ANALYSIS OF RISK FACTORS INFLUENCING ROAD CRASH INJURY SEVERITY IN URBAN PESHAWAR: A RANDOM PARAMETERS LOGIT APPROACH WITH HETEROGENEITY IN MEANS AND VARIANCES

BY

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DEDICATION

"Dedicated to my exceptional parents, adored siblings and respected teachers whose tremendous support and cooperation led me to this wonderful accomplishment"

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Praise be to Allah, Almighty for his uncountable blessings, and best prayers and peace be unto his best messenger Muhammad (SAW), his pure descendent, and his family and his noble companions. First I would like to thank my family. Without their love and support over the years none of this would have been possible. They have always been there for me and I am thankful for everything they have helped me achieve.

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Salman Haider Khan

TABLE OF CONTENTS

S. NO	TITLE	PAGE NO

LIST OF ACRONYMS

AJK	Azad Jammu and Kashmir
KPK	Khyber Pakhtunkhwa
RP	Random Parameter
RTCs	Road Traffic Crashes
AADT	Average Annual Daily Traffic
MNL	Multinomial Logit Model
DUI	Driving Under Influence
VRUs	Vulnerable Road Users
AVs	Autonomous Vehicles
SV	Single Vehicle
PDA	Peshawar Development Authority
WHO	World Health Organization
HSIS	Highway Safety Information System
NHTSA	National Highway Traffic Safety Administration
NHMP	National Highways and Motorway Police
FIR	First Information Report
PDO	Property Damage Only
AIC	Akaike Information Criteria
BIC	Bayesian Information Criteria
MI	Minor Injury
MJI	Major Injury
FI	Fatal Injury
LL	Log Likelihood

LIST OF TABLES

LIST OF FIGURES

FIGURES. NO	TITLE	PAGE NO

ABSTRACT

Road traffic crashes leading to severe and fatal injuries over the years have been increasing rapidly, which is alarming and should be dealt with effective road safety countermeasures to enhance road safety. Road traffic crashes, being the 8th leading cause of death, justify the importance of road safety as a matter of great concern. Keeping in view the criticality of RTCs, the topic of road safety was taken under consideration. This current research study focuses on the influence of various risk factors related to injury severity caused by road traffic crashes in urban Peshawar. Crash data for the period of two years (2018–2019) were obtained from the district office of Rescue 1122, i.e., a leading emergency response unit. For the in-hand crash data, a random parameters logit approach taking into consideration the possibility of heterogeneity in means and variances of parameter estimates was deployed. The final chosen model was the "random parameters logit model with heterogeneity in means and variances" because of its statistical superiority over the other models that do not account for the possibility of heterogeneity in means and variances. For analysis and model calibration of road crash severity, three levels of injury severity outcomes are considered, namely minor injury, major injury, and fatal injury. The crash data incorporated various risk factors, mainly victims' and driver's attributes; details of weather and lighting conditions; posted speed limits; roadway type and geometry; reported reason of crash; vehicle type; and various other crash-related characteristics. According to the study findings, the likelihood of a fatal injury increases for crashes involving old age road users (above 60 years), crashes occurring at an intersection, crashes due to vehicle brake failure, crashes involving pedestrian collisions with a datsun, and crashes involving motorcycle and car collisions with (heavy vehicle) trucks and buses, respectively. Whilst the risk factors associated with an increase in

major injuries include crashes involving middle-aged road users (18–30 and 41–50 years), crashes involving collisions of a motorcycle with Suzuki, Wagon, and Hiace, crashes involving motorists, crashes involving pedestrian collisions with Suzuki and Wagon, and crashes occurring due to motorcycle overspeeding. Furthermore, the likelihood of minor injury increases with crashes involving male road users compared to their female counterparts, drivers wearing seatbelts, involving collisions of pedestrians with rickshaws and motorcycles, and crashes involving collisions of passenger cars with Suzuki, rickshaws, and other passenger cars. The study's findings suggest that the public should be educated regarding road safety countermeasures by traffic police/wardens. Also, limit the use of heavy vehicles in the traffic streams, or they should be separated from the traffic streams within the city to avoid fatal crashes and provide separate facilities for vulnerable road users (pedestrians, motorcyclists, and bicyclists) to enhance the present road safety situation. Besides the aforementioned suggested road safety measures, some very basic and effective safety measures like seatbelt wearing, safe speed limits, and helmet use by motorcyclists should be adopted to improve road traffic safety effectively. Moreover, the findings of this research study will produce additional insights and interest in road safety that can be helpful for the infrastructure development authorities and highway agencies of the country, as well as for the law enforcement agencies in the enhancement of road safety through deploying the aforementioned counter measures.

CHAPTER 1

INTRODUCTION

1.1 Overview

Since road safety has become a significant and hard global issue over the last decade, it has always been a topic of essential relevance for scientific research. Motor vehicle travel is Pakistan's principal mode of transportation, providing essential mobility but also among the major causes of fatalities due to road traffic accidents. According to (WHO, 2018), road traffic accidents are the eighth most common cause of mortality for all age groups worldwide. However, it is the first and foremost cause of mortality among children and young people aged 5 to 29 globally. Pakistan, as well as other developing countries, has an alarming rate of road traffic crashes resulting in major injuries and fatalities. The fatality rate in Pakistan due to road traffic crashes is 14.4 per 10,000 registered vehicles, compared to Japan’s rate of 1.7 per 10,000 registered vehicles and Canada’s rate of 1.67 per 10,000 vehicles, despite the fact that Japan and Canada have substantially greater vehicle proportions than Pakistan (Haider & Badami, 2004). Moreover, 38,824 individuals were fatally injured in traffic crashes involving motor vehicles on US roads in the year 2020. From the year 2007 till now, the 2020 death toll has been the highest. This also reflects an increase of 6.8% over the 36,355 fatalities recorded in 2019, or 2,469 more individuals who died in road traffic accidents in the year 2020 (NHTSA, 2022). Also, in Pakistan, about 25,781 people are killed in motor-vehicle accidents each year, which is considerably a higher rate of road traffic deaths (WHO, 2015; Ahmed et al., 2016). Every year, around 1.35 million road users lose their lives in traffic accidents around the world. Over 50% of all road traffic deaths happen to cyclists, motorcyclists, and pedestrians, who are collectively known as "vulnerable road users" (WHO, 2018). Because of road traffic accidents, the majority of nations experience a GDP loss of 3%. Despite several government initiatives and actions to enhance road safety and reduce this worldwide problem, the results are still unsatisfying and alarming (GHE, 2016).

1.2 Road traffic safety in low and middle-income countries

For the following case, 90% of worldwide road traffic fatalities take place in low and middle-income countries, regardless of the fact that only 54% of the world's registered vehicles are registered in these nations, making them the worst victims of road traffic crashes (RTCs) (WHO, 2015). Later on in 2016, it was revealed that road traffic death rates per 100,000 people in low and middle-income nations were relatively higher, at 27.5 and 19.2 respectively, than in high-income countries, at 8.3. The likelihood of road traffic deaths is three times greater in low and middle income countries than in countries with higher income. Besides that, the rate of traffic fatalities was highest in Africa (26.6 per 100,000 people), followed by South-east Asia (20.7), and lowest in Europe (9.3 per 100,000 people) (WHO, 2018). Since 2013, the number of deaths caused by road traffic crashes (RTC's) has not decreased in any low-income country, whilst in the regions of the Americas and Europe, the rates of death due to road traffic crashes have been reduced since 2013.

Pakistan, being a lower-middle income country, is also vulnerable to road traffic crashes (RTC's) with 44,959 fatal accidents and 59,146 non-fatal accidents in which 55,141 people were fatally injured and 126,144 people were severely injured in the past decade, with the exception of data records from AJK and Gilgit-Baltistan, which could make the road crash rates even worse (Pakistan Bureau of Statistics, 2021). Also, the traffic stream in Pakistan and other developing countries is heterogeneous, which reflects a scenario of mixed and haphazard traffic conditions, including cars for passengers (private owned vehicles and taxis), heavy vehicles (buses, trucks, trailers, etc.), bikes, rickshaws, and animal-drawn carriages/carts.

High volatility in driver habits, such as frequent wrong overtaking maneuvers and aggressive lane changing, contributes significantly to traffic bulking, potentially jeopardizing safety and mobility (Akbar et al., 2018). The current study will concentrate on road traffic safety because of the large human and economic losses caused by road traffic crashes (RTCs). Stringent research studies are needed, particularly in developing countries like Pakistan, to explore the risk variables that have a substantial impact on the severity of a crash. Keeping this in mind, successful implementation of traffic safety plans necessitates a thorough understanding of the roadway and traffic conditions in developed countries with the lowest fatality rates, as they may not be valid or appropriate in developing countries with higher fatality rates. Nevertheless, some of the traffic laws that are successful worldwide and significantly effective in mitigating risk factors should be adopted straight away, like seat-belt wearing, implementing safe speed limits, following lane discipline, avoiding driving under influence (DUI), wearing a helmet, provision of sidewalks and pedestrian crossing facilities, adequate road design and traffic management, etc. to reduce RTCs.

1.3 Problem statement

A comprehensive understanding of the individual risk factors that affect the probability of occurrence of these crashes is necessary to decrease the severity and number of road traffic crashes. However, limited research studies have been carried out in Pakistan, keeping in view the staggering number of fatalities and injuries caused by road traffic crashes. Although research carried out on traffic safety in developed countries is extensive, there is a major difference related to the type of roadways, individual's perceiving risks, rules and regulations of traffic safety, and traffic conditions between developed and developing countries. The very first priority for all road users is safety, regardless of the fact that road traffic crash statistics are vulnerable. That necessitates a careful investigation of the risk factors that influence traffic accidents. Another problem being faced is related to road crash data, in which there is a significant number of road accidents with almost no details or very little details, which leads to discarding some of the cases that could help us in better determining the association of numerous risk factors with road traffic crashes. Also, there is no specific department that deals with road safety in Pakistan, which certainly would have helped in road traffic safety research.

1.4. Research Objectives

Research objectives are as follows:

- Understanding and identification of various risk factors involved in road crash severity with the help of literature review.
- Selection of a viable statistical modelling technique for analysis of road crash risk factors.
- To explore the significant risk factors that have an impact on the injury severity of road traffic crashes in urban Peshawar.

1.5 Overview of research methodology

A comprehensive methodology was established to achieve the intended results, the overview of which is shown in figure 1.1.

The major steps involved were as follows:

- Comprehensive review of literature related to road safety all over the world.
- Collection and collation of road traffic crash data.
- Examination of various statistical methodologies and the selection of a

suitable modelling framework.

- Estimation of random parameters mixed logit approach, considering heterogeneity in means and variances for the identification of factors related to risk influencing road crash severity in urban Peshawar.
- Analyzing model results and discussion.
- And finally conclusion and recommendation.

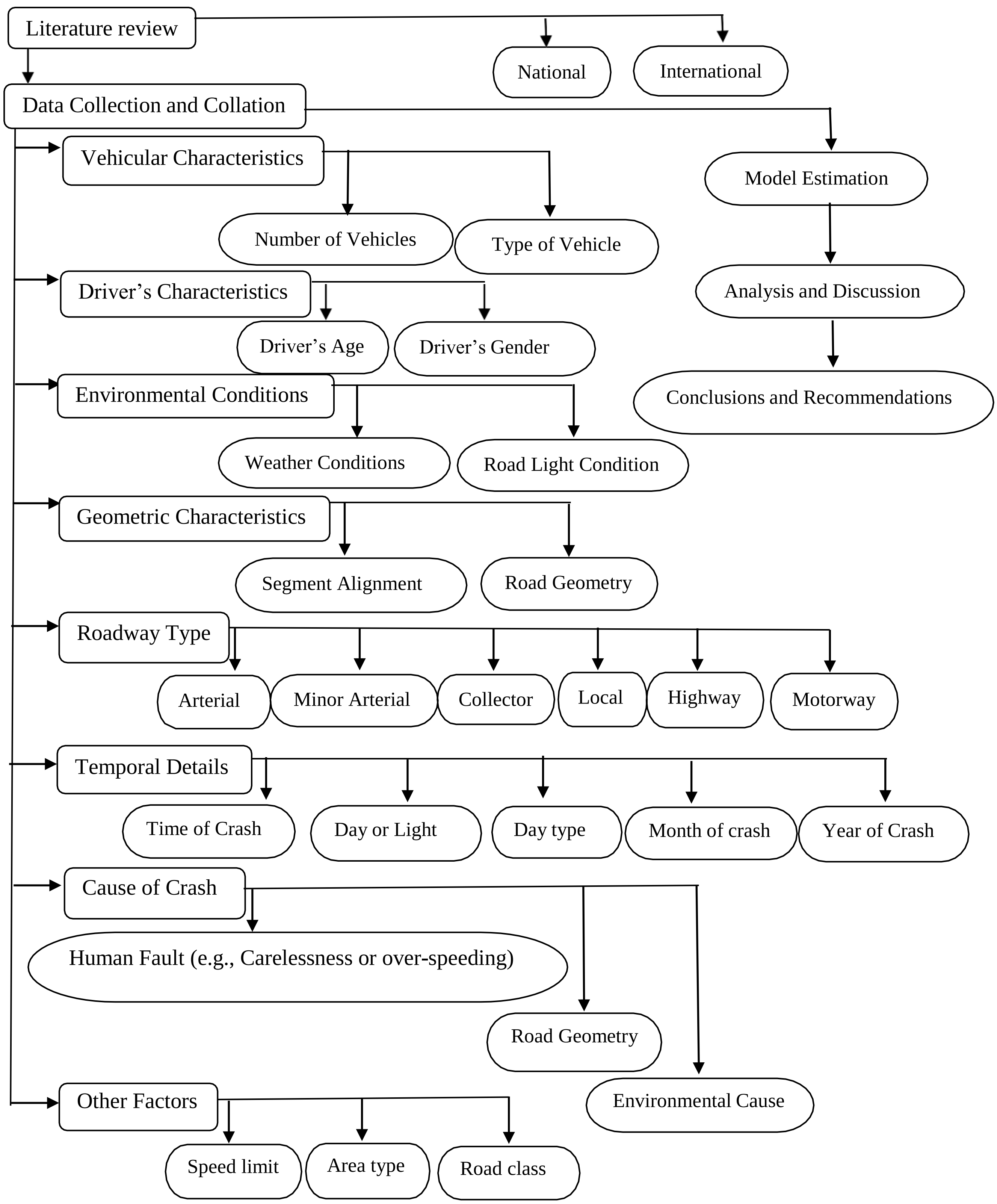

Fig 1.1: Overview of Methodology

1.6 Research Structure

The study is divided into five chapters, the first of which gives background information on the need to build a framework for road crash severity analysis, as well as a statement of the problem and goal of the study. The second chapter contains a comprehensive review of the literature associated with road safety using a variety of statistical techniques. Chapter 3 of the study presents the data description. The modelling framework, model estimation results, and discussion are covered in Chapter 4. Whereas, the research summary, conclusions, and recommendations have been presented in Chapter 5.

CHAPTER 2

LITERATURE REVIEW

2.1 Background

This chapter offers a detailed review of previous studies that implemented various methodological and statistical approaches to uncover the relation between various risk factors and road traffic crashes. In Pakistan, limited research has been carried on the proposed topic, particularly on the injury severity within the city, due to lack of reliable information. The reason being that, there is no linkages between the highways authority, law enforcing agencies and health department. Relevant research carried out elsewhere is discussed as follows:

2.2 Previous Methodological Approaches

Plenty of research work has been done worldwide to assess the injury severity caused by road traffic crashes and to determine the risk factors associated with them. Some of them are listed in Table 2.1. Two model classes are significant in the literature from a methodological standpoint. For instance, (Kim et al., 2007; S. Islam & Mannering, 2006; Manner & Wünsch-Ziegler, 2013) have used multinomial logit models, while (Kockelman & Kweon, 2002; Abdel-Aty, 2003), and (Christoforou et al., 2010) employed the alternate approach of the ordered probit model.

In order to assess safety performance and explain the impact of variables related to road geometric design on crash frequency, Vayalamkuzhi & Amirthalingam, (2016) evaluated the relationship amongst traffic safety and road geometric design features using negative binomial regression and Poisson regression. It was highlighted that the negative binomial regression model was more effective for identifying the causes of road traffic crashes. Whereas, a later research study by (Eboli et al., 2020) employed Logistic regression to know about the factors influencing road accident severity which is capable to interpret the weight of each factor involved in the accident severity analysis.

While utilizing an ordered probit model, Deng et al., (2006) concluded that head-on collisions are the major cause of fatal crashes on two-lane highways, constituting a substantial proportion of the highway network in the United States. However, results also revealed that narrow roadway segments and wet roadway surfaces were significantly associated with more serious head-on collisions. Also, the occurrence of the crashes at night and a high density of access points were closely associated with more severe head-on collisions. Another research study carried out by (Id et al., 2019) employed multivariate and ratio analysis with descriptive analysis to show that the major contributing risk factor in road traffic accidents is traffic volume. Also, road expansion, which is a mere 1.47 percent compared to a yearly vehicle increase of 4.14 percent, is what leads to traffic accidents.

