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Modeling Fatal Traffic Crash Occurrence in Small Indian Cities

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Abstract

This paper investigates the factors influencing the fatal road traffic crash occurrences in small Indian cities (less than 1 million population), Patiala and Rajpura. A total of 61 and 188 fatal crashes were recorded between 2013-2015 in Rajpura and Patiala respectively. The study models crash frequency using Negative Binomial regression technique and investigates the effects of critical highway-related correlates such as geometric design features and traffic factors. Further, elasticity analysis is carried out to quantify the impacts of paved road width and the number of lanes on crash rates. The results show that the number of lanes positively impacts the crash frequency in Rajpura. In Patiala, the width of paved roads, segment length and average daily traffic (ADT) are positively correlated with crash frequency. Intercity highways passing through rural areas near the city boundary are more prone to fatal crashes than the highway segments within urban areas. The model also shows that an increase in paved width and average daily traffic (ADT) on roads by one percent would increase the fatal crash rate by 0.7% and 0.436% respectively in Patiala and Rajpura. The findings concur with the results of previous studies that infrastructural improvements such as increasing the number of lanes and paved road width raise the crash frequency. Therefore, specific safety measures may be included in the road widening-schemes. Furthermore, the geometric standards and design specification of the highways in peri-urban areas need to be relooked to ensure traffic safety and crash reduction.

Keywords: Traffic Crashes; Negative binomial model; Urban traffic safety; Small-sized cities; India

1. Introduction

Road safety has become the primary transport-related issue in urban areas. The burden of road traffic injuries (RTIs) in India has been rising, and the number of deaths has more than doubled from 1991 through 2011 (Garg & Hyder 2006; Ponnaluri 2012; NCRB 2012). The total number of persons killed in road crashes increased by 4.6 percent from

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1,39,671 in 2014 to 1,46,133 in 2015 (MORTH 2015). The number of road deaths per 100,000 persons in India is two to four times higher than that in the developed countries, such as UK, Germany, France, and Canada (MOSPL 2015). RTIs shifted from tenth leading cause of death globally, in 1990, to fifth leading cause of death in 2013 (Naghavi 2015) whereas in India RTIs are the eighth leading cause of death and ninth leading cause of overall health loss. The estimated GDP loss due to RTIs is about 3% (Planning Commission, 2009). Thus the society as a whole incurs enormous costs in regard to the loss of productivity and property damage.

The percentage of Indians living in urban areas has noticeably increased from 27.8% in 2001 to 31.16% in 2011 (Census of India 2011a). Nearly 468 cities are having a population of more than 0.1 million in India (Census of India 2011b). These urban agglomerations and cities are classified into four categories: small-, medium-, large- and mega-cities. Nearly 30% of the population lives in about 372 small cities. Therefore analysis of travel patterns and safety issues in these cities will provide us with the platform for replicability and scalability in emerging cities.

No data on fatalities in cities with population less than 1 million is available in the public domain. The National Crime Records Bureau of India gives details only for cities with a population higher than one million (NCRB 2015). Thus it is imperative to identify the traffic crash patterns in urban areas and particularly in small cities as whose structure is different from mega-cities and hence remedial measures involving design amendments, and treatment strategies may be different. Thus obtaining the traffic crash scenarios and identifying critical influencing factors impacting the number of crashes is of vital importance. There are two significant factors which play an essential role in traffic crash rates: behavioral and non-behavioral. The behavioral factors are related to the drivers, and the non-behavioral are related to roadway design. This study focuses on the role of non-behavioral factors.

This study summarizes the results of preliminary data analysis on the fatal traffic crash records of Patiala and Rajpura. It further investigates the non-behavioral factors, mainly the road geometric and traffic characteristics - which influence crash frequency, using Negative Binomial modeling technique. Finally, the elasticity effects of significant factors have been computed to estimate their marginal effects on the frequency of fatal crashes. Correlating the pattern of crashes and non-behavioral factors will help transportation engineers identify the deficiencies in the roadway designs.

