Ferguson, S., Hakkert, A., 2003. Effects of red light cameras on violations and crashes: a review of the international literature. *Traffic Injury Prevention*, 4(1), 17-23.

Retting, R., Kyrychenko, S., 2002. Reduction in injury crashes associated with red light camera enforcement in Oxnard, California. *American Journal of Public Health*, 92(11), 1822-1825.

Retting, R., Weinstein, H., Solomon, M., 2003. Analysis of motor-vehicle crashes at stop signs in four U.S. cities. *Journal of Safety Research*, 34(5), 485-489.

Richter, M., Otte, D., Lehmann, U., Chinn, B., Schuller, E., Doyle, D., Sturrock, K., Krettek, C., 2001. Head injury mechanisms in helmet-protected motorcyclists: Prospective multicenter study. *Journal of Trauma*, 51(5), 949-958.

Rifaat, S., Chin, H., 2007. Accident severity analysis using ordered probit model. *Journal of Advanced Transportation*, 41(1), 91-114.

Rosman, D., Knuiman, M., 1994. A comparison of hospital and police road injury data. *Accident Analysis and Prevention*, 26(2), 215-222.

Ross, D., 1983. The prevention of leg injuries in motorcycle accidents. Injury. 15(2), 75-77.

Rothe, J., Cooper, P., 1987. *Motorcyclists: Image and reality*. Vancouver, BC: Insurance Corporation of British Columbia.

Roudsari, B., Kaufman, R., Koepsell, T., 2006. Turning at intersections and pedestrian injuries. *Traffic Injury Prevention*, 7(3), 283-289.

Roudsari, B., Mock, C., Kaufman, R., Grossan, D., Henary, B., Crandall, J., 2004. Pedestrian crashes: higher injury severity and mortality rate for light truck vehicles compared with passenger vehicles. *Injury Prevention*, 10(3), 154-158.

Rowland, J., Rivara, F., Salzberg, P., Soderberg, R., Maier, R., Koepsell, T., 1996. Motorcycle helmet use and injury outcome and hospitalization costs from crashes in Washington State. *American Journal of Public Health*, 86(1), 41-45.

Ryan, G., Legge, M., Rosman, D., 1998. Age related changes in drivers' crash risk and crash type. *Accident Analysis and Prevention*, 30(3), 379-387.

Savolainen, P., Mannering, F., 2007a. Effectiveness of motorcycle training and motorcyclists' risk-taking behaviour. *Transportation Research Record*, 2031, 52-58.

Savolainen, P., Mannering, F., 2007b. Probabilistic models of motorcyclists' injury severities in single- and multi-vehicle crashes. *Accident Analysis and Prevention*, 39(5), 955-963.

Scialfa, C., Guzy, L., Leibowitz, P., Garvey, P., Tyrrell, R., 1991. Age differences in estimating vehicle velocity. *Psychology and Aging*, 6(1), 60-66.

Sen, B., Smith, J., Najm, W., 2003. Analysis of lane change crashes. Report DOT-VNTSC-NHTSA-02-03. NHTSA, US Department of Transportation.

Sexton, B., Baughan, C., Elliott, M., Maycock, G., 2004. *The accident risk of motorcyclists*. TRL607. Crowthorne Berkshire.

Shankar, U., 2001. Fatal single vehicle motorcycle crashes (DOT HS 809 360). Washington, DC: National Highway Traffic Safety Administration.

Shankar, U., 2003. Alcohol involvement in fatal motorcycle crashes. Washington, DC: National Highway Traffic Safety Administration.

Shankar, V., Mannering F., 1996. An exploratory multinomial logit analysis of single-vehicle motorcycle accident severity. *Journal of Safety Research*, 27(3), 183-194.

Shankar, V., Mannering F., Barfield, W., 1995. Effect of roadway geometrics and environmental factors on rural freeway accident frequencies. *Accident Analysis and Prevention*, 27(3), 371-389.

Shankar, V., Mannering F., Barfield, W., 1996. Statistical analysis of accident severity on rural freeways. *Accident Analysis and Prevention*, 28(3), 391-401.

Shankar, V., Mannering, F., Barfield, W., 1995. Effect of roadway geometrics and environmental factors on rural freeway accident frequencies. *Accident Analysis and Prevention*, 27(3), 371-389.

Shin, K., Washington, S., 2007. The impact of red light cameras on safety in Arizona. *Accident Analysis and Prevention*, 39(6), 1212-1221.

