Empirical Study to Investigate Injury Severity of Vehicular Crashes on Motorways Using Ordered Probit Approach

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Certified that the contents and form of thesis titled “Empirical Study to Investigate Severity of Vehicular Crashes on Motorways Using Ordered Probit Approach” submitted by Numan Ahmad have been found satisfactory for the requirement of the degree.

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Associate Professor (Dr. Anwaar Ahmed, PhD)

To
My beloved parents and teachers, grandfather, loving aunts, siblings and my sweet niece Fatima
This is especially dedicated to my
Dear Baba who devotedly supported me at each step of my life.

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LIST OF ACRONYMS

RTC	Road Traffic Crash
RTF	Road Traffic Fatalities
RTI	Road Traffic Injuries
CRF	Crash Report Form
NTSB	National Transportation Safety Board
NHA	National Highway Authority
NHMP	National Highway and Motorway Traffic Police
LTV	Light Traffic Vehicle
HTV	Heavy Traffic Vehicle
WHO	World Health Organization
GT	Grand Trunk
M1	Peshawar to Islamabad (Motorway)
M2	Islamabad to Lahore (Motorway)
M3	Lahore to Faisalabad (Motorway)
FHWA	Federal Highway Administration
NHSTA	National Highway Traffic Safety Administration
GES	General Estimating System

ABSTRACT

Due to enormous human and economic losses in road traffic crashes (RTCs), number of research efforts have been made in past to explore the causative factors in road traffic crashes. Most of the past research efforts remain focused on crash frequency and crash injury severity analysis. Present research effort is focused on the analysis of the influence of the drivers' and vehicular characteristics, environmental conditions, crash pattern and causes of crashes on injury severity in motorways crashes. Data for present study have been extracted from the National Highways and Motorways Police (NHMP) records. Due to the ordinal nature of the response variable an ordered probit model has been estimated to study the association of crash injury severity with different explanatory variables. The model results revealed that crashes between lighter vehicles (passenger cars, pickups, panels and vans), crashes occurring during evening peak time, vehicles colliding via nose to tail pattern and crash involving new vehicles are more likely to be less severe. On the other hand dozing behind the wheel, over speeding, head-on collision and vehicle hitting pedestrian increase the probability of a crash to be more severe nature. Also, involvement of older drivers tends to increase the likelihood of the crash to be more severe. Marginal effects are presented to understand the effects of the significant variables on intermediate categories of the crash injury severity. The results of present research are expected to provide insight to planner and policy makers to enhance road safety on motorways and help in saving valuable lives.

CHAPTER 1. INTRODUCTION

1.1 Background

Road traffic crashes (RTCs) cause huge socio-economic losses in the form of various types of injuries (Peden et al. 2004, Ahmed e.t al 2014). Each year 1.24 million people die while 20-50 million suffer injuries in RTCs around the world (World Health Organization 2013). According to WHO (2013), the RTCs cause a total economic loss of US$518 billion per year across the globe. Also, RTCs are the key reason of mortality in young people i.e. 15-24 years (Mathers, Fat, and Boerma 2008). The under-developed and developing countries which contain only 48% of the world registered vehicles, suffer 90% of the overall road traffic fatalities (RTFs) (WHO 2009). According to the recent trend, the RTCs have been decreasing in high-income countries while they have been increasing in the low and middle-income countries (Koptis and Cropper 2005).

Pakistan being the sixth most populous country contains 180 million populations and 7,800,000 registered vehicles (WHO, 2013). According to WHO (2013), each year more than 30,000 RTFs and 400,000 road traffic injuries (RTIs) occur in RTCs. Likewise, Gaffar et al. (2004) estimated 1500 RTIs per 100,000 populations whereas Fatmi et al. (2007) reported 270,000 annual RTIs across the country. Lopez et al. (2006) reports RTCs as a second key cause of disability, fifth primary cause of healthy life losses and eleventh prime cause of pre-mature fatality in Pakistan. The annual RTFs per 10,000 vehicles in Pakistan are one of the highest across the globe (Haider M, Badami 2009). As a result of these crashes, Government of Pakistan pays a total of Rs.100 billion per annum (Ahmed 2007). In this research, an effort has been made to develop an ordered probit model for investigation of significant factors which affect the injury severity of freeway crashes. The crash data for 574 kilometers stretch of motorways were obtained from NHMP for the period of 7 years (i.e. 2009-15).The outcomes of the study are intended to recommend possible countermeasures for enhancing the road safety in the country.

1.2 Problem Statement

RTCs have been serious issue as every year millions of people face fatality and various injuries across the globe. As national road safety is the call of the day and developed countries have been spending enormous expenses on researches to investigate the factors affecting frequency and injury severity of RTCs. Also, such studies are intended to recommend countermeasures to improve the road traffic safety. The road traffic crash rate has increased in developing and under-developed countries whereas it has decreased in advanced countries. The commencement of national road safety and enhancement programs is necessary for awareness of drivers, planning and administrative agencies and general public on road traffic safety.

Researchers have focused on statistical models for frequency and severity analysis of RTCs to enhance the traffic safety. Little work has been done on severity analysis as compared to frequency analysis where as both are equally essential to understand overall safety trend on roads. The recent study is carried out to inspect the factors affecting injury severity of motorways vehicular crashes. The results will eventually help to suggest countermeasures to improve the safety on the facility.

1.3 Research Objectives

Pakistan belongs to the category of developing countries which are at higher risk of RTCs. Pakistan, having a population of 180 million, has a total road network of 260,000 kms, Only 11,900 kms of roads in the country are under the dominion of National Highway Authority, Pakistan (NHA). Also, the motorways are under the jurisdiction of the NHA. RTCs need proper consideration as it has become a serious issue on national level. The study is conducted for the following purposes:

- To develop an ordered probit model for injury severity of freeway's RTCs.
- To identify key contributing factors that affect injury severity of freeway traffic crashes.

1.4 Overview of the Study Approach

A detailed methodology was developed to successfully achieve the desired objectives. The methodology comprises of the following tasks:

- A comprehensive study of previous on frequency and injury severity of RTCs.
- Collection and collation of data.
- Study of various statistical approaches and selection of appropriate model.
- Estimation of ordered probit model for injury severity analysis.
- Model estimation results and discussion.
- Conclusions and recommendations.

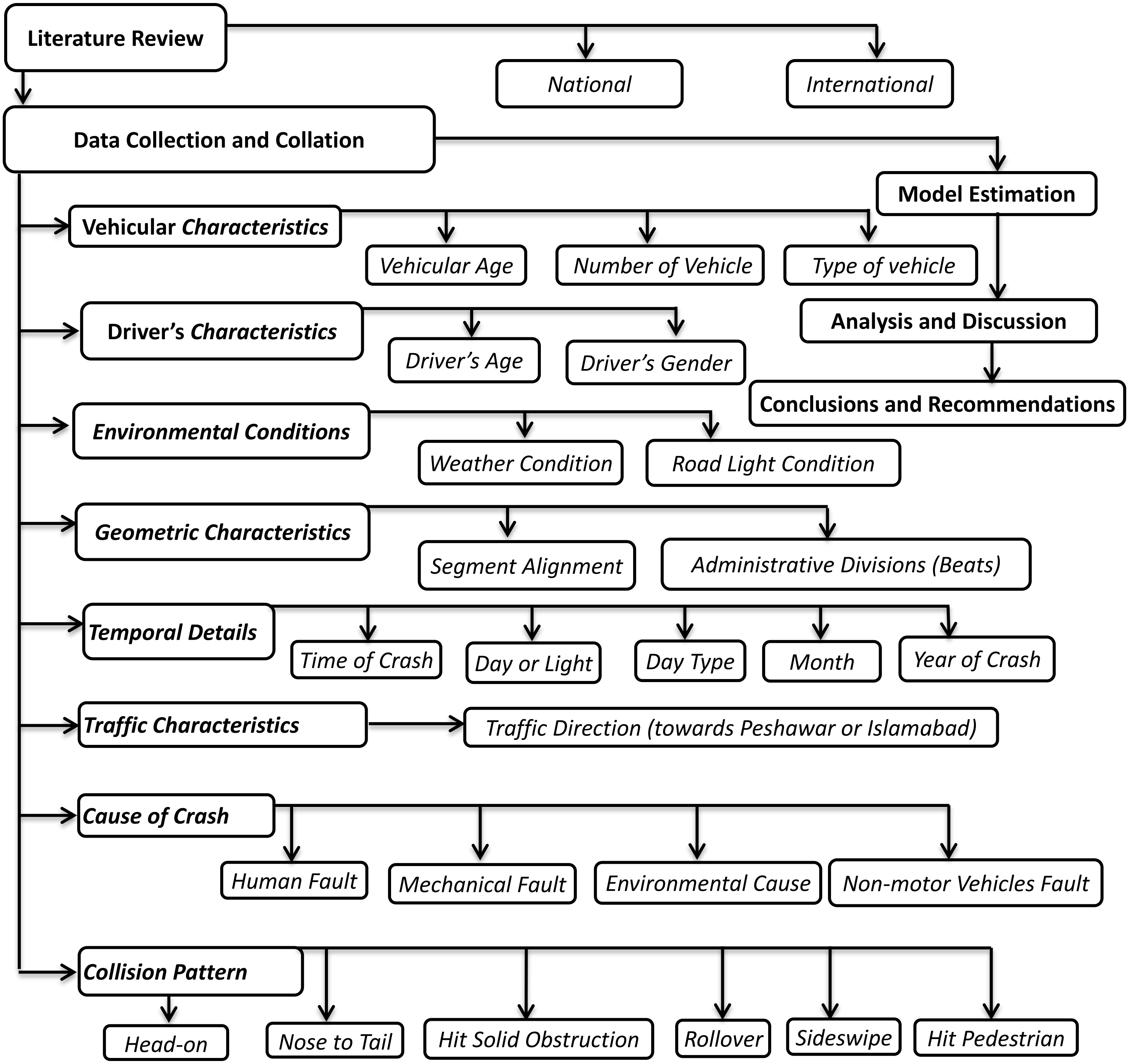

Figure 1.1: Overview of Study Approach

1.5 Organization of the thesis

The thesis includes five chapters in which chapter 1 provides contextual information for the requirement to establish a framework for injury severity analysis followed by the problem statement and objectives of the research. Chapter 2 includes a comprehensive review of the past literature regarding injury severity analysis via econometric approaches and to understand the association of various parameters with the injury severity of the road crashes. Chapter 3 discusses the collection and collation of data used in the model. Chapter 4 highlights modeling methodology, model results, analysis and discussion. In the end, Chapter 5 presents research summary, conclusions and recommendations.

CHAPTER 2. LITERATURE REVIEW

2.1 INTRODUCTION

This chapter consists of summary of various studies on crash frequency and crash severity analysis of RTCs. The studies on RTCs reveal that contributing factors belong to any of the three major classes: 1) human factors, 2) environmental factors and 3) vehicular factors. Human factors are regarded to cause comparatively more RTCs. The most dominant human factors are: dozing of drivers behind the wheel, carelessness driving, drunk-drive, underage driving, old age driving, avoiding restraints (i.e. seatbelts etc.) and over speeding. Environmental factors include weather conditions, light conditions and geometric characteristics which expose vehicles to RTCs of different severities. Whereas the vehicular factors consist of brake failure, tire bursts, tie rod failure, steering problem, wheel issue and any other mechanical problem.

In the recent past, the researchers have focused on statistical modeling to examine the factors influencing both frequency and injury severity of crashes. In crash frequency modeling (i.e. number of crashes on specified portion in a known time duration), count data models have been used because of the discrete and non-negative nature of the crash data. The count-data models which have been developed for the crashes frequency include; Poisson model (e.g. Ma 2009, Li et al. 2013), negative binomial model (e.g., Lord 2006, Malyshkina and Mannering 2010b), poisson lognormal model (e.g., Lord and Miranda-Moreno 2008), gamma model (e.g., Oh et al. 2006), generalized poisson model (e.g., Dissanayake et al. 2009) and zero-inflated models. Other flexible modeling techniques have also been successfully applied (e.g., Abdel-Aty and Radwan 2000, Anastasopoulos and Mannering 2009).

For proper enhancement of road traffic safety, both frequency and severity analysis of RTCs are equally important. Numerous efforts have been made to understand the association between explanatory factors; driver and vehicular characteristics, highway geometric features, climatic severity, traffic conditions and injury severity. The researchers used logistic regression (e.g., Yau 2004), bivariate models (e.g., Saccomanno et al. 1996, Yamamoto and Shankar 2004), multinomial and nested logit structures (e.g., Ulfarsson and Mannering 2004, Khorashadi et al. 2005), and discrete ordered probit model (e.g., O’Donnell and Connor 1996, Duncan et al. 1998, Kweon and Kockelman, 2002, Abdel-Aty 2003) for modeling injury severity of the crash. Abdel-Aty (2003) used the three approaches; ordered probit, multinomial logit and nested logit models for the exploration of injury severity of RTCs. Abdel-Aty (2003) concluded that ordered probit model is preferable over the latter two approaches due to the ordinal nature of the response variable.

2.2 Driver and Passenger Characteristics

The gender and age are two important drivers' characteristics affecting injury severity of RTCs. Evans (1991) estimated that a 70 years old driver is 3 times more exposed to fatality than a 20 years driver. This is due to the deterioration in physical, audio-visual and mental capabilities of old drivers. In 1998, Abdel-Aty et al. carried out a research to understand the relationship of driver age and injury severity of traffic crashes. In the same study, crash injury severity was classified into three categories (i.e. no injury, injury and fatality) and it was concluded that crash injury severity increases with age of drivers. In other individual effort by Zhang et al (2000), it was estimated that likelihood of fatality increases with increase in drivers' age. In 2012, Kim et al. led a research on the crashes involving single vehicle and remarked that the probability of fatal injuries rise with increase of drivers' ages (more than 65 years).Several other researchers report that as the age of drivers increase, their likelihood to get involved in fatal crashes also increases (Singleton et al. 2000, Kockelman and Kweon 2002, Abdel-aty 2003).

The drivers are accused for their faults in 25%-33% of the overall RTC which includes: over-speeding, dozing behind the wheel, driver fatigue, tail-gaiting, underage driving, drunk-drive and distraction during driving. Speeding is considered as a key cause for injury severity as more than 30% of the fatal crashes in US occurs due to over-speeding (NHTSA). O'Donnell and Connor (1996) estimated an ordered probit model by utilizing the crash data in Australia and determined that injury severity of the crashes rise with the vehicles' speed. Likewise, Renski et al (1998) concluded that increasing speed limit by 10 mph increases the chances of RTFs relatively more than that increased by 5 mph. Numerous researches suggest that over-speeding increases the likelihood of RTF (Singleton et al. 2000, Abdel-aty 2003, Yamamoto and Shankar 2004, Sunghee et al. 2010, Sobhani et al. 2011,).

A cautious driving enhances the safety of drivers and passengers. Fatigue driving and dozing of drivers behind the wheel affects the driving tasks which leads them to severe crashes.

The above mentioned factors are comparatively more critical for the truck drivers. In 2002, Connor J et al. carried out a case study in New Zeeland and found that dozing behind the wheel considerably increases the likelihood of RTFs. Also, the drivers who had less than 5 hours sleep during the last 24 hours and driving during 02:00 am to 05:00 am were determined as critical factors for RTFs. A study by Horne and Reyner (1995) revealed that dozing of drivers causes 20% of the more severe crashes on motorways. Several past researchers conclude that dozing behind the wheel increases the injury severity of RTCs (Khattak et al. 2003, Yamamoto and Shankar 2004, Sunghee et al. 2010).