Whereas, M. Ma et al., (2007) applied a generalized estimating equations modeling approach with a negative binomial link function to focus on safety analysis related to urban arterials under heterogeneous traffic patterns in Beijing, China. The accident data for 123.5 km of road segments and 108 signalized intersections were examined over a three-year period (2004 to 2007). Negative binomial regression was used in another study (Liu et al., 2018) to identify the potential risk variables of extremely serious traffic accidents.

By employing a multilevel ordered logit model, Haghighi et al., (2018) identified various factors related to roadway geometric features that were associated with a reduced likelihood of severe crashes. The contributing parameters included lane width of 10 ft., reduced shoulder width, and reduced number of roadside hazards, a higher density of driveways, longer length of barriers, and a barrier offset that is relatively shorter.

A recent study by Aidoo & Ackaah, (2021) linked severe driver injury with numerous risk factors such as driver gender, action taken by the driver against perceived risks, vehicle size, number of vehicles involved, and road width with the help of a generalized ordered logit model. (Haghighi et al., 2018) captured some unobserved characteristics in vehicle features, roadway conditions, environmental factors, and crash attributes by estimating a random-parameter ordered probit model.

There are variety of statistical techniques, reviewed in Table 2.2, applied to conduct road traffic safety research. Whereas, majority of the previous methodologies contemplate the effects of observable variables constricted against all observations, while the independent variables on the other hand have varied impact on each victim's injury outcomes. Thus, restricting the observable explanatory variables across all observations is wrong concept. Moreover, certain unobserved variables might significantly affect the injury severity of victim's e.g. speed of vehicle at the time of collision, victim's perception of risk, traffic volume on specific roadway entity and driver's behavior towards traffic and environmental characteristics etc. which are practically impossible to gather in developing countries' because of inadequate and restricted accident data collection systems, such as Pakistan. Having said that, if unobserved heterogeneity is not given consideration and observable variable impacts are limited to being consistent throughout each and every observation, will result in inadequately stating the model, and hence the parameters estimated will generally be ineffective and biased, resulting in incorrect inferences and predictions (F. L. Mannering et al., 2016). Considering all that, a random parameters mixed logit model was applied in our research study to explore significant risk factors influencing road crash severity in urban Peshawar. Nonetheless, the often-known random parameters technique is likely the one that gets used extensively of the different approaches because of its capacity to account for unobserved heterogeneity (F. L. Mannering et al., 2016). With the random parameters approach, the premise is to account for heterogeneity between data observations by permitting all the estimated parameters in the model to fluctuate across observations. In the recent past, some research studies related to traffic safety used random parameter models that consider the possible heterogeneity in means and the variances of random parameters (Waseem et al., 2019; Behnood & Mannering, 2017; Damsere-Derry et al., 2021; Zubaidi et al., 2021; M. Islam & Mannering, 2020).

Table 2.1: Systematic Review of Literature related to road traffic safety studies

Year	Author	Location	Context	Key Findings
2022	Zhang et al.	Pennsylvania, USA	Inferring the causal effect of work zones on crashes: Methodology and a case study	While, envisaging the effect of work zones on road crashes it was concluded that work zones have a significantly positive impact on crashes, particularly on busy roadways (high traffic volumes), pertaining to long-distance work zones and finally work zones that are active during the day rather than at night.
2021	Adanu et al.	Alabama, USA	Factors associated with driver injury severity of lane changing crashes involving younger and older drivers	This study's findings suggest that in lane-changing crashes, younger male drivers have a higher risk of suffering a severe injury than older male drivers.
2021	Al-Omari et al.	Florida, USA	Crash analysis and development of safety performance functions for Florida roads in	Safety performance functions (SPF) developed in this study revealed that variables like average annual

			the framework of the context classification system	daily traffic (AADT), signalized intersection, density of access points, speed limits and width of shoulder affects the frequency of crashes. While, variables including the presence of bicyclists' slots and concrete surfaces did not influence the crash frequency.
2020	Cantillo et al.	Cartagena, Colombia	An exploratory analysis of factors associated with traffic crashes severity in Cartagena, Colombia	Conclusions from this research indicated that the likelihood of fatal accidents on roadways with speed restrictions of more than 40 km/hr is greater, and that males and people aged 60 or above are the victims with the highest risk of fatal crashes.
2020	Azimi et al.	Florida, USA	Severity analysis for large truck rollover crashes using a random parameter ordered logit model	Factors associated with higher injury severity of roll over crashes incorporates, sandy road surface, driving aggressively, not wearing seatbelt, speeding (50-75 mph), downhill grade, unpaved shoulder, alignment of curvature, defective tires and crashes occurring in summer time period.
2019	Zhou & Chin	Singapore	Factors affecting the injury severity of out-of-control single-vehicle crashes in Singapore	Results indicated that variables such as age (65 and higher), driving under influence, error type of out of control vehicle, left and right turns in driving maneuvers, and vehicles driven after midnight are generally associated with severe injuries for

				both riders and drivers. Meanwhile, risk factors like wet, oily, or sandy surfaces are less likely to result in serious injury.
2018	Duddu et al.	North Carolina, USA	Modeling and comparing injury severity of at-fault and not at-fault drivers in crashes	The driver's age, physical condition, gender, vehicle type, and the number and type of traffic rule violations were found to have a major effect on the severity of injuries sustained by not-at-fault drivers.
2017	Chen et al.	Indiana, USA	Impact of road-surface condition on rural highway safety: A multivariate random parameters negative binomial approach	The positive sections of the parameter density function show that increased roughness normally increases the projected crash frequency because drivers may lose control of their vehicles. The negative sections show that higher surface roughness is often related with a lower predicted crash frequency, most likely because drivers are more likely to drive more cautiously.
2016	Shaheed et al.	Iowa, USA	Analysis of occupant injury severity in winter weather crashes: A fully Bayesian multivariate approach	Occupant-specific parameters (gender, seating position, occupant trapped status, ejection status, and occupant protection applied), as well as crash-level factors (road junction type, first harmful event and major cause of crash) were significant factors affecting occupant

				injury severity.
2015	Z. Ma et al.	China	Exploring factors contributing to crash injury severity on rural two-lane highways	The age group of 25-39 years of the at-fault driver, whether or not the at-fault driver has a license, alcohol consumption, over speeding, pedestrians' involvement, type of area, weather condition, pavement surface type, and the angle of collision were linked to higher crash injury severity.
2014	Çelik & Oktay	Erzurum and Kars, Turkey	A multinomial logit analysis of risk factors influencing road traffic injury severities in the Erzurum and Kars Provinces of Turkey	Drivers aged over 65; primary-educated drivers; single-vehicle accidents; accidents on state routes, also on highways or provincial roads; and the presence of pedestrian crosswalks, intended to increase the probability of fatal crashes.
2014	Amarasingha & Dissanayake	Kansas, USA	Gender differences of young drivers on injury severity outcome of highway crashes	Female driver injury severity was influenced significantly by variables such as; females having valid license, driving on the weekend, overturn crashes and accident with a pedestrian. While, male driver injury severity was associated with risk variables such as; driving on unleveled roadways, traveling on concrete surfaces, driving on wet roadway surface, rear end

				accidents and accident with a vehicle.
2011	Siskind et al.	Queensland, Australia	Risk factors for fatal crashes in rural Australia	Factors involved in fatal crashes were more likely to be speed, alcohol and the violation of rules concerning roadway. Fatal crash victims were 2 and half times more likely than non-fatal victims to be unrestrained inside the car.
2009	Pande & Abdel-Aty	Florida, USA	A novel approach for analyzing severe crash patterns on multilane highways	Various risk factors, such as speed limit, average daily traffic (ADT), K-factor, time of the day, day of week, type of median, pavement surface condition and presence of horizontal curvature, were significant factors causing severe rear-end crashes.

Table 2.2: Methodological Approaches used for road crash Severities in Past

Methodological Approach	Previously carried out by
Heteroskedastic ordered probit approach	(Lemp et al., 2011)
Multinomial logit model-Bayesian network	(C. Chen et al., 2015)
Random Parameters Ordered probit model	(Yu et al., 2020; Jalayer et al., 2018)
Ordered Logit Model	(Rezapour et al., 2019; C. Chen et al., 2016)
Random Parameters mixed logit model	(Kim et al., 2013; Mannera &W¨unsch-Zieglerb, 2013; Ye & Lord, 2014; Cerwick et al., 2014; Behnood & Mannering, 2016; Intini et al., 2020)
(Random parameters) count models	(Barua et al., 2015; Buddhavarapu et al., 2016; Saeed et al., 2019)
Multivariate Poisson log-normal	(Shalkamy & El-Basyouny, 2020)
Multivariate random parameters Tobit model	(Zeng et al., 2017; Guo et al., 2019)
Bivariate probit model	(Russo et al., 2014; Yuan et al., 2020)
Poison quantile regression model	(Tang et al., 2020)
Latent class binary logistic regression model	(Y. Chen et al., 2020; Samerei et al., 2021)
Poisson hierarchical model	(Khazraee et al., 2018)
Logistic Regression models	(Amarasingha & Dissanayake, 2014; Z. Wang et al., 2021; Zhao et al., 2019)
Hierarchical Bayesian random intercept approach	(Haq et al., 2020a; Haq et al., 2021b)
Bayesian spatial generalized ordered logit approach	(Zeng et al., 2019)
Multinomial generalized Poisson model	(Chiou & Fu, 2013)
Hierarchical Bayesian binary probit models	(R. Yu & Abdel-Aty, 2014)

2.3 Vulnerable road users (VRU's)

Since, our study includes the crashes involving various vulnerable road users in vast majority, they need to be defined and reviewed. Vulnerable road users generally include bicyclists, motorcyclists and pedestrians. Of all of these the least protected vulnerable road users are pedestrians, making them prone to severe or fatal injuries. In the recent, report of (WHO, 2018) it shows that pedestrians and cyclists accounts for 26 percent of the overall fatalities and those using motorcycles and motorized three-wheelers accounts for another 28 percent. Thus, cyclists, motorized two-wheelers, three-wheelers, and pedestrians represent more than 50 percent of the road crash fatalities. Whereas, (Hoque et al., 2008) concluded that vulnerable road users were responsible for approximately 80% of fatalities caused by road traffic crashes in urban settings. Although, the heavy burden of deaths sustained by vulnerable road users, most of the countries still ignore their presence in planning design and operation of roads that prioritize cars and other motorized transport vehicles. Moreover, the roads network in most of the countries lacks separate lanes for cyclists and adequate pedestrian crossings.

Recently, Zamani et al., (2021) used Los Angeles crash data for the year 2012-2017. Random parameter mixed logit model was estimated to discover the risk variables that major impact on the degree of pedestrian injury severity and to determine its stability over time. The study concluded that young pedestrians under the age of 31, increased the likelihood of minor injuries for 61.71 percent of the pedestrians and for the remaining pedestrians the probability of minor injuries was decreased. Moreover, middle-aged pedestrians between the ages of 30 and 50 had a lower risk of severe injuries. However, middle-aged pedestrians have no consistent effects on the likelihood of no and mild injuries over different periods of time. Also elderly pedestrians above the age of 50 significantly affect pedestrian injury severity having an increased probability of severe injury and decreased probability of no injury.

Habibovic & Davidsson, (2011) focused on intersection crashes between cars and VRU’s. According to the findings, the predominant factor that contributed to the crashes was the driver's inability to notice VRUs because of poor visibility, less awareness, or insufficient understanding. Moving on to a recent research study on autonomous vehicle crashes involving VRUs by (Kutela et al., 2022) found that vulnerable road users were directly and indirectly involved in crashes between AVs and VRU’s. Two of the components of VRU’s, i.e., cyclists and motorcyclists, have a high probability of being directly involved in collisions with AV’s in which bicyclists are more likely to be at-fault, while pedestrians are more likely to be involved indirectly.

2.4 Risk Factors

The literature reviewed shows that various efforts have been made in the past to discover the major factors of risk that add to the severity of road crashes using a diverse range of statistical models. The following factors were shown to be responsible for an increase in road crash severity: Victim’s age and gender (Morgan & Mannering, 2011), (Obeng, 2011), (Damsere-Derry et al., 2021), (Benlagha & Charfeddine, 2020), (Cantillo et al., 2020), (Shaheed et al., 2016), driver characteristics preferably driver’s age, driving under influence (DUI), aggressive driving etc. (Kaiser et al., 2016), (Berdoulat et al., 2013), (Z. Ma et al., 2015), (Behnood & Mannering, 2017), (Çelik & Oktay, 2014), (Zubaidi et al., 2021), (Duddu et al., 2018), (Zhou & Chin, 2019), (M. Islam & Mannering, 2020), roadway geometric characteristics (Wu et al., 2021), (Mehrara Molan et al., 2019), (Saeed et al., 2019), (Adanu et al., 2021), (Haghighi et al., 2018), risk factors related to speed (M. Islam et al., 2022), (Pande & Abdel-Aty, 2009), (De Pauw et al., 2014), (Vadeby & Forsman, 2018), (Alhomaidat et al., 2020), (Waseem et al., 2019), (Siskind et al., 2011), (Z. Ma et al., 2015), crashes involving heavy vehicles (Dong et al., 2015), (Waseem et al., 2019), (M. Islam et al., 2022) pavement surface condition (Morgan & Mannering, 2011), (S. Chen et al., 2017), risk factors related to volume of traffic (Milton et al., 2008), (S. Chen et al., 2019), (M. Islam et al., 2022), weather and lighting conditions (Naik et al., 2016), (Malin et al., 2019), (Zhai et al., 2019), (Waseem et al., 2019), (Fountas et al., 2020), risk factors related to vulnerable road users (VRU's) (Vanlaar et al., 2016), (Zamani et al., 2021), (Habibovic & Davidsson, 2011), (Kutela et al., 2022).

Moreover, it has been observed that in United States, speeding and drunk driving (also referred to as driving under influence) accounted for 58 percent of all road fatalities in 2014 (National Center for Statistics and Analysis, 2016).

2.4.1 Driver Characteristics

Several research studies have found driver's attributes significant while exploring risk factors contributing in road traffic crashes. For instance, (Duddu et al., 2018) conducted research in which they examined and compared the outcome of chosen variables on the severity of drivers. Injury severity of drivers' was explored while grouping them into 2 categories; at fault drivers and not at-fault drivers. The data used for the analysis and modelling was taken from highway safety and information system (HSIS) for the state of North Carolina. When compared to at-fault drivers, the study's findings showed that not-at-fault drivers' injury severity was affected more by their age, physical condition, and gender. It was further concluded that motorcyclists and drivers aged 70 and above are supposed to be the most vulnerable group of road users.

Another study (Zhou & Chin, 2019) investigated the risk parameters influencing the severity of injuries of uncontrolled single vehicle (SV) crashes using an order probit model. The data used for this study was derived from national crash records in Singapore from 2012-2014. The age of both the drivers and riders was found to be significant. That is, older drivers and riders (65 and above) are more susceptible to severe injuries. Results when compared to middle-aged riders and drivers, older riders and drivers' probabilities of being fatally injured are found to be 1.44% and 1.11% higher. Moreover, riding and driving under the influence (DUI) of alcohol is revealed to be significant and they are most likely to undergo severe injuries. Riders who were found to be riding under the influence of alcohol and involved in SV out of control crashes increased their probability of being fatally injured by 2.29%. (Z. Ma et al., 2015) by employing a generalized ordered logit approach explored risk factors that affect injury severity caused by crashes that occur on two-lane rural highways. The study concluded that the age of the driver at fault (25–39 years) and alcohol consumption tend to increase the crash injury severity.

2.4.2 Risk factor of speed

There is a significant association between road crash severity and speed. Research carried out in the past that has found the effect of speed on road crash severity includes: (Vadeby & Forsman, 2018), who analyzed the impact of updated speed limits on road traffic safety in Sweden. The findings of the study show a substantial decrease in fatalities when speed limits were reduced from 90 to 80 km/h on rural highways. The fatality rate was reduced by 41 percent, i.e., 14 deaths per year while there was no significant change in the number of seriously injured. On the contrary, the speed limit for motorways was raised to 120 km/h, for which an increase in the number of seriously injured was observed by 15 every year, whereas the fatality rate remained constant. Another study carried out in Belgium by (De Pauw et al., 2014) concluded that lowering the speed from 90 km/h to 70 km/h reduced injury severity in 62 percent of the locations. Specifically, for intersections and road sections there was a decrease in 43 percent and 70 percent of locations in crash rates respectively. Moreover, a decrease of 67 percent was found for all the locations in terms of fatal and serious crash injuries.

2.4.3 Victim's characteristics

In comparison between male and female occupants, male occupants were 23 percent and 37 percent less likely to undergo serious and possible injuries as long as they being involved in weather-related crashes. Also when male occupants were not involved in weather related crashes they were 44 percent and 25 percent less likely to be seriously and possibly injured. Also, the overall model reveals that the likelihood of male occupants when compared to female occupants of being seriously and possibly injured is less than 30 percent and 28 percent (Shaheed et al., 2016). Another study (Cantillo et al., 2020) found out that males and people at the age of 60 or above have a higher likelihood of sustaining a fatal injury in a crash. The suggested higher fatality risk related to males may reflect the fact that they are most likely to be involved in risky behavior when compared to females.