Siddiqui, N., Chu, X., Buttenplan, M., 2006. Crossing location, light conditions, and pedestrian injury severity. *Transportation Research Record*, 1982, 141-149.

Snijders, A., Bosker, R., 2000. *Multilevel Analysis. An Introduction to Basic and Advanced Multilevel Modelling*. SAGE Publications, London.

Sohn, S., Lee, S., 2003. Data fusion, ensemble and clustering to improve the classification accuracy for the severity of road traffic accidents in Korea. *Safety Science*, 41(1), 1-14.

Sohn, S., Shin, H., 2001. Pattern recognition for road traffic accident severity in Korea. *Ergonomics*, 44(1), 107-117.

Solberg, P., Oppenlander, J., 1966. Lag and gap acceptances at stop-controlled intersections. *Highway Research Record*, 118, 48-67.

Songchitruksa, P., Tarko, A., 2006. Practical method for estimating frequency of right-angle collisions at traffic signals. *Transportation research record*, 1953, 89-97.

Sparks, G., Neudorf, R., Smith, A., Wapman, K., Zador, P., 1993. The effect of daytime running lights on crashes between two vehicles in Saskatchewan: A study of a government fleet. *Accident Analysis and Prevention*, 25(5), 619-625.

Sparrow, F., 1985. Accident involvement and injury rates for small cars in Japan. *Accident Analysis and Prevention*, 17(5), 409-418.

Spek, A., Wieringa, P., Janssen, W., 2006. Intersection approach speed and accident probability. *Transportation Research Part F: Traffic Psychology Behaviour*, 9(2), 155-171.

Spicer, B., 1972. *A traffic conflict study at an intersection on the Andoversfold by-pass.* TRRL Report LR 520, Transport Research Laboratory, Crowthorne, England.

Srinivasan, K., 2002. Injury severity analysis with variable and correlated Thresholds – Ordered mixed logit formulation. *Transportation Research Record*, 1784, 132-142.

Stamatiadis, N., Taylor, W., McKelvey, F., 1991. Older drivers and intersection traffic control devices. *Journal of Transportation Engineering*, 117(3), 311-319.

Staplin, L., 1995. Simulator and field measures of driver age differences in left-turn gap judgements. *Transportation Research Record*, 1485, 49-55.

Staplin, L., Lyles, R., 1991. Age differences in motion perception and specific traffic manoeuvre problems. *Transportation Research Record*, 1325, 23-33.

Stone, M., Broughton, M., 2003. Getting off your bike: cycling accidents in Great Britain 1990-1999. *Accident Analysis and Prevention*, 35(4), 549-556.

Storr, P., Cooper, D., McDowell, M., 1980. Analysis of gap acceptance in a complex traffic manoeuvre. *European Journal Operational Research*, 5(2), 94-101.

Su, J-M., Wu, C-H., Hung, C-Y. 2006. Traffic characteristics of motorcycles on tangent sections of expressways. *Transportation Research Record*, 1969, 126-133.

Summala, H., Pasanen, E., Räsänen, M., Sievänen, J., 1996. Bicycle accidents and drivers' visual search at left and right turns. *Accident Analysis and Prevention*, 28(2), 1-12.

Sze, N., Wong, S., 2007. Diagnostic analysis of the logistic model for pedestrian injury severity in traffic crashes. *Accident Analysis and Prevention* 39(6), 1267-1278.

Tang, K.-H., 2003. A field study on validation of supplemental brake lamp with flashing turn signals for motorcycles. *International Journal of Industrial Ergonomics*, 31(5), 295-302.

Tang, K.-H., Tsai, L.-C., Lee, Y.-H., 2006. A human factors study on a modified stop lamp for motorcycles. *International Journal of Industrial Ergonomics*, 36(6), 533-540.

Theeuwes, J., Alferdinck, J., 1997. The effectiveness of side marker lamps: An experimental study. *Accident Analysis and Prevention*, 29(2), 235-245.

Thomson, G., 1980. The role frontal motorcycle conspicuity has in road accidents. *Accident Analysis and Prevention*, 12(3), 165-178.

Toy, E., Hammitt, J., 2003. Safety impacts of SUVs, vans, and pickup trucks in two-vehicle crashes. *Risk Analysis*, 23(4), 641-650.

