Analyzing Pedestrian Injury Severity Using Uncorrelated and Correlated Random Parameters Logit Model with Heterogeneity in Means and Variances

By

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THESIS ACCEPTANCE CERTIFICATE

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Date: ____

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"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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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Annex A

LIST OF ACRONYMS

RP	*Road Parameters*
RTCs	*Road Traffic Crashes*
TTTO	*Tehran Traffic and Transportation Organization*
AADT	*Average Annual Daily Traffic*
MNL	*Multinomial Logit Model*
KPK	*Khyber Pakhtunkhwa*
PDA	*Peshawar Development Authority*
WHO	*World Health Organization*
NHTSA	*National Highway Traffic Safety Administration*
FIR	*First Information Report*
RTI	*Road Traffic Injuries*
AIC	*Akaike Information Criteria*
BIC	*Bayesian Information Criteria*
MI	*Minor Injury*
MJI	*Major Injury*
FI	*Fatal Injury*
LL	*Log Likelihood*

ABSTRACT

Pedestrians are an integral part of traffic stream. However, in spite of their undeniable presence in the traffic stream, they are most susceptible to road traffic crashes due to least protection. Pedestrian safety is an issue of great concern in transportation sector especially in low and middle income countries as compared to the developed world where pedestrians are involved in nearly 50% of the road traffic fatalities. For the development and effective enforcement of pedestrian safety strategies, a thorough understanding of the ground realities and crash risk factors is very essential. The present study investigates the impact of various key factors on pedestrian injury severity using pedestrian crash data from Rescue 1122 Peshawar, a National Emergency Response Unit. Using pedestrian crash data for a period of four years (Jan 2016 to Dec 2019) for Peshawar city, present study estimated uncorrelated and correlated random parameters logit models with heterogeneity in means and variances, as well as random parameter logit model with no heterogeneity in means and variances, to investigate numerous risk factors associated with pedestrian injury severities. From a statistical performance standpoint, the correlated random parameters logit model with heterogeneity in means was statistically superior and was selected as the final model. Minor injury, major injury and fatal injury are used as three levels of pedestrian injury severity. Major risk factors that were considered for analysis include pedestrian and driver-specific attributes, roadway geometric details, climatic and visibility conditions and other accident-specific characteristics. Factors found with an increased likelihood of fatal injury to pedestrians were: old age pedestrians (above 50 years old), collision with heavy vehicles such as truck and bus, foggy weather and occurring in the month of March (Spring Season). The probability of major injury increased for pedestrian crashes involving: collision with Wagon, collision with Suzuki, Driver over speeding and collision with Motorcycle while the probability of minor injury increased with: Driver wearing seatbelt, collision with rickshaw, occurring on weekdays and involving middle age pedestrians (25 to 50 years old). The study recommends promoting public awareness regarding pedestrian safety through educational campaigns, limiting truck proportion in traffic stream and provision of pedestrian friendly road infrastructure to reduce pedestrian crashes. This is first of its kind study on pedestrian injury severity in Pakistan. Results are expected to develop better understanding of pedestrian crash risk factors and can serve as guidelines for different agencies such as City Traffic Police Peshawar and Peshawar Development Authority to enhance pedestrian safety in the city.

Chapter 1

INTRODUCTION

1.1 Overview

Least protected road users are called "Vulnerable Road Users". This includes pedestrians, cyclists and motorcyclists. Pedestrians have no protective shield against traffic accidents, which makes them most susceptible to traffic crashes. On average, one pedestrian fatality is reported every 2 hours and one pedestrian injury occurs every 8 minutes in United States of America (NHTSA, 2015). Road traffic accidents are the reason of annual 1.25 million fatalities globally out of which pedestrians have a share of 22% and cyclists experience 4% fatalities (WHO, 2015). In developing countries, the pedestrians and cyclists comprise of 33% of the road traffic fatalities while in some under-developed countries, this share is as high as 75 percent. Developing countries like Pakistan have an alarming rate of road traffic accident injuries and fatalities. Pakistan has a road traffic accident fatality rate of 14.4 out of every 10,000 registered vehicles whereas Japan has a fatality rate of 1.7 out of every 10,000 registered vehicles and Canada has fatality rate of 1.67 per 10,000 vehicles while Japan and Canada have significantly higher vehicle proportion than Pakistan (Haider & Badami, 2009). In developing countries pedestrians are forced to take high risks while crossing the road as their basic needs are not incorporated in the urban transportation megaprojects (Methorst, 2003). More often than not, pedestrians have to cross the road without pedestrian-specific road crossing facilities (Rankavat & Tiwari, 2016).

1.2 Pedestrian Safety in Developing Countries

Pedestrian crashes are quite high in developing countries as compared to developed countries. For instance, in 2013 it was found that almost 50% of the road traffic fatalities in Tehran, Iran were pedestrians (TTTO, 2013). Similar results were shown for Islamabad, Pakistan in another study (Zia et al., 2014). On the contrary, pedestrian fatality rate was only 19% in high income European countries (WHO, 2013). This issue of pedestrian safety firstly requires a comprehensive investigation of the safety barriers, ground realities and risk factors that lead to pedestrian accidents before devising efficient accident mitigation strategies. A major difference exists in the traffic composition, roadway use, provision and usage of pedestrian-specific road crossing facilities between the developing countries and the modern developed world.

Traffic stream in developing countries reflects a scenario of mixed and haphazard traffic conditions including passenger cars (private vehicles and taxis), heavy vehicles (buses, trucks etc.), bikes, rickshaws and animal drawn carriages/carts. Also, careless attitude towards driving due to wrong risk perception and lack of road safety education, low rate of using road safety gadgets particularly helmets and seatbelts because of low and inefficient policing are among the major issues in developing countries (Mohan, 1984; Sahdev et al., 1994; Li et al., 2008). Besides, both pedestrians and drivers exhibit more risky and aggressive behavior while crossing and driving on the roads respectively. This might be due to the lack of education, professional training, and enforcement of traffic regulations. Also, the usage of pedestrian-specific road crossing infrastructure in developing countries is very poor. Tanaboriboon & Jing (1994) concluded that pedestrians give preference to level signalized road crossings to overhead or subway crossings. Moreover, the usage of a pedestrian road crossing facility largely depends on its distance from the desired destination (Sisiopiku & Akin, 2003). Most of the pedestrian crossing facilities are not designed properly in the developing countries resulting in their under usage.

The kind of pedestrian crashes and the type of injuries sustained by pedestrians in developing nations are in contrast to the more advanced countries due to significant differences in roadway environments, individual behaviors and traffic conditions. Therefore, successful implementation of pedestrian safety strategies requires a careful review of the roadway and traffic conditions in the developed countries as they might not be valid and suitable to the situation in developing countries. However some worldwide successful and largely effective strategies might be accepted directly like making at grade intersections signalized, provision of sidewalks and pedestrian road crossing facilities such as underpasses, overhead pedestrian crossings, zebra crossing etc., regulating safe speed limits etc. to reduce RTCs involving pedestrians.

1.3 Problem Statement

In order to minimize the pedestrian crashes, a sound knowledge of individual impact of risk factors on the probability of occurrence of these accidents is necessary. Despite high pedestrian casualties in Pakistan, very limited studies have focused on pedestrian safety. Significant research has been made on pedestrian safety in developed countries but there is significant difference in the individual risk perception, type of pedestrian facilities and traffic conditions. Safety being the highest priority for all road users, such high percentage of pedestrian crashes is an alarming sign and demands the careful determination of risk factors leading to pedestrian accidents.

1.4 Study Objectives

The objectives set forth for this study are:

- Identification of pedestrian crash risk factors through literature search.
- To develop a suitable statistical modelling framework for pedestrian injury severity analysis.
- To identify key factors responsible for pedestrian crashes in Peshawar city.

1.5 Overview of the Study Approach

A detailed methodology was developed to successfully meet the desired objectives (Figure 1.1). Major tasks were the following:

- A comprehensive study of previous studies on pedestrian crashes around the globe.
- Collection and collation of pedestrian accident data.
- Study of various statistical approaches and selection of appropriate modelling framework.
- Estimation of correlated and uncorrelated random parameter mixed logit models for investigation of factors affecting pedestrian injury severity.
- Model results analysis and discussion.
- Conclusions and recommendations.

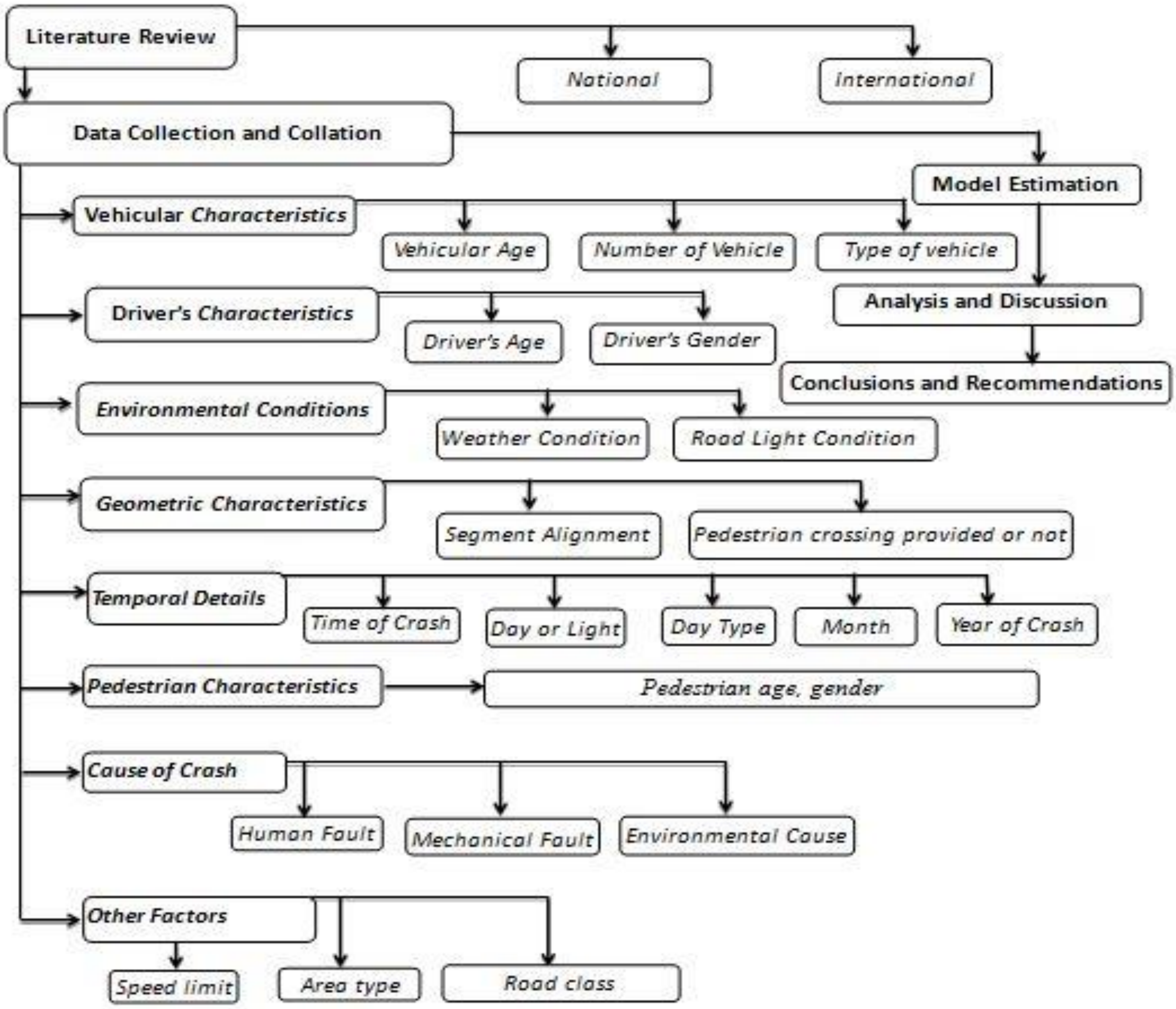

Fig 1.1: Overview of Study Approach

1.6 Study Structure

The study is composed of five chapters in which chapter 1 provides background knowledge for the requirement to develop a framework for pedestrian injury severity analysis, problem statement and study aim. Chapter 2 includes a detailed study of past literature regarding pedestrian injury severity analysis using various statistical approaches. Chapter 3 discusses the collection and collation of data used in this study. Chapter 4 discusses modeling framework, model estimation results and discussion. In the end, Chapter 5 presents research summary, conclusions and recommendations.

Chapter 2

LITERATURE REVIEW

2.1 Overview

This chapter presents a comprehensive assessment of previous studies employing different methodological and statistical approaches to identify the factors related to pedestrian crashes. Different analysis techniques adopted in earlier traffic safety research are discussed along with their pros and cons.