2. Literature review

2.1. Segmentation Criteria

In identifying the safety issues and factors influencing crash frequency the first step includes dividing the study roadway section into segments by some criteria. The two widely used segmentation approaches are fixed length segmentation and variable length segmentation. Several studies have estimated crash rates using fixed length segmentation approach, which includes studies conducted on rural freeways using 1.6 km segment length (Shankar et al. 1995), and 0.2 km segment length (Cenek et al. 1997). Recently Cafiso et al. (2013) evaluated five different segmentation approaches and concluded that fixed length segmentation approach gives the best result. However, it ignores the correlations between crash occurrence and roadway characteristics (Shankar et al. 1995; Geyer et al. 2008).

The second method of variable length segmentation has been widely applied. It is based on homogeneous road geometry and traffic flow characteristics on arterial roads (Abdel-Aty & Radwan 2000), divided two-lane rural highways (Cafiso et al. 2008) and highways (Borsos et al. 2014). Another method of segmentation is based on clustering of crashes; however, it does not control for the random fluctuation of crashes and involves frequent updating of segmentation with the changing crash clustering pattern (Fraley & Raftery 2002; Wong & Chung 2008). The method of variable segmentation of road network from 'intersection-to-intersection' is the most beneficial and appropriate as it does not require updating of segments even after infrastructural or geometric improvements are implied.

2.2. Approaches to Analyzing Crash Frequencies

Conventionally, models were developed using ordinary linear regression technique. However, it has been criticized by various researchers (Jovanis & Chang 1986; Hauer et al. 1988; Miaou & Lum 1993) since the linear regression assumes Gaussian error structure and linear in parameter association. However, road crashes are rare and random events with the distributional property of being discrete and non-negative, and the crash count on an entity can considerably fluctuate in a short period. These limitations prompted the use of Poisson or Negative Binomial regression models to describe crash rates. The Poisson model has a constraint that the mean and variance of the crash count should be equal. However previous research studies (Miaou 1994; Kulmala & Roine 1988; Kulmala 1995) shows that most crash data are over-dispersed and hence parameter estimates in Poisson regression are biased and underestimated (Miaou 1994).

The Negative Binomial regression model overcomes issues with the restrictive assumptions of Poisson model. It has been applied in several studies that model crash frequencies (Harwood et al. 2000; Hauer et al. 1988; Miaou 1994; Persaud 7 Dzbik 1993; Oh et al. 2003; McCarthy 1999; Carson & Mannering 2001; Rankavat & Tiwari 2015). Hadi et al. (1995) estimated a Negative Binomial model to explore the relationship among crash rates, annual average daily traffic and road environment factors on two-lane and multilane roads. Shankar et al. (1995) modeled the crash frequency using Negative Binomial model on rural freeways and found that geometric conditions exerted a significant influence on crash frequency. Abdel-Aty and Radwan (2000) predicted the crash frequency using Negative Binomial model and showed that heavy traffic volume and restricted road geometry increases the chances of a crash. Lord and Mannering (2010) modeled the relationship between crash frequency, traffic flow, geometric and environmental factors using Poisson, Negative Binomial, Poisson lognormal, Zero-inflated count model, random effect model and random parameter count model. Rankavat & Tiwari (2015) investigated the influence of built environment factors on pedestrian safety in Delhi.

Most of the previous research has found linear regression models unsuitable for modeling crash frequency. Since crash data are over-dispersed, Negative Binomial regression approach is suitable for modeling crashes.

2.3. Non-behavioral Factors influencing the crash frequency

Several studies have attempted to quantify the impacts of non-behavioral factors on crash frequencies. For example, Jovanis & Chang (1986) highlighted that vehicle miles of travel (VMT) significantly increases the no. of crashes. Agent & Deen (1975) found that highest fatality rates occurred on four-lane undivided highways in Kentucky. Milton & Mannering (1996) on the study on an arterial street in Washington found reduced shoulder and lane widths, sharp horizontal curve and high ADT as significant factors influencing crash frequency. The study also identified the number of lanes as a primary significant factor with positive correlation. Knuiman et al. (1993) modeled the effect of median width on crash rates using Negative Binomial regression model. It was found that crash rates decreased sharply when median width increased beyond 7.6 m. Jacob & Anjaneyulu (2013) found carriageway width and the number of curves as main significant variables. The study concluded that carriageway width is highly related to crashes because the increase in width leads to higher speeds and more number of overtaking maneuvers, eventually resulting in more crashes.