2.4.4 Heavy vehicles

The severity of road crashes has been influenced by heavy vehicles. (Dong et al., 2015) identified the risk factors that were involved in the severity of truck-involved crashes. The study concluded that low traffic volume with a high percentage of trucks is more likely to lead to a serious traffic crash, i.e., fatal/incapacitating injury. Another study (Waseem et al., 2019) focusing on motorcyclists' injury severity concluded that a motorbike when engaged in a collision with heavy vehicles like trucks and buses, is most probably to cause a fatal/severe injury.

2.4.5 Pavement surface condition

Pavement surface condition also comes under the umbrella of risk factors that influence road crash severity. A study conducted on rural Indiana highways over a 3-year period (S. Chen et al., 2017) stated that roads with increased roughness (in poor condition) tend to increase the crash frequency because of the loss of control of vehicles by drivers. That is the interpretation of the positive portion of the PDF (parameter density function). The negative portion of which dictates that increased surface roughness is generally linked with a decrease in crash frequency, with the possible reason being that drivers are expected to drive more carefully on roads in poor condition. Another study conducted by (Morgan & Mannering, 2011) estimated a separate mixed logit model for young and older males and females considering three weather related pavement surface conditions. The results showed that all the females and older male drivers were more likely to undergo severe injuries when crashes took place on wet and snow/icy surfaces. Whilst male drivers below the age of 45 years had a lower likelihood of severe injuries on wet and snow/icy surfaces relative to crashes that occurred on dry surfaces.

2.4.6 Weather and Lighting conditions

Weather as well as lighting conditions also have a substantial impact on the severity of road crashes. (Fountas et al., 2020) focused on the impact of lighting and weather conditions on the injury severities of SV crashes. Accident data from Scotland, UK, was used to identify risk factors associated with crash injury severity under different weather and lighting conditions. Results showed that crashes that involve vehicles that skid are more likely to result in minor injuries during daylight and in poor weather conditions. On the contrary, the model that takes into account daylight and fine weather, skidding vehicles also increases the threshold between serious and fatal injuries. Moreover, while considering run-off crashes, the possibility of serious or fatal injuries increases in daylight and fine weather conditions.

Naik et al., (2016) while using random parameters, multinomial and ordered response models investigated crash injury severity under different weather conditions. They concluded that severe crash injuries were associated with rain and warmer air temperatures in single-vehicle (SV) truck crashes, whilst less severe injuries were associated with higher levels of humidity.

2.5 Research carried out on National level

Ahmad et al., (2019) looked into how environmental factors, accident type, including the characteristics of the vehicles and drivers' involved in the crash, and other factors affected the severity of motorway crashes. The data set regarding motorway crashes was acquired from the national highway and motorway police (NHMP) of Pakistan for the period of seven years (2009–2015). In this particular study, four distinct levels of injury severity, property damage only (PDO), minor injury, major injury, and fatal injury, were used to estimate an ordered probit model. Motorway crash severity was significantly correlated with ten explanatory variables. The major factors of risk that enhanced the propensity of injury severity included speeding, drowsiness, wrong-way driving, illegal pedestrian crossing, and the drivers' increasing age.

Considering the criticality of vulnerable road users, Waseem et al., (2019) explored risk factors influencing the severity of motorcyclists' injuries using accident data for a one-year time span, i.e., from 1st, July, 2014 to 30th, June, 2015. To calibrate the model, four types of motorcyclist injury severity levels were used in the study: no injury, moderate injury, severe injury, and fatal injury. It was discovered that crashes involving middle-aged riders ranging from 25 to 50 years of age and motorcyclists with no formal education, taking place on roadways that have a posted speed limit of at least 70 km/h, collisions between motorcycles and heavy vehicles, collisions with an immovable object, and taking place in dry weather conditions all increase the risk of fatal/severe injury. Whilst, the crashes that took place on streets that are divided and roadways having a specified speed limit of 50 km/hr. or less, also concerning Chinese motorcycle brands, and finally, crashes involving a minimum of one motorcycle and an auto-rickshaw, increased the probability of minor injuries.

Road traffic studies conducted in Pakistan are limited specifically to either roadway segments or considering a pin-point victim, for instance, considering motorcyclists and pedestrians etc. Till now, no traffic study has been conducted with the goal of investigating risk factors affecting road crash severity, leading to numerous types of victim casualties, i.e., considering every single crash that occurs irrespective of its relevance to vulnerable road users and passenger car crashes etc.

CHAPTER 3
DATA STATISTICS

3.1 Accident Data and Source

This present research work is focused on the city of Peshawar, which is the provincial capital of KPK, Pakistan. For the proposed study, crash data was collected from Rescue 1122, District Office Peshawar, which is an emergency service department. The reason for obtaining data from Rescue 1122 was that lower-severity injuries were underreported in police FIR data, resulting in unrealistic coefficient estimation, incorrect inferences, and skewed results (Yamamoto et al., 2008; Ye & Lord, 2011). Moreover, in Pakistan, it is claimed that nearly 80% of traffic-related accidents go unreported to the police authorities (Ghaffar et al., 2001; Hyder & Morrow, 2000; Adnan A. Hyder et al., 2000).

The department reported a total number of 7,403 cases, along with victim-related details including name, age, and gender. The data also included the location of the accident, date, time, reason for the crash, and ultimately the vehicle involved in the crash. In addition to that, weather related data was obtained from an online website, i.e., www.timeanddate.com. Moreover, PDA was approached to acquire information pertaining to the geometric characteristics of the roads, and for the missing details, individual road segments were visited. The data has been collected for a time span of 2 years (Jan 2018 to Dec 2019). The concluded data set contains a total number of 5,765 observations after excluding records with missing details.

3.2 Data Description

Injury has been classified into 3 different levels with respect to increasing order of severity, i.e., (minor injury, major injury, and fatality), which are coded with the following choices. The interpretation of 3 different injury severity levels has been specified in Table 3.1. Moreover, about the victim's existing injury at the location of the accident was recorded by rescue 1122 ambulance staff in the emergency response form, who have experience in medical emergencies with a diploma in paramedics.

Table 3.1: Classification of injury severity level

Level	Definition	Description
1	Minor injury	Minor injury involves no risk to the life of victim undergone an accident. In general it includes (scrapings, lacerations or minor cuts etc.)
2	Major injury	Major injury entails a serious injury that puts the victim's life at stake. Includes (neck, head, spinal injury, single or multiple fractures, considerable bleeding etc.
3	Fatality	It denotes the victim's immediate death as a result of the accident.

Fig 3.1 Illustrates that out of all 5,765 cases involving different victims, 1,732 (30.04%) victims possessed minor injuries. 3,918 (67.96%) victims had major injuries, and 115 (2.00%) had fatal injuries.

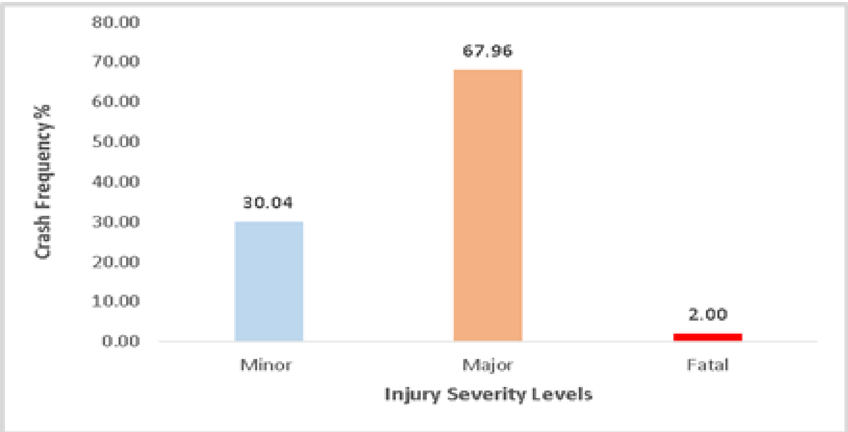

Fig 3.1: *Victim's Injury Severity Distribution*

3.3 Data Descriptive Statistics

The major components that were taken into account for the analysis include different types of vehicles involved, temporal details, driver attributes, environmental conditions, roadway characteristics, and accident specific factors. For each of the aforementioned characteristics, specific variables were included in the final dataset, and their classification is shown in Table 3.2. Whereas the description of variables is presented in Table 3.4. The severity of the victim's injuries was chosen as the response variable, and the final data set included 238 explanatory variables. Except for geometric characteristics of the road and environmental conditions, all other variables were collected from rescue's 1122 emergency response forms. Injuries sustained by male victims outnumbered female victims by a big margin given that roadways are used by males in the vast majority, which is instinctual given the social and demographic constraints. Male victims made up 97.02% of all the victims, while female victims made up 2.98%. Victims from the age group (18-30 years) experienced most of the road traffic crashes (52.33%), followed by the age groups (31-40 years) and (41-50 years) with 19.88% and 8.73%. When compared to weekends (28.88%), weekdays (71.12) had a much higher number of road traffic crashes. Drivers having a license were in the vast majority (98.65%), but most of them did not follow the very common rule of traffic laws that is wearing a seatbelt. Only 2.13% of the drivers involved in crashes were wearing seatbelts, while others were not wearing any sort of protective equipment. Whereas, wearing a seatbelt should be the utmost priority of drivers before they get to drive. Moreover, in daylight (66.56%) of all the road traffic crashes took place, which exceeded the number of accidents that happened during the night or in dark conditions. Road traffic crashes that occurred on urban arterials (37.71%) were more than those that occurred on highways, motorways, collectors and local roads. Victims undergone the highest number of crashes were pedestrians and motorcyclists, with (31.60%) and (28.88%) of the total crashes, followed by motorists (25.27%).

Road crash frequency was higher in August (9.40%), on Friday (15.09%), in the summer season (34.73%), in the off-peak hours (54.99%), in moderate visibility conditions (85.43%), on roadways with 2-lanes in each direction (46.23%), on straight road segments (65.55%), and on roadways having a speed limit of 60 km/hr. (29%).