2.2 Previous Methodological Approaches

Numerous statistical techniques have been used previously to ascertain pedestrian injury severity (see Table 2.1 for a summary of some of the significant studies). In research related to pedestrian injury severity, various statistical techniques including multinomial logit, ordered probit, hierarchical logistic regression etc. have been used (Kim et al., 2017). Output of Logistic regression models is a binary outcome on the basis of one or more explanatory variables. Impact of drunk driving and truck on pedestrian injury severity was assessed using logistic regression model (Roudsari et al., 2004; Miles-Doan, 1996). Siddique et al. (2006) analyzed pedestrian injury severity in California using ordered probit model. Both ordered probit and ordered logit models were also used to study correlation between risk factors and pedestrian injury severity (Davis, 2011; Park et al., 2012). Kim et al., (2017) applied hierarchical logit model to study the association of risk factors with pedestrian injury severity by also incorporating regional characteristics such as socio economic and demographic characteristics of a particular region in South Korea.

Numerous statistical approaches, summarized in Table 2.2, have been used to carry out an empirical assessment of the pedestrian injury severities. Most of the prior pedestrian injury severity models consider the observed variables fix across individual outcomes. On the contrary, the independent variables have a different influence on each pedestrian injury outcome and thus, considering the explanatory variables fixed across each outcome is wrong approach. Also, some unobserved factors affect pedestrian injury severity such as pedestrian's walking speed, vehicle speed, driver's or pedestrian's perception of risk etc. which are almost impossible to collect given the poor and limited accident data collection system in developing countries including Pakistan. Negligence of these unobserved attributes (known as unobserved heterogeneity) induces biasness in parameter values and inaccurate inferences (Mannering et al., 2016). To solve the issue of unobserved heterogeneity, Kim et al., (2010) developed mixed logit model to assess pedestrian injury outcomes in pedestrian accidents in North Carolina. Considering its ability to tackle unobserved heterogeneity, mixed logit model was employed in our study to identify significant risk factors affecting pedestrian injury severity in Peshawar City. Table 2.3 provides a summary of prior studies using random parameter models that account for heterogeneity in the means and variances of the random variables. These models allow the variation in means and variances of random parameters across observations, thus effectively capturing the unobserved variation in the effects of predictor variables. Some safety studies in the recent past have used correlated random parameter models to determine some degree of possible correlations among random parameters (Venkataraman et al. 2011, Coruh et al. 2015, Yu et al. 2015, Fountas et al. 2018a, 2018b, Hou et al. 2018, Caliendo et al., 2019, Saeed et al. 2019a, Hou et al. 2020, Matsuo et al. 2020).

Table 2.1 Past Pedestrian Injury Severity Related Studies

Year	Author	Location	Context	Key Findings
2019b	Chen & Fan	North Carolina, USA	Investigation of significant contributory factors to pedestrian injury severity in both rural and urban areas in North Carolina	Driver's physical condition, heavy trucks, dark light condition, speed limit between 35 and 50 mph and above 50mph found to significantly increase pedestrian injury severities in rural as well as urban areas.
2018	Li and Fan	North Carolina, USA	Modeling the severity of pedestrian injury in pedestrian-vehicle crashes in North Carolina	Young drivers (<24 years old) and older pedestrians (>54 years old), heavy and large-sized vehicles significantly increase pedestrian injury severity.
2017	Ni et al.	Shanghai, China	Analysis of pedestrians' safety perception at signalized intersections	All types of passengers appreciate the presence of refuge island on a wide street however the safety perception of providing an additional stop at refuge island varies among pedestrians.
2016	Behnood & Mannering	Chicago, Illinois, USA	Assessment of effects of economic recession on pedestrian injury severity	The risk factors concerned with pedestrian injury exhibit significant temporal instability due to combination of economic recession and varying influence of these parameters on pedestrian injury.
2015	Haleem et al.	Florida, USA	Analysis of pedestrian crash injury severity at signalized and non-signalized locations	Higher AADT, very old pedestrians, rainy weather etc. were associated with high pedestrian injury severity at signalized intersections while mid age and very old pedestrians, dark lighting, vans etc. caused severe pedestrian injury at unsignalized locations

Table 2.1 Past Pedestrian Injury Severity Related Studies (Continued)

2014	Islam and Jones	Alabama, USA	Investigation of significant contributory factors resulting in pedestrian at fault crashes in both rural and urban locations in Alabama	Female pedestrians, Crashes on weekends, pedestrians aged 24-64 increased the probability of severe pedestrian injury in urban areas while county road, dark lighting etc. were associated with severe injury in rural areas
2011	Tay et al.	South Korea	Identification of significant risk factors associated with pedestrian injury severity	Heavy vehicles, drunk drivers, female and old pedestrians, inclement weather conditions, pedestrian accidents on high speed roads etc. lead to severe and fatal pedestrian accidents.
2010	Ulfarsson et al.	North Carolina, USA	Exploration of assignment of fault in pedestrian-vehicle crashes	Pedestrians are found at fault in the vast majority of pedestrian accidents followed by driver at-fault accidents while pedestrians as well as drivers are found guilty in the least number of pedestrian accidents.
2008	Kim et al.	North Carolina, USA	Analysis of pedestrian injury severity with heteroskedasticity in pedestrian age	Male drivers, intoxicated drivers, old pedestrians, dark conditions, trucks and sport-utility vehicles, speeding etc. increase the probability of fatal pedestrian accidents.
2006	Siddiqui et al.	Florida, USA	Assessing the role of crossing locations, lighting conditions in pedestrian injury severity	The probability of fatal pedestrian crash at midblock is greater than that at the intersection at any light condition whereas road lights reduce the probability of pedestrian fatality by 75% at midblock locations and by 83% at intersections.
2001	Davis	Minnesota, USA	Analyzing pedestrian injury severity with respect to impact speed in pedestrian-vehicle crashes	The impact speed at which there is a 50% chance of fatal pedestrian accident ranges from 70-75 km/h for children and adults while it ranges from 45-50 km/h for old pedestrians above 60 years of age.

Table 2.2 Methodological Approaches used for Pedestrian Injury Severities in Past

Methodological Approach	**Previous research**
Ordered probit model	Siddiqui et al. (2006), Jang et al. (2013)
Ordered Logit Model	Davis (2001), Ni et al. (2017)
Heteroskedastic Logit Model	Kim et al. (2008)
Multinomial Logit Model	Ulfarsson et al. (2010), Tay et al. (2011), Zhou et al. (2013), Fan et al. (2015), Chen and Fan (2019a)
Hierarchical Ordered Model	Kim et al. (2017)
Latent class clustering and Partial Proportional Odds Model	Sasidharan and Menendez (2014), Li and Fan (2018), Sun et al. (2019), Li and Fan (2019)
Mixed (Random Parameters) Logit Model	Kim et al. (2010), Islam and Jones (2014), Haleem et al. (2015), Chen and Fan (2019b)
Random parameters generalized ordered probit model with heterogeneity in means and variances	Xin et al. (2017)
Multivariate Poisson Lognormal Model	Zhan et al. (2015)
Latent Class Multivariate Model	Narayanamoorthy et al. (2013), Nashad et al. (2016), Heydari et al. (2017)
Multivariate Random Coefficients Model	Bhat et al. (2017)
Mixed Generalized Ordered Response Model	Eluru et al. (2008)

Table 2.3. Past Research Effort Addressing Heterogeneity in Means and Variances

Modeling Frameworks	**Application**	**Previous Research**
Random parameters logit model with heterogeneity in parameter means	To explore the effect of passengers on driver-injury severities in single-vehicle crashes	Behnood and Mannering (2017a)
Random parameters logit model with heterogeneity in means and variances	To assess the contributory factors in cyclist injury severities in crashes involving bicycles	Behnood and Mannering (2017b)
Random parameters logit model with heterogeneity in means and variances	Dealing with occupant injury severity in crashes involving hybrid-vehicle	Seraneeprakarn et al. (201
Random parameters generalized ordered probit model with heterogeneity in means and variances	To study the effects of surroundings and environment on pedestrian injury severity	Xin et al. (2017)
Multilevel Bayesian heteroskedastic Poisson lognormal model with grouped random parameters allowing heterogeneity in means and variances of parameters	Standardization of different areas in terms of a chosen measure of safety for highway railway grade crossings	Heydari et al. (2018)
Random parameters logit model with heterogeneity in means and variances	Assessment of factors related to motorbike riders' injury severities	Waseem et al. (2019)
Random parameters logit model with heterogeneity in means	To study a driver's decisions related to a damaged vehcle after encountering a traffic accident	Hamed and Al-Eideh (2020)
Random parameters logit model with heterogeneity in means and variances	To study contrasts between single-vehicle crash-injury severities when aggressive and careful driving behavior is exhibited	Islam and Mannering (2020)

2.3 Risk Factors

Various attempts have been made in the past to identify major contributing risk factors concerned with injury severity of pedestrian accidents using statistical models. Factors concluded to be responsible for an increase in pedestrian injury severity were: pedestrian age & gender (Ulfarsson & Mannering, 2004; Kim et al., 2010; Li & Fan, 2019; Chen & Fan, 2019), heavy vehicles such as trucks, buses, construction machinery etc. (Kim et al., 2010; Kim et al., 2017; Li & Fan, 2019; Chen & Fan, 2019), driver characteristics such as driver age, drunk driving etc. (Zajac & Ivan, 2003; Leung & Starmer, 2005; Kim et al., 2010; Tay et al., 2011), roadway geometric conditions (Lee & Abdel-Aty, 2005; Kim et al., 2008; Rankavat & Tiwari, 2016; Li & Fan, 2019; Chen & Fan, 2019), roadway lighting conditions (Kim et al., 2008; Sullivan & Flanagan, 2011; Aziz et al., 2013; Chen & Fan, 2019), posted speed limit (Sze & Wong, 2007; Tay et al., 2011; Chen & Fan, 2019), roads of higher functional classification (Kim et al., 2010; Chen & Fan, 2019; Li & Fan, 2019).

2.3.1 Pedestrian Characteristics

Prior studies have identified pedestrian age more than 65 years and pedestrian gender especially female as the one highly susceptible to fatal crash. Older pedestrians require more reaction time and have more deteriorated capabilities as compared to young pedestrians (Chen & Fan, 2019). Moreover, female pedestrians were observed to have undergone more fatal crashes than male pedestrians due to their slower crossing speed and different physiological characteristics than male pedestrians. The authors suggested that road safety awareness campaigns should be run specially focusing older and female pedestrians (Ulfarsson & Mannering, 2004; Tay et al., 2011).

2.3.2 Driver Characteristics

Past studies have found out significant relationship between crash risk and driver characteristics. Kim et al., (2008) analyzed factors affecting pedestrian injury in North Carolina, USA considering 3 year pedestrian accident data from 1997 to 2000 through heteroskedastic model and found that increasing driver age reduces the likelihood of fatal pedestrian accidents. This is intuitive as older drivers tend to drive more carefully and do not exhibit risky or aggressive behavior. Kim et al., (2010) evaluated pedestrian crash data using mixed logit model and observed an increased likelihood of fatal pedestrian accidents caused by drunk driving. Drivers' vehicle operating skills are severely hampered when they are drunk (Leung & Starmer, 2005). Tay et al., (2011) used a multinomial logit model to assess pedestrian injury severity in South Korea. They found out that the factors of drunk driving and middle aged drivers had a major effect on each severity level of pedestrian injury.

2.3.3 Heavy Vehicles (Trucks, Machinery)

Heavy vehicles such as trucks, construction machines etc. were considered in many studies and were declared an extremely important factor in pedestrian crash injury severity. Kim et al., (2010) evaluated pedestrian crash data using mixed logit model and observed a 350% increase in fatal crash probability by truck as the vehicle type. Kim et al., (2017) assessed pedestrian injury severity through hierarchical ordered model in South Korea and observed that heavy vehicles including trucks, construction machines, farm machinery etc. were responsible for most severe pedestrian injury accidents. Another study using MNL model for analyzing pedestrian injury severity pointed out motorcycles and heavy trucks as the culprits for fatal and major severity pedestrian accidents (Chen & Fan, 2019). Li & Fan (2019) used latent class clustering and partial proportional odds model for assessment of pedestrian injury severity in North Carolina and concluded that pedestrians' collisions with trucks were most likely to cause most severe injury (capacitating and fatal) to pedestrians.

2.3.4 Roadway Type and Geometry

Roadway functional class and its associated road side objects have a significant effect on pedestrian injury severity. Chen & Fan (2019) used MNL model to investigate pedestrian injury severity in North Carolina, USA and found that the pedestrian crashes taking place on arterials and along curved sections increased the likelihood of fatal and major injury to pedestrians whereas those taking place on collectors and local streets increased the likelihood of minor injury to pedestrians. Pedestrian crashes occurring on high speed roads, link roads, bridges, tunnels and wider roads increase the pedestrian injury severity level (Tay et al., 2011).

2.3.5 Posted Speed Limit

Past studies have shown a significant association of posted speed limit with pedestrian injury severity. Pedestrian crashes on roads having speed limit above 50 km/h were found to cause severe injury to pedestrians (Sze & Wong, 2007). Pedestrian accidents on State roads having speed limit above 50 mph are highly likely to cause fatal injury to pedestrians (Chen & Fan, 2019). Majority of pedestrian accidents occur at locations with the posted speed limit ranging from 50 to 60 km/h (Nishimoto et al., 2019).