Some of the previous studies in India (Valli & Sarkar 1997; Valli 2005) have explored crash patterns on rural highways (Sharma & Landge 2013; Bandyopadhyaya & Mitra 2013), two-lane undivided highways (Dinu & Veeraragavan 2011) and multilane highways (Chikkakrishna et al. 2013); however, there are no detailed studies on the city-level traffic crash data, particularly of small cities. This study presents a mathematical model that explains the relationship between crash frequency and geometric and traffic characteristics. The elasticity effects of the significant factors have been computed to identify critical variables' relative influence on crash rate. Although the study focuses on fatal traffic crashes in two small cities of Punjab, the methodology applies to other small cities in India as well.

3. Data collection

Two small cities-Patiala and Rajpura with a population of 446,246 and 92,301 persons respectively and constituting an urban area of 70 km^2 and 25 km^2 respectively (Census of India 2011), have been chosen for analysis. Data has been collected for three years (2013, 2014 and 2015) where all the registered fatal road traffic crashes in Patiala and Rajpura in the form of first information report (FIR) available with the police. Data has been collected from the office of senior superintendent of police at Patiala where monthly records of all fatal RTI cases with the FIR number and police station names were enlisted. The files of all crashes registered in the five police stations in urban Patiala and two police stations in urban Rajpura were extracted, and the print of the FIRs was taken out from the Punjab police website, given the police station name and FIR number. The maps of the two cities with marked city boundaries were downloaded from Punjab Urban Development Authority (PUDA) website. Rajpura and Patiala recorded a total of 61 and 188 fatal crashes in 3 years respectively.

The ADT and geometric details of the roads in Patiala and Rajpura were obtained from the records of the Public Works Department (PWD) office, Municipal Corporation Department and the National Highway Authority of India (NHAI) for the years of 2013, 2014 and 2015. The record of ADT and geometric details of NH-01 were obtained from NHAI for each of the years. The relevant details of Major District Road (MDRs), National Highways (NHs), State Highways (SHs), Other District Roads (ODRs) and link roads have been collected from the PWD department of Punjab. However, few roads in Patiala were under the municipal corporation whose data had to be obtained from their department. The ADT details of one of the years were obtained, and Indian Roads Congress (IRC) guidelines were used to estimate the ADT for the other two years.

4. Data preparation

The data preparation for modeling involved preparing a digitized map and finding the crash location on it. The crash locations in the two cities were marked on Google Maps as per the description of the landmark in the registered FIRs, and the corresponding latitude and longitude were noted. The city boundaries of Patiala and Rajpura were marked by geo-referencing (in ArcGIS 10.1) the landmarks in the two cities using the maps obtained from PUDA website. The road network has been segmented by variable length method on intersection to intersection basis. The Rajpura city, Patiala city and rural Patiala along the major roads entering Patiala city has been segmented into 61, 356 and 122 segments respectively, as described in Table 1. The segment lengths vary between 0.023 km to 2.93 km in Rajpura and between 0.07 km to 2.13 km in Patiala with an average segment length of 0.31 and 0.16 km for Rajpura and Patiala, respectively. A total of 18.68 km and 72.74 km roadway has been digitized in Rajpura and Patiala respectively. They covered 11.36 km and 18.66 km of NHs, 4.97 km and 0.943 km of SHs, 0 km and 17.88 km of MDRs, 2.35 km and 27.59 km of ODRs, 0 km and 7.66 km of link roads in Rajpura and Patiala respectively. Fig. 1 shows the digitized road network layer in Google Maps along with the crash locations in Rajpura.