Fig 3.2: *Victim's Gender*

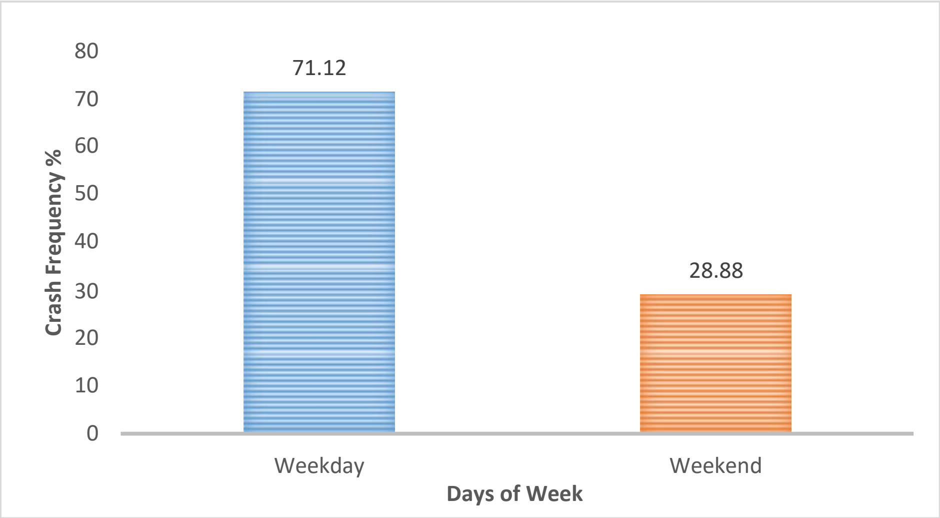

Fig 3.3: *Days of Week*

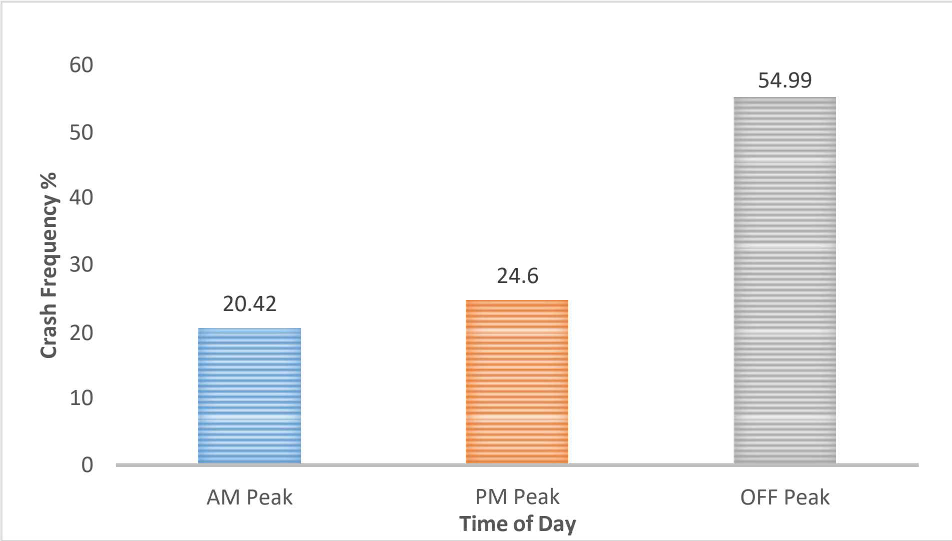

Fig 3.4: *Time of the Day*

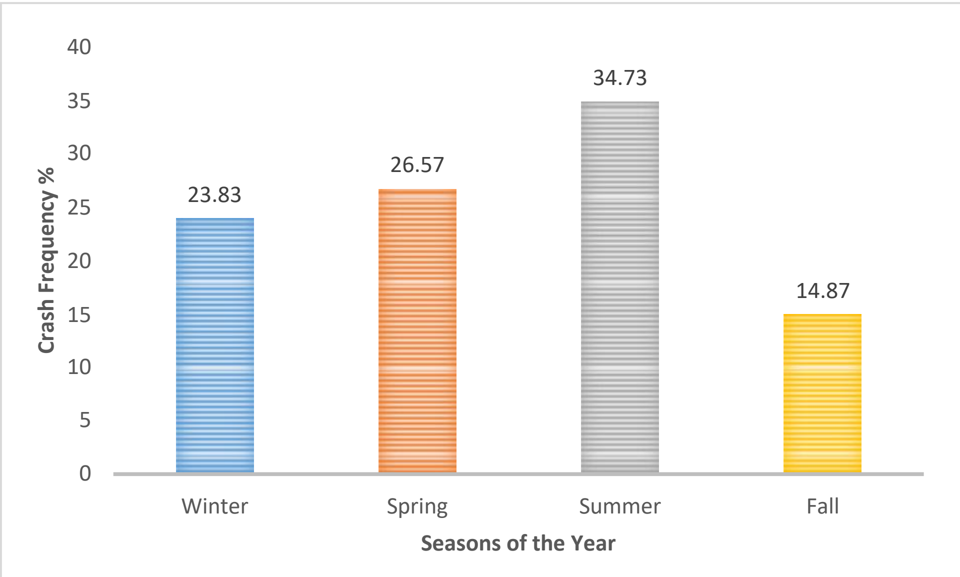

Fig 3.5: *Season of Crash*

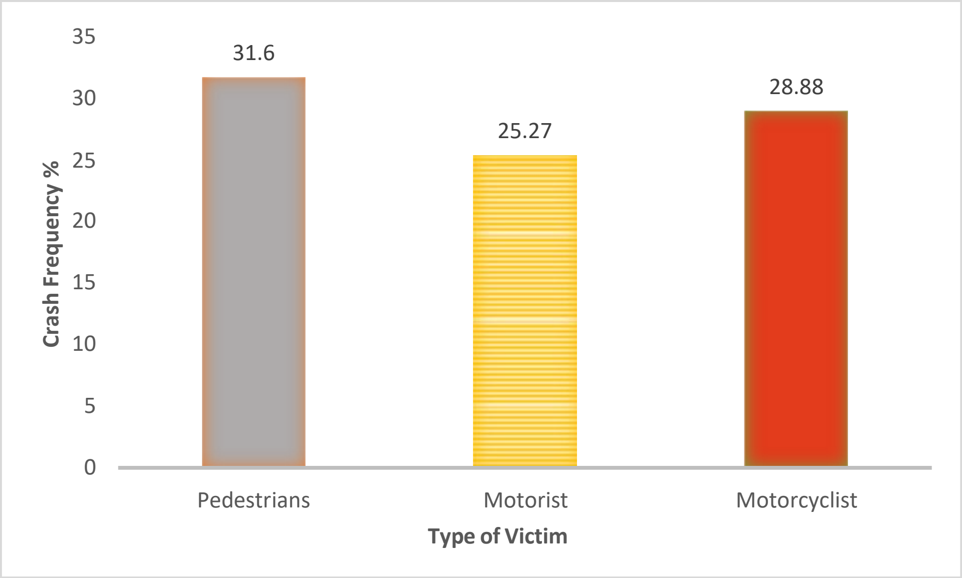

Fig 3.6: *Type of Victim*

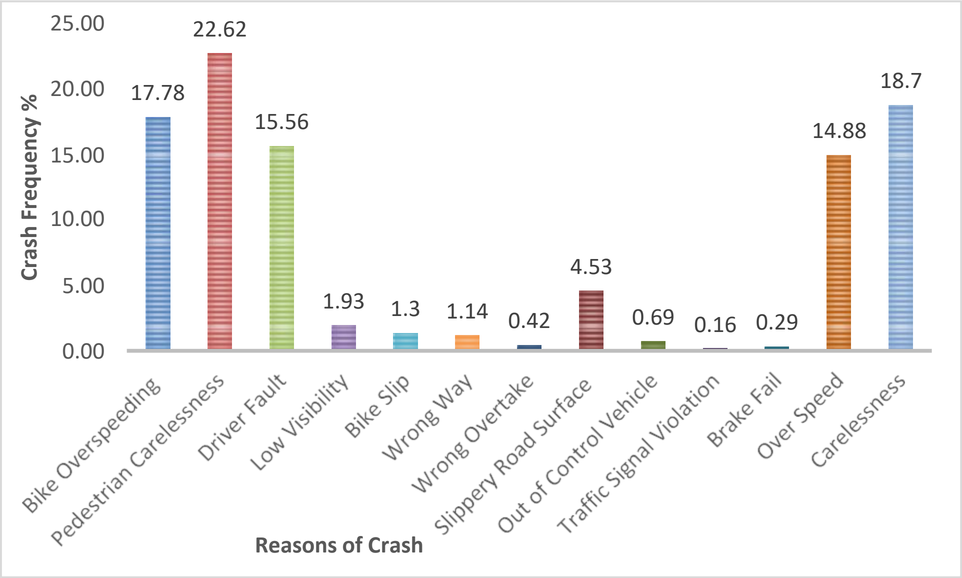

Fig 3.7: *Reasons Reported for Crash*

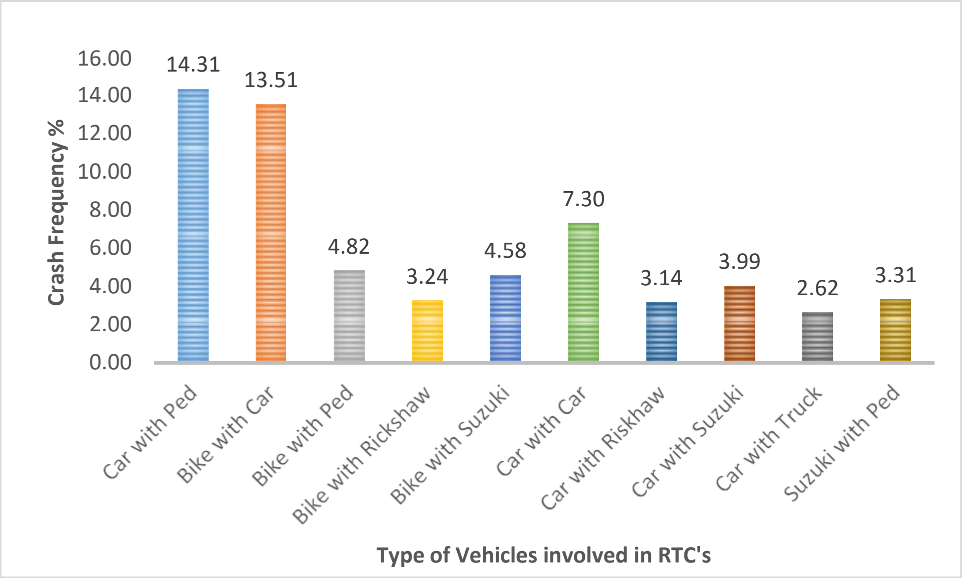

Fig 3.8: *Type of Vehicles Involved in Road Traffic Crashes*

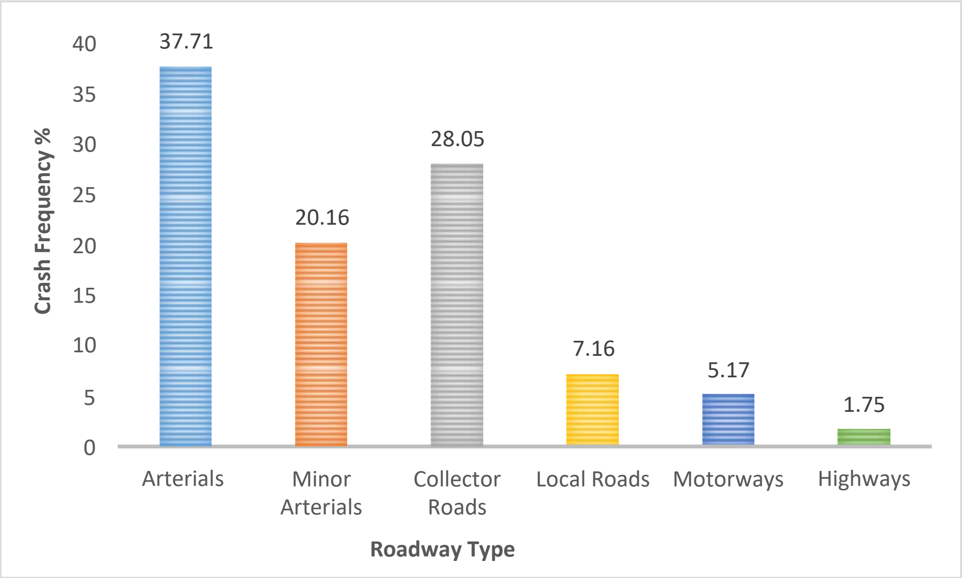

Fig 3.9: *Roadway Type*

Table 3.2: Classification of Independent Variables

Variables Category	Description of Explanatory Variables
Victim's Attributes	i. Gender ii. Age
Type of victims	i. Motorist ii. Motorcyclist iii. Pedestrian iv. Cyclist v. Rickshaw driver vi. Suzuki driver vii. Passenger/Driver
Temporal Details	i. Month ii. Day iii. Season iv. Weekday/Weekend v. Traffic hours
Victim driver Characteristics	i. Gender ii. Age iii. With/Without Seatbelt iv. Driver with or without license
Environmental Conditions	i. Weather forecast ii. Light condition iii. Visibility Condition
Roadway Characteristics	i. Provision of shoulder ii. Type of shoulder iii. Lanes per direction iv. Provision of median v. Type of median vi. Posted speed limit vii. Road with lights/without lights viii. Road signs ix. Traffic signals x. Frontage roads/Service roads
Type of roadways	i. Arterials ii. Minor Arterials iii. Collectors iv. Local Roads v. Highway vi. Motorway
Type of Vehicles involved in crash	i. Car ii. Motorcycle iii. Rickshaw iv. Bus v. Suzuki vi. Truck vii. Wagon viii. Datsun ix. Trailer x. Flying coach/ Hiace/Van xi. Jeep xii. Pickup xiii. Cycle

Some of the vehicles involved in crashes that are not common globally are presented in Table 3.3.

Table 3.3: Type of vehicles with pictures

SN	Type of vehicles	Pictures
1	Wagon	
2	Suzuki	
3	Rickshaw	
4	Flying coach/ Hiace/ Van	
5	Datsun	

Table 3.4: Response and Explanatory Variables with their Descriptions

Sr. No	Selected Variables Description
1	**Victim's injury severity:** 1) minor injury 2) major injury 3) fatal injury
2	**Victim's gender male indicator:** 1 if victim is male, 0 otherwise
3	**Victim's gender female indicator:** 1 if victim is female, 0 otherwise
4	**AM Peak indicator:** 1 for crash occurred in Morning Peak time , 0 otherwise
5	**PM Peak indicator:** 1 for crash occurred in Evening Peak time, 0 otherwise
6	**Off Peak indicator:** 1 for crash occurred in Off Peak time, 0 otherwise
7	**January indicator:** 1 for crash occurred in January, 0 otherwise
8	**February indicator:** 1 for crash occurred in February, 0 otherwise
9	**March indicator:** 1 for crash occurred in March, 0 otherwise
10	**April indicator:** 1 for crash occurred in April, 0 otherwise
11	**May indicator:** 1 for crash occurred in May, 0 otherwise
12	**June indicator:** 1 for crash occurred in June, 0 otherwise
13	**July indicator:** 1 for crash occurred in July, 0 otherwise
14	**August indicator:** 1 for crash occurred in August, 0 otherwise
15	**September indicator:** 1 for crash occurred in September, 0 otherwise
16	**October indicator:** 1 for crash occurred in October, 0 otherwise
17	**November indicator:** 1 for crash occurred in November, 0 otherwise
18	**December indicator:** 1 for crash occurred in December, 0 otherwise
19	**Monday indicator:** 1 for crash occurred on Monday, 0 otherwise
20	**Tuesday indicator:** 1 for crash occurred on Tuesday, 0 otherwise
21	**Wednesday indicator:** 1 for crash occurred on Wednesday, 0 otherwise
22	**Thursday indicator:** 1 for crash occurred on Thursday, 0 otherwise
23	**Friday indicator:** 1 for crash occurred on Friday, 0 otherwise
24	**Saturday indicator:** 1 for crash occurred on Saturday, 0 otherwise
25	**Sunday indicator:** 1 for crash occurred on Sunday, 0 otherwise
26	**Weekday indicator:** 1 for crash occurred on weekday, 0 otherwise
27	**Weekend indicator:** 1 for crash occurred on weekend, 0 otherwise
28	**Winter indicator:** 1 for crash occurred in winters, 0 otherwise
29	**Spring indicator:** 1 for crash occurred in spring, 0 otherwise
30	**Summer indicator:** 1 for crash occurred in summers, 0 otherwise
31	**Fall indicator:** 1 for crash occurred in fall, 0 otherwise
32	**Arterial indicator:** 1 for crash occurred on arterials, 0 otherwise
33	**Minor arterial indicator:** 1 for crash occurred on minor arterials, 0 otherwise
34	**Collector road indicator:** 1 for crash occurred on collector roads, 0 otherwise
35	**Local road indicator:** 1 for crash occurred on local roads, 0 otherwise
36	**Highway indicator:** 1 for crash occurred on highways 0 otherwise
37	**Motorway indicator:** 1 for crash occurred on motorways, 0 otherwise
38	**Seatbelt indicator:** 1 for victim wearing seatbelt, 0 otherwise
39	**License indicator:** 1 for driver having license, 0 otherwise
40	**Age below 10 indicator:** 1 for victim having age less than 10, 0 otherwise
41	**Age between 10 and 18 indicator:** 1 for victim having age between 10 and 18, 0 otherwise

42	**Age between 18-30 indicator:** 1 for victim having age between 18-30, 0 otherwise
43	**Age between 31-40 indicator:** 1 for victim having age between 31-40, 0 otherwise
44	**Age between 41-50 indicator:** 1 for victim having age between 41-50, 0 otherwise
45	**Age between 51-60 indicator:** 1 for victim having age between 51-60, 0 otherwise
46	**Age above 60 indicator:** 1 for victim having age above 60, 0 otherwise
47	**Road signs indicator:** 1 for crash occurred on road having road signs, 0 otherwise
48	**Traffic signals indicator:** 1 for road sections having traffic signals, 0 otherwise
49	**Frontage road indicator:** 1 for presence of frontage road, 0 otherwise
50	**Posted speed 30 km/hr. indicator:** 1 for crash occurred on road with posted speed limit of 30 km/hr., 0 otherwise
51	**Posted speed 40 km/hr. indicator:** 1 for crash occurred on road with posted speed limit of 40 km/hr., 0 otherwise
52	**Posted speed 50 km/hr. indicator:** 1 for crash occurred on road with posted speed limit of 50 km/hr., 0 otherwise
53	**Posted speed 60 km/hr. indicator:** 1 for crash occurred on road with posted speed limit of 60 km/hr., 0 otherwise
54	**Posted speed 80 km/hr. indicator:** 1 for crash occurred on road with posted speed limit of 80 km/hr., 0 otherwise
55	**Posted speed 120 km/hr. indicator:** 1 for crash occurred on road with posted speed limit of 120 km/hr., 0 otherwise
56	**Sunny Weather indicator:** 1 for crash occurred in sunny weather, 0 otherwise
57	**Cloudy Weather indicator:** 1 for crash occurred in cloudy weather, 0 otherwise
58	**Foggy Weather indicator:** 1 for crash occurred in foggy weather, 0 otherwise
59	**Rainy Weather indicator:** 1 for crash occurred in rainy weather, 0 otherwise
60	**Hazy Weather indicator:** 1 for crash occurred in hazy weather , 0 otherwise
61	**Clear Weather indicator:** 1 for crash occurred in clear weather, 0 otherwise
62	**Very poor visibility indicator:** 1 for crash due to very poor visibility, 0 otherwise
63	**Poor visibility indicator:** 1 for crash due to poor visibility, 0 otherwise
64	**Moderate visibility indicator:** 1 for crash due to moderate visibility, 0 otherwise
65	**Good visibility indicator:** 1 for crash due to good visibility, 0 otherwise
66	**Daylight indicator:** 1 for crash in daylight, 0 otherwise, 0 otherwise
67	**Dim light indicator:** 1 for crash in dim light, 0 otherwise
68	**Dusk indicator:** 1 for crash in dusk, 0 otherwise
69	**Dawn indicator:** 1 for crash in dawn, 0 otherwise
70	**Night with road lights indicator:** 1 for crash on road with road lights, 0 otherwise
71	**Night without road lights indicator:** 1 for crash on road without road lights, 0 otherwise
72	**1 lane on each direction indicator:** 1 for crash on road with one lane in each direction, 0 otherwise
73	**2 lane on each direction indicator:** 1 for crash on road with two lanes in each direction, 0 otherwise
74	**3 lane on each direction indicator:** 1 for crash on road with three lanes in each direction, 0 otherwise
75	**2 lane 2 way indicator:** 1 for crash on road with two lanes two way, 0 otherwise
76	**Interchange or check post indicator:** 1 for crash on interchange or check post, 0 otherwise
77	**Dedicated U-turn indicator:** 1 for road with dedicated U-turns, 0 otherwise
78	**Straight road indicator:** 1 for crash on straight road, 0 otherwise

79	**Curved road indicator:** 1 for crash on curved road, 0 otherwise
80	**Roundabout indicator:** 1 for crash on roundabout, 0 otherwise
81	**Intersection indicator:** 1 for crash at an intersection, 0 otherwise
82	**Bridge indicator:** 1 for crash on bridge, 0 otherwise
83	**Dry pavement indicator:** 1 for crash on dry pavement, 0 otherwise
84	**Wet pavement indicator:** 1 for crash on wet pavement, 0 otherwise
85	**Shoulder Provision indicator:** 1 for crash on road with shoulder, 0 otherwise
86	**Paved Shoulder indicator:** 1 for crash on road with paved shoulder,0 otherwise
87	**Unpaved Shoulder indicator:** 1 for crash on road with unpaved shoulder,0 otherwise
88	**Median Provision indicator:** 1 for roadway with median, 0 otherwise.
89	**curbstone indicator:** 1 for crash on road with curbstone median, 0 otherwise
90	**Cat eyes indicator:** 1 for crash on road with cat eyes as median, 0 otherwise
91	**Barriers indicator:** 1 for crash on roads with barriers as median, 0 otherwise
92	**Access point indicator:** 1 for crash on access point, 0 otherwise
93	**Pedestrian victim indicator:** 1 if the victim is pedestrian, 0 otherwise
94	**Motorist indicator:** 1 if the victim is motorist, 0 otherwise
95	**Motorcyclist indicator:** 1 if the victim is motorcyclist, 0 otherwise
96	**Cyclist indicator:** 1 if the victim is cyclist, 0 otherwise
97	**Rickshaw driver indicator:** 1 if the victim is rickshaw driver, 0 otherwise
98	**Driver indicator:** 1 if the victim is driver, 0 otherwise
99	**Cart driver indicator:** 1 if the victim is cart driver, 0 otherwise
100	**Passenger indicator:** 1 if the victim is passenger, 0 otherwise
101	**Bike over speeding indicator:** 1 for crash due to bike over speeding, 0 otherwise
102	**Pedestrian carelessness indicator:** 1 for crash due to pedestrian carelessness, 0 otherwise
103	**Driver's fault indicator:** 1 for crash due to driver's fault, 0 otherwise
104	**Bike slip indicator:** 1 for crash due to bike slip, 0 otherwise
105	**Low visibility indicator:** 1 for crash due to low visibility, 0 otherwise
106	**Wrong way indicator:** 1 for crash due to wrong way driving, 0 otherwise
107	**Wrong side overtake indicator:** 1 for crash due to wrong side overtake, 0 otherwise
108	**Slippery road surface indicator:** 1 for crash due to slippery road surface, 0 otherwise
109	**Out of control vehicle indicator:** 1 for crash due to out of control vehicle, 0 otherwise
110	**Traffic signal violation indicator:** 1 for crash due to traffic signal violation, 0 otherwise
111	**Brake fail indicator:** 1 for crash due to brake fail, 0 otherwise
112	**Over speeding indicator:** 1 for crash due to over speeding, 0 otherwise
113	**Carelessness indicator:** 1 for crash due to carelessness, 0 otherwise
114	**Bike with bike indicator:** 1 for crash between two bikes, 0 otherwise
115	**Bike with bus indicator:** 1 for crash between bike and bus, 0 otherwise
116	**Bike slip indicator:** 1 for bike slip, 0 otherwise
117	**Bike with car indicator:** 1 for crash between bike and car, 0 otherwise
118	**Bike with cycle indicator:** 1 for crash between bike and cycle, 0 otherwise