The gender of the driver is also considered as an important factor for severity of RTCs. Several studies in the past show that female drivers are comparatively more vulnerable to RTFs (Bédard et al. 2002, Eluru and Bhat 2007). Kockelman and Kweon (2002) while using three datasets from NASS-1998 (National Automotive Sampling System) developed six ordered probit models and concluded that female drivers are more vulnerable to fatal crashes. Based on study of Southern California (1998), female drivers were regarded to have more probability of RTFs (Ma and Kockelman, 2004).

2.3 Crash Pattern

Vehicles undergo certain types of crash patterns during RTCs which are associated with different crash severity. These patterns include; head on collision, nose to tail collision, rollovers, hitting fixed objects at 90^0, sideswipe and hitting pedestrian. In 2004, Singleton et al. combined two data sets; data of severe smashed vehicles and severely wounded people, for the severity analysis of RTCs. It was concluded that head on collisions, collisions with fixed objects and rollovers increase the probability of more severe injuries. In other independent studies, the collision of vehicles with either fixed objects or exhibiting head on collision with opposing vehicles increases the injury severity of a crash (Kockelman and Kweon 2001). Also, Rifaat and Chor (2005) used five years crash data (i.e. 1992-2001) of Singapore City to investigate the contributing factors affecting crash severity of single vehicles RTCS. It was concluded that along other contributing factors, collision of vehicles with trees increases the likelihood of more severe crashes.

Kockelman and Kweon (2002) and Duncan et al (1998) reported that rollover crashes are more likely fatal ones. In 2005, Holdridge et al. developed a nested logit model by using the 3.5

years crash data (i.e. Jan, 1993- Jul, 1996) to recognize the influence of the fixed shoulder objects on crash severity. The study results reveal that existence of utility poles, trees, guardrails, traffic poles, overhead poles, sign boxes and bridge rail on road shoulders increase the probabilities of RTFs once a single vehicular crash occurs in a built-up area. Other independent studies reveal that head on crashes are comparatively more severe than rear end crashes (Kockleman and Kweon 2001, Zhang Yang et al. 2011).

Sunghee et al. (2010) made an effort to identify the factors affecting injury severity on Korean Expressways. The data was collected by Korean Expressway Corporation for 5 years (i.e. 2004-2008) which comprise of 13,704 crashes. Sunghee et al. (2010) categorized the crash injury severity into no injury, injury and fatality. It was concluded that vehicle hitting pedestrian increases the probability of RTFs. The results also revealed that dozing behind the wheel, speeding, tire failures, pedestrian violations, involvement of two cars, involvement of more than four cars in a crash, stopping or parking on shoulder, existence of work zones and left curves (radius greater than 500 m) increases the probability of more severe crashes. In 2006, Chang and Wang conducted the injury severity analysis for Taipei, Taiwan by using the crash data of 2001. A CART model was estimated which showed that pedestrians' involvement leads to fatal crashes. Also, Eluru et al. (2008) considered pedestrian involvement as risk factors for crash severity.

2.4 Vehicular Characteristics

Road crashes involve different vehicles having different models, sizes, engine capacities and other characteristics. These factors significantly affect the road crashes injury severity. Kockelman and Kweon (2002) developed an ordered probit model for crash injury severity of two vehicle crashes by using GES data set which comprise of three independent files containing information of crash, vehicles and people. The dataset contained 30,358 crashes which were reported during the 5 years (i.e. 1995-2000). It was concluded that in two-vehicle crashes, the involvement of heavy vehicles increases the injury severity of occupants in the opposing vehicle; however the occupants in the heavier vehicles tend to have low injury severity. Similarly, Yamamoto and Shankar (2004) and Helai et al. (2008) consider less risk of RTFs for drivers of larger trucks. Other independent studies showed that probability of fatal crashes increases when passenger vehicles collide with heavy vehicles (i.e. trucks) rather than colliding with passenger cars (Farmer et al. 1997, Duncan et al. 1998, Sobhani et al. 2011).

The vehicle model (i.e. vehicular age) is also considered influential on crash severity of RTCs because old vehicles have comparatively low protection due to their deteriorated parts. O'Donnell and Connor (1996) applied ordered probit model and ordered logit model while using the police reported crash data of 1991 for New South Wales, Australia. The conclusion reveals that older vehicles are relatively more exposed to fatality. In 2005, Khorashadi et al. used a four year crash data while developing multinomial logit model for California and determined that cars with model year of 1981 or older are more likely to involve in RTFs. Also, other studies show that older vehicles are more probably involved in RTFs (Abdel-aty et al. 1998, Singleton et al. 2000, Kockelman and Kweon 2002, Abdel-aty 2003, Rana et al. 2010, Kim et al. 2012). The momentum (i.e. mass and speed) of the vehicles also affect the crash injury severity. In 2011, Sobhani et al., found that the probability of severe injury increases with the increase in mass and speed of the vehicles. Also, Wang and Qin (2014) conducted an individual research and presented that the likelihood of RTFs increases with the increase of impact force.

Besides, the mechanical characteristics are also considered to affect the crash injury severity. Mechanical characteristics include brake failure, tie rod failure, steering problem, tire burst and wheel issue etc. Sunghee et al. (2010) made an effort to explore the association of injury of freeways crashes with several contributing factors. Among other factors, it was concluded that the tire failure increases the injury severity.

2.5 Occupants Protection (Restraints)

The existence of safety restraints enhances the occupants' safety during RTCs. Elvik et al. (2004) determined that use of seatbelt decrease the likelihood of RTFs for the front seat occupants and rear ones by 40-50% and 25-75% respectively. In 2005, a study by Shimamura et al. shows that severity of drivers decreases when drivers fasten their seatbelts as compared to passengers using seatbelts. Abdel Wahab and Abdel-Aty (2002) developed artificial neural networks to examine the effects of various factors on the crash injury severity at three different locations; highways, signalized intersections and toll plazas. The crash data of Central Florida for the periods of (1996-1997) and (1999-2000) were used for the analysis. It was concluded that along other factors seatbelt use affects the crash injury severity. Also, Angel and Hickman (2009) conducted a research by utilizing 10 years crash data for the state of Utah. By developing multinomial logit models and linear models it was determined that fastening seatbelts decreases the injury severity in the RTCs. Besides seatbelts, Duncan et al. (1998) developed an ordered probit model for the crash data of North Carolina (1993-1995) and concluded that the use of child restraint tends to reduce the injury severity in RTCs. Air bags increases the probability of more severe crashes as they are deployed in a disastrous crash causing serious shocks to the occupants (Srinivasan 2002).

2.6 Environmental Characteristics

The weather and light condition significantly affect the crash injury severity. The change in weather may affect the surface conditions of the facility and drivers' behavior. Khattak and Knapp (2001) tried to recognize the impact of snowfall intensity and wind speed on injury severity. It was concluded that wind speed during snowy weather increase the probability of the fatal crashes. The severity of the RTCs decreases with the increase of snowfall intensity because during such situations the drivers are more cautious. In 2009, Wang et al. urbanized ordered probit model and partial proportional odd models for the crash data of Florida and found that along other contributing factors, bad weather increases the chances of no injury at diverging areas on freeways. Also, Duncan et al. (1998) conducted a research on two years crash data (1993-1995) for North Carolina and determined that snowy and icy road reduces the crash injury severity. Other independent researches also showed that bad weather decreases the probability of more severe crashes due to the cautious driving (Yamamoto and Shankar 2004, Eluru and Bhat 2007). In 2014, Islam and Hemandez determined the clear weather as a risk for fatality because drivers tend to move comparatively faster.

Crashes occurring at night time are more severe and faulty street lights at night time increases the probability of fatal crashes (Huang et al. 2008). Delen et al. (2006) led a study on a dataset attained from GES for the period of 1995-2000 during which 30,358 crashes have been reported. Delen et al. (2006) found no association of weather conditions with crash severity of RTCs. Wang et al. (2009) also found that light condition affects the crash injury severity.

2.7 Roadway Characteristics

The roadway features comprise of the roadway design, location, traffic control and vehicular volume. Grades are considered to affect the severity of RTCs. As Duncan et al (1998) showed that the existence of grades and wet grades increases the probability of RTFs. In 2012, Lemp et al. determined that occurrence of a crash on grade of +2% and -2% increases the probability of more severe crashes. It was aided that sometimes, the presence of such grades can decrease the likelihood of RTFs (i.e. heavy truck moving in a curve) because on such locations the driver is more careful. According to Chang and Mannering (1999), the presence of curve, inclining and declining grade influence the injury severity of the crash. In 2009, a study by Wang et al. shows that number of lanes significantly influence the crash injury severity.

2.8 Temporal Characteristics

The temporal characteristics; time of day, day of the week and month of crash are considered to have impact on crash injury severity. In 2013, Islam and Hernandez carried out injury severity analysis of large truck-crashes on US interstates by fusing three data sets GES (General Estimates System) to get a single detail dataset for econometric modeling. The results showed that the truck crashes occurring on weekends are less probable to be fatal ones. Also it was concluded that the RTCs in June or July or August tend to be more severe. The probability of more severe crashes increases with nighttime and darkness (Kockelman and Kweon 2002).

A study by Kockelman and Kweon (2002) shows that late night RTCs (midnight – 4:00am) on Friday, Saturday and Sunday are more serious. Also, Eluru et al (2008) found the late night (12:00am-06:00am) as hazardous time from crashes' severity point of view. In 2005, Rifaat and Chor used crash data of Singapore (police reported) for the period of 1992 to 2001. With the calibration of ordered probit model it was estimated that driving at night time increases the probability of RTFs. Also, crashes occurring in the morning time (5:31-8:00) have lesser probability to be severe (Khorashadi et al. 2005). Similarly, several researchers consider the peak hours as a key risk factor contributing to the fatal crashes (Shefer and Rietveld, 1997, Chang and Mannering 1999).

CHAPTER 3. RESEARCH METHODOLOGY

3.1 Introduction

The contemporary study is carried in order to understand how various vehicular, human, geometric and temporal characteristics affect injury severity of RTCs. Also, it is intended to study the association of the crash pattern with the injury severity. This study is carried to identify the contributing factors of injury severity of motorways crashes by estimating an ordered probit model.

3.2 Plan of the Study

In this research, three different motorways; M1 (Peshawar to Islamabad), M2 (Islamabad to Lahore) and M3 (Lahore to Faisalabad) having lengths of 155, 357 and 54 kilometers respectively, were selected for analysis. A total of 923 crashes have been reported during the 7 years period (2009- 2015) and were categorized into 4 levels of injury severity. Motorways provide efficiency and mobility exclusive of the signals and at grade intersections. Each side of the facility is provided with 3 lanes separated by either grass or concrete medians. Certain auxiliary lanes near at-grade interchanges are provided for entering and exiting into and from the through traffic respectively. The fencing is provided on each side of the facility to restrict pedestrians or stray animals from the roadway. Motorways are designed to provide mobility by restricting the accessibility only to the interchanges. The maximum speed limit for most of the segments is 120 kmph for light travelling vehicles (LTV) and 100kmph for heavier travelling vehicles (HTV). Due to existence of horizontal and especially steep vertical curves (in some cases grade equal or more than 7%) the posted speed limit is restricted to 70 kmph for LTV and 55 kmph for LTV (i.e. in Salt Range). Both the passenger and freight traffic can use motorways which lead to presence of variety of traffic on it i.e. 2-3-4 and 5- axles' vehicles.

3.3. Accident Data Collection and Collation

The data used in this research arre collected by NHMP for three different motorways (i.e. M-1, M-2 and M-3) having lengths of 155, 357 and 54 kilometers respectively. A total of 923 crashes were reported during the 7 years period (2009- 2015) and were categorized into 4 levels of injury severity (Figure 3.1).

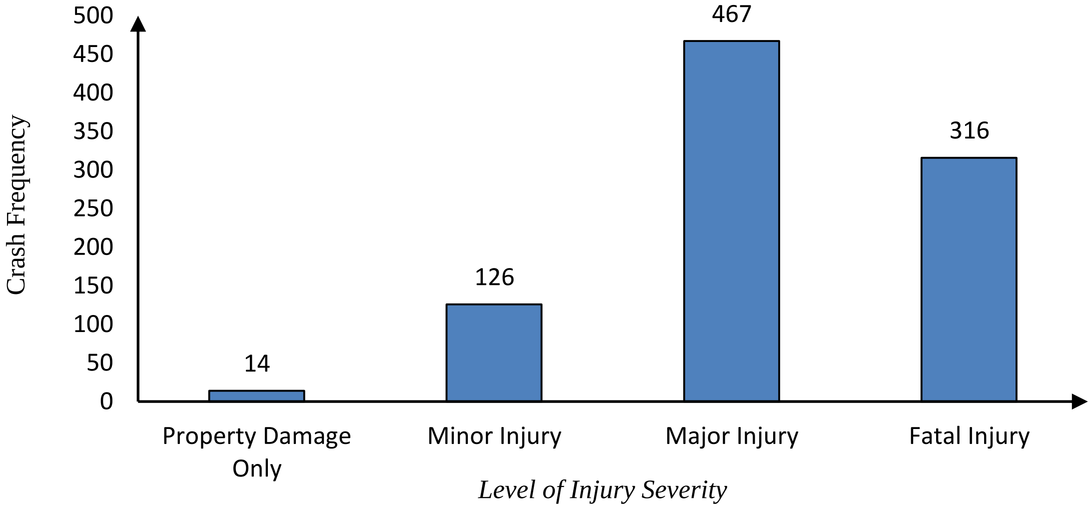

Figure 3.1: Crash Injury Severity Distribution on Motorways (2009-15).

The description of 4 levels of injury severity (i.e. property damage only, minor injury, major injury and fatality) is given in Table 3.1.

Table 3.1: Description of the Injury Severity Level of the Crash

Level	***Definition***	***Description***
0	Property Damage Only	No harm to the body of the occupants occurs.
1	Minor Injury	It extends no risk to the life of the affected person (i.e. abrasions, pain etc.)
2	Major Injury	It extends risk to the life of the affected person (i.e. neck and spinal injury etc.)
3	Fatal Injury	It results in immediate- or post-crash fatality.

A 4 pages crash report form was used by NHMP for collecting the crash information which contains 65 queries. The final data set contained details 47 different independent variables i.e. driver, vehicle, geometric and traffic characteristics, temporal and environmental conditions, crash pattern and causes of each crash on motorways. Each of the mentioned characteristics contained certain variables which were included in the final dataset are presented in (Table 3.2).