2.4 Research on Pedestrian Safety at National Level

Khan et al., (1999) conducted a study to determine pedestrian behavior as well as pedestrian environment characteristics i.e. extent of encroachment on sidewalks and illegal parking etc. in Karachi. Around 250 pedestrians were observed at ten locations of highest pedestrian crash risk in the city. Observed pedestrian behavior included three phenomena i.e. pedestrian crossing the road, walking on the road and walking on the sidewalk. It was observed that pedestrians who crossed the road one lane at a time, in the form of a group and crossed the road by running had more chances to disrupt the traffic stream as compared to those who crossed the entire road at once, singly and by walking respectively. On average 77% of the total sidewalk width in the city was occupied by encroachments and 33% of the total road width was occupied with illegal car parking which compelled the pedestrians to take more risks and led to increased pedestrian injury and fatality rate. The authors suggested that sincere efforts regarding improvement of pedestrian environment need to be done in order to reduce pedestrian loss of lives and enhance pedestrian safety.

Minhas et al., (2017) studied pedestrian road crossing behavior as well as driver behavior with the pedestrians at intersections in Lahore through video recordings at high pedestrian activity intersections in the city. Pedestrian road crossing behavior and driver behaviors were studied based on parameters of gender, age group, presence of traffic signal and land use of neighborhood. The results showed major variation in behavior of children and old age pedestrians than that of middle age pedestrians. The pedestrian behavior was more on the safe side in highly developed residential areas whereas driver behavior was safer in locations where traffic signals were present.

Shah et al., (2018) did a case study on pedestrian accidents in Peshawar city using police reported crash data from 2003-2012. No annual pattern could be established in pedestrian accidents during the study period. After the detailed analysis of crash data and engineering judgment during crash site visits, the authors came to the conclusion that there is great need of pedestrian-specific road crossing facilities, signs and markings at various locations in the city. Moreover, the study suggested more detailed and comprehensive after-crash data collection system and measures to control travel speed.

Till now, no study on pedestrian safety has been conducted in Pakistan with the aim to explore the significant contributory risk factors leading to pedestrian casualties using a statistical modeling approach. This is the pioneer research (to the best of our knowledge) in the country regarding pedestrian injury severity analysis through random parameter mixed logit model.

CHAPTER 3

ACCIDENT DATA STATISTICS

3.1 Crash Data

The study is based on Peshawar city, the provincial capital of KPK, Pakistan. The pedestrian accident data for current study were acquired from Rescue 1122 Divisional Office Peshawar, a leading emergency response unit in the country. The reason behind obtaining data from Rescue 1122 was the underreporting of lower severity injuries in the police FIR data, which leads to unrealistic coefficient estimation and biased results (Yamamoto et al., 2008). Around 4,000 emergency response forms were sorted out to extract the road traffic injuries (RTI) involving a pedestrian victim. The data included the personal attributes of the pedestrian victim i.e. name, age, gender etc. accident location, date, time, reason of the crash and the kind of vehicle involved in the crash. Weather data were obtained from online source i.e. www.timeanddate.com and geometric attributes of the road segments were acquired from Peshawar Development Authority (PDA). Further missing geometric details were obtained by visiting individual road segments. Data were collected for a period of 4 years (Jan 2016 to Dec 2019). The final data set contained 2,198 observations after omitting records with missing details.

3.2 Data Description

Victim’s actual injury at the scene of crash was noted in the emergency response form by the ambulance staff of rescue 1122, who are qualified medical emergency technicians having diploma in paramedics. Actual injuries are then categorized into 3 levels in increasing order of severity i.e. (minor injury, major injury and fatal injury) which are coded with the following options. The description of 3 levels of injury severity is given in Table 3.1

Table 3.1: Description of Crash Injury Severity Levels

Level	**Definition**	**Description**
1	Minor Injury	It includes no risk to the life of the victim (i.e. abrasions, lacerations or minor cuts with little or no bleeding etc.)
2	Major Injury	It reflects high severity injury inducing risk to the life of the victim (i.e. neck, head, spinal injury, single or multiple fractures, considerable bleeding etc.)
3	Fatal Injury	It reflects immediate fatality of the victim due to accident.

Out of 2,198 observations involving a pedestrian, there were 672 (30.58%) cases having minor injuries, 906 (41.22%) victims with major injuries, and 620 (28.20%) with fatal injuries.

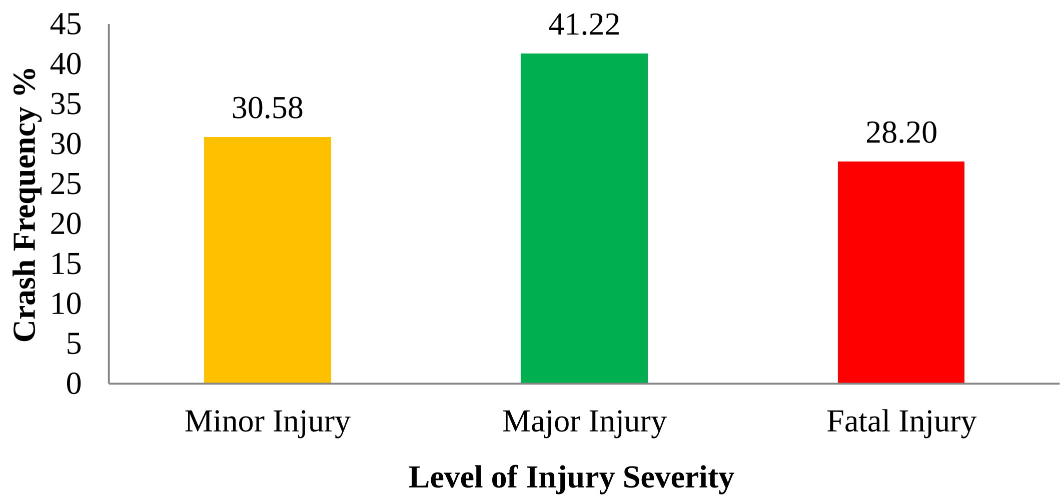

Fig 3.1: Injury Severity Distribution of Pedestrian Crashes

3.3 Data Descriptive Statistics

Major factors that were considered for analysis include pedestrian attributes, temporal details, driver characteristics, environmental conditions, roadway characteristics and crash specific factors. Each of the mentioned characteristics contained certain variables which were included in the final dataset as presented in (Table 3.2). Crash injury severity was taken as the response variable whereas 79 explanatory variables were included in the final data set. All the variables (except roadway characteristics and environmental conditions) were obtained from emergency response forms. According to data, male pedestrians (victims) were in the vast majority as compared to female pedestrians in Pakistan which is intuitive given the social and cultural constraints. Of the total victims, 98.59% were male pedestrians while female pedestrians' share was 1.41%. Pedestrians in the middle age (between 25 to 50 years) had undergone the highest number of crashes (47.41%). It was observed that a considerably large number of pedestrian accidents had occurred on weekdays (71.02%) as compared to those on weekends (28.98%). 89.81 percent of the drivers involved in pedestrian crashes were male whereas only 10.19% were female drivers. Only a meager 7.55% of the drivers were wearing a seatbelt while the rest were without any protective equipment at the instant of accident. Pedestrian accidents occurring in daylight (65.88%) were more than those occurred at night or dark conditions. Pedestrian crash frequency was higher in January (17.33%), on Friday (16.15%), in Spring season (33.39%), in off-peak hours (69.20%), in clear visibility conditions (67.93%), on roads having two lanes in each direction (43.63%), and on roads with a speed limit between 50-70 km/hr (73.34%).