Table 1. Fatal crashes on road segments in Rajpura, urban and rural Patiala for 2013-2015

Number of crashes, in 3 years, k	Number of Segments, Rajpura	Number of Segments, Urban Patiala	Number of Segments, Rural Patiala
0	43	299	83
1	11	47	24
2	3	7	11
3	1	2	4
4	2	1	-
5	1	-	-
Total	61	356	122

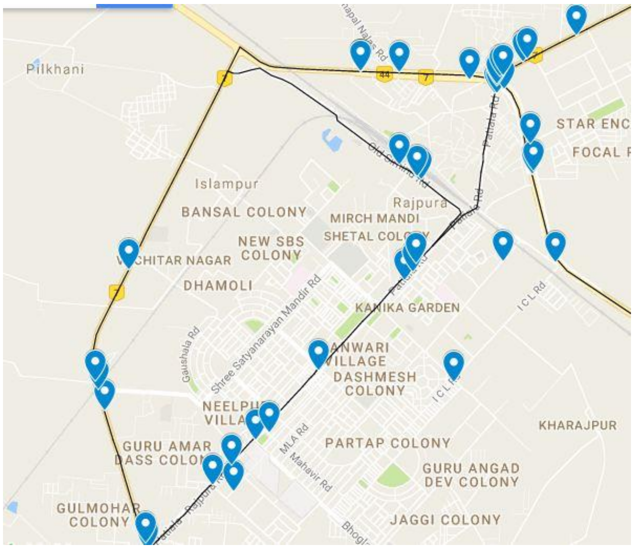

Fig. 1. Digitized road network layer in Google Maps along with the crash locations in Rajpura

The IRC code, IRC-37, recommends that traffic growth rate of 5% may be adopted if adequate data is not available. Further, IRC 106:1990, Guidelines for Capacity of Urban Roads in Plain areas, recommends that the design of two-way undivided roads be based on two-way total flows since the traffic carrying capacity of two way-undivided roads is relatively independent of the directional distribution of traffic. However, on dual or divided carriageways, the capacity is dependent on the directional split of traffic flow, and the design should, therefore, be based on peak hour traffic in the busier direction of flow. Thus using the above recommendations, the ADT for all the roads have been estimated taking the traffic growth rate of 5% and taking ADT of the peak direction of flow in case of divided highways and total traffic of both sides in case of undivided roads. The ADT has been obtained from the traffic census conducted in the year 2013 by taking the average of weekly traffic. The ADT for the year 2014 and 2015 has been then estimated by taking 5% traffic growth rate using the guidelines of IRC described above. The geometric detail of all the roads has been obtained by collecting the linear plans of all the major roads in Patiala and Rajpura which included the paved width of roads, road category, the number of lanes, divided or undivided highway information for each section of the roadway. The resulting database contained details of the crashes occurring on each road segment as the dependent variable with the ADT, segment length, number of lanes, divided or undivided road, the paved width of each of the road section as the independent variables. Table 2 shows the descriptive statistics of the data for Rajpura and Patiala. The average number of crashes in Rajpura and Patiala respectively are 0.54 and 0.26 crashes per segment in 3 years.

5. Method

5.1. Modeling Methodology

The inherent property of Poisson model is that the mean and variance of dependent variable should be equal. Previous research studies (Hadi et al. 1995; Shankar et al. 1995; McCarthy 1999; Carson & Mannering 2001) indicates that crash data is usually over-dispersed and thereby suggests using the Negative Binomial model as an alternative to Poisson model. The Negative binomial model develops from Poisson model as:

$$\ln \lambda_i = \beta x_i + \in \qquad (1)$$

Table 2. Descriptive statistics of Rajpura and Patiala data

Rajpura				
Explanatory variable	Min	Max	Mean	Standard deviation
Number of crashes per segment	0	5	0.54	1.09
Segment Length (km)	0.023	2.93	0.31	0.45
Number of lanes	3	6	3.71	0.72
Paved width (m)	6.7	25	15.38	5.04
ADT (in 1000 vehicles per day)	13.65	31.30	20.91	7.61
Patiala				
Number of crashes per segment	0	4	0.26	0.61
Segment Length (km)	0.07	2.13	0.16	0.24
Number of lanes	2	6	3.19	0.90
Paved width (m)	5.5	23	11.96	4.48
ADT (in 1000 vehicles per day)	1.74	55.39	17.44	13.03