Table 3.2: Classification of Independent Variables

Variables Category	***Explanatory Variables with Description***	
Vehicle Characteristics	(a). Age (b). Number of vehicles (c). Type of vehicles.	
Driver Characteristics	(a). Gender of driver (b). Age of the driver	
Temporal Details	(a). Time of the crash (b). Day-night. (c). Day type (d). Month (e). Year of the crash.	
Environmental conditions	(a). Weather condition (b). Road light condition	
Geometric characteristics	(a). Segment alignment (b). Beat/Administrative divisions	
Probable cause of crash	*(1). Human fault*	
	(a). Dozing behind the wheel	(b). Carelessness of driver
	(c). Improper pedestrian crossing	(d). Over-speeding
	(e). Dangerous u-turn	(f). Prohibited overtaking
	(g). Improper stop/lane changes	(h). Wrong parking
	(i). Prohibited overtaking	(j). Tail-gaiting
	(k). Faulty headlights	(l). Passenger fault
	(m). Diverted attention.	
	(2). Mechanical fault (a). Brake failure, (b). Tie rod failure, (c). Wheel problem (d). Steering issue (e). Other problem.	
	(3). Environmental causes (a). Bad weather (b). Surface condition (c). Poor visibility	
	(4). Other reasons (a). Wrongly parked non-motor vehicles (b). Improper non-motor crossings (c). One-way violation by non-motor vehicles (d). Any other reason	
Collision Pattern	(a). Head-on collision (b). Nose to tail (c). Rollover (d). Hit solid obstruction (e). Sideswipe (f). Hit animal (g). Hit pedestrian (h). Information missing	
Traffic Characteristics	Traffic direction (towards Peshawar or Lahore).	

The vehicles are classified into lighter vehicles (i.e. passenger cars, pickups, panels and vans) and heavier vehicles (i.e. buses, trucks and trailers). The driver's gender, driver's age and vehicular age (i.e. only for the first party in multi-vehicular crashes) are included in the dataset due to incomplete information of these variables for the second party.

Variables in crash report form which were excluded from final dataset due to incomplete data are: shoulder conditions, existence of work zone, vehicle registration type (private/commercial), crash location (rural/urban), occupants' seating position and length of skid marks. The causes of accidents are reported in terms of human faults, mechanical faults, and environmental conditions (Figure 3.2).

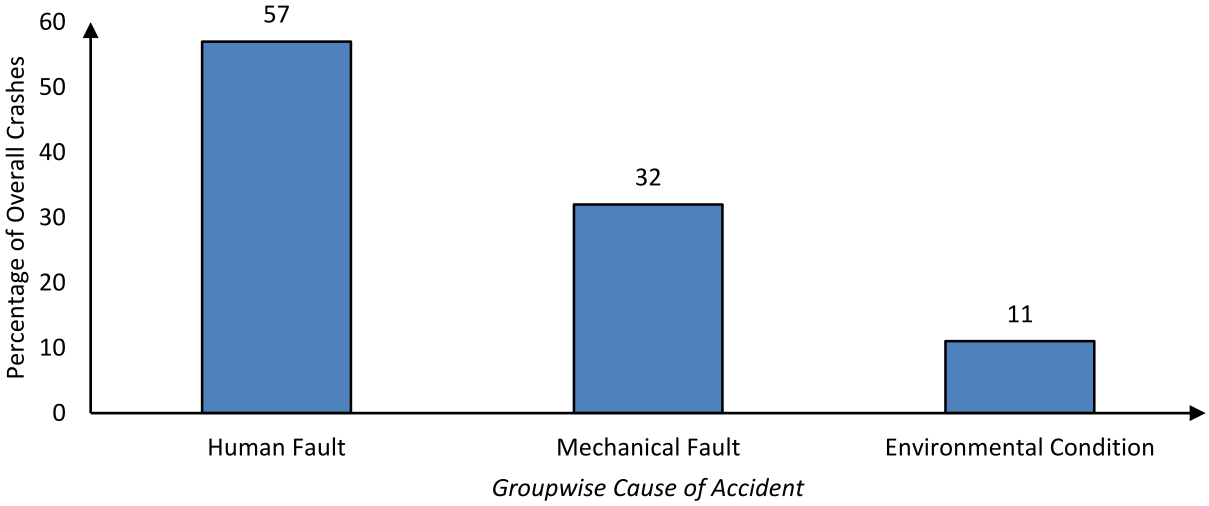

Figure 3.2: Group-Wise Distribution of Causes of Motorways Crashes

The overall stretch of the motorways is divided into beats for administrative divisions. The beats are numbered as 1 to 13 starting from Peshawar. The highest number of RTCs is reported in Kallar Kahar (i.e. Salt Range) which is numbered as beat-7 due to existence of steep grades (i.e. 7% grade in some areas).

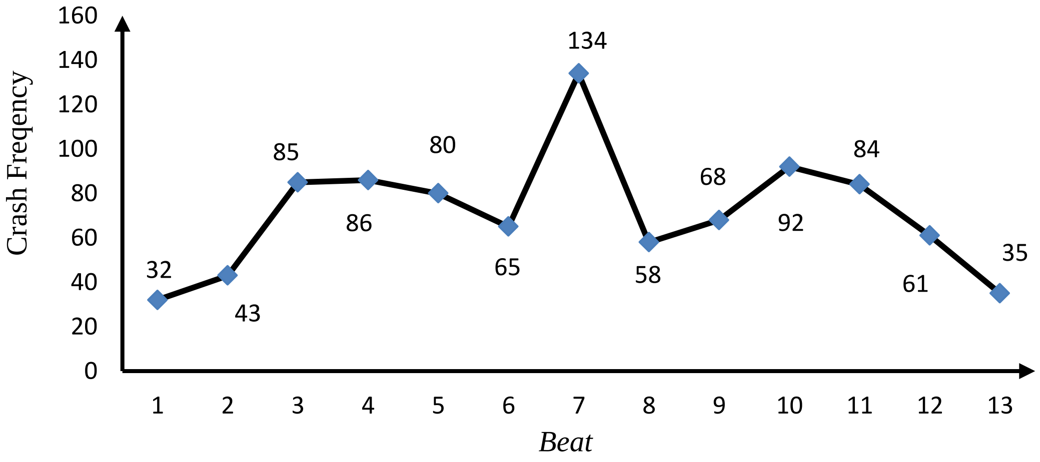

Figure 3.3: Crash Frequency Distribution on Various Beats of Motorways

Also, 52 fatalities which make 16.5 percent of overall fatalities occurred on Beat-7 (Figure 3.4). Due to this critical situation on Beat-7, the NHMP reduced the posted speed limits (i.e. as alternative countermeasure) for light travelling vehicles (LTVs) and heavy travelling vehicles (HTVs) from 70 km/h and 50 km/h to 50 km/h to 30 km/h respectively.

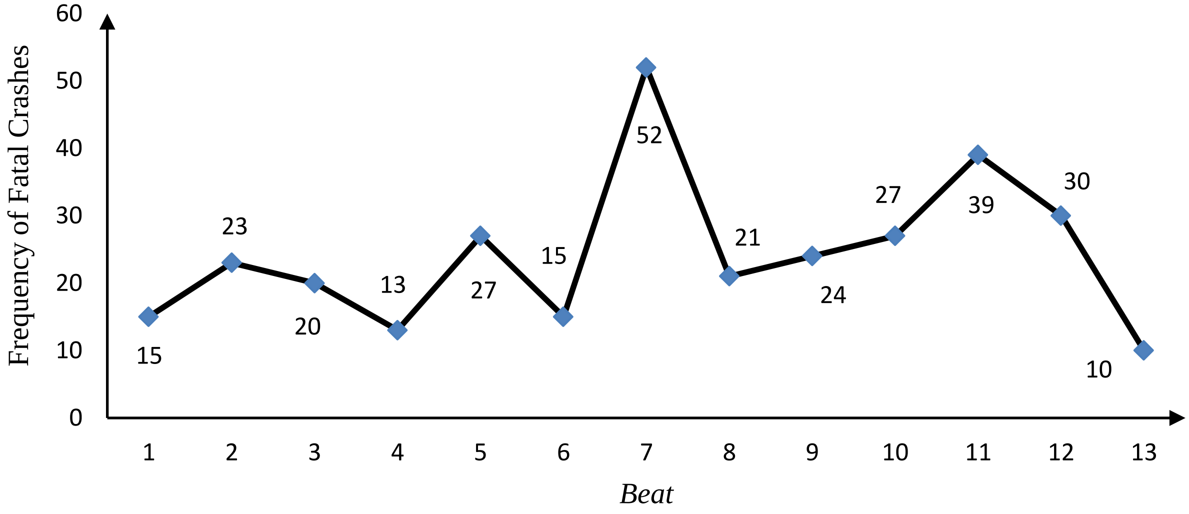

Figure 3.4: Frequency Distribution of Fatal Crashes on Various Beats of Motorways.

3.4. Various Explanatory Parameters and Crashes Injury Severity on Motorways

The data in this research are collected from NHMP which is an enforcement agency on motorways. Patrolling officers collect the crash data by filling four pages crash report form which are collected to zonal offices. The data of each zone is submitted to the computer bureau of NHMP on daily basis and are saved into the main computer database. The data of each crash contains detailed information pertaining to human features, vehicular details, environmental characteristics and crash pattern. Also, the sketch of crash is drawn on the crash report form for better understanding of the scenario. The injury severity is categorized on four levels ordinal scale i.e. property damage only, minor injury, major injury and fatality.

In the previous seven years, various types of vehicles ranging from passenger cars to large trailers were involved in freeway motor vehicle crashes. The vehicles were categorized into lighter vehicles (passenger cars, pickups, panels and vans) and heavier vehicles (buses, trucks and trailers). The involvement pattern of various vehicles is classified as lighter vehicles only (i.e. single vehicular crash), lighter vehicles vs. lighter vehicles, heavier vehicles only (i.e. single vehicular crash), lighter vehicles vs. heavier vehicles and heavier vehicles vs. heavier vehicles (Figure 3.5a).

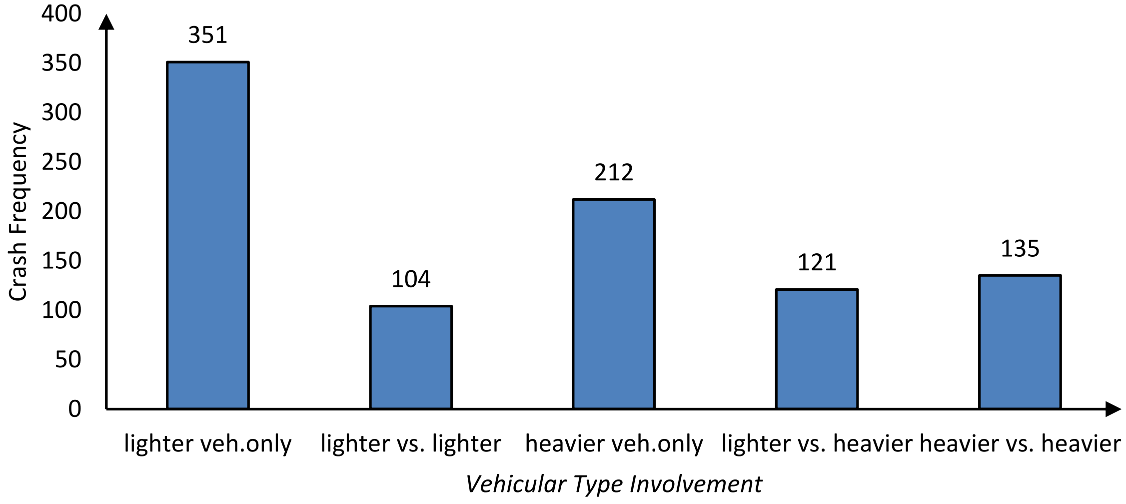

Figure 3.5a: Vehicular Type Involvement in a Crash

The comparison of crash between lighter vs. lighter vehicles and lighter vs. heavier vehicles shows that the percentage of more severe crashes is lower when lighter vehicles collide with lighter vehicles than others. (Fig 3.5b).

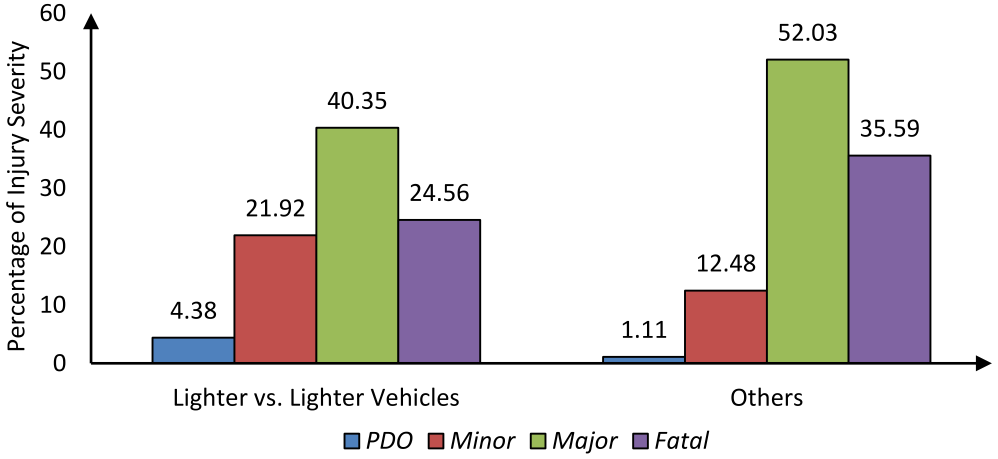

Figure 3.5b: Comparison of Lighter vs. Lighter Vehicles Crashes and Other

The time of day on which crash occurred are classified into three categories; morning peak (06:00am-10:00am), evening peak (04:00pm-08:00pm) and off peak hours. According to data statistics, 17%, 16% and 67% of the total crashes occurred during morning peak, evening peak and off peak respectively. The comparison of evening peak RTCs and others shows that the percentage of fatalities is lower in evening peak as compared to other time crashes (Figure 3.6).

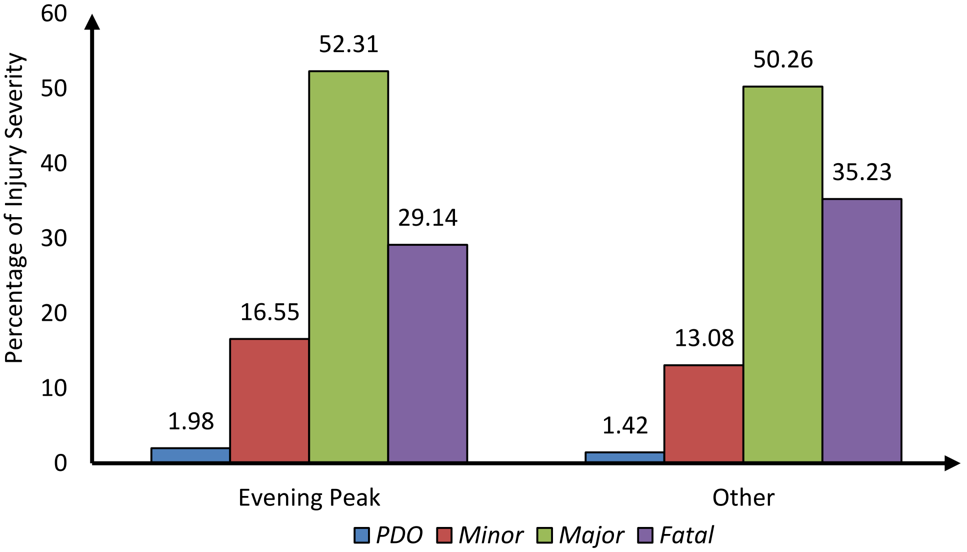

Figure 3.6: Comparative Frequency Distribution of Even Peak Crashes and Other

On motorways, dozing of the drivers behind the wheel caused the highest number of RTCs (i.e. 234) during 7 years analysis period. The comparison of RTCs which occurred due to dozing of driver with other those occurred due to other reasons reveals higher percentage of fatality.