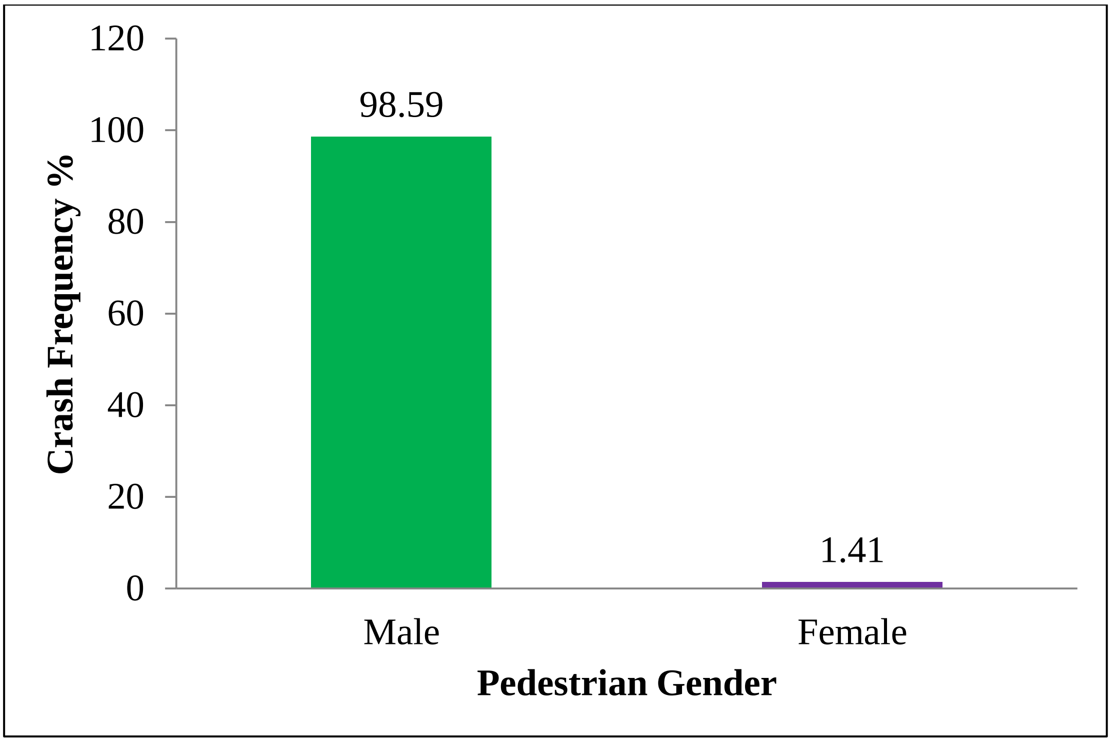

Fig 3.2: Pedestrian Gender based Crash Frequency Distribution

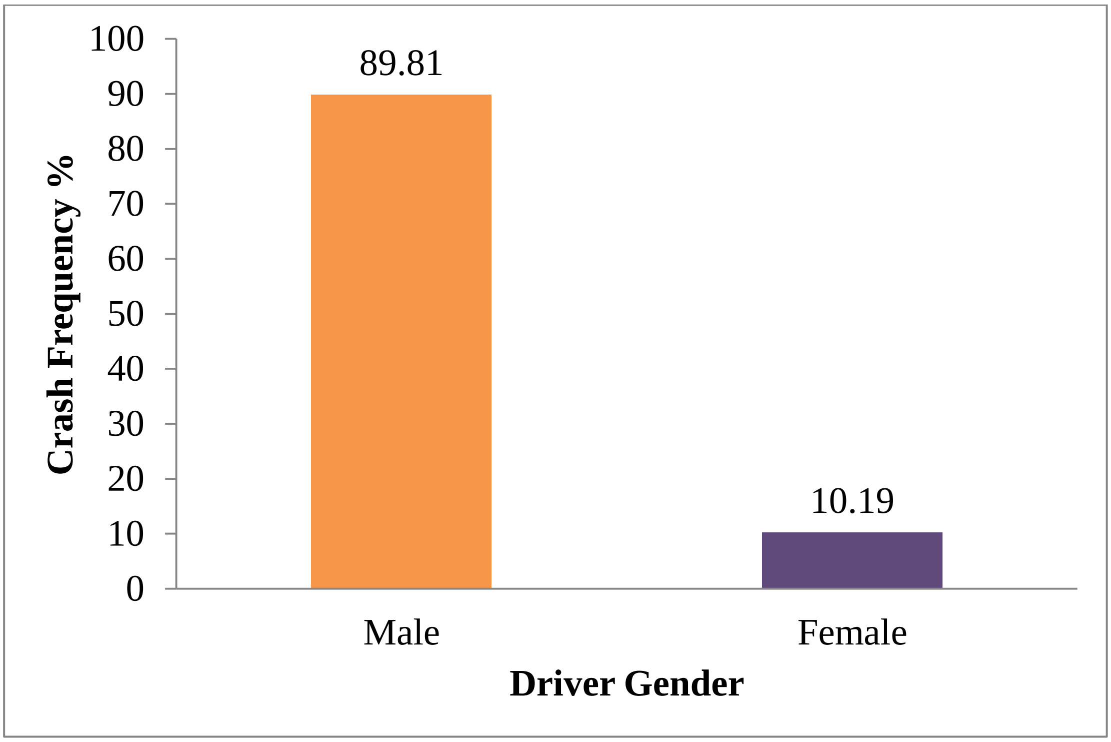

Fig 3.3: Driver Gender based Crash Frequency Distribution

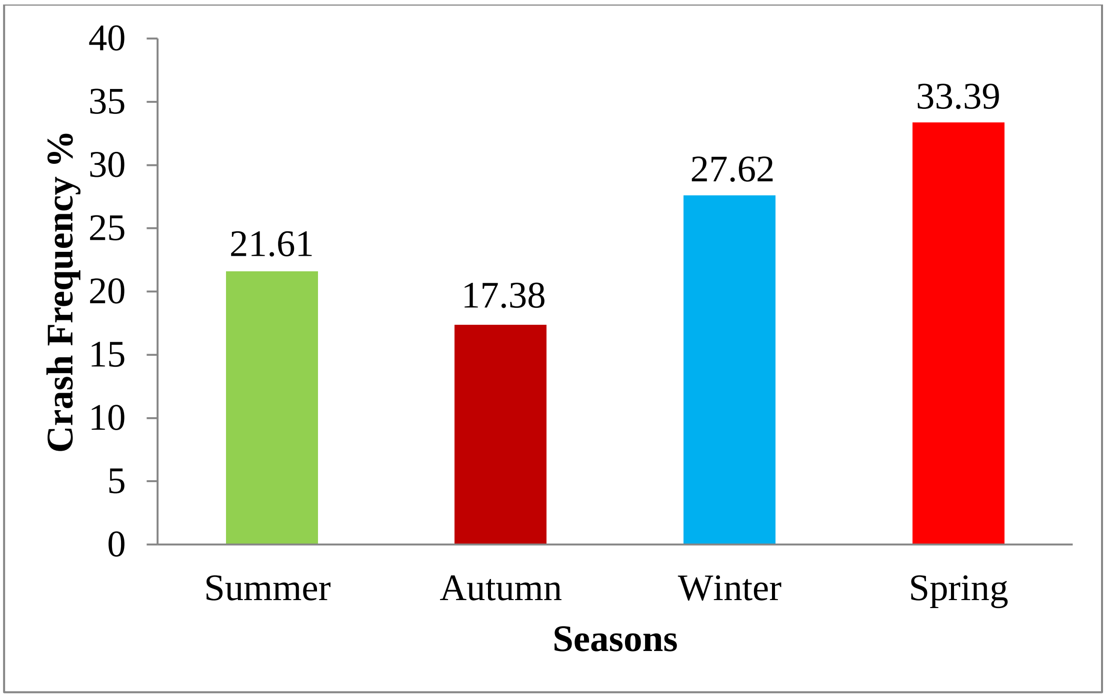

Fig 3.4: Seasonal Variation in Pedestrian Crash Frequency

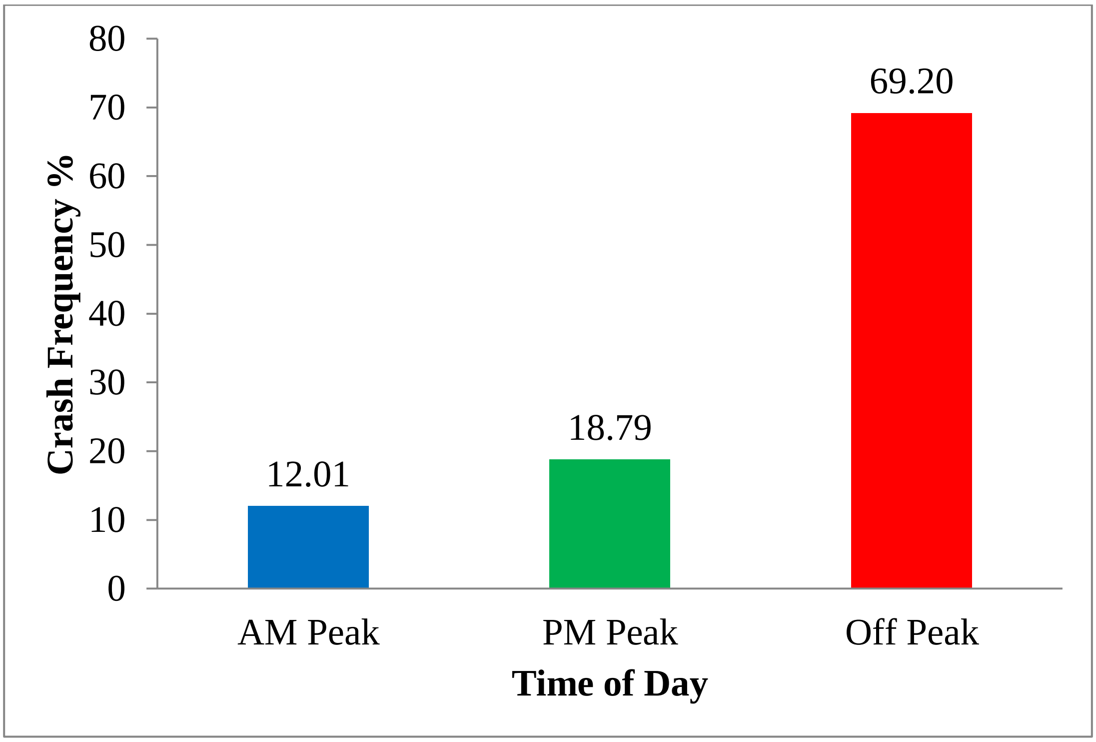

Fig 3.5: Temporal Variation in Pedestrian Crash Frequency

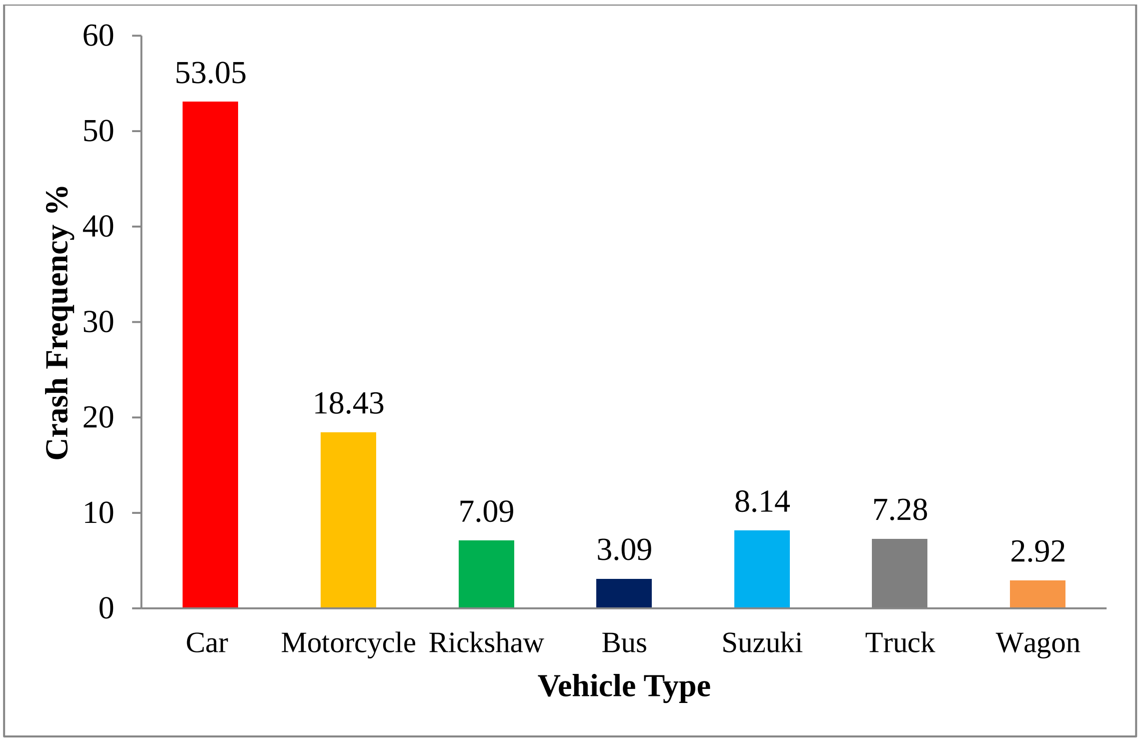

Fig 3.6: Pedestrian Crash Frequency based on Type of Vehicle involved

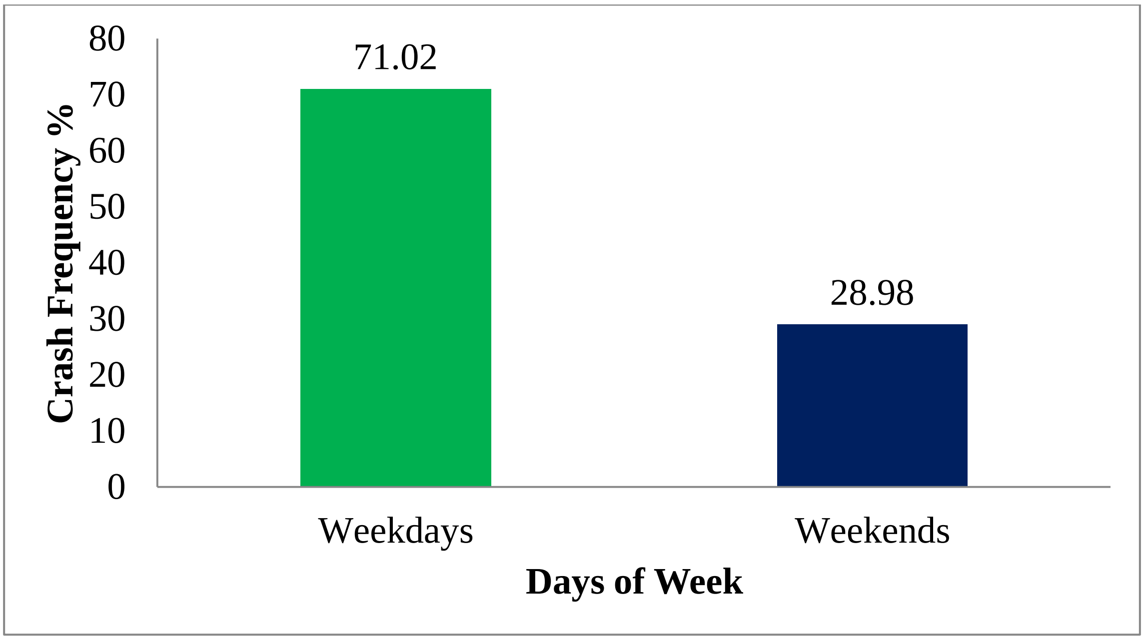

Fig 3.7: Pedestrian Crash Frequency based on Days of Week

Table 3.2: Classifications of Independent Variables

Variables Category	Explanatory Variables with Description
Pedestrian Attributes	i. Gender ii. Age
Temporal Details	i. Month ii. Day iii. Season iv. Weekday/Weekend v. Traffic hours
Driver Characteristics	i. Gender ii. Age iii. With/Without Seatbelt iv. Licensed/unlicensed Driver
Environmental Conditions	i. Weather forecast ii. Light condition iii. Visibility Condition
Roadway Characteristics	i. Provision of shoulder ii. Type of shoulder iii. Provision of footpath iv. Lanes per direction v. Provision of median vi. Type of median vii. Posted speed limit viii. Presence of pedestrian crossing facility
Type of Vehicle	i. Car ii. Motorcycle iii. Rickshaw iv. Bus v. Suzuki vi. Truck vii. Wagon

Table 3.3: Descriptions of Response and Explanatory Variables

Sr. No	Selected Variables Description
1.	**Pedestrian injury severity:** 1) minor injury 2) major injury 3) fatal injury
2.	**Pedestrian gender indicator:** 1 if pedestrian is male, 0 for female
3.	**AM Peak indicator:** 1 for crash in Morning Peak time , 0 otherwise
4.	**PM Peak indicator:** 1 for crash in Evening Peak time, 0 otherwise
5.	**Off Peak indicator:** 1 for crash in Off Peak time, 0 otherwise
6.	**January indicator:** 1 for crash in January, 0 otherwise
7.	**February indicator:** 1 for crash in February, 0 otherwise
8.	**March indicator:** 1 for crash in March, 0 otherwise
9.	**April indicator:** 1 for crash in April, 0 otherwise
10.	**May indicator:** 1 for crash in May, 0 otherwise
11.	**June indicator:** 1 for crash in June, 0 otherwise
12.	**July indicator:** 1 for crash in July, 0 otherwise
13.	**August indicator:** 1 for crash in August, 0 otherwise
14.	**September indicator:** 1 for crash in September, 0 otherwise
15.	**October indicator:** 1 for crash in October, 0 otherwise
16.	**November indicator:** 1 for crash in November, 0 otherwise
17.	**December indicator:** 1 for crash in December, 0 otherwise
18.	**Monday indicator:** 1 for crash on Monday, 0 otherwise
19.	**Tuesday indicator:** 1 for crash on Tuesday, 0 otherwise
20.	**Wednesday indicator:** 1 for crash on Wednesday, 0 otherwise
21.	**Thursday indicator:** 1 for crash on Thursday, 0 otherwise
22.	**Friday indicator:** 1 for crash on Friday, 0 otherwise
23.	**Saturday indicator:** 1 for crash on Saturday, 0 otherwise
24.	**Sunday indicator:** 1 for crash on Sunday, 0 otherwise
25.	**Weekday indicator:** 1 for crash on weekday, 0 otherwise
26.	**Young Pedestrian indicator:** 1 for pedestrian age less than 25, 0 otherwise
27.	**Middle Age Pedestrian Indicator:** 1 for pedestrian age between 25-50, 0 otherwise
28.	**Old Pedestrian Indicator:** 1 for pedestrian age more than 50, 0 otherwise
29.	**Driver Gender indicator:** 1 for male driver, 0 for female driver