Transport for London, 2005. *Pedal cyclist casualties in Great London.* Transport for London, London.

Treisman, A., 1996. *Feature binding, attention and object perception.* In: Humphreys, G.W., Duncan, J., Treisman, A., (Eds.), *Attention, Space and Action: Studies in Cognitive Neuroscience.* OUP, Oxford, 91-111.

Tsongos, N., Weiner, S., 1969. Comparison of day and night gap-acceptance probabilities. *Public Roads*, 35(7), 157-165.

Ulfarsson, G., Kim, S., Lentz, E., 2006. Factors affecting common vehicle-to-vehicle collision types: Road safety priorities in an aging society. *Transportation Research Record*, 1980. 70-78.

Ulfarsson, G., Mannering, F., 2004. Differences in male and female injury severities in sport-utility vehicle, minivan, pickup and passenger car accidents. *Accident Analysis and Prevention*, 36(2), 135-147.

Umar, R., Murry, G., Brian, L., 1996. Modelling of conspicuity-related motorcycle accidents in Seremban and Shah Alam, Malaysia. *Accident Analysis and Prevention*, 28(3), 325-332.

Viano, D., Culver, C., Evans, L., Frick, M., Scott, R., 1990. Involvement of older drivers in multivehicle side-impact crashes. *Accident Analysis and Prevention*, 22(2). 177-188.

Wachtel, A., Lewiston, D., 1994. Risk factors for bicycle-motor vehicle collisions at intersections. *ITE Journal*, 64(9), 30-35.

Wagner, F., 1966. An evaluation of fundamental driver decisions and reactions at an intersection. *Highway Research Record*, 118, 68-84.

Walker, I., 2007. Drivers overtaking bicyclists: Objective data on the effects of riding position, helmet use, vehicle type and apparent gender. *Accident Analysis and Prevention*, 39(2), 417-425.

Wang, J., Knipling, R., 1994. Lane changing/merge crashes: problem size assessment and statistical description. Report No. DOT HS 808-075. Department of Transportation Publication, Washington, DC.

Wang, X., Abdel-Aty, M., 2006. Temporal and spatial analyses of rear-end crashes at signalized intersections. *Accident Analysis and Prevention*, 38(6), 1137-1150.

Wang, X., Abdel-Aty, M., 2007. Right-angle crash occurrence at signalised intersections. *Transportation Research Record*, 2019, 156-168.

Wang, X., Abdel-Aty, M., 2008. Modelling left-turn crash occurrence at signalised intersections by conflicting patterns. *Accident Analysis and Prevention*, 40(1), 76-88.

Wang, X., Kockelman, K., 2005. Use of heteroscedastic ordered logit model to study severity of occupant injury. *Transportation Research Record*, 1908, 195-204.

Wang, Y., 1998. *Modelling vehicle-to-vehicle accident risks considering the occurrence mechanism at four-legged signalised intersections.* Ph.D. Dissertation, University of Tokyo.

Wang, Y., Ieda, H., Mannering, F., 2003. Estimating rear-end accident probabilities at signalised intersections: Occurrence-mechanism approach. *Journal of Transportation Engineering*, 129(4), 377-384.

Wang, Y., Nihan, N., 2001. Quantitative analysis on angle-accident risk at signalised intersections. In: Proceedings of the 9th World Conference on Transport Research.

Wang, Y., Nihan, N., 2004. Estimating the risk of collisions between bicycles and motor vehicles at signalized intersections. *Accident Analysis and Prevention*, 36(3), 313-321.

Washington, S., Karlaftis, M., Mannering, F., 2003. *Statistical and Econometric Methods for Transportation Data Analysis*. Chapman and Hall/CRC, Boca Raton, FL.

Watson, G., Zador, P., Wilks, A., 1980. The repeal of helmet use laws and increases motorcyclist mortality in the United States. *American Journal of Public Health*, 70(6), 579-585.

Weiss, A. 1992. The effects of helmet use on the severity of head injuries in motorcycle accidents. *Journal of the American Statistical Association*, 87(417), 48-56.

Wells, S., Mullin, B., Norton, R., Langley, J., Connor, J., Yee-Lay, R., Jackson, R. 2004. Motorcycle rider conspicuity and crash related injury: case-control study. *British Medical Journal*, 328(7444), 857-860A.

Williams, M., Hoffmann, E., 1979a. Motorcycle conspicuity and traffic accidents. *Accident Analysis and Prevention*, 11(3), 209-224.