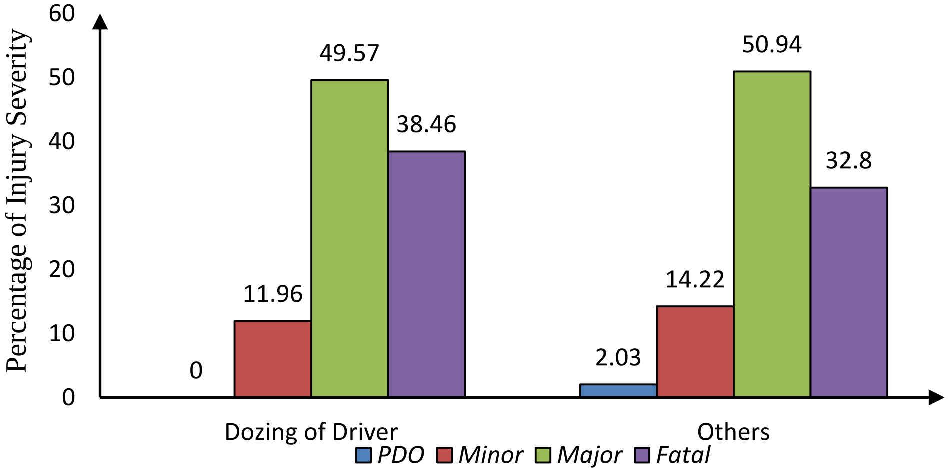

Figure 3.7: Explanatory Variable Dozing of Driver Group Frequency Distribution.

The descriptive statistics of the data indicate that only 2.82% of the RTCs occurred due to over speeding. The assessment of the crashes which occurred due to over speeding with those involving any other reasons, illustrates a greater percentage of fatal crashes in crashes due to over speeding than others (Figure 3.8).

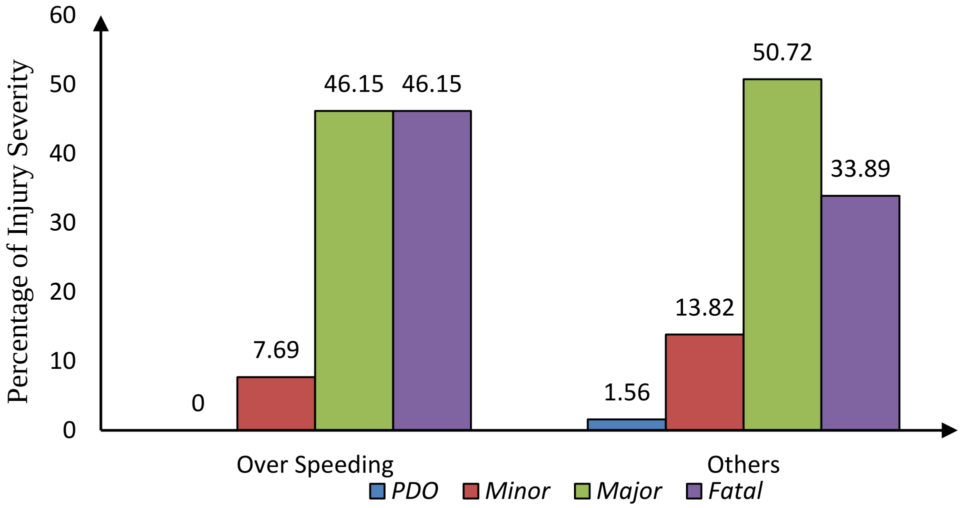

Figure 3.8: Explanatory Variable Over-speeding Group Frequency Distribution

Various types of crash patterns were reported on motorways during last seven years (Figure 3.9).

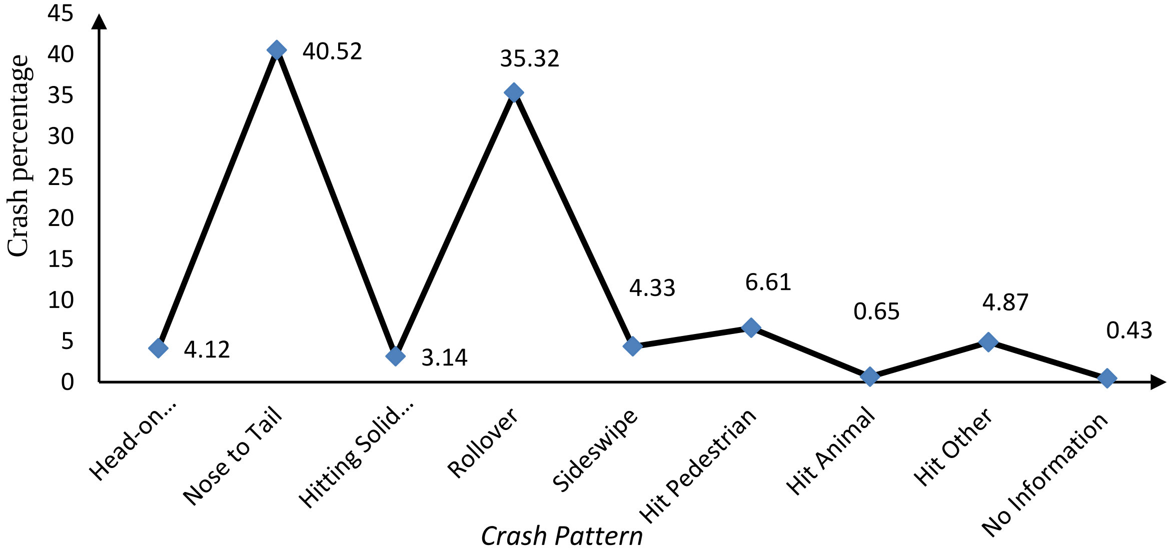

Figure 3.9: Crash Pattern Frequency Distribution

The comparison of frequency distribution of motorways crashes on the basis of different crash pattern shows that "hit pedestrian" and "head-on collision" had the 1st and 2nd highest percentage of fatality respectively (Figure 3.10). Also, the "head on collision of vehicles" shows greater percentage of fatal crashes as compared to others (Figure 3.11) where as the "nose to tail crashes" reveals lower percentage of more severe crashes as compared to other crash patterns (Figure 3.12). The data statistics in both cases are consistent with the model estimation results.

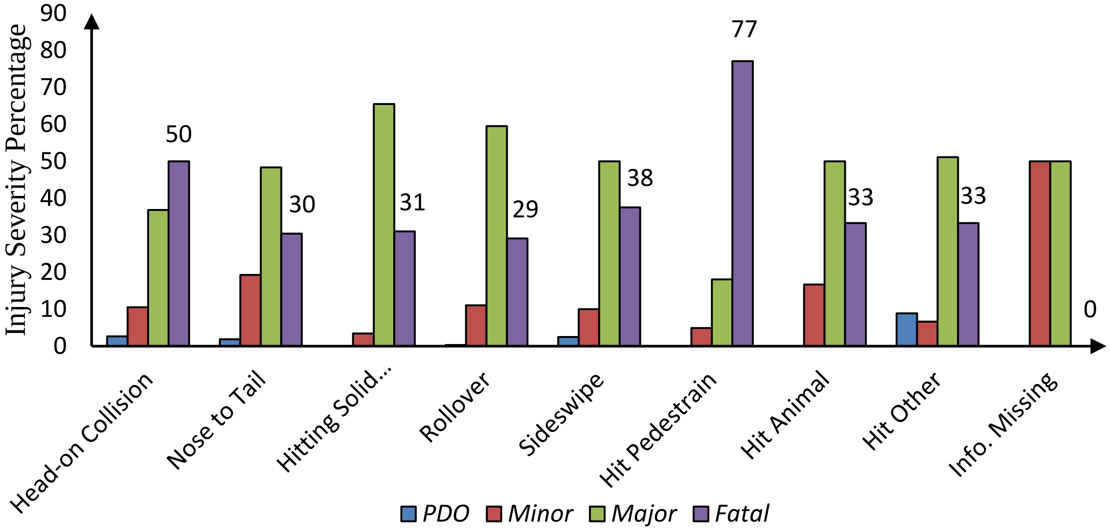

Figure 3.10: Frequency Distribution of Injury Severity of All Crash Patterns.

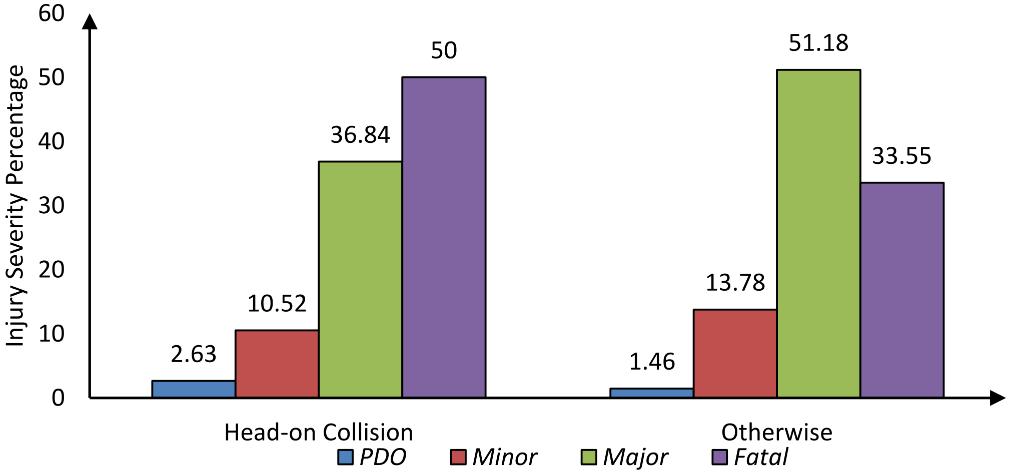

Figure 3.11: Comparison of Head-on Collision of Vehicles with Other Crash Pattern.

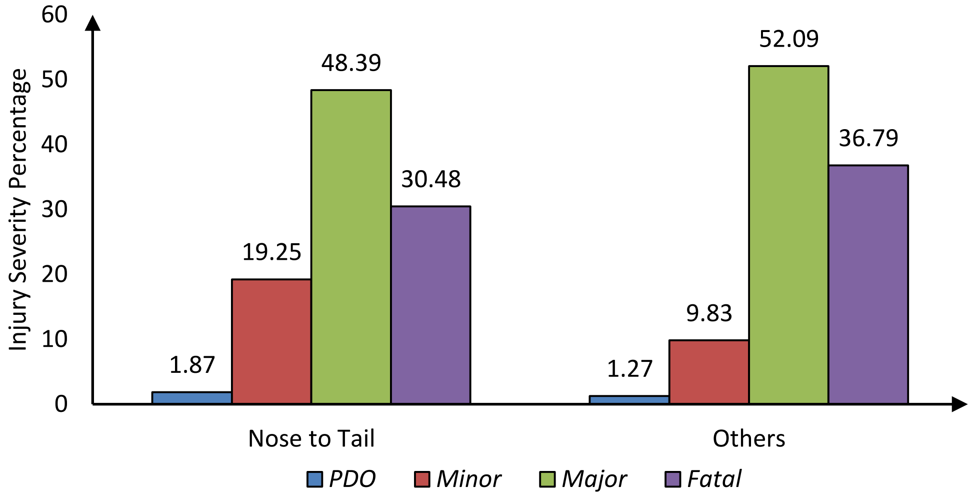

Figure 3.12: Comparison of Nose to Tail with Other Crash Patterns.

Vehicles of different models are involved in motorways crashes. The data contain vehicular age (i.e. first vehicle) for only 59% of the crashes whereas 41% of the information was missing. On the basis of model, the first vehicles are classified into two categories; new vehicles (i.e. age is less than 7 years) and old vehicles (i.e. age is greater than 7 years). The comparison of frequency distribution of these two model classes shows a greater percentage of fatalities for crashes involving older vehicles (Figure 3.13).

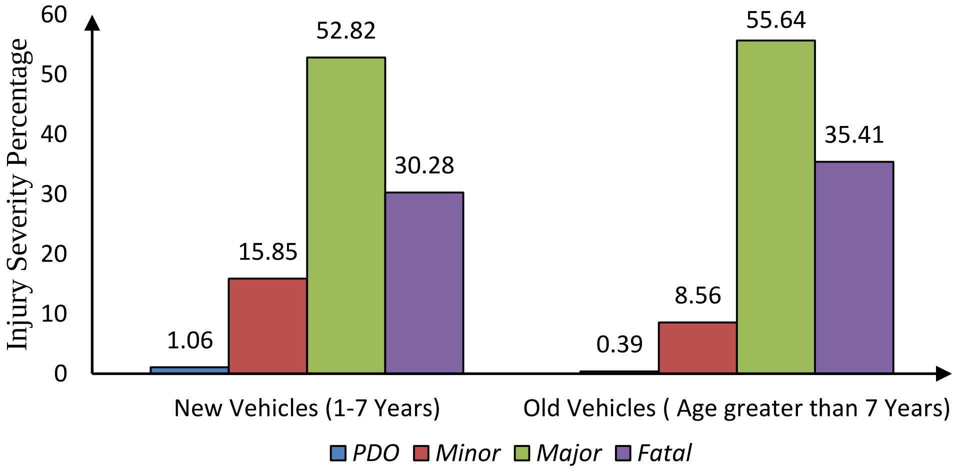

Figure 3.13: Explanatory Variable Vehicular Age Group Frequency Distribution.

On the basis ages, drivers are classified into young drivers (age is less than 40 years) and older drivers (age is greater than 40 years). Only 57% of the crashes contain information of drivers’ age for the first vehicle whereas 43% of the crashes do not contain the information on the driver age. The comparison of frequency distribution on the basis of available data on driver's ages shows a higher percentage of fatal injuries in older drivers (37%) than young drivers (30%) (Figure 3.14).

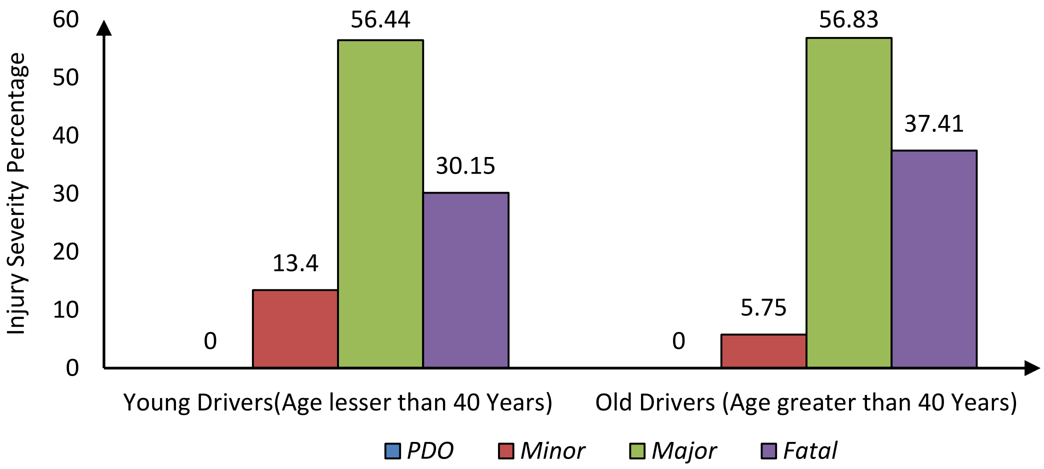

Figure 3.14: Explanatory Variable Drivers Age Group Frequency Distribution.