Where λ i is the expected number of crashes on roadway section i; β is a vector of estimable coefficients; x_i is the vector of explanatory variables on the roadway section i; $\in$ is the error term. There is an addition of an error term $\in$ which allows the mean to differ from the variance such that:

$$\mathrm{Var}[n_i]= E[n_i][1+\alpha E[n_i]] \tag{2}$$

Where α is the variance of the gamma-distributed error term, $\exp(\in)$ with mean 1 and variance α^2, and n_i is the number of crashes on roadway section i over a time period t. Thus the Negative Binomial distribution is of the form as described in Equation 3:

$$P(n_i)=\frac{\Gamma((1/\alpha)+n_i)}{\Gamma(1/\alpha)n_i!}\left(\frac{1/\alpha}{(1/\alpha+\lambda_i)}\right)^{1/\alpha}\left(\frac{\lambda_i}{(1/\alpha)+\lambda_i}\right)^{n_i} \tag{3}$$

The corresponding likelihood function is in equation 4:

$$L(\lambda_i)= \prod_{i=1}^{N}\frac{\Gamma((1/\alpha)+n_i)}{\Gamma(1/\alpha)n_i!}\left(\frac{1/\alpha}{(1/\alpha+\lambda_i)}\right)^{1/\alpha}\left(\frac{\lambda_i}{(1/\alpha)+\lambda_i}\right)^{n_i} \tag{4}$$

Here, ‘n’ is the total number of roadway sections. The statistical significance of the estimated coefficient determines the appropriateness of the model to be chosen. If α is significantly different from zero, the Negative Binomial is the most appropriate choice. However, if α is not significantly different from zero, the Negative Binomial model simply reduces to a Poisson model with $\mathrm{var}[n_i]=E[n_i]$ (Washington et al., 2010).

It is important to mention that the variables in the model could be related, leading to the issue of multicollinearity. Though multicollinearity does not affect the performance of the model as it only increases the standard errors of the coefficients by making them less significant (Ramanathan, 1998) but it was accounted for in this study by estimating the pairwise correlations amongst explanatory variables. In this study, the correlation acceptance value has been set to be less than 0.6. The decision on whether or not to keep a variable in the model was based on primarily two criteria. The first criterion is the *p*-value of the variables estimated coefficient should be significant at the 10% level. The second criterion is that the addition of variable improves the goodness of fit of the model. Furthermore, the variables should have meaningful signs and magnitudes supporting the theoretical expectations of the crash process else they were omitted.

The performance of the developed model was analyzed using the deviance value, log likelihood ratio and adjusted log likelihood ratio. The deviance value is computed as described in Equation 5. It has been used for testing the overall goodness of fit as suggested by Agresti (1990).

$$X^2= 2(LL(\beta_R)-LL(\beta_U)) \tag{5}$$

Where, $LL(\beta_R)$ is the log likelihood at the convergence of the restricted model, and $LL(\beta_U)$ is the log likelihood of the unrestricted model. The value of p^2 statistic lies between zero and one, and the statistic close to one indicates the model is predicting the outcomes with near certainty. The disadvantage of p^2 statistic is that it will always improve as additional parameters are estimated even though they may be statistically insignificant. The issues with p^2 statistic have been addressed using a corrected p^2 ($\hat{p}^2$) and is estimated as described in Equation 6:

$$\hat{p}^2 = 1 - \frac{LL(\beta) - k}{LL(0)} \tag{6}$$

Here, k is the number of parameters estimated in the model.

5.2. Elasticity Analysis

Elasticity analysis has been conducted to estimate the relative effect of explanatory variables on crash frequency. As formulated in the previous studies (Abdel-Aty & Radwan 2000); Washington et al. 2003; Ma et al. 2017) the elasticity is computed as described in Equations 7 and 8:

$$E_{x_{ij}}^{\lambda_i} = \beta_j * x_{ij} \tag{7}$$

$$E_{x_{ij}}^{\lambda_i} = \frac{\exp(\beta_j) - 1}{\exp(\beta_j)} \tag{8}$$

Here, β_j is the coefficient of the j^{th} explanatory variable and x_{ij} is the value of the j^{th} explanatory independent variable for segment i. Further for simplification, the elasticity coefficient of the ^{jth} explanatory variable may be denoted as E_j and equation 7 and 8 can be as Equations 9 and 10 respectively.

$$E_J = \beta_j * \hat{x}_j \tag{10}$$

$$E_j = \frac{\exp(\beta_j) - 1}{\exp(\beta_j)} \tag{11}$$

Where $\hat{x}_j$ is the average of the j^{th} explanatory variable (Washington et al., 2010).