Williams, M., Hoffmann, E., 1979b. Alcohol use and motorcycle accidents. *Accident Analysis and Prevention*, 11(3), 199-207.

Wittenberg, E., Goldie, S., Graham, J., 2001. Predictors of hazardous child seating behaviour in fatal motor vehicle crashes: 1990 to 1998. *Pediatrics*, 108(2), 438-442.

Wulf, G., Hancock, P., Rahimi, M., 1989a. Motorcycle conspicuity: an evaluation and synthesis of influential factors. *Journal of Safety Research*, 20(4), 153-175.

Wulf, G., Hancock, P., Rahimi, M., 1989b. Some causes of automobile-motorcycle collisions. Proceedings of Human Factors Society, 33, 910-914.

Yamamoto, T., Hashiji, J., Shankar, V, in press. Underreporting in traffic accident data, bias in parameters and the structure of injury severity models. *Accident Analysis and Prevention*.

Yamamoto, T., Shankar, V, 2004. Bivariate ordered-response probit model of driver's and passenger's injury severities in collisions with fixed objects. *Accident Analysis and Prevention*, 36(5), 869-876.

Yan, X., Radwan, E., 2006. Analyses of rear-end crashes based on classification tree models. *Traffic Injury Prevention*, 7(3), 276-282.

Yan, X., Radwan, E., Abdel-Aty, M., 2005. Characteristics of rear-end accidents at signalised intersections using multiple logistic regression model. *Accident Analysis and Prevention*, 37(6), 983-995.

Yuan, W., 2000. The effectiveness of the 'ride-bright' legislation for motorcycles in Singapore. *Accident Analysis and Prevention*, 32(4), 559-563.

Zador, P., 1985. Motorcycle headlight-use laws and fatal motorcycle crashes in the U.S., 1975-83. *American Journal of Public Health*, 75(5), 43-46.

Zador, P., Ciccone, M., 1993. Automobile driver fatalities in frontal impacts: Air bags compared with manual belts. *American Journal of Public Health*, 83(5), 661-666.

Zajac, S., Ivan, J., 2003. Factors influencing injury severity of motor vehicle-crossing pedestrian crashes in rural Connecticut. *Accident Analysis and Prevention*, 35(3), 369-379.

Zambon, F., Hasselberg, A., 2006. Factors affecting the severity of injuries among young motorcyclists – a Swedish nationwide cohort study. *Traffic Injury Prevention*, 7(2), 143-149.

Zegeer, C., Deen R., Mayes, J., 1981. Effect of lane and shoulder widths on accident reduction on rural two-lane roads. *Transportation Research Record*, 809, 33-43.

Zhang, C., Ivan, J., 2005. Effects of geometric characteristics on head-on crash incidence on two-lane roads in Connecticut. *Transportation Research Record*, 1908, 136-140.

Zhang, J., Lindsay J., Clarke, K, Robbins, G., Mao, Y., 2000. Factors affecting the severity of motor vehicle traffic crashes involving elderly drivers in Ontario. *Accident Analysis and Prevention*, 32(1), 117-125.

APPENDIX A - STATS19 ACCIDENT RECORD FORMS

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 / Northing

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 road
6 Single carriageway - 2 lanes (one in each direction)
7 Single carriageway - 3 lanes (two way capacity)
8 Single carriageway - 4 or more lanes (two way capacity)
9 Unknown

1.15 Speed Limit (mph) [0]

1.16 Junction Detail [0]

00 Not at or within 20 metres of junction
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 markings
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 metres or physical crossing facility not controlled by authorised person
1 Control by school crossing patrol
2 Control by other authorised person

1.20b Pedestrian Crossing - Physical Facilities

0 No physical crossing facility within 50 metres
1 Zebra crossing
4 Pelican, puffin, toucan or similar non-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 and lit
5 Darkness: street lights present but unlit
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 deep)
6 Oil or diesel
7 Mud

1.24 Special Conditions at Site

0 None
1 Automatic traffic signal out
2 Automatic traffic signal partially defective
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 carriageway
2 Other object in carriageway
3 Involvement with previous accident
4 Dog in carriageway
5 Other animal or pedestrian in carriageway