Table 3.3: Descriptions of Response and Explanatory Variables (Continued)

Sr. No	Selected Variables Description
30.	**Young Driver indicator:** 1 for driver age less than 25, 0 otherwise
31.	**Middle Age Driver Indicator:** 1 for driver age between 25-50, 0 otherwise
32.	**Old Age Driver Indicator:** 1 for driver age more than 50, 0 otherwise
33.	**Seatbelt indicator:** 1 for driver wearing seatbelt, 0 otherwise
34.	**Driving License indicator:** 1 for licensed driver, 0 otherwise
35.	**Motorcycle indicator:** 1 if pedestrian was hit by Motorcycle, 0 otherwise
36.	**Car indicator:** 1 if pedestrian was hit by Car, 0 otherwise
37.	**Rickshaw indicator:** 1if pedestrian was hit by Rickshaw, 0 otherwise
38.	**Suzuki indicator:** 1 if pedestrian was hit by Suzuki, 0 otherwise
39.	**Bus indicator:** 1 for pedestrian crash with Bus, 0 otherwise
40.	**Wagon indicator:** 1 if pedestrian was hit by Wagon, 0 otherwise
41.	**Truck indicator:** 1 for pedestrian crash with Truck, 0 otherwise
42.	**Carelessness indicator:** 1 for crash due to carelessness by pedestrian, 0 otherwise
43.	**Over speeding indicator:** 1 for crash due to over speeding by driver, 0 otherwise
44.	**Pedestrian Fault indicator:** 1 for crash due to pedestrian fault, 0 otherwise
45.	**Poor Visibility indicator:** 1 for crash due to poor visibility, 0 otherwise
46.	**Driver Dozing indicator:** 1 for crash due to driver dozing, 0 otherwise
47.	**Slippery Road indicator:** 1 for crash due to slippery road surface, 0 otherwise
48.	**Sunny Weather indicator:** 1 for crash in sunny weather, 0 otherwise
49.	**Cloudy Weather indicator:** 1 for crash in cloudy weather, 0 otherwise
50.	**Foggy Weather indicator:** 1 for crash in foggy weather, 0 otherwise
51.	**Rainy Weather indicator:** 1 for crash in rainy weather, 0 otherwise
52.	**Hazy Weather indicator:** 1 for crash in hazy weather , 0 otherwise
53.	**Clear Weather indicator:** 1 for crash in clear weather, 0 otherwise
54.	**Clear Visibility indicator:** 1 for crash in clear visibility condition, 0 otherwise
55.	**Hazy Visibility indicator:** 1 for crash in hazy visibility condition, 0 otherwise
56.	**Foggy Visibility indicator:** 1 for crash in foggy visibility condition, 0 otherwise
57.	**Day Light indicator:** 1 for crash in daylight, 0 otherwise
58.	**Fading Light indicator:** 1 for crash in fading light condition, 0 otherwise
59.	**Night with Road Lights indicator:** 1 for night crash with road lights ON, 0 otherwise

Table 3.3: Descriptions of Response and Explanatory Variables (Continued)

Sr. No	Selected Variables Description
60.	**Night without Road Lights indicator:** 1 for crash at night with no or OFF road lights, 0 otherwise
61.	**Dawn indicator:** 1 for crash at dawn, 0 otherwise
62.	**Dusk indicator:** 1 for crash at dusk, 0 otherwise
63.	**2 lanes per direction indicator:** 1 for crash on 2 lanes per direction road ,0 otherwise
64.	**3 lanes per direction indicator:** 1 for crash on 3 lanes per direction road ,0 otherwise
65.	**4 lanes per direction indicator:** 1 for crash on 4 lanes per direction road,0 otherwise
66.	**2 lane 2 way road indicator:** 1 for crash on 2 lane 2 way road, 0 otherwise
67.	**Straight Road indicator:** 1 for crash on straight road segment, 0 otherwise
68.	**Curved Road indicator:** 1 for crash on curved road segment, 0 otherwise
69.	**Shoulder Provision indicator:** 1 for shoulder present,0 otherwise
70.	**Paved Shoulder indicator:** 1 for crash on road with paved shoulder, 0 otherwise
71.	**Footpath provision Indicator:** 1 for footpath present, 0 otherwise
72.	**Median Provision indicator:** 1 for crash on road with median, 0 otherwise.
73.	**Curbstone median indicator:** 1 for crash on road with curbstone median, 0 otherwise
74.	**Cat eyes median indicator:** 1 for crash on road with cat eyes, 0 otherwise
75.	**Overpass/Underpass provision indicator:** 1 for overpass or underpass present at crasl location, 0 otherwise
76.	**Speed limit <50 km/h indicator:** 1 for speed limit less than 50 km/h, 0 otherwise
77.	**Speed limit 50-70 km/h indicator:** 1 for speed limit between 50-70 km/h, 0 otherwise
78.	**Speed limit > 70 km/h indicator:** 1 for speed limit more than 70 km/h, 0 otherwise
79.	**Intersection indicator:** 1 for crash at an intersection, 0 otherwise

Table 3.4: Descriptive Statistics of Key Variables

Factors	**Proportion**
Crash Severity	
Minor injury/Major injury/Fatal	30.58/41.22/28.20
Month	
January/February/March/April/May/June/July/ August/September/October/November/December	17.33/5.91/10.24/11.74/11.42/10.42/ 6.59/4.60/5.69/7.73/3.43/4.37
Day	
Monday/Tuesday/Wednesday/Thursday/Friday/S aturday/Sunday	14.56/13.56/14.19/12.56/16.15/13.65/ 15.33
Weekday/Weekend	71.02/28.98
Weather	
Sunny/Cloudy/Foggy/Clear/Haze/Rain	19.52/41.45/1.68/5.37/28.65/3.23
Season of the Year	
Summer season (Jun, Jul, Aug) /Autumn (Sept, Oct, Nov)/ Winter (Dec, Jan, Feb) / Spring (Mar, Apr, May)	21.61/17.38/27.62/33.39
Time of Day	
AM Peak (7am-10am)/PM Peak (6pm-9pm)/off-peak hours	12.01/18.79/69.20
Roadway Type	
2 lane each side /3 lane each side /4 lane each side /2 lane 2- way road	43.63/39.99/0.64/15.74
Posted Speed Limits	
below 50kmph /50-70kmph/above 70kmph	12.28/73.34/14.38
Driver Details	
Gender: Male/Female	89.81/10.19
Age: Below 25yrs/25-50yrs/Above 50yrs	17.42/78.39/4.19
With Seatbelt/Without Seatbelt	7.55/92.45
With License/Without License	93.72/6.28
Pedestrian Details	
Gender: Male/Female	98.59/1.41
Age: Below 25yrs/25-50yrs/Above 50yrs	43.77/47.41/8.82
Light Conditions	
Daylight/Dawn/Dusk/Fading Light/Night time with ON road lights/Night time with OFF or no road lights	65.88/0.23/2.64/6.73/24.11/0.41

Table 3.4: Descriptive Statistics of Key Variables (Continued)

Visibility Conditions	
Foggy/Clear /Hazy	4.82/67.93/27.25
Crash Characteristics	
Car/Motorcycle/Rickshaw/Bus/Suzuki/Truck/Wagon	53.05/18.43/7.09/3.09/8.14/7.28/2.92
Reported Crash Reason	
Carelessness/Driver dozing/Over speeding/Pedestrian fault/Poor visibility	61.92/0.59/17.42/15.70/4.37

Chapter 4

STUDY METHODOLOGY AND MODEL ESTIMATION RESULTS

4.1 Introduction

Statistical modelling of data related to traffic accidents is typically concerned with estimating the probability of occurrence of an accident and severity of the injury caused by it. The probability of occurrence of accident is mostly determined by observing the number of traffic crashes happening on a specific location in a certain time period. On observing an accident, the injury severities of accident victims are often considered as discrete quantities, i.e. no injury, minor injury, major injury, and fatality (Savolainen et al., 2011; Mannering and Bhat, 2014).

4.2 Mixed Logit Model

Based on the advantages and drawbacks of different statistical modeling approaches employed in pedestrian injury severity analysis, the study used mixed logit model to point out significant factors leading to pedestrian accidents. Due to unavailability of certain important variables like vehicle mechanical condition, amount of traffic, speed of vehicle and driving skills (behavioral differences, reaction time and driver experience level) that could affect pedestrian's severity outcomes, unobserved heterogeneity exists in the data and it can hamper the impact of observed independent variables on severity of injuries sustained by pedestrians, inducing biasness in parameter estimation (Mannering et al., 2016). Mixed logit model can solve the problem of unobserved heterogeneity. This model permits the values of parameters to vary across the observations. To counter the possibility of misspecifications, a random parameters logit model incorporating the possibility of heterogeneity in the means and variances of the random parameters is used. The pedestrian injury severity function is given as follows according to Milton et al., (2008)

$$P_{in} = \beta_i X_{in} + \varepsilon_{in} \quad (1)$$

P_{in} is pedestrian accident injury severity for category *i* (minor injury, major injury, fatal injury) for each individual accident n; X_{in} denotes the observed explanatory characteristics (pedestrian/ crash/ driver/ weather/ temporal-specific variables); β_i denotes the coefficients of explanatory variables and ε_{in} denotes the error term. The possibility of unobserved heterogeneity is incorporated by permitting βi to vary across crashes defined as (Seraneeprakarn et al. 2017; Behnood and Mannering, 2017a, 2017b; Waseem et al., 2019; Alnawmasi and Mannering, 2019; Washington et al., 2020).

$$\beta_i = \beta + \Theta_i Z_i + \sigma_i \text{ EXP } (\omega_i W_i)_{\upsilon i} \quad (2)$$

β is the mean value of parameter across all accidents, Z_i and W_i are vectors of attributes capturing heterogeneity in the mean and standard deviation (σ_i, with parameter vector ω_i) respectively, Θ_i is a corresponding vector of estimable parameters, and υ_i denotes the disturbance term. Moreover, to incorporate possible correlation among random parameters, β_i takes the form as follows:

$$\beta_{CRP} = \beta_i + C\omega_m \quad (3)$$

where $\boldsymbol{\omega_m}$ is a random error term following a distribution (for instance, normal, lognormal, exponential, etc.) and $\boldsymbol{C}$ is the variance-covariance matrix called Cholesky matrix (Saeed et al., 2019a).

According to McFadden, (1981) ε_{in} are generally considered to follow extreme value distribution, then applying multinomial logit model we get:

$$P_n(i) = \frac{EXP[\beta_i X_{in}]}{\sum EXP[\beta_I X_{in}]} \quad (4)$$

$P_n(i)$ denotes the probability of pedestrian injury severity category i for crash n and I denotes set of all injury severity outcomes. A mixing distribution introduced in multinomial logit model permits parameters to vary across crashes. The observed predictor variables are considered to be fixed or random in the mixed logit model. In this way, unobserved heterogeneity is accommodated in the crash data. The variables which are random in the model are supposed to be the ones occurring due to unobserved heterogeneity in the crash data. The model formulation (with mixing distribution) giving pedestrian injury severity probabilities are (McFadden and Train, 2000):

$$P_{in}=\int_x P_n(i) f(\beta_i/\varphi_i) d\beta_i \quad (5)$$

$f(\beta_i/\varphi_i)$ denotes the density function of β_i while φ_i is a vector of mean and variance which are the parameters of the density function. A simulated maximum likelihood approach is used for the estimation of the model in Eq. (5) using 500 Halton draws (McFadden and Train, 2000; Train, 2009). In the current study, multiple distributions were empirically checked for $f(\beta_i/\varphi_i)$; however, the normal distribution proved to statistically outperform other distributions. Past studies also found normal distribution to yield the best statistical fit to the model (Alnawmasi and Mannering, 2019; Waseem et al., 2019).

To investigate the statistical superiority of the competing models i.e. random parameters logit model with no heterogeneity in means and variances, uncorrelated random parameters model with heterogeneity in means, and correlated random parameters model with heterogeneity in means, several empirical test statistics were used which include Akaike information criterion, Bayesian information criterion, and likelihood ratio tests. The likelihood ratio tests (Eq. 6) were performed to evaluate the relative statistical superiority of the alternative models estimated in this study.

$$\chi^2 = -2[LL(\beta_A) - LL(\beta_B)] \quad (6)$$

where $LL(\beta_A)$ and $LL(\beta_B)$ are the log-likelihood at convergence for the two models whose comparison is to be made. χ^2 is a chi-square distributed test statistic having degrees of freedom equal to the difference in the number of estimated parameters in the two models. Given its statistical dominance, the model with the smallest BIC, smallest AIC, and greatest log-likelihood (at convergence) values is presented and discussed as the final model. Nevertheless, the goodness-of-fit statistics of all the competing models are included for a ready reference and comparison in Table 4.3.