3.5 Selection of Response (Y) and Explanatory Variables (X)

The motor vehicles crashes on motorways fall into any of the four severity levels once a crash occurs. The injury severity is modeled as a response variable. The data set contained 47 explanatory variables belonging to any one of the following groups; drivers and vehicular characteristics, geometric features, crash patterns and environmental conditions. A brief description of all the explanatory variables which were part of the dataset is given in the Table 3.3

Table 3.3: Description of Response and Explanatory Variables

S.No.	***Selected Variable and Description***
1	***Crash injury severity:*** 0 if no injury, 1 if minor, 2 if major & 3 if fatal injury.
2	***Number of vehicles.***
3	***Type of vehicles*****:** Lighter vehicles (passenger cars, pickups, panels and vans) and heavier vehicles (buses, trucks and trailers).
4	***Weather condition*****:** 1 if the weather is clear, otherwise 0
5	***Time of crash:*** 1 if crash occurs during morning peak (6:00am-10:00am), 2 if occurs during evening peak (04:00pm-08:00pm) and 3 if occurs during off peak (10:00am to 04:00pm and 08:00pm-06:00am).
6	***Road light conditions:*** 1 if crash occurs during day light, 2 if during light without road lights, 3 night with road lights and 4 if night without road lights.
7	***Type of day:*** 1 if crash occurs on weekend (Saturday and Sunday), 0 otherwise.
8	***Year of the crash:*** Year in which crash occurs (i.e. 2009-2015).
9	***Beat*****:** Unique id of the road segment (i.e.1 to 13 administrative divisions by NHMP).
10	***Dozing indicator variable*****:** 1 if crash occurs due to dozing behind the wheel, 0 otherwise.
11	***Carelessness indicator variable:*** 1 if crash occurs due to carelessness of drivers, 0 otherwise.
12	***Pedestrian indicator variable:*** 1 if crash occurs due to improper crossing by pedestrian, 0 otherwise.
13	***Tire burst indicator variable:*** 1 if crash occurs due to tire bursts, 0 otherwise.
14	***Over-speeding indicator variable:*** 1 if crash occurs due to over-speeding, 0 otherwise.
15	***Poor visibility indicator variable:*** 1 if crash occurs due to poor visibility, 0 otherwise.
16	***Non-motor vehicle indicator variable:*** 1 if crash occurs due to improper crossing by non-motor vehicles (i.e. animals, bicycles etc.), 0 otherwise.
17	***Slip indicator variable:*** 1 if crash occurs due to slippery road, 0 otherwise.
18	***Improper manure indicator variable:*** 1 if crash occurs due to improper stopping/turning/lane changing by motor vehicles, 0 otherwise.
19	***Dangerous u-turn indicator variable:*** 1 if crash occurs while vehicles taking dangerous U-turn, 0 otherwise.
20	***Wrong parking indicator variable:*** 1 if crash occurs due to wrongly parked non-motor vehicles (i.e. bicycles/animals etc.), 0 otherwise.
21	***Dangerous overtaking indicator variable:*** 1 if crash occurs due to dangerous overtaking, 0 otherwise.
22	***Bad weather indicator variable:*** 1 if crash occurs due to rain or wind, 0 otherwise.
23	***Tail gaiting indicator variable:*** 1 if crash occurs due to tail gaiting of vehicles, 0 otherwise
24	***Faulty lights indicator variable:*** 1 if crash occurs due to faulty lights of motor vehicles, 0 otherwise.

Table 3.3: Description of Response and Explanatory Variables (continued)

S.No.	***Selected Variable and Description***
25	***Passenger indicator variable:*** 1 if crash occurs due to passenger fault, 0 otherwise.
26	***Diverted attention indicator variable*:** 1 if crash occurs due to diverted attention of drivers, 0 otherwise.
27	***Other indicator variable:*** 1 if crash occurs due to any other reason, 0 otherwise.
28	***Non-motor violation indicator variable:*** 1 if crash occurs due to one way violation by non-motor vehicles (bicycle/animals/animal carts), 0 otherwise.
29	***Brake failure indicator variable:*** 1 if crash occurs due to brake failure, 0 otherwise
30	***Tie rod indicator variable:*** 1 if crash occurs due to breaking of tie rods, 0 otherwise.
31	***Wheel indicator variable:*** 1 if crash occurs due to wheel failure, 0 otherwise.
32	***Steering indicator variable:*** 1 if crash occurs due to steering issue, 0 otherwise.
33	***Other mechanical indicator variable:*** 1 if crash occurs due to any other mechanical issue in vehicles, 0 otherwise.
34	***Head-on Collision indicator variable:*** 1 if head-on collision between vehicles occurs, 0 otherwise.
35	***Nose-tail indicator variable:*** 1 if nose of one vehicle hits tail of other, 0 otherwise.
36	***Any obstacle indicator variable:*** 1 if vehicles hit solid obstruction, 0 otherwise
37	***Rollover indicator variable:*** 1 if a vehicle rollovers during a crash, 0 otherwise.
38	***Sideswipe indicator variable:*** 1 if a vehicle sideswipe during a crash, 0 otherwise.
39	***Vehicle-pedestrian indicator variable:*** 1 if a vehicle hits pedestrian, 0 otherwise.
40	***Animal indicator variable:*** 1 if a vehicle hits animal indicator, 0 otherwise.
41	***Hit-other indicator variable:*** 1 if a vehicle hits any other thing, 0 otherwise.
42	***Missing indicator variable:*** 1 if crash pattern of vehicles is missing, 0 otherwise.
43	***Direction indicator variable:*** 1 if a vehicle travels towards Peshawar, 0 otherwise.
44	***Curve indicator variable:*** 1 if crash occurs on straight road, 0 otherwise.
45	***Gender indicator variable:*** 1 if the involved driver is male, 0 otherwise
46	***Month indicator variable:*** month in which crash occurred
47	***Vehicle age indicator variable:*** 1 if the vehicle age at the time of crash is less than 7 years, 0 otherwise
48	***Driver age indicator variable:*** 1 if the driver age is greater than 40, 0 otherwise

The descriptive statistics of significant explanatory variables in the final model of this research are given below (Table 3.4).

Table 3.4: Descriptive Statistics of Significant Independent Variables

Variable Description	***Mean***	***Std. Dev.***	***Min.***	***Max.***
Lighter vehicle indicator	0.1090	0.3120	0	1
Evening peak indicator	0.1589	0.3659	0	1
Dozing indicator	0.2846	0.4516	0	1
Over speeding indicator	0.0351	0.1842	0	1
Head-on indicator	0.0536	0.2254	0	1
Nose to tail indicator	0.3844	0.4869	0	1
Pedestrian indicator	0.0517	0.2217	0	1
New vehicle indicator	0.2384	0.4265	0	1
Older driver indicator	0.1848	0.3885	0	1

3.6 Methodological Approach

Frequent approaches have been used for modeling injury severity under different assumptions. Most commonly used practices include; ordered probit, multinomial logit, nested logit and ordered logit models. Studies have shown that multinomial logit and nested logit models do not have the ability to account for the ordinal data (Greene, 2002; Duncan et al., 1998). The independence of irrelevant alternatives (IIA Assumption) being an undesirable property in multinomial logit model and complex structure of the nested logit model make the ordered probit model an appropriate approach for modeling of ordinal data (Abdel-Aty, 2003). According to Ye and Lord (2014), the ordered probit model produces rather better results even with a small sample space. In present research, the injury severity is categorized into four levels in an increasing order i.e. property damage only (PDO), minor, major and fatal injury).

Mckelvey and Zavoina (1975) suggested substitution of ordered probit model to the ordinary linear regression. In ordered probit model the latent variable $Y_i{}^*$ is indicated as a linear function in the given equation (Washington et al., 2003).

$$Y_i{}^* = \beta X_i + \varepsilon_i \tag{1}$$

Where $Y_i{}^*$ is a latent injury severity for the i_{th} crash, β is a vector of parameters to be estimated, X_i is the vector of observed non-random dependent variable which defines the discrete ordering for each observation and ε_i is the random error term; assumed to follow the normal distribution (mean=0 & Variance=1). The cumulative distribution is denoted with a symbol of $\varphi(.)$.

Once a crash occurs, the injury severity of each crash may belong to a category n, if $\mu_n - 1 < Y_i{}^* < \mu_n$. The observed injury severity variable Y_i is related to $Y_i{}^*$ according to the model as follows:

$$Y_i = \begin{cases} 0 \;\; if -\infty \le Y_i{}^* \le \mu_1 & (PDO/No\ injury) \\ 1 \;\; if \;\; \mu_1 < Y_i{}^* \le \mu_2 & (Minor\ injury) \\ 2 \;\; if \;\; \mu_2 < Y_i{}^* \le \mu_3 & (Major\ injury) \\ 3 \;\; if \;\; \mu_3 < Y_i{}^* \le \infty & (Fatal\ injury) \end{cases} \tag{2}$$

The levels of the injury severity Y_i are in association with the latent variable $Y_i{}^*$ through threshold μ_n, where $n = 1, 2,3, ..n$. The relationship of latent (i.e. continuous) injury severity variable, $Y_i{}^*$, and the observed injury severity level, Y_i, is shown with the help of the figure as given below,

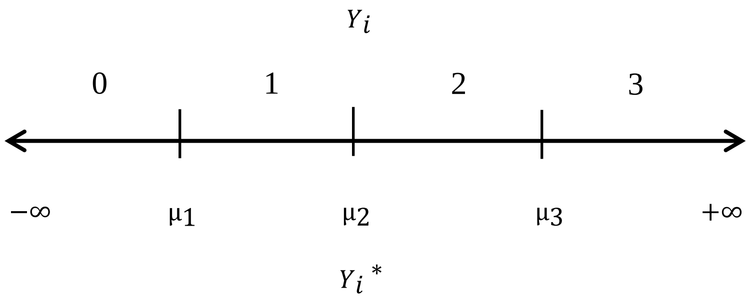

Figure 1: Relationship of Latent and Coded Injury Severity Variables

The likelihood that an accident will have injury severity level i, is equal to the likelihood that the latent injury severity tendency, $Y_i{}^*$ will consider a value between two fixed threshold parameters ($\mu_n - 1$ and μ_n). Washington et al. (2003) suggested the following equation to estimate the probabilities of various levels of injury severity.

$$Prob(Y = 0) = Prob(Y_i{}^{*} \leq \mu_1) = \varphi(\mu_1 - \beta X_i)$$
$$Prob(Y = 1) = Prob(\mu_1 < Y_i{}^{*} \leq \mu_2) = \varphi(\mu_2 - \beta X_i) - \varphi(\mu_1 - \beta X_i)$$
$$Prob(Y = n) = Prob(\mu_{n-1} < Y_i{}^{*} \leq \mu_n) = \varphi(\mu_n - \beta X_i) - \varphi(\mu_{n-1} - \beta X_i) \qquad (3)$$
$$Prob(Y = N) = Prob(\mu_N < Y_i{}^{*}) = 1 - \varphi(\mu_N - \beta X_i)$$

Where μ_n and μ_{n-1} are the lower and upper thresholds respectively for the injury severity level n. The threshold values must fulfil the condition i.e. $\mu_1 < \cdots \mu_n < \cdots < \mu_{n-1}$, in order to estimate positive probabilities. In this study, the total estimated thresholds (i.e.μ_s) are two (where as it should be three in accordance with severity levels which are four). When a constant term is included in the model, the total number of thresholds parameters are equal to $n - 2$, because the NLOGIT (i.e. LIMDEP) cannot estimate one of the threshold parameters. Greene (2000) suggested μ_1 equal to zero (i.e. $\mu_1 = 0$) to resolve the issue. Once the probabilities have been predicted, the impact of the specific factors can be understood. The positive value of β suggests an increase in the probability of the highest level of injury severity while negative value of β suggests a decrease in the probability of the highest injury severity level with an increase in the value of explanatory parameter X_i. However, estimation of effects for values of β on the intermediate severity levels is uncertain which is why the marginal effects for each level is believed to work out (Washington et al., 2003). The equation for the marginal effects is as follows,

$$\frac{\partial Prob(\mathrm{Y=n})}{\partial \mathrm{x}} = -[\varphi\,(\mu_n - \beta X_i) - \varphi(\mu_{n-1} - \beta X_i)]\beta \qquad n = 0,1,2,3 \qquad (4)$$

The above equation is only appropriate when the variable is continuous. In case of categorical variable (i.e. binary or dummy variables), the following equation can be used to estimate the marginal effects for a categorical variable (Greene, 2007).

$$\mathrm{Xi} = \mathrm{P}(\mathrm{Y} = \mathrm{n}|\mathrm{X_i} = 1) - \mathrm{P}\,(\mathrm{Y} = \mathrm{n}|\mathrm{X_i} = 0) \qquad (5)$$

CHAPTER 4. MODEL ESTIMATION AND DISCUSSION

Due to categorical and ordinal nature of crash injury severity, the ordered probit model is nominated as appropriate model. After consulting previous researches on injury severity of RTCs, it was concluded that multinomial and nested logit models can include only few significant variables and have low goodness of fit as compared to ordered probit model. The results of the ordered probit model (95% level of confidence) are presented (Table 4.1).

Table-4: Ordered Probit Model Results (Estimated Coefficients, T-stats and Marginal Effects)

Variable	***Coefficient***	***t-stat***	***Marginal Values***			
			PDO	***Minor***	***Major***	***Fatal***
Constant	2.618	22.477				
Lighter vehicle indicator	-0.335	-2.059	0.0055	0.0671	0.0378	-0.1103
Evening peak indicator	-0.274	-1.987	0.0041	0.0529	0.0355	-0.0925
Dozing indicator	0.372	3.120	-0.0035	-0.0591	-0.0737	0.1363
Over speeding indicator	0.554	1.975	-0.0034	-0.0700	-0.1396	0.2130
Head-on indicator	0.475	1.975	-0.0032	-0.0638	-0.1144	0.1813
Nose to tail indicator	-0.336	-2.684	0.0044	0.0612	0.0511	-0.1167
Pedestrian indicator	1.599	5.682	-0.0048	-0.1161	-0.4429	0.5639
New vehicle indicator	-0.284	-2.115	0.0040	0.0538	0.0391	-0.0969
Older driver indicator	0.508	3.872	-0.0040	-0.0731	-0.1136	0.1907
Threshold 1	1.429	17.711				
Threshold 2	3.153	37.150				

(Note: Model summary statistics: Number of observations=923; degrees of freedom = 9; log likelihood = -496.0150; restricted log likelihood = -537.0112; adjusted McFadden's Pseudo rho-squared (ρ^2) *= 0.0763. Dependent variable injury severity particulars: Fatal injury coded 3; Major injury coded 2; Minor injury coded 1 and Property damage only coded 0).*

The current study estimates an ordered probit model due to the ordinal nature of the response variable to explore the impact of various factors on the injury severity of motorways crashes. Out of 47 variables in the dataset, 9 variables have been found statistically significant (at 95% level of confidence) in the final model (Table 4.1). The ordered probit model only estimates the results for highest and lowest levels which is why marginal effects (Table 4.1) are determined to understand the impact of unit change in the value of explanatory variable"$\mathbf{X_i}$” (beyond its mean value) on the likelihoods of intermediate levels of injury severity while keeping all other explanatory variables at their mean values.

The model results present a negative coefficient for the lighter vehicle indicator which shows that collision of lighter vehicles (both parties) in a crash decreases the likelihood of fatal injuries on freeways. The weaker impact of the lighter vehicles (small masses) on each other during the crash decreases the injury severity. This finding is intuitive and consistent with the past studies (Duncan et al. 1998, Kockelman and Kweon 2002, Sobhani et al. 2011).