119	**Bike with Datsun indicator:** 1 for crash between bike and Datsun, 0 otherwise
120	**Bike with flying coach indicator:** 1 for crash between bike and flying coach, 0 otherwise
121	**Bike with footpath indicator:** 1 for crash between bike and footpath, 0 otherwise
122	**Bike with jeep indicator:** 1 for crash between bike and jeep, 0 otherwise
123	**Bike with median indicator:** 1 for crash between bike and median, 0 otherwise
124	**Bike with pedestrian indicator:** 1 for crash between bike and pedestrian, 0 otherwise
125	**Bike with pickup indicator:** 1 for crash between bike and pickup, 0 otherwise
126	**Bike with rickshaw indicator:** 1 for crash between bike and rickshaw, 0 otherwise
127	**Bike with Suzuki indicator:** 1 for crash between bike and Suzuki, 0 otherwise
128	**Bike with tractor indicator:** 1 for crash between bike and tractor, 0 otherwise
129	**Bike with trailer indicator:** 1 for crash between bike and trailer, 0 otherwise
130	**Bike with truck indicator:** 1 for crash between bike and truck, 0 otherwise
131	**Bike with wagon indicator:** 1 for crash between bike and wagon, 0 otherwise
132	**Bus with cycle indicator:** 1 for crash between bus and cycle, 0 otherwise
133	**Bus with Datsun indicator:** 1 for crash between bus and Datsun, 0 otherwise
134	**Bus with pedestrian indicator:** 1 for crash between bus and pedestrian, 0 otherwise
135	**Bus with truck indicator:** 1 for crash between bus and truck, 0 otherwise
136	**Car overturn indicator:** 1 for crash due to car overturning, 0 otherwise
137	**Car with bus indicator:** 1 for crash between car and bus, 0 otherwise
138	**Car with car indicator:** 1 for crash between car and car, 0 otherwise
139	**Car with cart indicator:** 1 for crash between car and cart, 0 otherwise
140	**Car with cycle indicator:** 1 for crash between car and cycle, 0 otherwise
141	**Car with datsun indicator:** 1 for crash between car and datsun, 0 otherwise
142	**Car with flying coach indicator:** 1 for crash between car and flying coach, 0 otherwise
143	**Car with footpath indicator:** 1 for crash between car and footpath, 0 otherwise
144	**Car with jeep indicator:** 1 for crash between car and jeep, 0 otherwise
145	**Car with median indicator:** 1 for crash between car and median, 0 otherwise
146	**Car with pedestrian indicator:** 1 for crash between car and pedestrian, 0 otherwise
147	**Car with pickup indicator:** 1 for crash between car and pickup, 0 otherwise
148	**Car with rickshaw indicator:** 1 for crash between car and rickshaw, 0 otherwise
149	**Car with Suzuki indicator:** 1 for crash between car and Suzuki, 0 otherwise
150	**Car with tractor indicator:** 1 for crash between car and tractor, 0 otherwise
151	**Car with trailer indicator:** 1 for crash between car and trailer, 0 otherwise
152	**Car with truck indicator:** 1 for crash between car and truck, 0 otherwise
153	**Car with wagon indicator:** 1 for crash between car and wagon, 0 otherwise
154	**Datsun with bus indicator:** 1 for crash between Datsun and bus, 0 otherwise
155	**Datsun with cart indicator:** 1 for crash between Datsun and cart, 0 otherwise
156	**Datsun with cycle indicator:** 1 for crash between Datsun and cycle, 0 otherwise
157	**Datsun with jeep indicator:** 1 for crash between Datsun and jeep, 0 otherwise
158	**Datsun with pedestrian indicator:** 1 for crash between Datsun and pedestrian, 0 otherwise
159	**Datsun with tractor indicator:** 1 for crash between Datsun and tractor, 0 otherwise
160	**Datsun with trailer indicator:** 1 for crash between Datsun and trailer, 0 otherwise

161	**Datsun with truck indicator:** 1 for crash between Datsun and truck, 0 otherwise
162	**Flying coach with bus indicator:** 1 for crash between flying coach and bus, 0 otherwise
163	**Flying coach with Datsun indicator:** 1 for crash between flying coach and Datsun, 0 otherwise
164	**Flying coach with pedestrian indicator:** 1 for crash between flying coach and pedestrian, 0 otherwise
165	**Flying coach with truck indicator:** 1 for crash between flying coach and truck, 0 otherwise
166	**Jeep with pedestrian indicator:** 1 for crash between jeep and pedestrian, 0 otherwise
167	**Jeep with wagon indicator:** 1 for crash between jeep and wagon, 0 otherwise
168	**Pickup with pedestrian indicator:** 1 for crash between pickup and pedestrian, 0 otherwise
169	**Rickshaw with bus indicator:** 1 for crash between rickshaw and bus, 0 otherwise
170	**Rickshaw with cart indicator:** 1 for crash between rickshaw and cart, 0 otherwise
171	**Rickshaw with cycle indicator:** 1 for crash between rickshaw and cycle, 0 otherwise
172	**Rickshaw with datsun indicator:** 1 for crash between rickshaw and datsun , 0 otherwise
173	**Rickshaw with flying coach indicator:** 1 for crash between rickshaw and flying coach , 0 otherwise
174	**Rickshaw with jeep indicator:** 1 for crash between rickshaw and jeep, 0 otherwise
175	**Rickshaw with pedestrian indicator:** 1 for crash between rickshaw and pedestrian, 0 otherwise
176	**Rickshaw with pickup indicator:** 1 for crash between rickshaw and pickup, 0 otherwise
177	**Rickshaw with Suzuki indicator:** 1 for crash between rickshaw and Suzuki, 0 otherwise
178	**Rickshaw with tractor indicator:** 1 for crash between rickshaw and tractor , 0 otherwise
179	**Rickshaw with truck indicator:** 1 for crash between rickshaw and truck, 0 otherwise
180	**Rickshaw with wagon indicator:** 1 for crash between rickshaw and wagon, 0 otherwise
181	**Suzuki overturn indicator:** 1 for crash due to Suzuki overturning, 0 otherwise
182	**Suzuki with bus indicator:** 1 for crash between Suzuki and bus, 0 otherwise
183	**Suzuki with cycle indicator:** 1 for crash between Suzuki and cycle, 0 otherwise
184	**Suzuki with datsun indicator:** 1 for crash between Suzuki and datsun, 0 otherwise
185	**Suzuki with flying coach indicator:** 1 for crash between Suzuki and flying coach, 0 otherwise
186	**Suzuki with pedestrian indicator:** 1 for crash between Suzuki and pedestrian, 0 otherwise
187	**Suzuki with pickup indicator:** 1 for crash between Suzuki and pickup, 0 otherwise
188	**Suzuki with Suzuki indicator:** 1 for crash between Suzuki and Suzuki, 0 otherwise
189	**Suzuki with tractor indicator:** 1 for crash between Suzuki and tractor, 0 otherwise
190	**Suzuki with trailer indicator:** 1 for crash between Suzuki and trailer, 0 otherwise
191	**Suzuki with truck indicator:** 1 for crash between Suzuki and truck, 0 otherwise
192	**Suzuki with wagon indicator:** 1 for crash between Suzuki and wagon, 0 otherwise
193	**Tractor with cart indicator:** 1 for crash between tractor and cart, 0 otherwise
194	**Tractor with pedestrian indicator:** 1 for crash between tractor and pedestrian, 0 otherwise

195	**Trailer with pedestrian indicator:** 1 for crash between trailer and pedestrian, 0 otherwise
196	**Truck with pedestrian indicator:** 1 for crash between truck and pedestrian, 0 otherwise
197	**Truck with tractor indicator:** 1 for crash between truck and tractor, 0 otherwise
198	**Wagon with bus indicator:** 1 for crash between wagon and bus, 0 otherwise
199	**Wagon with flying coach indicator:** 1 for crash between wagon and flying coach, 0 otherwise
200	**Wagon with cycle indicator:** 1 for crash between wagon and cycle, 0 otherwise
201	**Wagon with pedestrian indicator:** 1 for crash between wagon and pedestrian, 0 otherwise
202	**Wagon with tractor indicator:** 1 for crash between wagon and tractor, 0 otherwise
203	**Wagon with truck indicator:** 1 for crash between wagon and truck, 0 otherwise
204	**V1 indicator:** 1 for crash involving victims from group ages below 10 and 10-18, 0 otherwise
205	**V2 indicator:** 1 for crash involving victims from group ages below10 and 18-30, 0 otherwise
206	**V3 indicator:** 1 for crash involving victims from group ages below 10 and 31-40, 0 otherwise
207	**V4 indicator:** 1 for crash involving victims from group ages below 10 and 51-60, 0 otherwise
208	**V5 indicator:** 1 for crash involving victims from group ages 10-18 and 18-30, 0 otherwise
209	**V6 indicator:** 1 for crash involving victims from group ages 10-18 and 31-40, 0 otherwise
210	**V7 indicator:** 1 for crash involving victims from group ages 10-18 and 41-50, 0 otherwise
211	**V8 indicator:** 1 for crash involving victims from group ages 10-18 and above 60, 0 otherwise
212	**V9 indicator:** 1 for crash involving victims from group ages 18-30 and 31-40, 0 otherwise
213	**V10 indicator:** 1 for crash involving victims from group ages 18-30 and 41-50, 0 otherwise
214	**V11 indicator:** 1 for crash involving victims from group ages 18-30 and 51-60, 0 otherwise
215	**V12 indicator:** 1 for crash involving victims from group ages 18-30 and above 60, 0 otherwise
216	**V13 indicator:** 1 for crash involving victims from group ages 31-40 and 41-50, 0 otherwise
217	**V14 indicator:** 1 for crash involving victims from group ages 31-40 and 51-60, 0 otherwise
218	**V15 indicator:** 1 for crash involving victims from group ages 31-40 and above 60, 0 otherwise
219	**V16 indicator:** 1 for crash involving victims from group ages 41-50 and 51-60, 0 otherwise
220	**V17 indicator:** 1 for crash involving victims from group ages 51-60 and above60, 0 otherwise
221	**V18 indicator:** 1 for crash involving victims from group ages 10, 10--18, 18-30, 0 otherwise
222	**V19 indicator:** 1 for crash involving victims from group ages 18-30, 31-40, 41-50, 0 otherwise
223	**V20 indicator:** 1 for crash involving victims from group ages 18-30, 31-40, 51-60, 0 otherwise

224	**V21 indicator:** 1 for crash involving victims from group ages 10-18, 18-30, 31-40, 0 otherwise
225	**V22 indicator:** 1 for crash involving victims from group ages 18-30, 31-40, above 60, 0 otherwise
226	**V23 indicator:** 1 for crash involving victims from group ages below10, 18-30, 51-60, 0 otherwise
227	**V24 indicator:** 1 for crash involving victims from group ages 18-30, 41-50, 51-60, 0 otherwise
228	**V25 indicator:** 1 for crash involving victims from group ages 10-18, 31-40, above 60, 0 otherwise
229	**V26 indicator:** 1 for crash involving victims from group ages below 10, 18-30, 31-40, 0 otherwise
230	**V27 indicator:** 1 for crash involving victims from group ages below 10, 18-30, 41-50, 0 otherwise
231	**V28 indicator:** 1 for crash involving victims from group ages 10-18, 18-30, 41-50, 0 otherwise
232	**V29 indicator:** 1 for crash involving victims from group ages 10-18, 41-50, above 60, 0 otherwise
233	**V30 indicator:** 1 for crash involving victims from group ages 31-40, 41-50, 51-60, 0 otherwise
234	**V31 indicator:** 1 for crash involving victims from group ages below 10, 18-30, 31-40, 41-50, 0 otherwise
235	**V32 indicator:** 1 for crash involving victims from group ages 10-18, 31-40, 41-50, 51-60, 0 otherwise
236	**V33 indicator:** 1 for crash involving victims from group ages 18-30, 31-40, 41-50, 51-60, 0 otherwise
237	**V34 indicator:** 1 for crash involving victims from group ages 10-18, 18-30, 31-40, 41-50, above 60, 0 otherwise
238	**V35 indicator:** 1 for crash involving victims from group ages below10, 10-18, 18-30, 31-40, 41-50, 0 otherwise

Table 3.5: Key variable descriptive statistics

Factors	Proportion
Severity of crash	
Minor injury/major injury fatal injury	30.04/67.96/2.00
Month	
January/February/March/April/May/June/July/ August/September/October/November/December	8.43/7.77/9.00 /8.97/8.60/8.78/8.83/9.4 7.72/7.11/7.75/7.63
Day	
Monday/Tuesday/Wednesday/Thursday/Friday/Saturday/Sunday	14.52/14.19/13.77/13.98/15.09/ 13.70/14.74
Weekday/Weekend	71.12/28.88
Season of the year	
Summer season (Jun, Jul, Aug) /Fall (Sept, Oct, Nov)/ Winter (Dec, Jan, Feb) / Spring (Mar, Apr, May	34.73/14.87/ 23.83/26.57
Time of the day	
AM Peak (7am-10am)/PM Peak (4pm-7pm)/off-peak hours	20.42/24.60/54.99
Roadway geometric details	
1 lane each direction/2 lane each direction/3 lane each direction/ 2 lane 2-way roadway	3.71/46.23/34.78/15.28
Median Present/Median not Present	82.93/17.07
Shoulder Present/ Shoulder not Present	33.29/66.71
Posted Speed Limit **(**In km/hr.**)**	
30/40/50/60/80/120	7.13/17.64/27.04/29.00/17.48/1.70
Victim's details	
Gender: Male/Female	97.02/2.98
Age group: Below 10yrs/10-18yrs/18-30yrs/31-40yrs/41-50yrs/51-60yrs/Above 60yrs	3.10/6.78/52.33/19.88/ 8.73/6.18/3.00
Pedestrian/Motorist/Motorcyclist/Cyclist/Rickshaw driver/Driver/Cart Driver/Passenger	31.60/25.27/28.88/0.99/5.86/ 6.54/0.14/0.71
Driver details:	
With License/Without license	98.65/1.35
With seatbelt/Without seatbelt	2.13/97.87

Weather and light conditions	
Sunny/Rainy/Haze/Cloudy/Foggy/Clear	12.52/5.39/28.64/46.56/3.14/3.75
Dawn/Daylight/ Dim light/Dusk/Night with road lights/ Night without road light	1.96/ 66.56/3.38/5.38/17.47 /5.26
Visibility Conditions	
Poor/Moderate/Good/Very Poor	13.91/85.43/0.43/0.23
Roadway Type	
Arterials/Minor Arterials/Collector Roads/Local Roads/Highway/Motorway/	37.71/20.16/28.05/7.16/ 5.17/1.75

CHAPTER 4

RESEARCH METHODOLOGY AND MODEL ESTIMATION RESULTS

4.1 Overview

Statistical modelling of road traffic crash data usually focuses on assessing the crash likelihood and the injury severity caused by it. However, the accident probability is determined by the total number of traffic accidents that take place in a specified area within a specific period of time. After witnessing an accident, the severity of injury caused by the accident to the victim is noted and assessed within 30 days of the road crash by the police officers in the US, and they are generally considered as discrete quantities, that could be either no injury/property damage only, minor injury, major/severe injury, or fatal injury, including a plethora of information that can be used as explanatory variables in injury severity modelling (F. L. Mannering & Bhat, 2014), also discussed in section 7.3 of (F. Mannering, 2018). Another research study (P. T. Savolainen et al., 2011) states that present road crash injury severity modelling techniques generally have either a binary discrete response outcome as dependent variables (e.g., injury or no injury, incapacitating or non-incapacitating) or multiple discrete outcomes (e.g., no injury, possible injury, severe injury, or fatality). Moreover, the crash severity is typically determined by the individual who was injured the most severely in that particular crash.

4.2 Mixed Logit Model

Various methodological approaches have been used in the past all over the world (as discussed in chapter 2 of this study) to analyze the severity of injuries sustained in road traffic crashes. This particular study deployed a “random parameter mixed logit approach with heterogeneity in means and variances” of the random parameters to assess the influence of risk factors on road crash injury severity. The frequency and severity of the crashes may be affected by some unobservable risk factors, or the observation of such risk factors may be nearly impossible to gather. However, if by any means, the unobserved risk factors (unobserved heterogeneity) are found to be associated with the risk factors that have been observed, the results drawn could have biased parameters, leading to incorrect inferences. Moreover, (F. L. Mannering & Bhat, 2014) discussed age as an example to explain unobserved heterogeneity. They said that age is associated with several prevailing factors that have the potential to affect injury severity caused by crashes, such as the victim's physical health, bone fragility, body posture at the time of the crash, reaction time that may reduce the severity of the crash, and many more. So, incorporating only age as an explanatory variable by assuming its effect to be the same across the population will lead us to incorrect inferences and predictions drawn from the rest of the parameter estimates as well. (F. L. Mannering et al., 2016) also discussed various explanatory variables with possible heterogeneous effects. Moving on to some other important missing variables like vehicle operating speed or speed at the time of crash, driver behavior, vehicle condition, vehicle's model year information, traffic volume, victim perception of risk, total number of occupants in a vehicle, etc. may also influence crash-injury severity. (Al-Bdairi et al., 2020) carried out a research study on investigating the driver injury severities in animal-vehicle crashes and confirmed the superiority of the "random parameters logit approach with heterogeneity in means and variances".