4.3 Temporal Stability

Traffic safety studies in the recent past suggest that the impact of risk factors associated with injury severity does not remain constant with the passage of time (Mannering, 2018). For instance, Behnood & Mannering (2016) observed the impact of various explanatory variables associated with pedestrian injury severity in Chicago varied each year in the analysis period. Similar temporal instability was observed by Alnawmasi & Mannering (2019) for motorcyclist injuries in Florida in data from 2012-2016 and Behnood & Mannering (2019) for truck crashes in Los Angeles from 2010-2017. The temporal stability of uncorrelated and correlated pedestrian injury-severity models is determined with the following test:

$$\chi^2_{g} = -2[LL(\beta_{2016\text{-}19,g}) - LL(\beta_{2016,g}) - LL(\beta_{2017,g}) - LL(\beta_{2018,g}) - LL(\beta_{2019,g})] \quad (7)$$

where, $LL(\beta_{2016\text{-}19,g})$ is the log-likelihood at convergence of the overall pedestrian injury-severity from 2016 to 2019 for model type *g* (either uncorrelated or correlated model) and $LL(\beta_{2016,g})$, $LL(\beta_{2017,g})$, $LL(\beta_{2018,g})$, $LL(\beta_{2019,g})$ are the log-likelihoods at convergence of the model using data for the respective year only for model type *g*. Results of temporal instability in the data are presented in Table 4.1.

Table 4.1: Results of Temporal Instability in Pedestrian Crash Data

Model Goodness of Fit Values	Uncorrelated RP Logit Model	Correlated RP Logit Model
Log-likelihood at convergence of overall model LL($\beta_{2016\text{-}2019}$)	-2018.1991	-2006.5026
Log-likelihood at convergence of 2016 model LL(β_{2016})	-451.3738	-450.6363
Log-likelihood at convergence of 2017 model LL(β_{2017})	-444.2583	-443.727
Log-likelihood at convergence of 2018 model LL(β_{2018})	-513.1634	-510.5692
Log-likelihood at convergence of 2019 model LL(β_{2019})	-471.5371	-469.7098
$\chi 2$ Value	275.733	263.7206
Degrees of Freedom	21	22
Level of Confidence	99%	99%
Critical X2 value	38.932	40.289
Conclusion	**Temporally unstable**	**Temporally unstable**

RP : Random Parameter

These tests suggest temporal instability is clearly present in both uncorrelated and correlated random parameters logit models for pedestrian injury severity. Tables containing results of yearly random parameter logit models are attached in Annex A.

4.4 Model Estimation Results

The traditional models i.e. (ordered probit, multinomial logit) require comprehensive data for estimation of factors leading to pedestrian injury severity. Pakistan like other developing countries has poor accident data collection system which is considered a big hurdle in accurate model estimation. Therefore, the present study uses random parameters mixed logit model with heterogeneity in means and variances which is quite capable to counter the problems related to limited data and can certainly accommodate the unobserved heterogeneity. Moreover, both uncorrelated and correlated logit models were estimated and the model with lower AIC and BIC values and higher log-likelihood at convergence value was selected as the final model (Correlated Random Parameters Logit Model with Heterogeneity in Means) in our case.

Table 4.2 shows the correlated random parameters logit model estimation results. All parameters presented in Table 4.2 were significant at confidence level of 90% and higher (p value less than 0.10). Parameters with statistically significant standard deviation under the assumed distribution were considered random. Parameters were considered fixed if standard errors of the parameter values were not statistically different from zero. Normal distribution provided the best statistical fit for the random variables. All the significant parameters are discussed below:

Table 4.2: Results of Correlated Random Parameters Logit Model

Variable	Parameter Estimate	t – stat
Constant [MI]	1.169	2.43
Constant [MJI]	0.57	6.45
Random parameters (normally distributed)		
Over speeding [MJI]	1.448	3.67
Standard Deviation of Over speeding (normally distributed)	2.306	2.62
Weekday indicator [MI]	0.354	2.37
Standard Deviation of Weekday (normally distributed)	1.30	3.60
Heterogeneity in mean of random parameter		
March indicator : Over speeding indicator [MJI]	-1.264	-1.65
Pedestrian characteristics		
Pedestrian gender indicator [MI]	-0.775	-1.69
Middle age pedestrian indicator [MI]	0.357	2.69
Old pedestrian indicator [FI]	0.873	4.76
Driver characteristics		
Seatbelt indicator [MI]	1.32	5.30
Crash characteristics		
Rickshaw indicator [MI]	3.064	8.06
Bus indicator [FI]	1.398	5.1
Car indicator [MI]	-1.309	-7.29
Wagon indicator [MJI]	0.579	1.94
Suzuki indicator [MJI]	0.901	4.28

Table 4.2: Results of Correlated Random Parameters Logit Model (Continued)

Variable	**Parameter Estimate**	**t – stat**
Motorcycle indicator [MJI]	0.318	1.89
Truck indicator [FI]	3.21	13.62
Visibility Conditions		
Foggy indicator [FI]	1.32	3.37
Temporal Characteristics		
March indicator [FI]	0.363	1.79
Reported Crash Reason		
Pedestrian fault indicator [FI]	-0.288	-1.78

Correlated Random Parameters	**Over speeding indicator [MJI]**	**Weekday indicator [MI]**
Over speeding indicator [Correlation Matrix Coefficients]	2.3061[1.0000]	1.30[0.999]
Weekday indicator [Correlation Matrix Coefficients]	1.30[0.999]	0.0061[1.0000]

Number of Observations	2198
Number of estimated parameters	23
Log-likelihood at zero LL(0)	-2382.2883
Log-likelihood at convergence LL(β)	-2006.5026
$R^2 = 1 – LL(\beta)/LL(0)$	0.157

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

Table 4.3: Direct Marginal Effects of the Correlated Random Parameters Logit Model

Variable	Minor	Major	Fatal
Minor Injury			
Pedestrian gender indicator	-0.1063	0.0648	0.0415
Seatbelt indicator	0.0184	-0.0112	-0.0073
Rickshaw indicator	0.0155	-0.0092	-0.0062
Car indicator	-0.0947	0.0571	0.0376
Weekday indicator	0.0596	-0.0385	-0.0211
Middle age pedestrian indicator	0.0254	-0.0158	-0.0096
Major Injury			
Wagon indicator	-0.0022	0.0035	-0.0013
Suzuki indicator	-0.0092	0.0146	-0.0053
Over speeding indicator	-0.0074	0.0126	-0.0052
Motorcycle indicator	-0.0071	0.0114	-0.0043
Fatal Injury			
Old age pedestrian Indicator	-0.0050	-0.0094	0.0144
Truck Indicator	-0.0152	-0.0132	0.0284
Bus Indicator	-0.0049	-0.0044	0.0093
Foggy Indicator	-0.0019	-0.0027	0.0046
March indicator	-0.0023	-0.004	0.0063
Pedestrian fault indicator	0.0023	0.0043	-0.0066

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

Model Statistics	**RP Model with no Heterogeneity in Means (A)**	**Uncorrelated RP Model with Heterogeneity in Means (B)**	**Correlated RP Model with Heterogeneity in Means (C)**
Number of Parameters	20	22	23
Log-likelihood at zero	-2382.2883	-2382.2883	-2382.2883
Log likelihood at convergence	-2022.0096	-2018.1991	-2006.5026
Akaike Information Criteria	4084.0192	4080.3982	4059.005
Bayesian Information Criteria	4110.859	4109.922	4089.871
Number of Observations	2198	2198	2198
	A vs B	**A vs C**	**B vs C**
Degrees of freedom	2	3	1
Level of confidence	95%	95%	95%
Computed Chi square	7.621	31.014	23.393
Critical Chi square	5.9915	7.815	3.841
Statistically Superior Model	**B**	**C**	**C**

RP: Random Parameters

4.5 Result Discussion

4.5.1 Random Parameters with Heterogeneity in Means and Variances

In the current study, a rigorous statistical analysis was carried out to identify the random parameters; however, only the “Over speeding indicator” and “Weekday indicator” were found to have random parameters with heterogeneity in the means. The variables were checked for heterogeneity in the variance as well, but they did not exhibit heterogeneity in the variance. March indicator was found to have an impact on the mean of the over speeding variable. The mean of over speeding indicator decreased if the pedestrian accident occurred in March. This means that there is less likelihood of major injury to pedestrians in March for the over speeding indicator. This finding is quite plausible and relevant. As noted in Table 4.2, the March indicator has been found to increase the likelihood of fatal injuries to pedestrians mainly due to the increased pedestrian activity and higher driving speeds selected by drivers with the perception of pleasant weather and safe driving conditions in March.

4.5.2 Pedestrian Characteristics

Pedestrian gender was found to be significant fixed parameter for minor injury outcome. It was found that male pedestrians are less likely to undergo minor crashes as compared to female pedestrians. Table 4.3 indicates that probability of sustaining minor injury by male pedestrians is reduced by 0.1063 while probability of sustaining major and fatal injury has an increase of 0.0648 and 0.0415 respectively. This might be linked to a clear majority of male pedestrians on roads in Peshawar as compared to female pedestrians due to social and cultural constraints as well as the safer behavior of drivers towards female pedestrians as compared to male pedestrians. It is consistent with past research. Tarko & Azam (2011) and Li & Fan (2019) found that male pedestrians have high chances of undergoing major and fatal accidents than their female counterparts.

Crashes involving middle age pedestrians i.e. 25 to 50 years old show more likelihood of minor injury than major and fatal injuries. Table 4.3 suggests an increase in minor injury probability of middle age pedestrians of 0.0254 whereas major and fatal injuries experience a decrease in probability of 0.0158 and 0.0096 respectively. Middle age pedestrians represent the pedestrian age group with the highest traffic sense, high walking speed, more experience, better health and physical condition as compared to young pedestrians (less than 25 years of age) and aged pedestrians (above 50 years of age). Based on these superior capabilities, middle age pedestrians are least susceptible to major and fatal injuries (Li & Fan, 2019).

Old age pedestrians (Above 50 years old) had a high tendency of undergoing fatal accidents .Table 4.3 indicates an increase of 0.0144 in the likelihood of fatality experienced by old age pedestrians in a pedestrian-vehicle accident while minor and major injuries have their probabilities reduced by 0.005 and 0.0094 respectively. This is intuitive as old people have deteriorated health and physical capabilities and cannot withstand major injuries as compared to young and middle age people. This is consistent with past research. Old age pedestrians tend to get involved in fatal pedestrian crashes (Chen & Fan, 2019; Tay et al., 2011; Sze & Wong, 2007).

Pedestrian fault proved to be a significant fixed parameter in fatal injury category. Pedestrian fault includes error from the pedestrian in judging vehicle speed, crossing the road without proper gap available between the vehicles etc. The model results indicated that pedestrian at fault accidents had less chances of causing fatal injury to the pedestrians. Table 4.3 shows an increase of 0.0023 and 0.0043 in the likelihood of minor and major injury while fatal injury undergoes a decrease of 0.0066. A suitable explanation could be the compensation of pedestrian fault with driving at a slow or reasonable speed. Driver driving at a slow or medium speed has sufficient time to take necessary action to avoid pedestrian accident in case of a pedestrian error of judgment which compensates the pedestrian error and even in case of an accident, the pedestrian certainly not experiences fatality but in case of driving at a high speed or over speeding, pedestrian fault cannot be compensated and leads to fatality or major injury to the pedestrian.

4.5.3 Driver Characteristics

Pedestrian accidents with drivers wearing seatbelt have high tendency of resulting in minor injury to pedestrians. Table 4.3 shows an increase of 0.0184 in the likelihood of minor injury while major and fatal injury outcomes undergo a decrease of 0.0112 and 0.0073 respectively. This might be attributed to the driver's education and awareness of road safety hazards. It is consistent with past research. Educated road users wear safety equipment i.e. helmets, seatbelts etc. and obey traffic rules, hence they show least rate of involvement in high severity traffic accidents (Kulanthayan et al., 2000; Houston & Richardson, 2008; Hung et al., 2008).

The parameter for over speeding indicator proved to be random with a normal distribution under major injury category (having mean value of 1.448 with standard deviation 2.306). This accounts for the parameter value being less than zero for 18.38% of accidents and more than zero for 81.62% of accidents (z = -0.63 and using table for standard normal distribution). This implies that over speeding is highly likely to cause major injury to pedestrians. Also Table 4.3 shows the pedestrians' probability of sustaining major injury increases by 0.0126 while the minor and fatal injuries have a reduction in likelihood of occurrence of 0.0074 and 0.0052 respectively. This randomness of the parameter is due to unobserved heterogeneity in the data. The unobserved heterogeneity arises due to the absence of important details such as model of the vehicle/vehicle age, vehicle fitness/mechanical condition, engine capacity of the vehicle, reason for over speeding, pedestrian physical characteristics such as weight, size etc. which were missing and were not accounted in the model estimation.

4.5.4 Vehicle Type

Pedestrian accidents involving collision with rickshaw show high tendency to cause minor injury. Table 4.3 indicates an increase of 0.0155 in minor injury possibility while the likelihood of major and fatal injury decreases by 0.0092 and 0.0062 respectively. This is intuitive as rickshaws have low speed and low momentum as compared to cars and other heavy vehicles. Light vehicles are mostly linked with less severe pedestrian accidents (Damsere-Derry et al., 2003; Kim et al., 2008b) whereas pedestrian accidents involving Cars show little tendency to cause minor injuries to the victims due to high speed and momentum of car. Table 4.3 indicates a decrease of 0.0947 in minor injury while the likelihood of major and fatal injury increases by 0.0571 and 0.0376 respectively.