The negative coefficient of new vehicle indicator (vehicular age in a single vehicular crash lesser than 7 years) reveals that involvement of new vehicles in a crash decreases the propensity of the fatal crashes and increases the odds of property damage only. This is intuitive and consistent with the past literature because new vehicles are easily able to stop, overtake and change lanes in case of any hazardous conditions due to their un-deteriorated parts (O'Donnell and Connor 1996, Kockelman and Kweon 2002, Khorashadi et al. 2005).

Crash pattern was also considered as a contributing variable. The model results showed that head-on collision of vehicles increases the likelihood of fatal crashes. The huge impact of colliding vehicles on each other (the speed superimposes because both vehicles colliding against each other) during freeways crashes increases the probability of fatal crashes and decreases the probability of property damage only crashes. This finding is consistent with the previous studies (O'Donnell and Connor 1996, Kockelman and Kweon 2002, Singleton et al. 2004).

Also crashes involving vehicles hitting pedestrian are more probable to be fatal ones. This is intuitive because freeways encourage fast drive and restrict pedestrians by the provision of fencing on either side of the facility, so it becomes difficult for drivers to control their vehicles by suddenly observing pedestrian on facility. This finding is also in consistence with past researches (Eluru et al. 2007, Sunghee et al. 2010).

On the other hand, the estimation results show that for a unit increase in nose to tail indicator, there is 34.4% decrease in the probability of fatal crashes. The relative speed of the vehicles in nose to tail crashes is usually lower as they travel in the same direction which leads to less severe injury. Also, the drivers of the following vehicles hit the brakes in such condition which reduces the severity. This finding is in agreement with several past researches (Kockleman and Kweon 2002, Zhang Yang et al. 2011).

Human factors, such as dozing of driver behind the wheel and over-speeding were also examined. The model results reveal that crashes tend to be more severe if occur due to dozing of the drivers behind the wheel and over-speeding. Dozing behind the wheel leads to adversely affect the hearing, visual, mental and physical capabilities of the drivers and hence they lose their grip on the vehicles. This finding is consistent with the past studies (Khattak et al. 2003, Yamamoto and Shankar 2004, Sunghee et al. 2010).

Also, a unit increase in the over-speeding indicator (i.e. keeping other explanatory variables at their mean values), there is expectedly 55.1% increase the propensity of fatal injuries. This finding is intuitive and consistent with the previous researches (Abdel-aty 2003, Yamamoto and Shankar 2004, Sunghee et al. 2010, Sobhani et al. 2011).

The environmental characteristics are explored to understand their impact on the freeways crash injury severity. Evening peak indicator and month indicator are found significant. The estimation results reveal that a unit increase in the evening peak indicator (04:00pm-08:00pm) from its mean value (i.e. keeping all other independent variables constant), decreases the probability of the fatal crashes by 28%. During evening peak time, speed decreases and the drivers become more active with the increase in traffic and fading light. This result is consistent with the past researches (Shefer and Rietveld 1997, Chang and Mannering 1999).

Another important characteristic, drivers' age (when age is greater than 40 years) was found in strong positive association with motorways crash injury severity. The model results suggest that probability of fatal crashes increases by a factor of 0.551 with drivers' aging. The aging drivers face muscular deterioration, joints' and skeletal weakness, fading mental and audio-visual capabilities. This finding is also in consistent with the past researches (Kockelman and Kweon 2002, Abdel-aty 2003, Singleton et al. 2004).

The marginal effects of each independent variable on the intermediate levels of injury severity are presented in the same of tornado plots in order to have better understanding (Figure 4.1, Figure 4.2 and Figure 4.3).

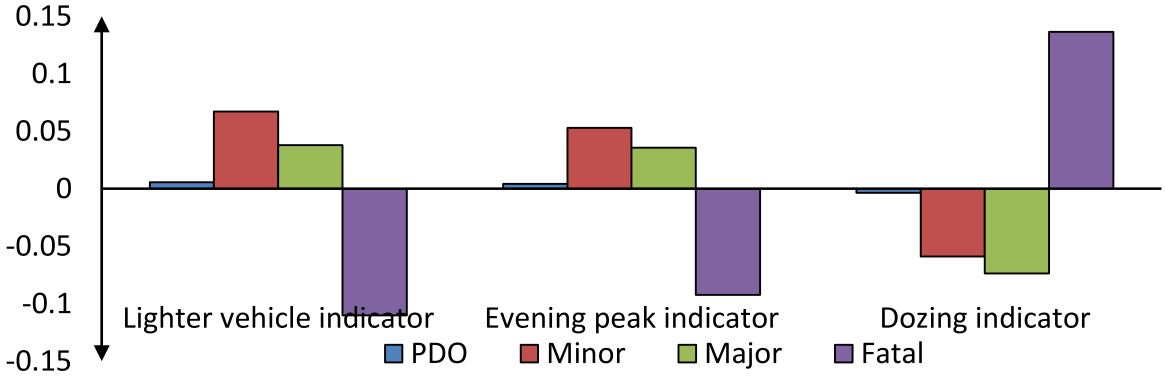

Figure 4.1: Tornado Plots for Marginal Effects of Significant Independent Variables (1)

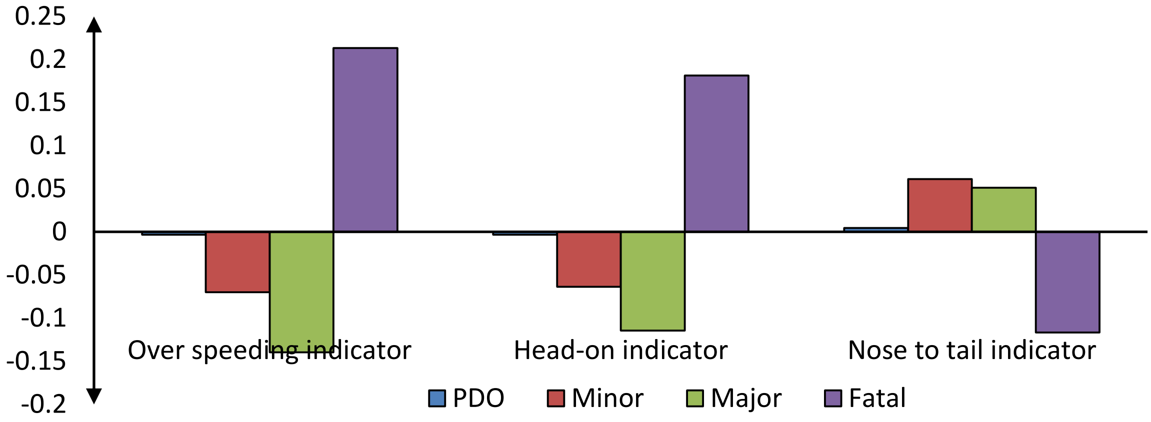

Figure 4.2: Tornado Plots for Marginal Effects of Significant Independent Variables (2)

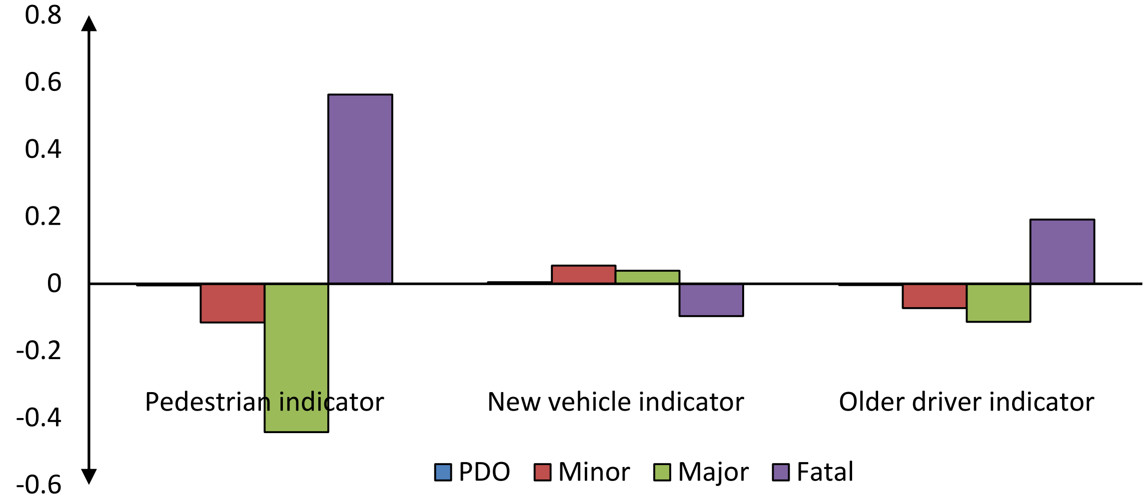

Figure 4.3: Tornado Plots for Marginal Effects of Significant Independent Variables (3)

The goodness of model was checked via adjusted McFadden's Pseudo rho-squared (ρ^2) which came to be 0.0763. All the findings are consistent with the past researches. The same criteria is used by Khattak (2001) who got the adjusted McFadden's Pseudo rho-squared (ρ^2) as 0.0319, 0.0671 and 0.0660 while developing ordered probit models for driver-1, driver-2 and driver-3 respectively. Likewise, Khattak et al. (2002) and Kockelman and Kweon (2002) presented their ordered probit models with a value of 0.057 and 0.0451-0.0868 respectively. Michalaki et al. (2015) while estimating ordered logistic regressions for motorways crashes in England came up with adjusted McFadden's Pseudo rho-squared (ρ^2) values as 0.0708 and 0.1241 for crashes occurring on hard shoulders and main carriage ways respectively.

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Synopsis of the Research

This research is focused on the identification of factors affecting crash injury severity on motorways in Pakistan which is expected to help in enhance the traffic safety on motorways. A systematic study of the relevant literature was done which provided in depth understanding of the injury severity analysis of RTCs on international level. The three approaches which have been commonly used for modeling crash injury severity include; ordered probit model, multinomial logit model and nested logit model. On the basis of having better goodness of fit, including more significant variables and due to ordinal nature of the response variable ordered probit model is estimated. Crash data of the past 7 years (i.e. 2009-2015) were collected for three different motorways; M1, M2 and M3 having lengths of 155, 357 and 54 kilometers respectively. The data set contains information on human and vehicular characteristics, crash pattern and environmental conditions. A number of trails were made via Nlogit to estimate an ordered probit model in order to investigate the association of crash injury severity with certain independent variables. The model results show the following variables in significant association with injury severity of motorways RTCs; dozing of drivers, over speeding, evening peak hours, vehicular type, vehicular age and driver age. Also, the three crash patterns; head-on collision of vehicles, vehicles colliding in nose to tail pattern and vehicle hitting pedestrian had significant association with the response variable. The value of adjusted McFadden’s Pseudo rho-squared (ρ^2) (i.e. 0.0763) validates the model as the best among all the trials when compared with relevant researches in the past.

5.2 Conclusions and Recommendations

The dramatic increase in the quantity of vehicles across the globe has increased the vulnerability of the people to road traffic crashes. These crashes, depending on the associated factors, can be of various severity levels. The recent study is focused on the identification of key risk factors and their association with various injury severity levels of motorways RTCs. The research findings suggest that freeway’s injury severity is significantly associated with; the vehicle type, evening peak time, collision pattern, vehicular age, driver's age, dozing of driver behind the wheel and over-speeding. The vehicle hitting pedestrian, older drivers and dozing of drivers tend to increases the probability of fatal crashes. The crash involving collision between lighter vehicles (passenger cars, pickups, panels and vans) tends to be a less severe. Also, nose to tail crash pattern and new vehicles (age lesser than 7 years in a singular crash) decreases the probability of fatality. The results suggests that over speeding, head on collision of vehicles and older drivers (age greater than 40 years) increase the likelihood of fatal crashes.

The study findings are expected to suggest the highways agencies (i.e. National Highways Authority) and enforcement organizations (i.e. NHMP) to take appropriate countermeasures for enhancement of traffic safety on national motorways. The research findings suggest involvement of heavy vehicles in a crash (i.e. buses, trucks and trailers) as a safety hazard for occupants of passenger cars. The appropriate surveillance and enforcement of traffic laws on heavier vehicles using the motorways can overcome the consequences. Also, repair of fencing on motorways (i.e. where broken) and restricting the unloading of passengers on the facility can reduce the pedestrians' crashes. Also, drivers should be educated to avoid fatigue driving via seminars and conferences. The emergency countermeasure in this regard can be 15 to 20 minutes rest after every 2 hours' drive. The model results predict that involvement of older vehicles and older drivers both increases the probability of fatal crashes. Proper check and scanning of old model vehicles (i.e. age greater than 7 years) and old age drivers (i.e. drivers' age greater than 40 years) prior to permission of their travel on motorways can reduce a substantial proportion of fatal injuries. The association of over speeding with more severe crashes makes it unavoidable to use technological equipment for speed law enforcement to discourage over speeding and issue tickets once driver is involved. The provision of proper separation media in work zone for opposing traffic as well as restricting one way violation of vehicles can reduce the significant portion of head on collisions which causes fatal crashes.

There is a need of improvement in the reporting and recording system of National Highway and Motorway Police, Pakistan (NHMP). The patrolling officers should be trained and educated on proper collection of the data on vehicular age, driver's age and gender of the driver. Various other questions present in crash report from (e.g. crash location type, length of skid marks and seating position of the affected occupants etc.) should be properly answered and marked. The improvement in data collection process will certainly provide opportunities for advanced research in the field of traffic safety in the country which can enhance traffic safety on motorways.