6. Results and Discussion

6.1. Preliminary Data Analysis

The preliminary analysis of the FIR data provides a basic understanding of the safety scenario in Patiala and Rajpura.

6.1.1. Road user victim type and impacting vehicle/object

Fig. 2 shows the distribution of road traffic fatalities by road user type and the impacting vehicle/objects for the cities of Patiala and Rajpura for years 2013, 2014 and 2015. It can be observed in both the cities that the largest percentage of fatalities is of the motorized two-wheeler (MTW) occupants struck by cars and trucks. Pedestrians hold the second largest percentage of fatalities. All the victims of hit and run cases are the vulnerable road users (VRUs). Twenty-seven percent of the fatal crashes in both cities have been reported as hit and run. Leaving the victim and crash scene unattended increases the likelihood of a fatality as it delays the medical assistance. It shoulbe be highighted that about 35% of the fatalities occur within 1-2 hour of crash occurrence (Roess et al. 2004). Future research is therefore needed to identify the influencing risk factors to check hit and run cases.

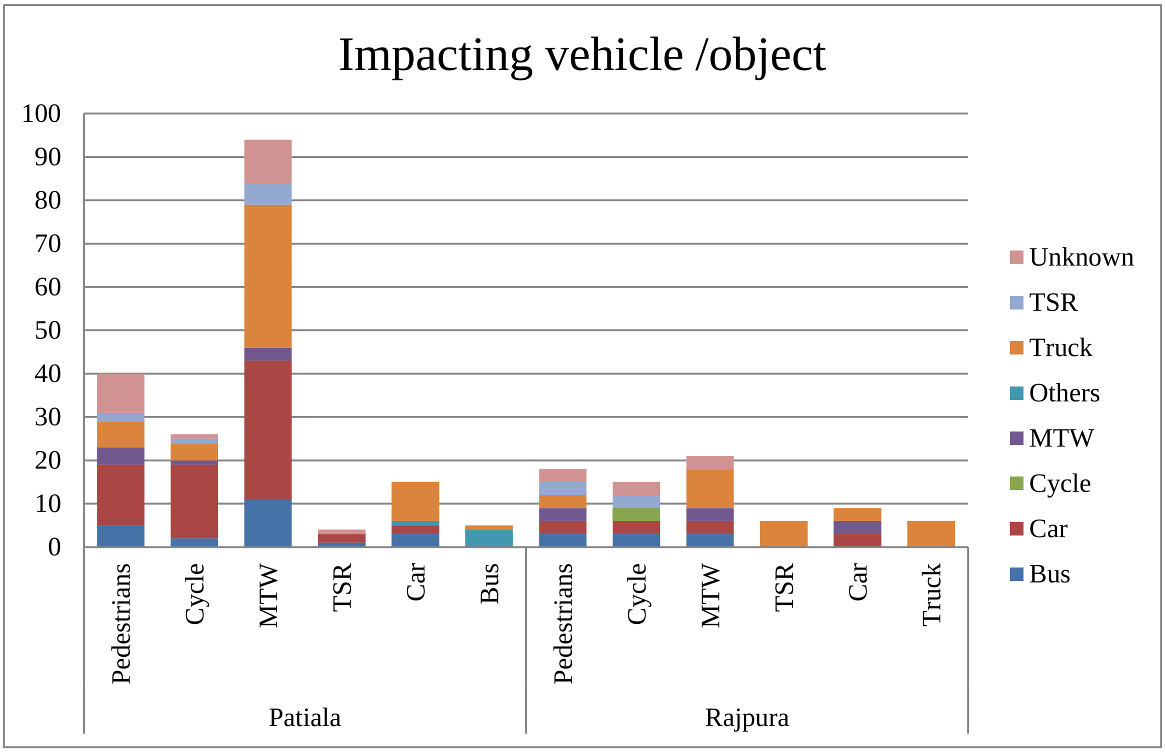

Fig. 2. Road traffic fatalities by road user categories and impacting vehicles/objects in Patiala and Rajpura (the numbers in the bars represent the corresponding number of fatalities)