Pedestrian crashes involving collisions with Wagon and Suzuki result in major injury which is intuitive as Wagon and Suzuki have high mass and momentum as compared to lighter vehicles such as rickshaws, bicycles etc. Table 4.3 indicates an increase of 0.0035 in likelihood of major injury to pedestrians in case of accident with Wagon while possibility of minor and fatal injury outcomes decreases by 0.0022 and 0.0013 respectively. Whereas the pedestrians' probability of sustaining major injury in case of accident with Suzuki increases by 0.0146 while the possibility of minor and fatal injuries reduces by 0.0092 and 0.0053 respectively.

Motorcycle indicator also had a significant impact on major injury. Table 4.3 indicates a rise of 0.0114 in likelihood of major injury while the possibility of minor and fatal injury is reduced by 0.0071 and 0.0043 respectively. This is also intuitive as both the driver and pedestrian get dragged on the road when a motorcycle-pedestrian accident occurs leaving both severely injured and sometimes resulting in fatality of either the driver or pedestrian. Sometimes the foot of pedestrian gets stuck in the wheel of motorcycle causing major injury or permanent disability to the pedestrian. Motorcycle accidents with pedestrian or other roadside objects have a high likelihood to cause major injuries than fatal injuries (Waseem et al., 2019).

Heavy vehicle indicators such as truck and bus indicators were found to be significant in causing fatal injury to pedestrians. Pedestrian accidents with trucks of all types and buses of all types were found to cause fatal injury to the pedestrians. Table 4.3 indicates a rise of 0.0284 in the possibility of fatal injury to pedestrians in case of accident with truck while the likelihood of minor and major injuries decreases by 0.0152 and 0.0132 respectively. On the other hand, possibility of fatal injury has an increase of 0.0093 in case of accident with bus while the likelihood of minor and major injuries reduces by 0.0049 and 0.0044 respectively. It is intuitive as trucks and buses have very high momentum as compared to all other vehicles in the traffic. This finding is in accordance with previous studies. Buses and loaded trucks tend to cause fatal pedestrian accidents (Chen & Fan, 2019; Tay et al., 2011).

4.5.5 Temporal Properties

The weekday indicator proved to be another random parameter with normal distribution under minor injury outcome having mean 0.354 and standard deviation 1.30. This means that the parameter value is less than zero for 31.51% of pedestrian crashes while it is greater than zero for 68.49% of the crashes. Table 4.3 indicates a rise of 0.0596 in the possibility of minor injury to pedestrians in case of accident on weekday whereas the possibility of major and fatal injuries reduces by 0.0385 and 0.0211 respectively. It might be attributed to high traffic volume on weekdays especially near congestion or congestion conditions in peak timings with the vehicles operating at very low speeds therefore, very less chances of severe injury pedestrian accidents. This result is in accordance with past research as traffic volume on weekends is lower than that on weekdays which results in high speed travel, thus increasing the chances of higher injury severity pedestrian crashes on weekends as compared to weekdays (Chen & Fan, 2019; Islam & Jones, 2014).

Month of March proved to be significant fixed factor in causing fatal pedestrian accident. It was observed that pedestrian accidents taking place in March were more likely to cause fatal injury to pedestrians. Table 4.3 shows the pedestrians' possibility of undergoing fatal injury rises to 0.0063 while the likelihood of undergoing minor and major injuries falls to 0.0023 and 0.0040 respectively. It might be attributed to the increased pedestrian activity as well as higher driving speeds selected by drivers with the perception of pleasant weather and safe driving conditions (Waseem et al., 2019).

4.5.6 Weather Characteristics

Foggy weather was found to be more likely to cause pedestrian fatality. Table 4.3 shows an increase of 0.0046 in the pedestrians' possibility of undergoing fatal injury while the possibility of undergoing minor and major injuries decreases by 0.0019 and 0.0027. Siddique et al., (2006) as well as Kim et al., (2017) emphasized that pedestrian crashes of the highest injury severity occurred on foggy days.

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Research Summary

This study is aimed at the identification of contributory factors related to pedestrian injury severity in Peshawar, Pakistan with the objective to enhance traffic safety environment for the most vulnerable and least protected road users i.e. pedestrians. A comprehensive study of the previous relevant research was carried out which provided detailed knowledge of the injury severity analysis of RTCs involving pedestrians on international level. Various statistical modeling approaches were employed in past studies for modeling pedestrian injury severity including ordered probit, multinomial logit, nested logit etc. Owing to its high flexibility, better goodness of fit and incorporating unobserved heterogeneity in crash injury severity analysis, random parameters mixed logit model with heterogeneity in means was employed in this study. Pedestrian crash data were taken from Rescue 1122 Sub Divisional Office Peshawar for duration of four years (Jan 2016 to Dec 2019). Both uncorrelated and correlated random parameters logit models with heterogeneity in means and variances were estimated for pedestrian crash injury severity analysis. Temporal instability of the risk factors related to pedestrian crashes was also incorporated in the analysis. Significant factors that were found associated with different crash injury severity include driver and pedestrian personal attributes, roadway geometry and weather and lighting characteristics. A number of trials were made via NLOGIT 6 to estimate random parameters logit model in order to investigate the relation of pedestrian crash injury severity with observed independent variables. Initially model was estimated using 40 Halton draws for the selection of random variables and its distribution. The final model was revised using 500 Halton draws at a confidence level of 90% (P value <= 0.10).

Final model with highest number of significant factors and better model statistical fitness parameters i.e. McFadden Pseudo R-squared (0.169), Log likelihood at zero (-2382.2883) and Log likelihood at convergence (-2006.5026) validates and justifies the selection of final model.

5.2 Conclusions

General conclusions of the study are:

1. The likelihood of fatal injury to pedestrians increases for pedestrian accidents containing: Old age pedestrians (above 50 years old), collision with heavy vehicles such as Truck and Bus, foggy weather and occurring in the month of March (Spring Season).
2. The likelihood of major injury to pedestrians increases for pedestrian accidents involving: collision with Wagon, collision with Suzuki, Over Speeding and collision with Motorcycle.
3. The likelihood of minor injury to pedestrians increases for pedestrian accidents involving driver wearing seatbelt, collision with rickshaw, occurring on weekdays and involving middle age pedestrians (25 to 50 years old).
4. Crashes involving male pedestrians and crashes involving cars are found less likely to cause minor injury.

5.3 Recommendations

The study findings though exploratory are expected to provide guidelines for different organizations concerned with road safety such as National highways authority (NHA), Peshawar development authority (PDA) and City Traffic Police Peshawar to develop appropriate counter measures to ensure overall traffic safety with a special focus on pedestrian protection against key risk factors identified in this study. The research findings advocate the need for the following:

- Road Safety awareness programs and education campaigns to be conducted by local agencies to promote public awareness on pedestrian safety. The educational campaigns to focus on both the drivers and pedestrians regarding traffic laws and right of way guidelines.
- Heavy vehicles such as trucks were found to be involved in significant number of fatal crashes. Means to be adopted to segregate vulnerable road users (pedestrians) from heavy traffic through provision of separate lane.
- Strict enforcement of traffic rules and enforcement to ensure that pedestrians cross road at designated place.
- Pedestrian road crossing facilities should be provided in areas having high pedestrian volume.
- Appropriate structural modifications such as enhanced lane marking, zebra crossing, street lights at likely crossing places to be installed.

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Annex A: Temporal Instability Results

Table 1: 2016 Uncorrelated RP Logit Model with Heterogeneity in Means and Variances

Variables	Parameter Estimate	t-stat	Marginal Values		
			Minor	**Major**	**Fatal**
Random parameter (normally distributed)					
Constant [MJI]	0.665	2.65			
Standard Deviation of Parameter Distribution (normally distributed)	(-5.667)	(-2.84)			
Heterogeneity in mean of random parameter					
Constant [MJI]: Overspeeding Indicator	1.235	1.79			
Heterogeneity in variance of random parameter					
Constant [MJI]: Weekday Indicator	-0.84	-2.08			
Pedestrian characteristics					
Pedestrian gender indicator [MI]	-1.974	-4.46	-0.1666	0.0623	0.1044
Old pedestrian indicator [FI]	1.198	2.19	-0.0061	-0.0091	0.0152
Driver characteristics					
Seatbelt indicator [MI]	2.186	3.03	0.0154	-0.0065	-0.0089
Crash characteristics					
Rickshaw indicator [MI]	5.85	5.68	0.0303	-0.0281	-0.0022
Bus indicator [FI]	1.476	1.74	-0.0031	-0.0036	0.0067
Car indicator [MI]	-1.47	-4.14	-0.0408	0.0131	0.0276
Truck indicator [FI]	2.678	4.09	-0.0073	-0.0181	0.0253

Table 1: 2016 Uncorrelated RP Logit Model with Heterogeneity in Means and Variances (Continued)

Variables	**Parameter Estimate**	**t-stat**	**Marginal Values**		
Reported Crash Reason			**Minor**	**Major**	**Fatal**
Carelessness indicator [MI]	2.347	5.08	0.1824	-0.0694	-0.1129
Number of Observations			551		
Number of estimated parameters			12		
Log-likelihood at constants LL(0)			-592.0549		
Log-likelihood at convergence LL(β)			-451.3738		
$R^2 = 1 – LL(\beta)/LL(0)$			0.237		

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

Table 2: 2016 Correlated RP Logit Model with Heterogeneity in Means and Variances

Variables	Parameter Estimate	t-stat	Marginal Values		
			Minor	**Major**	**Fatal**
Random parameter (normally distributed)					
Constant [MJI]	1.495	2.44			
Standard Deviation of Parameter Distribution (normally distributed)	(5.746)	(2.55)			
Heterogeneity in mean of random parameter					
Constant [MJI]: Off Peak Indicator	-0.826	-1.69			
Pedestrian characteristics					
Pedestrian gender indicator [MI]	-2.037	-4.30	-0.1796	0.0817	0.0979
Old pedestrian indicator [FI]	1.2	1.83	-0.0057	-0.0076	0.0133
Driver characteristics					
Seatbelt indicator [MI]	2.16	2.80	0.0165	-0.0072	-0.0093
Crash characteristics					
Rickshaw indicator [MI]	4.96	4.39	0.0292	-0.0253	-0.0039
Car indicator [MI]	-1.465	-3.28	-0.0427	0.017	0.0257
Truck indicator [FI]	3.12	3.61	-0.007	-0.0174	0.0244
Suzuki Indicator [MJI]	1.074	1.73	-0.0072	0.0144	-0.0072
Reported Crash Reason					
Carelessness indicator [MI]	2.797	4.10	0.2188	-0.1208	-0.098

Table 2: 2016 Correlated RP Logit Model with Heterogeneity in Means and Variances (Continued)

Variables	**Parameter Estimate**	
Correlated Random Parameters	**Constant (MJI)**	**Carelessness indicator (MI)**
Constant (MJI) [Correlation Matrix Coefficients]	5.746[1.000]	-0.795[-0.99905]
Carelessness indicator (MI) [Correlation Matrix Coefficients]	-0.795[-0.99905]	0.0347[1.000]
Number of Observations	551	
Number of estimated parameters	20	
Log-likelihood at constants LL(0)	-592.0549	
Log-likelihood at convergence LL(β)	-450.6363	
$R^2 = 1 – LL(\beta)/LL(0)$	0.238	

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

Table 3: 2017 Uncorrelated RP Logit Model with Heterogeneity in Means and Variances

Variables	Parameter Estimate	t-stat	Marginal Values		
			Minor	**Major**	**Fatal**
Constant [MI]	1.653	2.78			
Random parameter (normally distributed)					
Constant [MJI]	0.664	2.11			
Standard Deviation of Parameter Distribution (normally distributed)	(5.354)	(3.02)			
Heterogeneity in mean of random parameter					
Constant [MJI]: August Indicator	4.157	1.72			
Pedestrian characteristics					
Old pedestrian indicator [FI]	2.506	3.07	-0.0086	-0.0112	0.0198
Crash characteristics					
Car indicator [MI]	-2.854	-4.87	-0.2201	0.0672	0.1529
Truck indicator [FI]	6.85	5.87	-0.0056	-0.0132	0.0188
Wagon indicator [MJI]	4.358	1.81	-0.0057	0.0062	-0.0005
Suzuki indicator [MJI]	4.952	2.52	-0.015	0.0162	-0.0013
Motorcycle indicator [MJI]	3.614	3.25	-0.0487	0.0537	-0.005
Bus indicator [FI]	4.238	3.51	-0.0072	-0.0034	0.0105
Reported Crash Reason					
Carelessness indicator [MI]	1.542	4.25	0.1208	-0.0506	-0.0703

Table 3: 2017 Uncorrelated RP Logit Model with Heterogeneity in Means and Variances (Continued)

Parameters	**Parameter Estimates**
Number of Observations	509
Number of estimated parameters	13
Log-likelihood at constants LL(0)	-526.5823
Log-likelihood at convergence LL(β)	-444.2583
$R^2 = 1 – LL(\beta)/LL(0)$	0.156