By permitting the estimated parameters to vary across observations, the random parameter logit modeling technique deals with the problem of unobserved heterogeneity. The injury-severity of victims caused by road traffic crashes in urban Peshawar is taken into account with possible injury outcomes such as minor injury, major injury, and fatal injury. To address the possible unobserved heterogeneity, a random parameter mixed logit approach accounting for possible heterogeneity in means and variances of the random parameters is applied. Function for the determination of injury severity caused by road traffic crashes is given by according to (M. Islam & Mannering, 2020):

$$\boldsymbol{S_{kn} = \beta_k X_{kn} + \varepsilon_{kn}} \tag{1}$$

In the above equation, S_{kn} is the function of injury-severity that determines the likelihood of an injury-severity outcome k in a road crash n. Whereas, X_{kn} is a vector of explanatory variables that influence injury severity level k caused by road traffic crashes, β_k indicates coefficients of explanatory variables, and ε_{kn} represents the error term.

According to (McFadden, 1981) assuming the error term ε_{kn} to follow generalized extreme value distributed, then the standard multinomial logit model (MNL) results as;

$$P_n(k) = \frac{EKP[\beta_k K_{in}]}{\sum_{\forall K} EKP[\beta_k K_{In}]} \tag{2}$$

Where $P_n(k)$ represents the probability of a road traffic crash n that will result in an injury severity outcome k also K denotes the set of all the three possible injury severity outcomes. Moreover, the mixing distribution introduced in the multinomial logit model allows parameters to vary across all the crash observations. In a mixed logit model, observed predictor variables are inspected to be random or fixed, which compensates for the unobserved heterogeneity in the crash data. Nevertheless, the unobserved heterogeneity in the crash data tends to produce the random parameters. So, by allowing one or two of the parameter estimates in the vector β_k to vary across the observations, Equation 2 can be interpreted as (Train, 2009; Washington et al., 2020):

$$P_n(k) = \int \frac{EKP[\beta_k K_{in}]}{\sum_{\forall K} EKP[\beta_k K_{In}]} f(\beta_k/\varphi_k) d\beta_k \quad (3)$$

Here $f(\beta_k/\varphi_k)$ represents the density function of β_k whilst φ_k is the vector of parameters that describe the density function (mean and variances). For estimation of the model in Eq. (3), a simulated maximum likelihood approach is accompanied by using 500 Halton draws (McFadden and Train, 2000; Train, 2009). In this particular study, several distributions were empirically explored for the term $f(\beta_k/\varphi_k)$ during model estimation, resulting in the statistical superiority of the normal distribution over the rest of the distributions. So, in all the model estimations a normal distribution was used (also found to be superior in past research such as Islam et al., 2020a; Islam & Mannering, 2020b; Behnood & Mannering, 2017; Alnawmasi & Mannering, 2019; Milton et al., 2008).

To incorporate the possible unobserved heterogeneity in the means and variances of the parameters, let β_{kn} vary across the observed crashes specified as (Waseem et al., 2019; Seraneeprakarn et al., 2017; Alnawmasi & Mannering, 2019; Behnood & Mannering, 2017; Islam et al., 2020a; Islam & Mannering, 2020b; Washington et al., 2020):

$$\beta_{kn} = \beta + \Theta_{kn} Z_{kn} + \sigma_{kn} \text{EXP}(\Psi_{kn} W_{kn}) \upsilon_{kn} \quad (4)$$

In the aforementioned equation, β refers to the parameter estimate mean across all the observed crashes, whereas Z_{kn} and W_{kn} are the vectors of crash specific explanatory variables that capture heterogeneity in means and the standard deviation (σ_{kn} with corresponding parameter vector Ψ_{kn}), respectively, Θ_{kn} is known as the corresponding vector of estimable parameters, and finally υ_{kn} represents the disturbance term.

Furthermore, to investigate which of the competing models is statistically superior in this study, i.e., the "random parameter logit model with and without heterogeneity in means and variances", various empirical test statistics were conducted, including the log-likelihood ratio test, Akaike's information criteria, and Bayesian information criterion tests. Eq. (5) represents the likelihood ratio tests that were carried out in this research to assess the alternative estimated models statistical superiority.

$$3^2 = -2[LL(\beta_A) - LL(\beta_B)] \quad (5)$$

In this equation, $LL(\beta_A)$ and $LL(\beta_B)$ are the "log likelihoods at convergence" values for the competing models. However, 3^2 is a test statistic following a chi-square distribution with degrees of freedom equal to the difference in the estimated parameters of the two models. The final model that has been presented and discussed is the one with the highest log-likelihood at convergence values and the smallest AIC and BIC values. Nevertheless, for convenient reference and comparison, Table 4.4 presents the goodness-of-fit data statistics of each competing model.

4.3 Temporal Stability

According to contemporary traffic safety research, the influence of risk factors related to injury severity does not remain stable over time. Since, crash data analyzed in this study were of 2 years, temporal instability in the model is likely to exist (F. Mannering, 2018). As an illustration (Zubaidi et al., 2021), while investigating the severity of drivers' injuries involved in road crashes at unsignalized intersections, they discovered the existence of significant temporal instability in the four years (2015–2018) of crash data. Temporal instability was also observed by (K. Wang et al., 2021) in both models, i.e., injury severity and vehicle damage models, while analyzing 2 years of data for an intersection in Connecticut, and was also observed by (M. Islam

& Mannering, 2021) for both male and female drivers, i.e., the factors effecting the injury severities of drivers varied over time significantly. Also, to learn about temporal instability in pedestrians' and bicyclists' injury severities, see (Behnood & Mannering, 2016) and (Hosseini et al., 2022).

The determination of the temporal stability of "a random parameter logit approach with heterogeneity in means and variances of random parameters" is given by the following test (M. Islam et al., 2020);

$$\chi^2_g = -2[LL(\beta_{Total,g}) - LL(\beta_{2018,g}) - LL(\beta_{2019,g})] \quad (6)$$

In the aforementioned equation, LL ($\beta_{Total,g}$) is the overall model log likelihood at convergence, i.e., the model run for all the data in hand (2018–2019) for the model type g (i.e., "RP logit model with and without heterogeneity in means and variances"), whilst LL ($\beta_{2018,g}$) and LL ($\beta_{2019,g}$) denote the log likelihood at the convergence of a model type g for the crash data of year 2018 and 2019 respectively. Table 4.1 displays the results of temporal instability.

Table 4.1: Temporal Instability Results

Model Goodness of Fit Values	RP Logit Model without heterogeneity in means and variances	RP Logit Model with heterogeneity in means and variances
Overall model log-likelihood at convergence LL($\beta_{2018-2019}$)	-3751.88	-3722.56
2018 model log-likelihood at convergence LL(β_{2018})	-1475.79	-1468.61
2019 model log-likelihood at convergence LL(β_{2019})	-2136.95	-2127.9
$\chi 2$ Value	278.28	252.1
Degrees of Freedom	29	31
Level of Confidence	99%	99%
Critical X2 value	49.585	52.17
Conclusion	**Temporally unstable**	**Temporally unstable**

RP (Random Parameter)

The above tests show that temporal instability exists in both the random parameter logit approaches with and without heterogeneity in means and variances (calculated X^2 > critical X2 value). Also, tables that contain yearly results are attached in Annex A.

4.4 Model Estimation Results

As summarized in the literature review, there are various statistical modelling techniques used for the determination of significant risk factors affecting road crash severity. Traditional modelling techniques such as ordered probit, multinomial logit need a huge amount of data to estimate the risk factors that lead to road traffic crashes. Pakistan where there is no specific department for road safety, the crash data could not be relied upon directly. Also, the problem related to underreporting of road crash data by police department and poor data collection systems because of limited resources makes it difficult for the estimation of an accurate model. (P. T. Savolainen et al., 2011) suggested that simple models, like those that presume fixed parameters, require fewer data in general to produce appropriate estimation findings. Because of this, simpler models could be chosen in circumstances where data is limited. Keeping in view all the scenarios, the ongoing research work accompanied the "random parameters mixed logit modelling framework with and without heterogeneity in means and variances", knowing its capability of countering the problems related to data and unobserved heterogeneity by letting the parameters vary across observations. Ultimately, the model finalized had lower AIC and BIC values and greater log-likelihood at convergence values (random parameters logit model with heterogeneity in means and variances) in our case.

The results for the random parameters logit model are presented in Table 4.2. The parameters listed in Table 4.2 were significant at a confidence level of 90% or higher (p<0.10). Furthermore, the significant parameters with a statistically significant standard deviation under the predicted distribution were declared as random parameters. All other parameters were found to be fixed if the standard error values of parameters were not statistically different from zero. Also, a normal distribution resulted in the best statistical fit for the random variables.

Moreover, the marginal effects were calculated to examine the impact of explanatory factors on the likelihood of injury severity. It basically gives an insight into the impact of a one-unit increase in an explanatory variable on the likelihood of an injury outcome. Table 4.3 displays the marginal effects averaged across all crash observations. All the other significant parameters in this study are discussed below.

Table 4.2: "Results of Random Parameters Logit approach with heterogeneity in means and variances"

Variable	**Parameter Estimate**	**t − stat**
Constant [MJI]	3.63295	6.73
Constant [FI]	1.16916	1.70
Random parameter (normally distributed)		
Victim Pedestrian [MI]	-1.62467	-2.26
Standard Deviation of Victim Pedestrian (normally distributed)	1.82779	2.60
Heterogeneity in mean of random parameter		
Pedestrian Carelessness [MI]	2.00811	3.61
Heterogeneity in variance of random parameter		
Rainy weather indicator [MI]	0.69400	2.02
Victim characteristics		
Victim Motorist Indicator [MJI]	0.19570	1.69
Victim Motorcyclist Indicator [MJI]	-1.01240	-8.22
Victim Gender Male Indicator [MI]	2.53016	4.74

Old-age Victim Indicator [FI]	1.04933	2.52
V10 Indicator [MJI]	1.62551	2.50
Driver characteristics		
Seatbelt indicator [MI]	0.46786	2.31
License indicator [FI]	-1.40507	-3.26
Crash characteristics		
Rickshaw with Pedestrian Indicator [MI]	1.37295	3.37
Car with Car Indicator [MI]	1.01484	8.04
Bike with Pedestrian Indicator [MI]	2.32080	4.76
Car with Suzuki Indicator [MI]	0.73214	4.72
Car with Rickshaw Indicator [MI]	0.82565	4.65
Bike with Wagon Indicator [MJI]	1.37065	3.75
Bike with Suzuki Indicator [MJI]	1.40005	7.11
Suzuki with Pedestrian Indicator [MJI]	0.68591	2.39
Wagon with Pedestrian Indicator [MJI]	1.69968	4.11
Bike with Flying Coach Indicator [MJI]	1.57850	3.44
Car with Truck Indicator [FI]	1.57955	4.93
Datsun with Pedestrian Indicator [FI]	1.31513	2.41
Bike with Bus Indicator [FI]	1.56271	3.29
Weather Condition		
Foggy weather indicator [MI]	-0.35600	-1.70
Reported Crash Reason		
Brake Fail indicator [FI]	1.55650	2.06
Bike Over Speeding [MJI]	1.18121	10.28

Lighting Conditions		
Dusk Indicator [MJI]	-0.25264	-1.84
Posted speed limit		
Speed 40 (Km/hr.) Indicator [FI]	-0.87805	-2.52
Segment Alignment		
Intersection Indicator [FI]	0.98953	3.20
Road way type		
Highway indicator [FI]	1.20767	4.58
Number of Observations	5765	
Number of estimated parameters	33	
Log-likelihood at constants LL(0)	-4046.1863	
Log-likelihood at convergence LL(β)	-3722.56075	
R2 = 1 – LL(β)/LL(0)	0.08	

Table 4.3: Marginal Effects of the "Random Parameters Logit Model with heterogeneity in means and variances"

Variables/Indicators	Minor Injury	Major Injury	Fatal Injury
Minor Injury			
Foggy	-0.0016	0.0016	0.0001
Victim Pedestrian	-0.0206	0.0200	0.0006
Seatbelt	0.0022	-0.0021	-0.0001
Victim Gender Male	0.4232	-0.4099	-0.0133
Rickshaw with Pedestrian	0.0059	-0.0057	-0.0001
Car with Car	0.0178	-0.0175	-0.0003
Bike with Pedestrian	0.0142	-0.0139	-0.0003
Car with Suzuki	0.0070	-0.0068	-0.0002
Car with Rickshaw	0.0063	-0.0061	-0.0001
Major Injury			
Bike with Wagon	-0.0019	0.0020	-0.0001
Bike with Suzuki	-0.0066	0.0071	-0.0005
Suzuki with Pedestrian	-0.0024	0.0026	-0.0002
Bike Over Speeding	-0.0294	0.0317	-0.0023
Motorist	-0.0091	0.0099	-0.0008

Motorcyclist	0.0042	-0.0548	0.0506
Dusk	0.0024	-0.0026	0.0002
Wagon with Pedestrian	-0.0022	0.0023	-0.0001
Bike with Flying Coach	-0.0013	0.0014	-0.0001
V10	-0.0007	0.0007	0.0000
Fatal Injury			
Car with Truck	-0.0007	-0.0025	0.0032
Highway	-0.0010	-0.0028	0.0038
License	0.0070	0.0180	-0.0250
Victim's Age above 60	-0.0003	-0.0009	0.0012
Speed 40	0.0005	0.0011	-0.0016
Brake Fail	-0.0001	-0.0003	0.0004
Datsun with Pedestrian	-0.0001	-0.0006	0.0008
Bike with Bus	-0.0004	-0.0007	0.0012
Intersection	-0.0007	-0.0017	0.0025

Table 4.4: Competing Models' Goodness-of-Fit Statistics

Model Statistics	**RP Model without Heterogeneity in Means and variances (A)**	**RP Model with Heterogeneity in Means and variances (B)**
Number of Parameters	31	33
Log-likelihood at zero	-4046.1863	-4046.1863
Log likelihood at convergence	-3751.88467	-3722.56075
Akaike Information Criteria (AIC)	7565.8	7511.1
Bayesian Information Criteria (BIC)	7772.215	7730.886
Number of Observations	5765	5765
	A vs B	**B vs A**
Degrees of freedom	2	2
Confidence level	95%	95%
Chi square (Computed)	58.647	58.647
Chi square (Critical)	5.99	5.99
Statistically Superior Model	**B**	**B**

RP **(Random Parameter)**

4.5 Result Discussion

4.5.1 Random Parameters with Heterogeneity in Means and Variances

The random parameters were identified using a meticulous statistical analysis in the current study. Nevertheless, only the “victim pedestrian” parameter was identified to be random, with varying effects on the severity of road traffic crash injuries. It is pertinent to know that the random parameter “victim pedestrian” also signifies heterogeneity in means and variances significantly. The mean and variance of the victim pedestrian variable were shown to be affected by the "pedestrian carelessness" and "rainy" indicators. The victim pedestrian indicator's "mean" increased if the road crash took place because of pedestrian carelessness as the reported crash reason. Nonetheless, for the victim pedestrian indicator, pedestrians undergoing an accident have a higher likelihood of minor injury if the crash occurs because of the carelessness of the pedestrian. Pedestrian carelessness generally includes improper road crossing, failing to observe the approaching vehicle and its speed, etc. This is intuitive as pedestrians being careless on the roads because of limited pedestrian facilities are specifically observed by the drivers. Thus, drivers try to compensate for their carelessness by applying the brakes well before they notice any pedestrian activity (e.g., pedestrians crossing the road). Alternatively, in many situations, drivers reduce their speeds where pedestrian activity is higher, which reduces the likelihood of causing a major or fatal injury to the pedestrian. Moreover, regarding the heterogeneity in variance of "victim pedestrian," road traffic crashes involving pedestrians during rainy weather were observed to have a greater variance.

4.5.2 Victim’s Characteristics

Victim gender male was identified to be a significant fixed parameter for the outcome of minor injury. The study revealed that males are most likely to go through minor injuries as compared to females. Marginal effects (Table 4.3) suggest that the possibility of minor injury sustained by males is increased by 0.4232 while that of major and fatal injury is reduced by 0.4099 and 0.0133 respectively. This is intuitive as male road users are in the vast majority and are much more aware of the risk factors that can possibly cause a road traffic crash. In comparison to their female counterparts, males are more conversant with road traffic crashes. That helps them to avoid extreme risk-taking, thus decreasing the likelihood of major and fatal injuries. This finding of ours is consistent with past research which concludes that there is a lower risk of severe injuries to males than their female counterparts (Obeng, 2011). Also with (Evans, 2001; Ulfarsson & Mannering, 2004). Moreover, (M. Islam et al., 2022) also found that male drivers were most likely to go through a minor injury.