6.1.2. Road Traffic Fatalities according to Road User Type

The variation of Fatalities according to road user type is shown in Fig.3. In both cities, it is observed that the VRU fatalities account for more than 75% of the total fatalities with MTW occupant fatalities constituting the highest proportion. In Patiala VRUs form 87% of the road traffic fatalities with MTW fatalities constituting 51% of the total fatalities whereas in Rajpura VRUs form 75% of the total road traffic fatalities with the MTW fatalities representing 44% of the fatalities. FIR data does not have information on whether MTW users are using helmets. The MTW fatalities can be significantly reduced if the existing mandatory MTW laws are enforced. The high proportion of MTW fatalities in small cities is possible because the proportion of MTW ownership is highest in small cities relative to large cities (Mohan et al. 2009).

6.1.3. Collision Type versus Percentage of Fatal Crashes

Fig. 4 shows a variation of collision type versus percentage of fatal crashes. In both cities the highest rate of fatal crashes are of ‘vehicles hit from back’ followed by ‘hit pedestrian’ collision type. The cases with ‘unknown collision type’ are the hit and run cases, and the ‘others’ category constitutes the cases in which the victim who got killed while boarding vehicle.

It has been further observed that 77% and 75% of the crashes in Patiala and Rajpura occurred on straight roads. Thus ‘pedestrian’ and ‘vehicle hit from back’ collisions occur mostly on the straight roads of smaller cities, away from intersections.

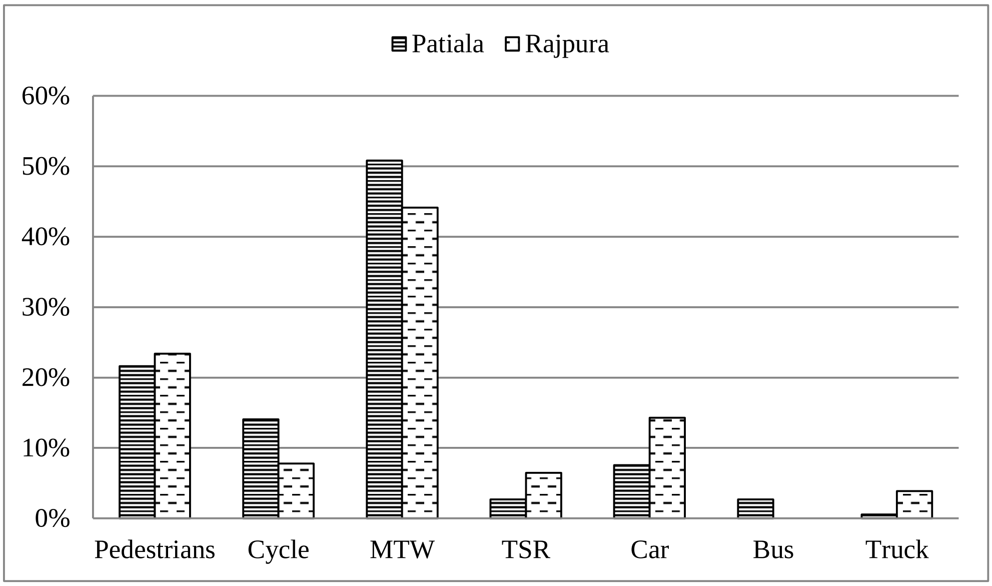

Fig. 3. Road traffic fatalities in Patiala and Rajpura according to road user type.