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

Table 4: 2017 Correlated RP Logit Model with Heterogeneity in Means and Variances

Variables	**Parameter Estimate**	**t-stat**	**Marginal Values**		
			Minor	**Major**	**Fatal**
Constant [MI]	2.569	2.54			
Random parameters (normally distributed)					
Constant [MJI]	2.046	3.468			
Standard Deviation of Parameter Distribution (normally distributed)	(7.889)	(2.67)			
Carelessness indicator [MI]	3.468	2.91	0.1723	-0.1187	-0.0537
Standard Deviation of Parameter Distribution (normally distributed)	(2.453)	(1.78)			
Heterogeneity in mean of random parameter					
Constant [MJI]: Foggy Weather Indicator	2.046	2.09			
Pedestrian characteristics					
Old pedestrian indicator [FI]	3.802	2.37	-0.0078	-0.0103	0.0181
Crash characteristics					
Car indicator [MI]	-3.836	-3.62	-0.2646	0.094	0.1706
Truck indicator [FI]	10.427	3.27	-0.0059	-0.0152	0.0211
Wagon indicator [MJI]	8.34	2.00	-0.0074	0.0078	-0.0005
Suzuki indicator [MJI]	6.263	2.47	-0.0179	0.0184	-0.0005
Motorcycle indicator [MJI]	5.579	2.88	-0.0591	0.061	-0.0019
Bus indicator [FI]	6.677	2.54	-0.0085	-0.0023	0.0108

Table 4: 2017 Correlated RP Logit Model with Heterogeneity in Means and Variances (Continued)

Variables	**Parameter Estimate**	
Correlated Random Parameters	**Constant[MJI]**	**Carelessness indicator [MI]**
Constant [MJI] [Correlation Matrix Coefficients]	7.889[1.000]	2.452[0.99977]
Carelessness indicator [MI] [Correlation Matrix Coefficients]	2.452[0.99977]	0.05235[1.000]
Number of Observations		509
Number of estimated parameters		16
Log-likelihood at constants LL(0)		-526.5823
Log-likelihood at convergence LL(β)		-443.727
$R^2 = 1 – LL(\beta)/LL(0)$		0.157

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

Table 5: 2018 Uncorrelated RP Logit Model with Heterogeneity in Means and Variances

Variables	Parameter Estimate	t-stat	Marginal Values		
			Minor	**Major**	**Fatal**
Constant [FI]	-2.469	-6.78			
Random parameter (normally distributed)					
Constant [MJI]	-7.662	-3.41			
Standard Deviation of Parameter Distribution (normally distributed)	(9.209)	(3.36)			
Heterogeneity in mean of random parameter					
Constant [MJI]: Carelessness Indicator	4.245	2.64			
Heterogeneity in variance of random parameter					
Constant [MJI]: Morning Peak Indicator	-0.741	-2.8			
Pedestrian characteristics					
Old pedestrian indicator [FI]	2.701	4.53	-0.0189	-0.0061	0.0251
Crash characteristics					
Car indicator [MI]	-2.726	-6.84	-0.1926	0.0326	0.1599
Truck indicator [FI]	7.773	7.38	-0.0032	-0.0179	0.0211
Bus indicator [FI]	3.659	3.28	-0.0195	-0.0041	0.0237
Driver characteristics					
Seatbelt indicator [MI]	3.032	2.52	0.0123	-0.0061	-0.0062
Reported Crash Reason					
Overspeeding indicator [MJI]	8.205	2.98	-0.0263	0.0573	-0.031
Pedestrian fault indicator [FI]	-2.266	-4.56	0.0161	0.0011	-0.0172

Table 5: 2018 Uncorrelated RP Logit Model with Heterogeneity in Means and Variances (Continued)

Parameters	**Parameter Estimates**
Number of Observations	601
Number of estimated parameters	12
Log-likelihood at constants LL(0)	-652.5725
Log-likelihood at convergence LL(β)	-513.1634
$R^2 = 1 - LL(\beta)/LL(0)$	0.213

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

Table 6: 2018 Correlated RP Logit Model with Heterogeneity in Means and Variances

Variables	**Parameter Estimate**	**t-stat**	**Marginal Values**		
			Minor	**Major**	**Fatal**
Constant [FI]	-2.595	-7.14			
Random parameters (normally distributed)					
Constant [MJI]	-5.99	-2.84			
Standard Deviation of Parameter Distribution (normally distributed)	(7.124)	(2.79)			
Car indicator [MI]	-1.768	-3.38	-0.1572	0.0268	0.1304
Standard Deviation of Parameter Distribution (normally distributed)	(1.915)	(1.96)			
Heterogeneity in mean of random parameter					
Constant [MJI]: Carelessness Indicator	3.512	2.41			
Pedestrian characteristics					
Old pedestrian indicator [FI]	2.794	4.57	-0.0184	-0.0064	0.0248
Crash characteristics					
Truck indicator [FI]	8.18	7.83	-0.0027	-0.0211	0.0238
Bus indicator [FI]	3.791	3.44	-0.0189	-0.0053	0.0242
Driver characteristics					
Seatbelt indicator [MI]	3.106	2.58	0.0154	-0.0083	-0.0071
Reported Crash Reason					
Overspeeding indicator [MJI]	7.321	2.75	-0.0307	0.0621	-0.0314
Pedestrian fault indicator [FI]	-2.544	-3.52	0.0155	0.0006	-0.0161

Table 6: 2018 Correlated RP Logit Model with Heterogeneity in Means and Variances (Continued)

Variables	**Parameter Estimates**	
Correlated Random Parameters	**Constant (MJI)**	**Car indicator (MI)**
Constant (MJI) [Correlation Matrix Coefficients]	7.124[1.00000]	1.91503[0.99998]
Car indicator (MI) [Correlation Matrix Coefficients]	1.91503[0.99998]	0.1062[1.00000]
Number of Observations	601	
Number of estimated parameters	15	
Log-likelihood at constants LL(0)	-652.5725	
Log-likelihood at convergence LL(β)	-510.5692	
$R^2 = 1 – LL(\beta)/LL(0)$	0.217	

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

Table 7: 2019 Uncorrelated RP Logit Model with Heterogeneity in Means and Variances

Variables	Parameter Estimate	t-stat	Marginal Values		
			Minor	**Major**	**Fatal**
Constant [MI]	0.846	2.25			
Random parameter (normally distributed)					
Constant [MJI]	-2.469	-2.21			
Standard Deviation of Parameter Distribution (normally distributed)	(12.512)	(2.12)			
Heterogeneity in mean of random parameter					
Constant [MJI]: October Indicator	5.979	1.8			
Heterogeneity in variance of random parameter					
Constant [MJI]: Weekday Indicator	-0.754	-1.8			
Driver characteristics					
Seatbelt indicator [MI]	0.865	2.04	0.0133	-0.0028	-0.0105
Crash characteristics					
Car indicator [MI]	-2.723	-7.75	-0.1992	0.0296	0.1696
Truck indicator [FI]	6.036	5.86	-0.0069	-0.0135	0.0204
Suzuki indicator [MJI]	6.344	2.66	-0.0134	0.016	-0.0025
Bus indicator [FI]	5.626	2.35	-0.0038	-0.006	0.0097
Pedestrian characteristics					
Old pedestrian indicator [FI]	1.496	2.4	-0.0124	-0.0038	0.0162
Reported Crash Reason					
Overspeeding indicator [MJI]	4.363	2.69	-0.0137	0.0528	-0.0391

Table 7: 2019 Uncorrelated RP Logit Model with Heterogeneity in Means and Variances (Continued)

Variables	Parameter Estimate	t-stat	Marginal Values		
			Minor	**Major**	**Fatal**
Pedestrian fault indicator [FI]	-1.971	-4.15	0.0317	0.0063	-0.038
Carelessness indicator [MI]	1.57	4.1	0.1034	-0.0211	-0.0824
Number of Observations			537		
Number of estimated parameters			14		
Log-likelihood at constants LL(0)			-587.5902		
Log-likelihood at convergence LL(β)			-471.5371		
$R^2 = 1 – LL(\beta)/LL(0)$			0.197		

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

Table 8: 2019 Correlated RP Logit Model with Heterogeneity in Means and Variances

Variables	Parameter Estimate	t-stat	Marginal Values		
			Minor	**Major**	**Fatal**
Constant [MI]	0.92	2.04			
Random parameter (normally distributed)					
Constant [MJI]	-2.446	-2.19			
Standard Deviation of Parameter Distribution (normally distributed)	(7.331)	(2.67)			
Heterogeneity in mean of random parameter					
Constant [MJI]: Curved Indicator	2.575	1.83			
Heterogeneity in variance of random parameter					
Constant [MJI]: Monday Indicator	-0.548	-1.76			
Driver characteristics					
Seatbelt indicator [MI]	0.946	1.97	0.0141	-0.0033	-0.0108
Crash characteristics					
Car indicator [MI]	-2.88	-5.27	-0.1969	0.0369	0.1600
Truck indicator [FI]	6.736	3.99	-0.0062	-0.0135	0.0197
Suzuki indicator [MJI]	7.06	2.49	-0.0135	0.0157	-0.0023
Bus indicator [FI]	6.76	1.81	-0.0024	-0.0065	0.0089
Pedestrian characteristics					
Old pedestrian indicator [FI]	1.595	2.27	-0.0123	-0.0036	0.0159
Reported Crash Reason					
Overspeeding indicator [MJI]	3.84	2.48	-0.0105	0.0416	-0.0311

Table 8: 2019 Correlated RP Logit Model with Heterogeneity in Means and Variances (Continued)

Variables	**Parameter Estimate**	**t-stat**	**Marginal Values**		
			Minor	**Major**	**Fatal**
Pedestrian fault indicator [FI]	-2.043	-4.14	0.0296	0.0065	-0.0361
Carelessness indicator [MI]	1.873	2.74	0.1105	-0.0386	-0.072

Correlated Random Parameters	**Constant (MJI)**	**Carelessness indicator (MI)**
Constant (MJI) [Correlation Matrix Coefficients]	7.331[1.00000]	0.75903[0.79375]
Carelessness indicator (MI) [Correlation Matrix Coefficients]	0.75903[0.79375]	0.581[1.00000]
Number of Observations	537	
Number of estimated parameters	19	
Log-likelihood at constants LL(0)	-587.5902	
Log-likelihood at convergence LL(β)	-469.7098	
R2 = 1 – LL(β)/LL(0)	0.20	

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

Table 9: Overall Uncorrelated RP Logit Model with Heterogeneity in Means

Variables	Parameter Estimate	t-stat	Marginal Values		
			Minor	**Major**	**Fatal**
Constant [MI]	0.934	2.11			
Constant [MJI]	0.469	5.49			
Random parameter (normally distributed)					
Over speeding [MJI]	1.011	4.29	-0.0073	0.0187	-0.0114
Standard Deviation of Over speeding (normally distributed)	(1.717)	(2.12)			
Heterogeneity in mean of random parameter					
March indicator [MJI]	-1.14	-2.09			
Pedestrian characteristics					
Pedestrian gender indicator [MI]	-0.783	-1.92	-0.1291	0.0798	0.0493
Middle age pedestrian indicator [MI]	0.272	2.51	0.0233	-0.0147	-0.0086
Old pedestrian indicator [FI]	0.88	4.97	-0.0059	-0.0097	0.0156
Driver characteristics					
Seatbelt indicator [MI]	1.087	5.72	0.0184	-0.0113	-0.0072
Crash characteristics					
Rickshaw indicator [MI]	2.596	7.95	0.0139	-0.0081	-0.0058
Bus indicator [FI]	1.422	5.42	-0.0059	-0.0046	0.0105
Car indicator [MI]	-1.188	-8.03	-0.104	0.063	0.041
Wagon indicator [MJI]	0.699	2.49	-0.0031	0.0047	-0.0015
Suzuki indicator [MJI]	0.86	4.54	-0.0108	0.0159	-0.0051
Motorcycle indicator [MJI]	0.372	2.37	-0.0105	0.0153	-0.0048

Table 9: Overall Uncorrelated RP Logit Model with Heterogeneity in Means (Continued)

Variables	Parameter Estimate	t-stat	Marginal Values		
			Minor	**Major**	**Fatal**
Truck indicator [FI]	3.036	13.10	-0.0159	-0.0153	0.0313
Visibility Conditions					
Foggy indicator [FI]	1.104	2.9	-0.0016	-0.0025	0.004
Temporal Characteristics					
Weekday indicator [MI]	0.461	3.78	0.0584	-0.0362	-0.0223
March indicator [FI]	0.343	1.77	-0.0027	-0.004	0.0066
Reported Crash Reason					
Carelessness indicator [MI]	0.314	2.63	0.0351	-0.0212	-0.0139
Pedestrian fault indicator [FI]	-0.471	-2.89	0.004	0.0071	-0.011
Number of Observations			2198		
Number of estimated parameters			22		
Log-likelihood at constants LL(0)			-2382.2883		
Log-likelihood at convergence LL(β)			-2018.1991		
$R^2 = 1 - LL(\beta)/LL(0)$			0.152		

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