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-motor vehicle
- 16 Ridden horse
- 17 Agricultural vehicle (includes diggers etc.)
- 18 Tram / Light rail
- 19 Goods vehicle 3.5 tonnes mgw and under
- 20 Goods vehicle over 3.5 tonnes and under 7.5 tonnes mgw
- 21 Goods vehicle 7.5 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 lane to right
- 13 Overtaking moving vehicle on its offside
- 14 Overtaking stationary vehicle on its offside
- 15 Overtaking on nearside
- 16 Going ahead left hand bend
- 17 Going ahead right 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 Bridge - side
- 07 Bollard / refuge
- 08 Open door of vehicle
- 09 Central island of 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 contacted at time of accident
- 6 Not provided (medical reasons)

2.24 Hit and Run

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

2.25 DETR Special Projects

2.26 Vehicle Registration Mark (VRM)
Special codes:
- 2 Foreign / Diplomatic
- 3 Military
- 4 Trade plates
- 9 Unknown

2.27 Driver Postcode
Special codes:
- 1 Unknown
- 2 Non-UK resident
- 3 Parked and unattended

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

Estimated if necessary

Years

3.9 Severity of Casualty

1 Fatal
2 Serious
3 Slight

3.10 Pedestrian Location

00 Not a pedestrian
01 In carriageway, crossing on pedestrian crossing facility
02 In carriageway, crossing within zig-zag lines at crossing approach
03 In carriageway, crossing within zig-zag lines at crossing exit
04 In carriageway, crossing elsewhere within 50 metres of pedestrian crossing
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 refuge, central island or central reservation
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 - masked by parked or stationary vehicle
3 Crossing from driver's offside
4 Crossing from driver's offside - masked by parked or stationary vehicle
5 In carriageway, stationary - not crossing (standing or playing)
6 In carriageway, stationary - not crossing (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 B - THE NORMAL PROBABILITY INTEGRAL $1-\Phi(u)$

x	0	1	2	3	4	5	6	7	8	9
0.0	0.5000	0.4960	0.4920	0.4880	0.4840	0.4801	0.4761	0.4721	0.4681	0.4641
0.1	0.4602	0.4562	0.4522	0.4483	0.4443	0.4404	0.4364	0.4325	0.4286	0.4247
0.2	0.4207	0.4168	0.4129	0.4090	0.4052	0.4013	0.3974	0.3936	0.3897	0.3859
0.3	0.3821	0.3783	0.3745	0.3707	0.3669	0.3632	0.3594	0.3557	0.3520	0.3483
0.4	0.3446	0.3409	0.3372	0.3336	0.3300	0.3264	0.3228	0.3192	0.3156	0.3121
0.5	0.3085	0.3050	0.3015	0.2981	0.2946	0.2912	0.2877	0.2843	0.2810	0.2776
0.6	0.2743	0.2709	0.2676	0.2643	0.2611	0.2578	0.2546	0.2514	0.2483	0.2451
0.7	0.2420	0.2389	0.2358	0.2327	0.2296	0.2266	0.2236	0.2206	0.2177	0.2148
0.8	0.2119	0.2090	0.2061	0.2033	0.2005	0.1977	0.1949	0.1922	0.1894	0.1867
0.9	0.1841	0.1814	0.1788	0.1762	0.1736	0.1711	0.1685	0.1660	0.1635	0.1611
1.0	0.1587	0.1562	0.1539	0.1515	0.1492	0.1469	0.1446	0.1423	0.1401	0.1379
1.1	0.1357	0.1335	0.1314	0.1292	0.1271	0.1251	0.1230	0.1210	0.1190	0.1170
1.2	0.1151	0.1131	0.1112	0.1093	0.1075	0.1056	0.1038	0.1020	0.1003	0.0985
1.3	0.0968	0.0951	0.0934	0.0918	0.0901	0.0885	0.0869	0.0853	0.0838	0.0823
1.4	0.0808	0.0793	0.0778	0.0764	0.0749	0.0735	0.0721	0.0708	0.0694	0.0681
1.5	0.0668	0.0655	0.0643	0.0630	0.0618	0.0606	0.0594	0.0582	0.0571	0.0559
1.6	0.0548	0.0537	0.0526	0.0516	0.0505	0.0495	0.0485	0.0475	0.0465	0.0455
1.7	0.0446	0.0436	0.0427	0.0418	0.0409	0.0401	0.0392	0.0384	0.0375	0.0367
1.8	0.0359	0.0351	0.0344	0.0336	0.0329	0.0322	0.0314	0.0307	0.0301	0.0294
1.9	0.0287	0.0281	0.0274	0.0268	0.0262	0.0256	0.0250	0.0244	0.0239	0.0233
2.0	0.0228	0.0222	0.0217	0.0212	0.0207	0.0202	0.0197	0.0192	0.0188	0.0183
2.1	0.0179	0.0174	0.0170	0.0166	0.0162	0.0158	0.0154	0.0150	0.0146	0.0143
2.2	0.0139	0.0136	0.0132	0.0129	0.0125	0.0122	0.0119	0.0116	0.0113	0.0110
2.3	0.0107	0.0104	0.0102	0.0099	0.0096	0.0094	0.0091	0.0089	0.0087	0.0084
2.4	0.0082	0.0080	0.0078	0.0075	0.0073	0.0071	0.0069	0.0068	0.0066	0.0064
2.5	0.0062	0.0060	0.0059	0.0057	0.0055	0.0054	0.0052	0.0051	0.0049	0.0048
2.6	0.0047	0.0045	0.0044	0.0043	0.0041	0.0040	0.0039	0.0038	0.0037	0.0036
2.7	0.0035	0.0034	0.0033	0.0032	0.0031	0.0030	0.0029	0.0028	0.0027	0.0026
2.8	0.0026	0.0025	0.0024	0.0023	0.0023	0.0022	0.0021	0.0021	0.0020	0.0019
2.9	0.0019	0.0018	0.0018	0.0017	0.0016	0.0016	0.0015	0.0015	0.0014	0.0014
3.0	0.0013	0.0013	0.0013	0.0012	0.0012	0.0011	0.0011	0.0011	0.0010	0.0010