Variable v10 was discovered to be significant in the category of major injury. Whereas, v10 denotes middle-aged victims (18-30 and 41-50 years). It has been observed that middle-aged victims are more likely to go through major injuries. Whereas, the average marginal effects in Table 4.3 suggest that the possibility of middle-aged victims (18–30 and 41–50 years) undergoing major injury is increased by 0.0007 and that of minor injury is reduced by 0.0007. This could be explained as middle-aged people are in high propensity on the roads as compared to other groups (10-18 and above 50), as the majority of them belong to the working class and encounter every type of traffic condition, i.e., peak hours/rush hours. They are also highly exposed to a variety of risk factors on a daily basis, making them prone to road traffic crashes and leading to a higher likelihood of major injuries.

Crashes involving Old age victims (above the age of 60) were associated with fatal injury, i.e., there is a higher chance of fatal injury when victims involved in the crashes belong to an old age group. Marginal effects demonstrate that the possibility of fatal injury increases by 0.0012 for victims with the age of above 60, whilst the possibility of minor and major injuries decreases by 0.0003 and 0.0009, respectively. This result is plausible as the health of road users above the age of 60 has deteriorated, i.e., they have weak physical health and have lower bone density as compared to young road users. Moreover, older road users have lower perception reaction times, thus making them vulnerable to road traffic crashes that lead to fatalities. This finding is in line with prior research studies (Cantillo et al., 2020; Reeves et al., 2019).

Pedestrians involved in crashes were observed to have a lower likelihood of minor injury and an increased likelihood of major and fatal injury. The averaged marginal effects show that there is a decrease in the minor injury severity of pedestrians by 0.0206 and an increase in major and fatal injuries by 0.0200 and 0.0006 respectively. Pedestrians' having a higher likelihood of major and fatal injury can clearly be linked with the least protection of pedestrians among all other road users. Thus, with no protective shield when pedestrians undergo a road crash, there is a high possibility of them going through a major injury because of the direct contact of the pedestrian with the other road user, which could lead to a fatality if the impact is a little more. This particular outcome is in accordance with the past research (Yahaya et al., 2021).

Crashes in which motorists are involved show an increase in the likelihood of major injury, i.e., motorists are most likely to undergo a major injury. However, the marginal effects reveal that the possibility of major injury for motorists increases by 0.0099, whereas the possibility of minor injury and fatal injury is reduced by 0.0091 and 0.0008 respectively. This finding could be associated with the higher speed and momentum of vehicles as compared to lighter vehicles like rickshaws, bicycles, and motorcycles, which leads to a higher risk of causing major injuries to motorists.

A major injury is shown to be less probable in motorcycle riders. The marginal effects suggest that the chances of major injury are reduced by 0.0548, whereas the chances of fatal injury increased by 0.0042, and that of minor injury are also increased by 0.0506 for 28.88% of the population of victims in the crash data. The possible explanation for this risk factor could be that motorcyclists are vulnerable road users in traffic streams and most of those operating without taking safety measures, i.e., wearing helmets, which makes them highly susceptible to fatal injury. Also, the misconception of motorcyclists allows them to tackle the traffic stream with ease because of lesser volume occupied by a motorcycle gives other vehicles less reaction time. Hence, forcing themselves to take risks, which leads to improper passing/wrong overtaking, following other vehicles closely, exceeding speed limits and occupying the fast lanes while violating the traffic laws, makes them the most vulnerable group of road users involved in road traffic crashes. The following safety measures, i.e., wearing helmets and introducing automatic anti-lock breaking systems on motorcycles, should be adopted as possible countermeasures. (Cantillo et al., 2020) found that the presence of motorcyclists was the most significant parameter that increased the probability of fatal crashes in Cartagena, Columbia. This outcome is also aligned with previous research (Waseem et al., 2019), which concluded that motorcyclists with no education, riders involved in single vehicle crashes, and if the crash occurred on weekdays, were involved with an increased likelihood of fatal injury.

4.5.3 Driver Characteristics

It was revealed in this study that drivers wearing seatbelts were observed to have a significantly increased likelihood of minor injuries. Table 4.3 suggests that the possibility of minor injury for those drivers wearing seatbelts is increased by 0.0022. On the contrary, the possibility of major and fatal injury is reduced by 0.0021 and 0.0001 respectively. This is intuitive as seatbelt usage prevents the forward movement of the drivers as they continue to move forward when a crash event takes place, which helps them not to eject from their seats, preventing major injuries. This result aligns with the results of previous studies, in which it was concluded that using lap and shoulder belts increased the likelihood of no injury by 0.21 when compared to those who did not use them (M. Islam & Mannering, 2020), also with (M. Islam et al., 2022).

Road traffic crashes involving drivers with licenses were observed to be less likely to result in a fatal injury. The averaged marginal effects reveals that the possibility of fatal injury is reduced by 0.0250 for the driver having a license. Whereas the possibility of minor and major injury is increased by 0.0070 and 0.0180, respectively. Drivers having licenses are expected to be more cognitive of traffic laws; hence, they drive carefully without violating traffic laws. This may also be attributed to lower risk-taking and greater knowledge of traffic safety laws by the drivers who have a license, thus helping them to be on the safer side.

Motorcycle over-speeding was found to be associated with causing major injuries to the victims. An increase in the possibility of major injuries was noted for crashes that occur due to motorcycle over-speeding by 0.0317 as mentioned in Table (4.3). Additionally, the possibility of minor as well as fatal injury, is reduced by 0.0294 and 0.0023 correspondingly. The fact that when the crash reason is reported to be motorcycle overspeeding, it reflects that motorcycles gain higher momentum with the least protection in comparison to passenger cars, Suzuki, and buses, etc., making them highly susceptible to major injuries. (P. Savolainen & Mannering, 2007) also found that there is a greater possibility of major and fatal injury when the crash takes place because of motorcycle over speeding.

4.5.4 Vehicle type

Crashes between a rickshaw and pedestrian, bike and pedestrian, car and car, car and Suzuki, and car and rickshaw were significantly linked to an increased likelihood of minor injury. The marginal effects for all of these significant parameters can be reviewed in Table (4.3). It can be observed that the possibility of minor injury is increased by 0.0059 when a pedestrian is hit by a rickshaw, whereas the possibility of major and fatal injury is reduced by 0.0057 and 0.0001 respectively. This is also intuitive as rickshaws have generally lower speed and momentum compared to other vehicles like passenger cars and heavy vehicles, thus resulting in injuries that are less severe to pedestrians. Also, owing to the lower speed of rickshaws, pedestrians arguably have a higher reaction time. This research conclusion is also aligned with existing research (Kim et al., 2008; Damsere-Derry et al., 2010).

Moreover, crashes that take place between a pedestrian and a motorcycle also tend to cause minor injuries to the pedestrians. Marginal effects indicate a 0.0142 increase in minor injury probability and a 0.0139 and 0.0003 decrease in major and fatal injury probabilities. This result can also be referred to lower momentum of the motorcycle and less space occupied on the roadways by the motorcycles.

Car with car and car with Suzuki indicators had a significant influence on the minor injury. Table (4.3) recommends an increase of 0.0178 in the likelihood of minor injury for the crashes between a car and a car, whereas the possibility of major and fatal injury is reduced by 0.0175 and 0.0003 respectively. This is intuitive, as cars involved in a crash will generally have the same speed and momentum. Also, motorists' having an outer protective shield increases the likelihood of the motorists' incurring a minor injury. Both the colliding vehicles' having the same momentum will make it more likely that motorists will experience minor injuries.

For the crashes between cars and Suzuki, an increase in the likelihood of sustaining a minor injury is induced by 0.0070 while that of major and fatal injury is reduced by 0.0068 and 0.0002 in the order given. Another indicator representing the crashes between car and rickshaw is also associated with minor injury severity category. The marginal effects indicate that there is an increase in the minor injury severity by 0.0063 and a decrease in the major and fatal injuries by 0.0061 and 0.0001 sequentially.

However, crashes between a bike and wagon, a bike and Suzuki, Suzuki and pedestrian, wagon and pedestrian, and a bike and flying coach were significantly associated with an increased likelihood of major injury. For the crashes between a bike and wagon and between a bike and Suzuki, Table 4.3 suggests an increase in the major injuries by 0.0020 and 0.0071. Conversely, the possibility of minor injury is reduced by 0.0019 and 0.0066, and that of fatal injury is reduced by 0.0001 and 0.0005 accordingly. Also, when a motorcycle and a flying coach are involved in a crash, there is an increased likelihood that the motorcyclist will undergo major injury. Marginal effects demonstrate that there is an increase in major injury by 0.0014 and a decrease in the minor and fatal injuries by 0.0013 and 0.0001, respectively.

Furthermore, pedestrians who come into contact with Suzuki and the wagon are most likely to undergo major injuries. Table 4.3 indicates that pedestrians' probability of undergoing a major injury increases by 0.0026 and 0.0023 when they are hit by a Suzuki or a wagon, respectively. Whereas the possibility of minor injury reduces by 0.0024 and 0.0022, and fatal injury reduces by 0.0002 and 0.0001. Pedestrians, being the least protected road users, are highly susceptible to major and fatal injuries when involved in a crash. In general, the most suitable explanation could be the higher speed and momentum of the Suzuki and wagon, which can cause major injuries to pedestrians. This may also be attributed to the wagons being driven at the extreme left of the roadways, where pedestrian activities are the highest.

Also, the variable datsun with a pedestrian was significant under the category of fatal injury; that is, the crash between a datsun and a pedestrian is most likely to cause a fatal injury. The averaged marginal effects show that there is an increase in the possibility of fatal injury by 0.0008 and a decrease in minor and major injury by 0.0001 and 0.0006 sequentially.

Road traffic crashes involving heavy vehicles, such as crashes between a car and truck or a motorcycle and bus, were discovered to have a substantial impact on fatal injuries. Table 4.3 suggests that there is an increase in the possibility of fatal injury by 0.0032 and a decrease of 0.0007 and 0.0025 in minor and major injuries when a car and truck are involved in a crash. Moreover, the motorcyclist is at a much higher risk of fatal injury in a crash with a bus. It was revealed that every time a bus of any type is involved in a crash with a motorcycle results in 0.0012 higher possibility of fatal injury, whereas a decrease in the possibility of minor and major injury by 0.0004 and 0.0007 is reported, respectively. Trucks and buses, being heavy vehicles, have greater mass and occupy a greater area of roadways, which are associated with fatal crashes. Collision of a motorcycle with heavy vehicles resulting in a fatal injury is consistent with past research (P. Savolainen & Mannering, 2007), as the study reveals that motorcycle crashes with heavy vehicles (tractors and trailers) increase the probability of a fatal crash. Also, (M. Islam et al., 2022) concluded that trucks have a higher tendency to cause severe injuries to the victims who are involved in a crash.

4.5.5 Road Alignment and type of roadway

Road alignment specifically intersection was identified to significantly increase the risk of fatal injury. The possibility of fatal injury is increased by 0.0025, and that of minor and major injury is reduced by 0.0007 and 0.0017, respectively, as shown in Table (4.3). This result could be associated with the poor condition of intersections in Peshawar city, with most of them being operated without proper traffic signals or traffic signals that are not functional, resulting in chaos at the intersection region. The intersection being operated without traffic wardens and proper traffic signals allow drivers to take risks and make their way out of the intersection, which results in sideways collisions most of the time, leaving the drivers and occupants of the vehicles fatally injured.

Crashes take place on various roadway types, but in our study, the significant fixed parameter was the roadway type of highway with a higher likelihood of causing fatal crashes. Furthermore, the marginal effects suggest that the possibility of fatal injury is increased by 0.0038 for the crashes taking place on highways, whilst a reduction of 0.0010 in minor injury and 0.0028 in a major injury possibility, respectively. This result is aligned with prior research (Li et al., 2009), which found a higher fatal risk for crashes occurring on highways because of higher speed limits on highways relative to city roads. Moreover, drivers believe that highways are constructed to higher standards and with better-paved surfaces, so they tend to overspeed, which leads to fatal crashes. This finding may also be attributed to higher accessibility on highways in Pakistan, conceivably jeopardizing safety and mobility and leading to fatal crashes.

4.5.6 Mechanical fault

Brake failure due to some mechanical fault in the vehicle increases the probability of fatal injury. The averaged marginal effects reveal that the possibility of fatal injury is increased by 0.0004 for the crashes that happened because of vehicle brake failure. Concurrently, the possibility of minor and major injury is reduced by 0.0001 and 0.0003, respectively. This result is also intuitive as drivers react primarily by applying brakes when they come across a risky situation, which leads to crashes. If the brake fails, that will result in a crash with the same speed, and momentum as the vehicle was travelling before running into the crash, increasing the likelihood of a fatal crash. This research finding aligns with prior research (Al-Bdairi & Hernandez, 2017).

4.5.7 Posted speed limit

Roads with a posted limit of 40 km/hr were found to have crashes that are less likely to cause a fatal injury to the victims involved in the crash. As suggested in Table (4.3), the possibility of fatal injury is reduced by 0.0016 for the crashes that took place on road sections having the posted limit of 40km/hr. In contrast, the possibility of minor and major injuries increased by 0.0005 and 0.0011, respectively. Roads with a speed limit of 40km/hr are usually collector roads that are in the vicinity or run through residential areas that limit vehicles to operate at safe speeds. Therefore, crashes taking place on these road segments tend to have a lower likelihood of fatal injuries. This result is consistent with past research studies, which also found a decrease in crash rates after speed limit restrictions (De Pauw et al., 2014). Also, (Z. Ma et al., 2015) concluded that crashes that occur due to speeding vehicles are most likely to cause severe injuries relative to those crashes that do not involve overspeeding.

4.5.8 Lighting Condition

The variable dusk was discovered as a key fixed component in this study. Dusk was known to be less likely to cause major injuries to the victims involved in crashes taking place in dusk conditions. The averaged marginal effects reveal that the possibility of major injury is reduced by 0.0026 while the possibility of minor and fatal injuries is increased by 0.0024 and 0.0002, respectively. As dusk is associated with time before complete darkness, drivers tend to drive carefully and reduce their speeds, which helps them prevent crashes resulting in major injuries.

4.5.9 Weather conditions

Foggy weather was significantly associated with minor injury severity of road traffic crashes. Moreover, the marginal effects reveal that the possibility of minor injury is reduced by 0.0016 for crashes occurring in foggy weather. On the other hand, the possibility of major and fatal injuries is increased by 0.0016 and 0.0001, respectively. In foggy weather, drivers face multiple problems related to restricted visibility and, secondly, what speed is to be chosen given the visibility (Al-ghamdi, 2007). This research finding of ours also aligns with previous studies (Abdel-aty et al., 2011; Theofilatos & Yannis, 2014; Y. Wang et al., 2017), which also observed the frequency of fatal crashes increases in adverse weather conditions like fog.

CHAPTER 5

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

The current research focused on discovering risk factors affecting road crash injury severity in urban Peshawar, Pakistan. Keeping in view the alarming rates of RTC's, the objective of identifying various risk factors was to aim at the enhancement of road traffic safety conditions for all road users. Research carried out globally was reviewed comprehensively, which resulted in detailed information about the analysis of road crash severities with recent advancements being made in the field of traffic safety. Different statistical modelling techniques have been employed in previous studies to model road crash data, such as ordered probit, multinomial logit, multivariate/Bivariate models etc. For a detailed review, see (Table 2.2 of this study). In the present research, "a random parameter mixed logit model with heterogeneity in means and variances" was adopted because of its high flexibility, superior goodness of fit, incorporation of data-related issues, and finally, to tackle the problem of unobserved heterogeneity in the analysis. The data were obtained from Rescue 1122 (a leading emergency response unit) district office of Peshawar for the duration of two years (January 2018 to December 2019). Moreover, random parameters logit models with and without heterogeneity in means and variances were computed to identify risk factors affecting road crash severity in urban Peshawar. A log-likelihood test was conducted to incorporate temporal instability of various risk factors related to road crashes into the analysis. Significant risk factors linked with different crash injury severity levels include victim and driver characteristics, roadway type and geometry, weather and lighting conditions, posted speed limit, vehicle type, mechanical fault and reason for the crash. The random parameters mixed logit model estimation took place via NLOGIT 6 software by conducting a number of trials to explore the relationship between road crash severity and independent explanatory variables. Initially, the model was estimated using 40 Halton draws to select random variables and their distribution. However, 500 Halton draws were used to revise and estimate the final model at a 90% confidence level or with a P value of less than or equal to 0.10 ($p<=0.10$). The model was ultimately chosen depending on the model having the most significant number of factors and the best statistical parameters for the model, which include McFadden Pseudo R-squared (0.412), log-likelihood at zero (-4046.1863) and log-likelihood at convergence (-3722.56075), which not only validates but also supports the models' ultimate selection.