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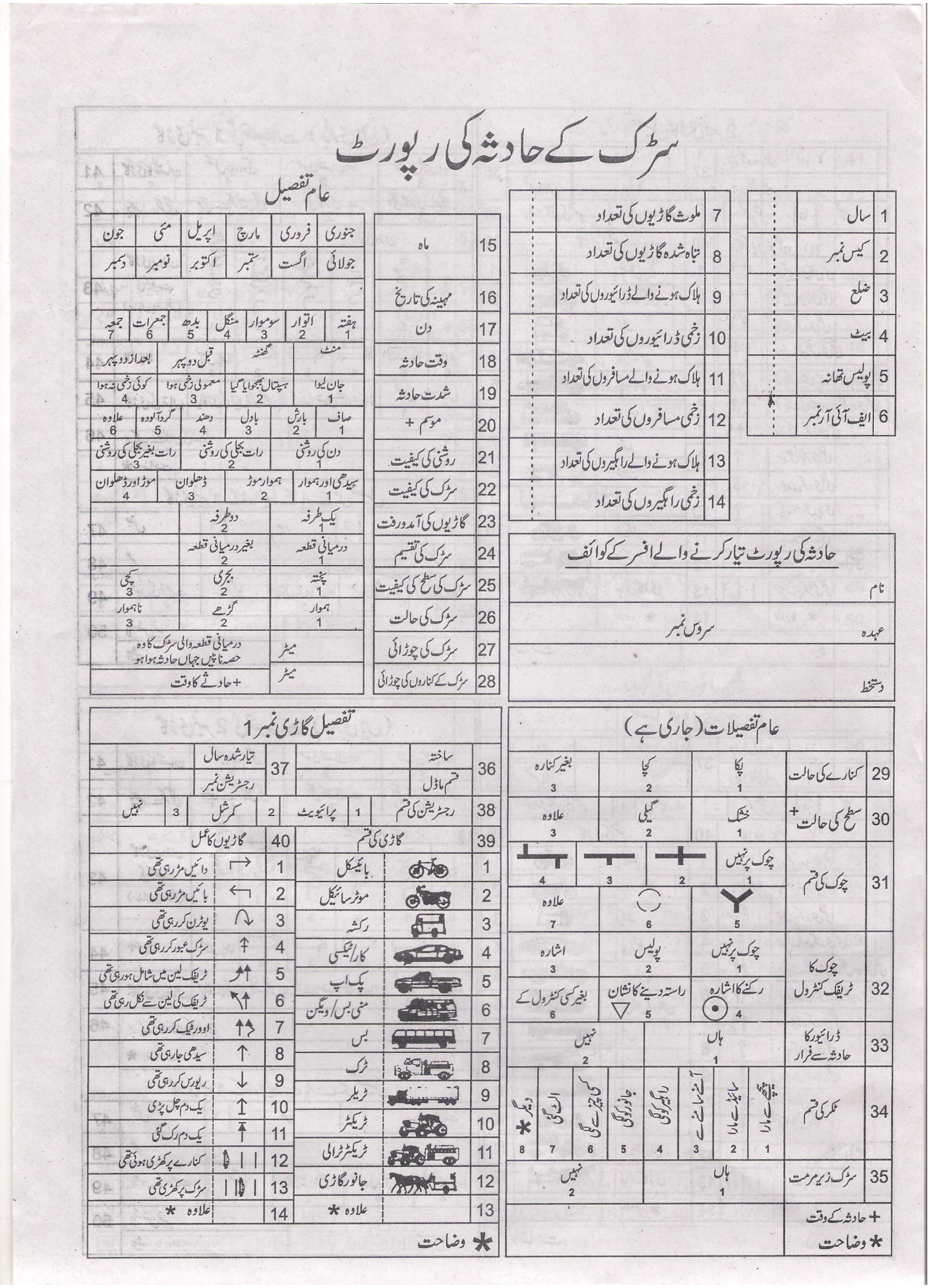
Appendix: Sample Crash Report Form (1)



سڑک کے حادثہ کی رپورٹ

1	سال	
2	کیس نمبر	
3	ضلع	
4	بیٹ	
5	پولیس تھانہ	
6	ایف آئی آر نمبر	

7	ملوث گاڑیوں کی تعداد	
8	تباہ شدہ گاڑیوں کی تعداد	
9	ہلاک ہونے والے ڈرائیوروں کی تعداد	
10	زخمی ڈرائیوروں کی تعداد	
11	ہلاک ہونے والے مسافروں کی تعداد	
12	زخمی مسافروں کی تعداد	
13	ہلاک ہونے والے راگیروں کی تعداد	
14	زخمی راہگیروں کی تعداد	

عام تفصیل

15	ماہ	جنوری	فروری	مارچ	اپریل	مئی	جون
		جولائی	اگست	ستمبر	اکتوبر	نومبر	دسمبر
16	مہینہ کی تاریخ						
17	دن	ہفتہ 1	اتوار 2	سوموار 3	منگل 4	بدھ 5	جمعرات 6 / جمعہ 7
18	وقت حادثہ	منٹ	گھنٹہ	قبل دوپہر	بعداز دوپہر		
19	شدت حادثہ	جان لیوا 1	ہسپتال بھجوایا گیا 2	معمولی زخمی ہوا 3	کوئی زخمی نہ ہوا 4		
20	موسم +	صاف 1	بارش 2	بادل 3	دھند 4	گردآلودہ 5	علاوہ 6
21	روشنی کی کیفیت	دن کی روشنی 1	رات بجلی کی روشنی 2	رات بغیر بجلی کی روشنی 3			
22	سڑک کی کیفیت	سیدھی اور ہموار 1	ہموار موڑ 2	ڈھلوان 3	موڑ اور ڈھلوان 4		
23	گاڑیوں کی آمدورفت	یک طرفہ 1	دوطرفہ 2				
24	سڑک کی تقسیم	درمیانی قطعہ 1	بغیر درمیانی قطعہ 2				
25	سڑک کی سطح کی کیفیت	پختہ 1	بجری 2	کچی 3			
26	سڑک کی حالت	ہموار 1	گڑھے 2	ناہموار 3			
27	سڑک کی چوڑائی	میٹر	درمیانی قطعہ والی سڑک کا وہ حصہ ناپیں جہاں حادثہ ہوا ہو				
28	سڑک کے کناروں کی چوڑائی	میٹر	+ حادثے کا وقت				

حادثہ کی رپورٹ تیار کرنے والے افسر کے کوائف

نام

عہدہ سروس نمبر

دستخط

عام تفصیلات (جاری ہے)

29	کنارے کی حالت	پکا 1	کچا 2	بغیر کنارہ 3					
30	سطح کی حالت +	خشک 1	گیلی 2	علاوہ 3					
31	چوک کی قسم	چوک پر نہیں 1	2	3	4	5	6	علاوہ 7	
32	چوک کا ٹریفک کنٹرول	چوک پر نہیں 1	پولیس 2	اشارہ 3	رکنے کا اشارہ ⊙ 4	راستہ دینے کا نشان ▽ 5	بغیر کسی کنٹرول کے 6		
33	ڈرائیور کا حادثہ سے فرار	ہاں 1	نہیں 2						
34	ٹکر کی قسم	پیچھے سے مارا 1	سائیڈ سے مارا 2	آمنے سامنے سے 3	راہگیر کو لگی 4	جانور کو لگی 5	کسی چیز سے لگی 6	الٹ گئی 7	دیگر * 8
35	سڑک زیر مرمت	ہاں 1	نہیں 2						

+ حادثہ کے وقت

* وضاحت

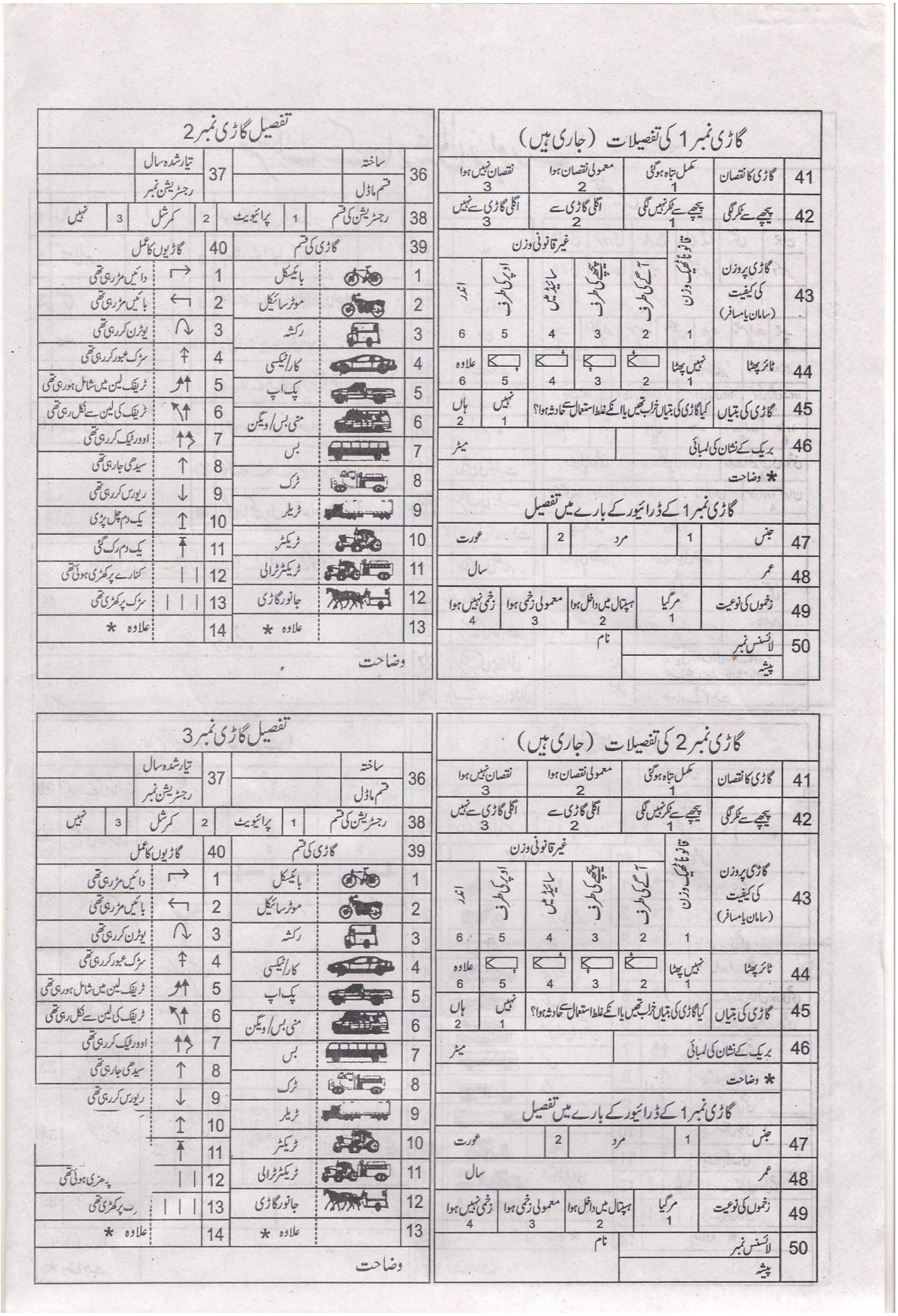
تفصیل گاڑی نمبر 1

36	ساختہ		37	تیار شدہ سال	
	قسم ماڈل			رجسٹریشن نمبر	
38	رجسٹریشن کی قسم	1 پرائیویٹ	2 کمرشل	3 نہیں	

39		گاڑی کی قسم	40		گاڑیوں کا عمل
1		بائیسکل	1	↱	دائیں مڑ رہی تھی
2		موٹر سائیکل	2	↰	بائیں مڑ رہی تھی
3		رکشہ	3	↷	یوٹرن کر رہی تھی
4		کار/ٹیکسی	4	↟	سڑک عبور کر رہی تھی
5		پک اپ	5	↗↑	ٹریفک لین میں شامل ہو رہی تھی
6		منی بس/ ویگن	6	↖↑	ٹریفک کی لین سے نکل رہی تھی
7		بس	7	↑↱	اوورٹیک کر رہی تھی
8		ٹرک	8	↑	سیدھی جا رہی تھی
9		ٹریلر	9	↓	ریورس کر رہی تھی
10		ٹریکٹر	10	↥	یک دم چل پڑی
11		ٹریکٹر ٹرالی	11	⤒	یک دم رک گئی
12		جانور گاڑی	12		کنارے پر کھڑی ہوئی تھی
13		علاوہ *	13		سڑک پر کھڑی تھی
			14		علاوہ *

* وضاحت

Appendix: Sample Crash Report Form (2)



گاڑی نمبر 1 کی تفصیلات (جاری ہیں)

41	گاڑی کا نقصان	مکمل تباہ ہوگئی 1	معمولی نقصان ہوا 2	نقصان نہیں ہوا 3			
42	پیچھے سے ٹکر لگی	پیچھے سے ٹکر نہیں لگی 1	اگلی گاڑی سے 2	اگلی گاڑی سے نہیں 3			
43	گاڑی پر وزن کی کیفیت (سامان یا مسافر)	قانونی حد تک وزن	غیر قانونی وزن				
			آگے کی طرف	پیچھے کی طرف	سائیڈ میں	اوپر کی طرف	اندر
		1	2	3	4	5	6
44	ٹائر پھٹا	نہیں پھٹا 1	2	3	4	5	علاوہ 6
45	گاڑی کی بتیاں	کیا گاڑی کی بتیاں خراب تھیں یا انکے غلط استعمال سے حادثہ ہوا؟	نہیں 1	ہاں 2			
46	بریک کے نشان کی لمبائی	میٹر					
	* وضاحت						

گاڑی نمبر 1 کے ڈرائیور کے بارے میں تفصیل

47	جنس	1	مرد	2	عورت
48	عمر	سال			
49	زخموں کی نوعیت	مرگیا 1	ہسپتال میں داخل ہوا 2	معمولی زخمی ہوا 3	زخمی نہیں ہوا 4
50	لائسنس نمبر	نام			
	پیشہ				

تفصیل گاڑی نمبر 2

36	ساختہ			37	تیار شدہ سال		
	قسم ماڈل				رجسٹریشن نمبر		
38	رجسٹریشن کی قسم	1	پرائیویٹ	2	کمرشل	3	نہیں

39	گاڑی کی قسم	40	گاڑیوں کا عمل
1	بائیسکل	1	↱ دائیں مڑ رہی تھی
2	موٹر سائیکل	2	↰ بائیں مڑ رہی تھی
3	رکشہ	3	↷ یوٹرن کر رہی تھی
4	کار/ٹیکسی	4	↑ سڑک عبور کر رہی تھی
5	پک اپ	5	↑↑ ٹریفک لین میں شامل ہو رہی تھی
6	منی بس/ویگن	6	↖↑ ٹریفک کی لین سے نکل رہی تھی
7	بس	7	↑↑ اوورٹیک کر رہی تھی
8	ٹرک	8	↑ سیدھی جا رہی تھی
9	ٹریلر	9	↓ ریورس کر رہی تھی
10	ٹریکٹر	10	↥ یک دم چل پڑی
11	ٹریکٹر ٹرالی	11	⤒ یک دم رک گئی
12	جانور گاڑی	12	| | کنارے پر کھڑی ہوئی تھی
13	علاوہ *	13	| | | سڑک پر کھڑی تھی
		14	علاوہ *

وضاحت

گاڑی نمبر 2 کی تفصیلات (جاری ہیں)

41	گاڑی کا نقصان	مکمل تباہ ہوگئی 1	معمولی نقصان ہوا 2	نقصان نہیں ہوا 3			
42	پیچھے سے ٹکر لگی	پیچھے سے ٹکر نہیں لگی 1	اگلی گاڑی سے 2	اگلی گاڑی سے نہیں 3			
43	گاڑی پر وزن کی کیفیت (سامان یا مسافر)	قانونی حد تک وزن	غیر قانونی وزن				
			آگے کی طرف	پیچھے کی طرف	سائیڈ میں	اوپر کی طرف	اندر
		1	2	3	4	5	6
44	ٹائر پھٹا	نہیں پھٹا 1	2	3	4	5	علاوہ 6
45	گاڑی کی بتیاں	کیا گاڑی کی بتیاں خراب تھیں یا انکے غلط استعمال سے حادثہ ہوا؟	نہیں 1	ہاں 2			
46	بریک کے نشان کی لمبائی	میٹر					
	* وضاحت						

گاڑی نمبر 1 کے ڈرائیور کے بارے میں تفصیل

47	جنس	1	مرد	2	عورت
48	عمر	سال			
49	زخموں کی نوعیت	مرگیا 1	ہسپتال میں داخل ہوا 2	معمولی زخمی ہوا 3	زخمی نہیں ہوا 4
50	لائسنس نمبر	نام			
	پیشہ				