APPENDIX C - PUBLICATIONS

Unpublished conference paper

1. Pai, C-W., Saleh, W., Maher, M., 2006. Exploring Injury Severity among Motorcyclists at T-junctions in the UK: an application of the ordered probit model. Paper presented in 38th annual UTSG conference. January 4th – 6th. Dublin. Ireland.
2. Pai, C-W., Saleh, W., 2007. Exploring motorcyclist injury severity resulting from approach-turn collisions at three-legged junctions in the UK. Paper presented in 39th annual UTSG conference. January 3rd – 5th. Leeds. UK.
3. Pai, C-W., Saleh, W., 2007. An exploration of motorcyclist injury severity under different junction control measures at three-legged junctions in the UK. In: Proceedings of 11th WCTR international conference. June 24 – 28, Berkeley, USA.
4. Pai, C-W., Saleh, W., 2008. An analysis of motorcyclist injury severity in angle crashes at T-junctions – Focusing on the effects of motorists' right-of-way violations, junction control measures, and manoeuvres. Paper presented in 40th annual UTSG conference. January 3rd – 5th. Southampton. UK.

Published conference paper

1. Pai, C-W., Saleh, W., & Maher, M., 2006. An Analysis of Injury Severity among Motorcyclists at T-junctions in the UK using the ordered probit model. The 5th International Conference on Traffic & Transportation Studies (ICTTS 2006). August 2 – 4. Xi'an, China.

Refereed journal paper

1. Pai, C-W., Saleh, W., 2007. An analysis of motorcyclist injury severity under various traffic control measures at three-legged junctions in the UK. *Safety Science*, 45(8), 832-847.

2. Pai, C-W., Saleh, W., 2007. Exploring motorcyclist injury severity resulting from various crash configurations at T-junctions in the UK – an application of the ordered probit models. *Traffic Injury Prevention*, 8(1), 62-68.
3. Pai, C-W., Saleh, W., 2008. Exploring motorcyclist injury severity in approach-turn collisions at T-junctions: focusing on the effects of driver's failure to yield and junction control measures. *Accident Analysis and Prevention*, 40(2), 479-486.
4. Pai, C-W., Saleh, W., in press. Modelling motorcyclist injury severity by various crash types at T-junctions in the UK. *Safety Science*.
5. Pai, C-W., Saleh, W., 2008. Modelling motorcyclist injury severity resulting from sideswipe collisions at T-junctions in the UK: new insights into the effects of manoeuvres. *International Journal of Crashworthiness*, 13(1), 89-98.
6. Pai, C-W., Saleh, W., under review. What exacerbates motorcyclist injury severity in angle crashes at T-junctions? An examination of motorist's failure to give way and junction control measures. *Safety Science*.