5.2 Study conclusions

The following is an overview of the overall conclusions of the study:

1. Risk factors associated with an increased likelihood of fatal injuries include: old age road users (above 60 years), crashes occurring at an intersection and on highways, crashes occurring due to brake failure, crashes involving collisions of cars and motorcycles with heavy vehicles, and pedestrian collisions with datsun. However, the likelihood of fatal injury is reduced by drivers having a license and crashes occurring on the road segments with a posted limit of 40 km/hr.
2. Road users are more likely to suffer major injuries in crashes involving middle-aged road users (18-30 and 41-50 years), occurring due to motorcycle overspeeding, involving motorists, involving pedestrian collisions with a wagon and Suzuki, and finally, involving the collision of a motorcycle with a wagon, Suzuki, and Hiace.

3. Risk factors involved in the increasing likelihood of minor injuries include; crashes involving male road users, drivers wearing seatbelts, crashes involving rickshaws with pedestrians and motorcycles with pedestrians and crashes between two passenger cars and a passenger car with a Suzuki and rickshaw. While crashes occurring in foggy weather decrease the likelihood of a minor injury.

5.3 Recommendations

The risk factors identified in this research study are capable of generating in detail discussion about road safety in the country, particularly in Peshawar. Considering the seriousness of the issue, the discussion can be evaluated by the organizations that deal with road networks and road traffic crashes, such as the Peshawar development authority (PDA), National highway authority (NHA), and traffic police Peshawar to ensure road traffic safety by developing suitable safety measures keeping in view the risk factors revealed in this particular research. Moreover, the results of this study prescribe the demand for the following recommendations:

1. Considering road safety as a threat to the lives of road users, road safety awareness programs should be started and delivered to the drivers for safe and efficient use of roadways. In road safety awareness programs, the very basic safety measures should be made compulsory, like wearing a seatbelt and helmet, avoiding overspeeding/reckless driving, and any violation of the mentioned compulsory safety measures should not be tolerated at all.

2. Pedestrians and motorcyclists are an integral part of the traffic stream. Their safety should be given the utmost priority by law-enforcement agencies. For instance, pedestrians' safety could be provided by constructing pedestrian

crossing facilities like (underpass/overpass), sidewalks and crosswalks. For motorcyclists, primarily helmet usage should be made compulsory by the traffic police. Also, motorcycle overspeeding should be dealt with zero tolerance, and motorcyclists should not be allowed to operate in the fast lanes.

3. The state should consider building a road safety department that deals with road traffic safety issues. In addition, it should contain up-to-date data, including some of the missing variables like the operating speed of vehicles, driver behaviour, etc., so that it can be reviewed by researchers to better understand the risk factors that affect road traffic crashes that will help the country in reducing the probability of road traffic crashes.
4. Trucks and buses being heavy vehicles, are involved in fatal crashes. Effective countermeasures should be taken, like separating them from the main traffic stream by providing separate lanes for them.
5. Intersections should operate under proper traffic signals to ensure the efficient flow of traffic and enhanced road safety.
6. Vehicles should be checked for any sort of mechanical fault before they are driven on the roadways because the safety of other road users is also compromised, including them.
7. Strict actions should be taken against sluggish drivers and every other road user who tends to violate traffic laws. Their driving license should be cancelled upon several number of warnings.

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Annex A: Temporal Instability Results

Table 1: Overall Random parameters logit model with no heterogeneity in means and variances

Variables	Parameter Estimate	t-stat	Marginal Effects		
			Minor	**Major**	**Fatal**
Constant [MJI]	1.65258	8.46			
Constant [FI]	-2.21825	-10.62			
Random parameter (normally distributed)					
Victim Pedestrian [MI]	-1.68509	-2.05	-0.0349	0.0340	0.0009
Standard Deviation of Victim Pedestrian (normally distributed)	2.23165	2.47			
Victim characteristics					
Victim Motorist indicator [MJI]	0.27901	2.08	-0.0129	0.0140	-0.0010
Victim Motorcyclist indicator [MJI]	-1.01141	-7.05	0.0500	-0.0539	0.0039
Old age victim indicator [FI]	0.96563	2.46	-0.0002	-0.0008	0.0011
V10 indicator [MJI]	1.64054	2.64	-0.0007	0.0007	0.0000
Rickshaw driver [MI]	0.59660	3.68	0.0078	-0.0077	-0.0002
Driver characteristics					
Seatbelt indicator [MI]	0.50188	2.43	0.0023	-0.0023	-0.0001
Crash characteristics					
Car with car indicator [MI]	1.23024	9.26	0.0216	-0.0212	-0.0004
Rickshaw with pedestrian indicator [MI]	1.36868	2.90	0.0056	-0.0055	-0.0001
Bike with pedestrian indicator [MI]	2.21779	4.02	0.0132	-0.0130	-0.0002

Car with suzuki indicator [MI]	0.83605	5.05	0.0079	-0.0077	-0.0002
Suzuki with pedestrian indicator [MJI]	0.61778	2.04	-0.0020	0.0022	-0.0002
Bike with flying coach/Hiace [MJI]	1.55921	3.46	-0.0013	0.0014	-0.0001
Bike with Suzuki indicator [MJI]	1.58578	7.87	-0.0074	0.0078	-0.0004
Bike with Wagon indicator [MJI]	1.48131	4.15	-0.0020	0.0021	-0.0001
Car with truck indicator [FI]	1.71541	5.24	-0.0008	-0.0028	0.0035
Datsun with pedestrian indicator [FI]	1.31021	2.41	-0.0001	-0.0006	0.0007
Flying coach/Hiace with pedestrian indicator [FI]	1.35862	3.11	-0.0002	-0.0010	0.0013
Bike with bus indicator [FI]	1.61939	3.25	-0.0004	-0.0008	0.0012
Weather Characteristics					
Foggy weather indicator [MI]	-0.39872	-1.84	-0.0018	0.0017	0.0001
Road Surface condition					
Dry pavement surface indicator [MI]	0.41870	2.49	0.0664	-0.0644	-0.0020
Reported crash reason					
Driver fault indicator [MI]	0.54206	5.27	0.0173	-0.0167	-0.0007
Bike over speeding indicator [MJI]	1.04361	8.01	-0.0255	0.0275	-0.0020
Brake Fail indicator [FI]	1.54752	1.88	-0.0001	-0.0003	0.0004
Pedestrian carelessness indicator [MI]	1.81465	3.47	0.0533	-0.0517	-0.0015
Posted speed limit					
Speed 40km/hr. indicator [FI]	-0.88132	-2.60	0.0005	0.0012	-0.0016
Segment alignment					

Intersection indicator [FI]	1.02409	3.45	-0.0007	-0.0018	0.0026
Highway indicator [FI]	1.13366	4.18	-0.0008	-0.0026	0.0035
Number of observations	5765				
Number of estimated parameters	31				
Log likelihood at constant	-4046.1863				
Log likelihood at convergence	-3751.88467				
R2 = 1 – LL(β)/LL(0)	0.0728				

[MI]= Minor Injury, [MJI] = Major Injury, [FI] = Fatal Injury

Table 2: 2018 Random parameters logit model with heterogeneity in means and variances

Variables	**Parameter Estimate**	**t – stat**
Constant [MJI]	1.67807	10.55
Constant [FI]	-2.34058	-7.07
Random parameter (normally distributed)		
Motorist [MJI]	2.31506	2.36
Standard Deviation of Motorist (normally distributed)	5.23109	2.50
Heterogeneity in mean of random parameter		
Car with truck [FI]	2.00811	3.61
Heterogeneity in variance of random parameter		
Summer [MJI]	0.69400	2.02
Victim characteristics		
Victim Motorcyclist Indicator [MJI]	-0.57609	-3.93
Old-age Victim Indicator [FI]	1.13915	2.12
Age between 10 and 18 Indicator [MJI]	-0.45791	-1.97
Age between 18 and 30 Indicator [MI]	1.37483	8.29
Age between 31 and 40 Indicator [MI]	1.21297	6.71
Victim gender female [FI]	2.06707	2.41
Victim driver indicator [MJI]	0.71343	2.87
Driver characteristics		
Seatbelt indicator [MI]	1.51200	2.22
Crash characteristics		
Rickshaw with pedestrian Indicator [MI]	0.80530	5.14
Car with car Indicator [MI]	2.08214	2.68
Bike with pedestrian Indicator [MI]	1.62511	5.97

Car with Suzuki Indicator [MI]	0.88036	2.62
Car with rickshaw Indicator [MI]	0.56275	2.36
Wagon with pedestrian Indicator [MJI]	1.07339	2.59
Bike with Suzuki Indicator [MJI]	0.64285	2.16
Bike with flying Coach Indicator [MJI]	1.16376	2.12
Car with truck Indicator [FI]	2.82284	3.63
Bike with datsun Indicator [FI]	1.79386	1.69
Car with bus Indicator [MJI]	-2.15344	-2.04
Roadway geometric characteristics		
One lane each direction indicator [MI]	0.64056	2.57
Road signs indicator [FI]	-0.84850	-2.16
Reported Crash Reason		
Over speeding [FI]	1.29981	3.34
Bike Over Speeding [MJI]	1.92934	9.97
Lighting Conditions		
Dawn Indicator [MJI]	1.80308	2.82
Pavement surface condition		
Pavement wet Indicator [MJI]	0.59342	2.67
Segment Alignment		
Intersection Indicator [FI]	1.02395	2.15
Visibility condition		
Poor visibility indicator [FI]	0.91946	2.33
Roadway type		
Highway [FI]	1.38297	2.34
Number of Observations	2317	
Number of estimated parameters	34	

Log-likelihood at constants LL(0)	-1655.1467
Log-likelihood at convergence LL(β)	-1468.61621
R2 = 1 – LL(β)/LL(0)	0.11

[MI]= Minor Injury, [MJI] = Major Injury, [FI] = Fatal Injury

Table 3: 2018 Random parameters logit model with no heterogeneity in means and variances

Variables	**Parameter Estimate**	**t – stat**
Constant [MJI]	1.68118	11.41
Constant [FI]	-2.33045	-7.20
Random parameter (normally distributed)		
Motorist [MJI]	3.05277	2.67
Standard Deviation of Motorist (normally distributed)	4.84340	2.66
Victim characteristics		
Victim Motorcyclist Indicator [MJI]	-0.57621	-3.90
Old-age Victim Indicator [FI]	1.12304	2.15
Age between 10 and 18 Indicator [MJI]	-0.46007	-2.00
Age between 18 and 30 Indicator [MI]	1.37807	8.60
Age between 31 and 40 Indicator [MI]	1.21466	6.77
Victim gender female [FI]	2.04972	2.55
Victim driver indicator [MJI]	0.72343	2.84
Driver characteristics		
Seatbelt indicator [MI]	1.46349	2.13
Crash characteristics		
Rickshaw with pedestrian Indicator [MI]	0.80674	5.51
Car with car Indicator [MI]	2.67381	2.98
Bike with pedestrian Indicator [MI]	1.62741	6.10
Car with Suzuki Indicator [MI]	0.90363	2.65
Car with rickshaw Indicator [MI]	0.56470	2.16
Wagon with pedestrian Indicator [MJI]	1.07335	2.54
Bike with Suzuki Indicator [MJI]	0.64290	2.09

Bike with flying Coach Indicator [MJI]	1.16438	2.17
Car with truck Indicator [FI]	2.22964	3.14
Bike with datsun Indicator [FI]	1.77996	1.66
Car with bus Indicator [MJI]	-2.82077	-2.32
Roadway geometric characteristics		
One lane each direction indicator [MI]	0.64422	2.54
Road signs indicator [FI]	-0.82656	-2.37
Reported Crash Reason		
Over speeding [FI]	1.30126	3.62
Bike Over Speeding [MJI]	1.93030	10.13
Lighting Conditions		
Dawn Indicator [MJI]	1.82591	3.07
Pavement surface condition		
Pavement wet Indicator [MJI]	0.59996	2.59
Segment Alignment		
Intersection Indicator [FI]	1.01093	2.11
Visibility condition		
Poor visibility indicator [FI]	0.93828	2.58
Roadway type		
Highway indicator [FI]	1.36593	2.75
Number of Observations	2317	
Number of estimated parameters	32	
Log-likelihood at constants LL(0)	-1655.1467	
Log-likelihood at convergence LL(β)	-1475.79316	
R2 = 1 – LL(β)/LL(0)	0.10	

[MI]= Minor Injury, [MJI] = Major Injury, [FI] = Fatal Injury

Table 4: 2019 Random parameters logit model with heterogeneity in means and variances

Variables	**Parameter Estimate**	**t – stat**
Constant [MJI]	2.49499	8.17
Constant [FI]	-1.05441	-2.95
Random parameter (normally distributed)		
Motorist [MJI]	2.20729	2.58
Standard Deviation of Motorist (normally distributed)	4.39827	2.47
Heterogeneity in mean of random parameter		
Car with truck [FI]	3.78740	3.06
Heterogeneity in variance of random parameter		
Road signs indicator [MJI]	-0.35227	-1.70
Victim characteristics		
Age below 10 Indicator [MJI]	1.44904	4.35
Age between 18 and 30 Indicator [MI]	0.96933	8.22
Age between 31 and 40 Indicator [MI]	0.77432	5.51
Victim gender male [MI]	1.35038	4.65
Victim driver indicator [MJI]	0.75504	4.19
Crash characteristics		
Rickshaw with pedestrian Indicator [MI]	1.04410	4.26
Car with car Indicator [MI]	1.69915	2.61
Bike with pedestrian Indicator [MI]	1.42352	7.26
Suzuki with pedestrian Indicator [MJI]	0.64048	2.62
Bike with wagon Indicator [MJI]	2.50558	3.35
Wagon with pedestrian Indicator [MJI]	1.54057	2.93
Bike with Suzuki Indicator [MJI]	1.75222	6.64

Bike with flying Coach Indicator [MJI]	2.64248	2.54
Car with truck Indicator [FI]	3.89120	4.80
Bike with datsun Indicator [FI]	1.82650	2.92
Car with bus Indicator [MJI]	2.78774	2.23
Bus with pedestrian [FI]	1.86974	2.35
Roadway geometric characteristics		
One lane each direction indicator [MI]	0.47156	2.04
Reported Crash Reason		
Over speeding [FI]	1.43138	4.77
Bike Over Speeding [MJI]	0.91957	7.70
Carelessness indicator [MI]	0.36673	2.62
Brake fail indicator [FI]	2.50145	2.11
Pavement surface condition		
Pavement wet Indicator [MJI]	0.34833	3.02
Roadway type		
Highway [FI]	1.41293	3.58
Number of Observations	3448	
Number of estimated parameters	30	
Log-likelihood at constants LL(0)	-2386.2011	
Log-likelihood at convergence LL(β)	-2127.9029	
R2 = 1 – LL(β)/LL(0)	0.10	

[MI]= Minor Injury, [MJI] = Major Injury, [FI] = Fatal Injury

Table 5: 2019 Random parameters logit model with no heterogeneity in means and variances

Variables	Parameter Estimate	t – stat
Constant [MJI]	2.50830	9.02
Constant [FI]	-1.00342	-3.06
Random parameter (normally distributed)		
Motorist [MJI]	3.96312	2.62
Standard Deviation of Motorist (normally distributed)	5.82682	2.45
Victim characteristics		
Age below 10 Indicator [MJI]	1.44772	4.24
Age between 18 and 30 Indicator [MI]	0.98202	8.21
Age between 31 and 40 Indicator [MI]	0.78782	5.36
Victim gender male [MI]	1.36231	5.15
Victim driver indicator [MJI]	0.72901	3.91
Crash characteristics		
Rickshaw with pedestrian Indicator [MI]	1.04634	4.55
Car with car Indicator [MI]	3.00636	2.75
Bike with pedestrian Indicator [MI]	1.42920	7.75
Suzuki with pedestrian Indicator [MJI]	0.64945	2.61
Bike with wagon Indicator [MJI]	2.51048	3.44
Wagon with pedestrian Indicator [MJI]	1.55025	3.19
Bike with Suzuki Indicator [MJI]	1.75928	6.65
Bike with flying Coach Indicator [MJI]	2.65232	2.58
Car with truck Indicator [FI]	2.73240	4.12
Bike with datsun Indicator [FI]	1.80282	2.85
Car with bus Indicator [MJI]	3.97659	1.97

Bus with pedestrian [FI]	1.83564	2.38
Roadway geometric characteristics		
One lane each direction indicator [MI]	0.46901	2.17
Reported Crash Reason		
Over speeding [FI]	1.45893	5.12
Bike Over Speeding [MJI]	0.93040	7.83
Carelessness indicator [MI]	0.31570	2.05
Brake fail indicator [FI]	2.51271	1.96
Pavement surface condition		
Pavement wet Indicator [MJI]	0.36388	3.14
Roadway type		
Highway [FI]	1.34388	3.67
Number of Observations	3448	
Number of estimated parameters	28	
Log-likelihood at constants LL(0)	-2386.2011	
Log-likelihood at convergence LL(β)	-2136.95043	
R2 = 1 – LL(β)/LL(0)	0.10	

[MI]= Minor Injury, [MJI] = Major Injury, [FI] = Fatal Injury