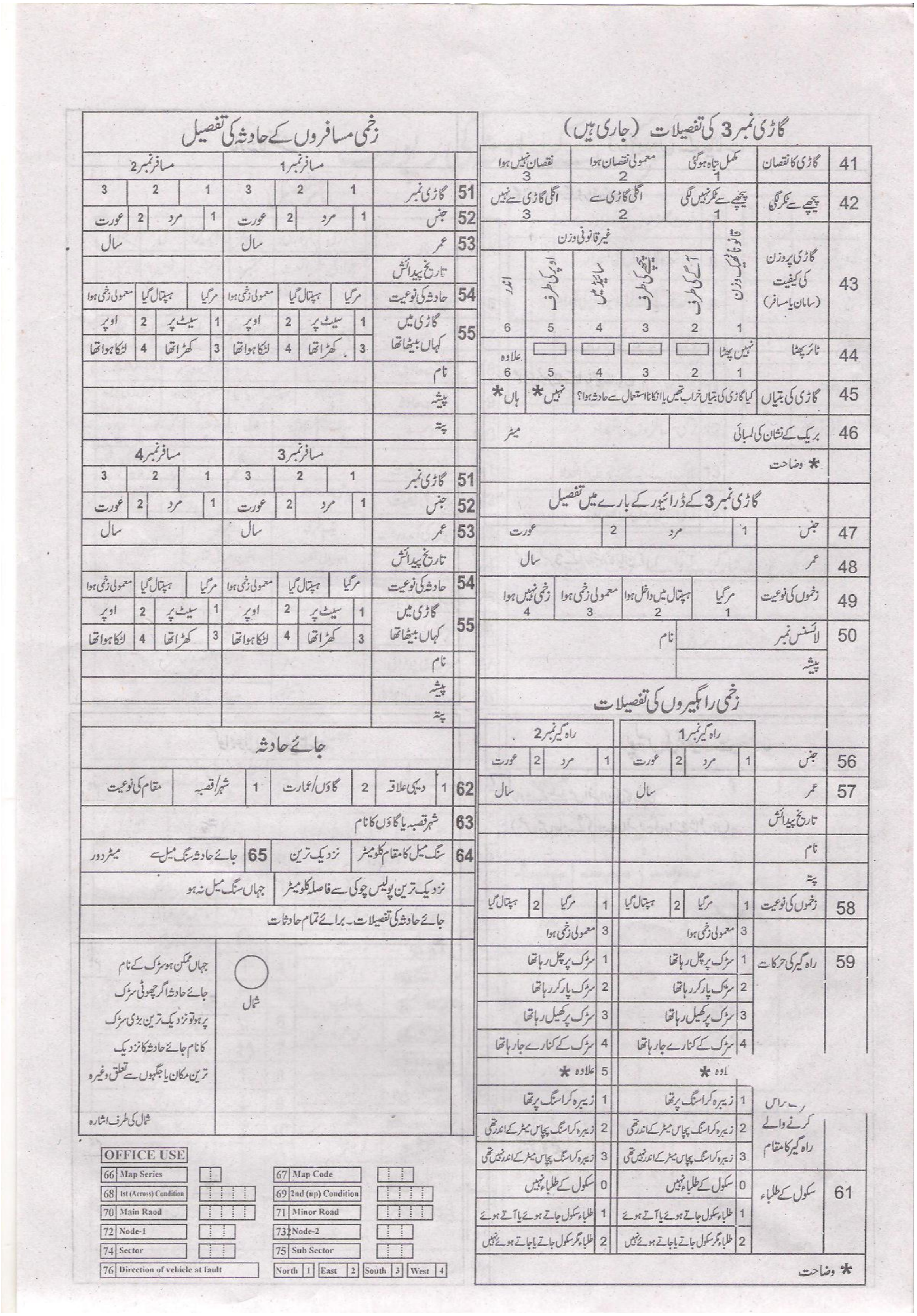
تفصیل گاڑی نمبر 3

36	ساختہ			37	تیار شدہ سال		
	قسم ماڈل				رجسٹریشن نمبر		
38	رجسٹریشن کی قسم	1	پرائیویٹ	2	کمرشل	3	نہیں

39	گاڑی کی قسم	40	گاڑیوں کا عمل
1	بائیسکل	1	↱ دائیں مڑ رہی تھی
2	موٹر سائیکل	2	↰ بائیں مڑ رہی تھی
3	رکشہ	3	↷ یوٹرن کر رہی تھی
4	کار/ٹیکسی	4	↑ سڑک عبور کر رہی تھی
5	پک اپ	5	↑↑ ٹریفک لین میں شامل ہو رہی تھی
6	منی بس/ویگن	6	↖↑ ٹریفک کی لین سے نکل رہی تھی
7	بس	7	↑↑ اوورٹیک کر رہی تھی
8	ٹرک	8	↑ سیدھی جا رہی تھی
9	ٹریلر	9	↓ ریورس کر رہی تھی
10	ٹریکٹر	10	↥
11	ٹریکٹر ٹرالی	11	⤒
12	جانور گاڑی	12	| | پہڑی ہوئی تھی
13	علاوہ *	13	| | | ر پر کھڑی تھی
		14	علاوہ *

وضاحت

Appendix: Sample Crash Report Form (3)



گاڑی نمبر 3 کی تفصیلات (جاری ہیں)

41	گاڑی کا نقصان	مکمل تباہ ہوگئی 1	معمولی نقصان ہوا 2	نقصان نہیں ہوا 3
42	پیچھے سے ٹکر لگی	پیچھے سے ٹکر نہیں لگی 1	اگلی گاڑی سے 2	اگلی گاڑی سے نہیں 3

			غیر قانونی وزن				
43	گاڑی پر وزن کی کیفیت (سامان یا مسافر)	قانوناً ٹھیک وزن 1	آگے کی طرف 2	پیچھے کی طرف 3	سائیڈ میں 4	اوپر کی طرف 5	اندر 6
44	ٹائر پھٹا	نہیں پھٹا 1	☐ 2	☐ 3	☐ 4	☐ 5	علاوہ 6
45	گاڑی کی بتیاں	کیا گاڑی کی بتیاں خراب تھیں یا انکا نا استعمال سے حادثہ ہوا؟				نہیں *	ہاں *
46	بریک کے نشان کی لمبائی					میٹر	

* وضاحت

گاڑی نمبر 3 کے ڈرائیور کے بارے میں تفصیل

47	جنس	1	مرد	2	عورت		
48	عمر	سال					
49	زخموں کی نوعیت	مرگیا 1	ہسپتال میں داخل ہوا 2	معمولی زخمی ہوا 3	زخمی نہیں ہوا 4		
50	لائسنس نمبر	نام					
	پیشہ						

زخمی راہگیروں کی تفصیلات

		راہ گیر نمبر 1				راہ گیر نمبر 2			
56	جنس	1	مرد	2	عورت	1	مرد	2	عورت
57	عمر	سال				سال			
	تاریخ پیدائش								
	نام								
	پتہ								
58	زخموں کی نوعیت	1	مرگیا	2	ہسپتال گیا	1	مرگیا	2	ہسپتال گیا
		3	معمولی زخمی ہوا			3	معمولی زخمی ہوا		
59	راہ گیر کی حرکات	1	سڑک پر چل رہا تھا			1	سڑک پر چل رہا تھا		
		2	سڑک پار کر رہا تھا			2	سڑک پار کر رہا تھا		
		3	سڑک پر کھیل رہا تھا			3	سڑک پر کھیل رہا تھا		
		4	سڑک کے کنارے جا رہا تھا			4	سڑک کے کنارے جا رہا تھا		
			اوہ *			5	علاوہ *		
	راس کرنے والے راہ گیر کا مقام	1	زیبرہ کراسنگ پر تھا			1	زیبرہ کراسنگ پر تھا		
		2	زیبرہ کراسنگ پچاس میٹر کے اندر تھی			2	زیبرہ کراسنگ پچاس میٹر کے اندر تھی		
		3	زیبرہ کراسنگ پچاس میٹر کے اندر نہیں تھی			3	زیبرہ کراسنگ پچاس میٹر کے اندر نہیں تھی		
61	سکول کے طلباء	0	سکول کے طلباء نہیں			0	سکول کے طلباء نہیں		
		1	طلباء سکول جاتے ہوئے یا آتے ہوئے			1	طلباء سکول جاتے ہوئے یا آتے ہوئے		
		2	طلباء مگر سکول جاتے یا جاتے ہوئے نہیں			2	طلباء مگر سکول جاتے یا جاتے ہوئے نہیں		

* وضاحت

زخمی مسافروں کے حادثہ کی تفصیل

		مسافر نمبر 1						مسافر نمبر 2					
51	گاڑی نمبر	1		2		3		1		2		3	
52	جنس	1	مرد	2	عورت			1	مرد	2	عورت		
53	عمر	سال						سال					
	تاریخ پیدائش												
54	حادثہ کی نوعیت	مرگیا		ہسپتال گیا		معمولی زخمی ہوا		مرگیا		ہسپتال گیا		معمولی زخمی ہوا	
55	گاڑی میں کہاں بیٹھا تھا	1	سیٹ پر	2	اوپر			1	سیٹ پر	2	اوپر		
		3	کھڑا تھا	4	لٹکا ہوا تھا			3	کھڑا تھا	4	لٹکا ہوا تھا		
	نام												
	پیشہ												
	پتہ												

		مسافر نمبر 3						مسافر نمبر 4					
51	گاڑی نمبر	1		2		3		1		2		3	
52	جنس	1	مرد	2	عورت			1	مرد	2	عورت		
53	عمر	سال						سال					
	تاریخ پیدائش												
54	حادثہ کی نوعیت	مرگیا		ہسپتال گیا		معمولی زخمی ہوا		مرگیا		ہسپتال گیا		معمولی زخمی ہوا	
55	گاڑی میں کہاں بیٹھا تھا	1	سیٹ پر	2	اوپر			1	سیٹ پر	2	اوپر		
		3	کھڑا تھا	4	لٹکا ہوا تھا			3	کھڑا تھا	4	لٹکا ہوا تھا		
	نام												
	پیشہ												
	پتہ												

جائے حادثہ

62	1	دیہی علاقہ	2	گاؤں/عمارت	1	شہر/قصبہ	مقام کی نوعیت
63	شہر قصبہ یا گاؤں کا نام						
64	سنگ میل کا مقام کلومیٹر	نزدیک ترین	65	جائے حادثہ سنگ میل سے	میٹر دور		
	نزدیک ترین پولیس چوکی سے فاصلہ کلومیٹر	جہاں سنگ میل نہ ہو					
	جائے حادثہ کی تفصیلات۔ برائے تمام حادثات						

جہاں ممکن ہو سڑک کے نام جائے حادثہ اگر چھوٹی سڑک پر ہو تو نزدیک ترین بڑی سڑک کا نام جائے حادثہ کا نزدیک ترین مکان یا جگہوں سے تعلق وغیرہ

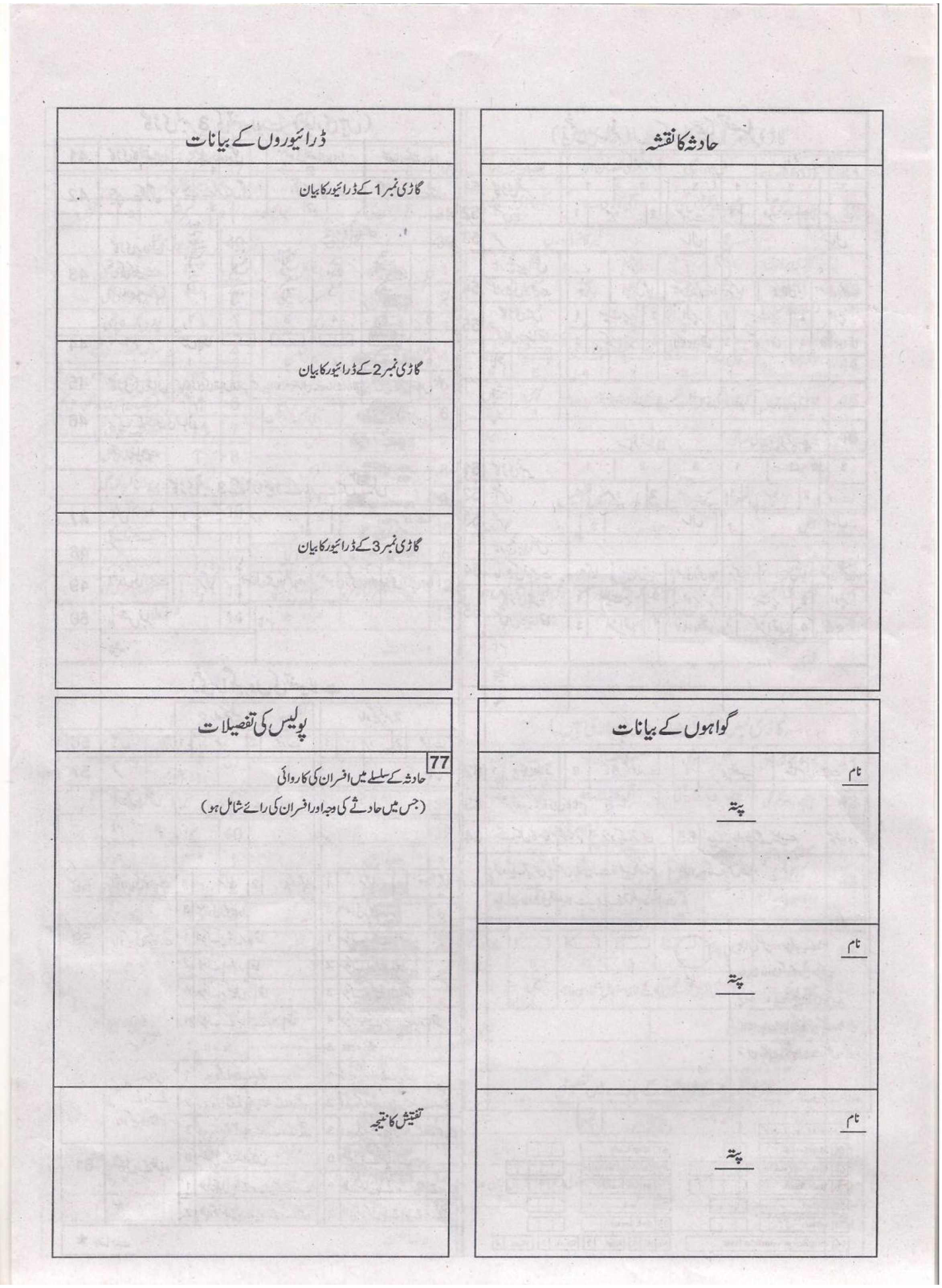
شمال

شمال کی طرف اشارہ

OFFICE USE

66	Map Series	☐☐	67	Map Code	☐☐☐
68	Ist (Across) Condition	☐☐☐☐☐	69	2nd (up) Condition	☐☐☐☐☐
70	Main Raod	☐☐☐☐☐	71	Minor Road	☐☐☐☐☐
72	Node-1	☐☐☐	732	Node-2	☐☐☐
74	Sector	☐☐☐	75	Sub Sector	☐☐☐
76	Direction of vehicle at fault		North 1	East 2	South 3 West 4

Appendix: Sample Crash Report Form (4)



حادثہ کا نقشہ

ڈرائیوروں کے بیانات

گاڑی نمبر 1 کے ڈرائیور کا بیان

گاڑی نمبر 2 کے ڈرائیور کا بیان

گاڑی نمبر 3 کے ڈرائیور کا بیان

گواہوں کے بیانات

نام

پتہ

نام

پتہ

نام

پتہ

پولیس کی تفصیلات

77 حادثہ کے سلسلے میں افسران کی کاروائی

(جس میں حادثے کی وجہ اور افسران کی رائے شامل ہو)

تفتیش کا نتیجہ