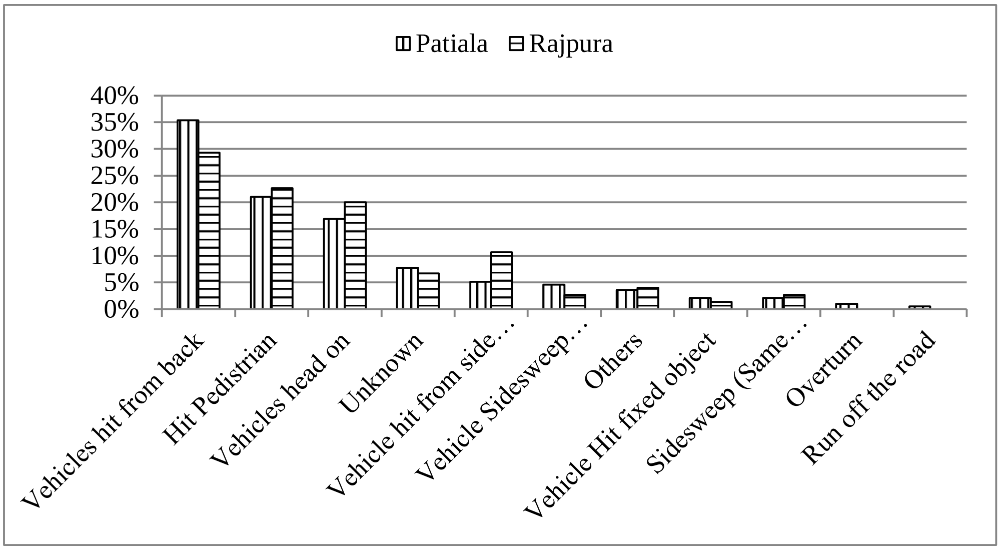

Fig. 4. The pattern of collision type versus percentage of fatal crashes in Patiala and Rajpura

6.1.4. Variation of crashes with time

Fig. 5 shows the variation of crashes with time. Both cities have a higher number of crashes in the afternoon as compared to forenoon.

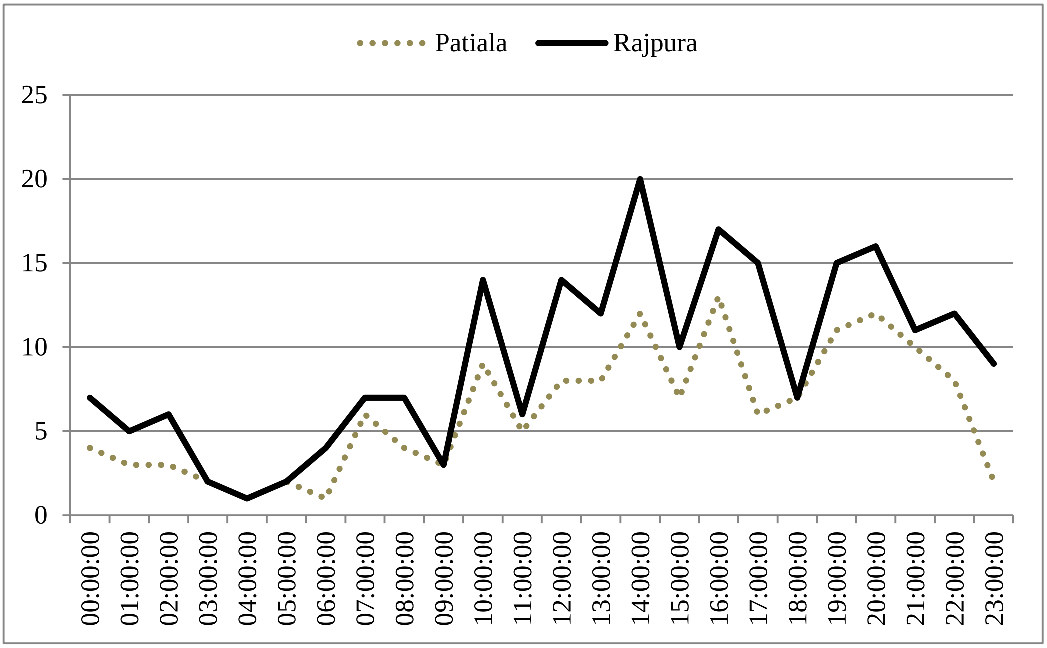

Fig. 5. Road traffic fatalities in Patiala and Rajpura according to road user type.

6.1.5. Day-wise variation of crashes

Fig. 6 shows the day wise variation of fatal crashes. In both cities, Tuesday recorded higher percentage of crashes compared to other days. Further research is needed to understand the variation in accidents across days.

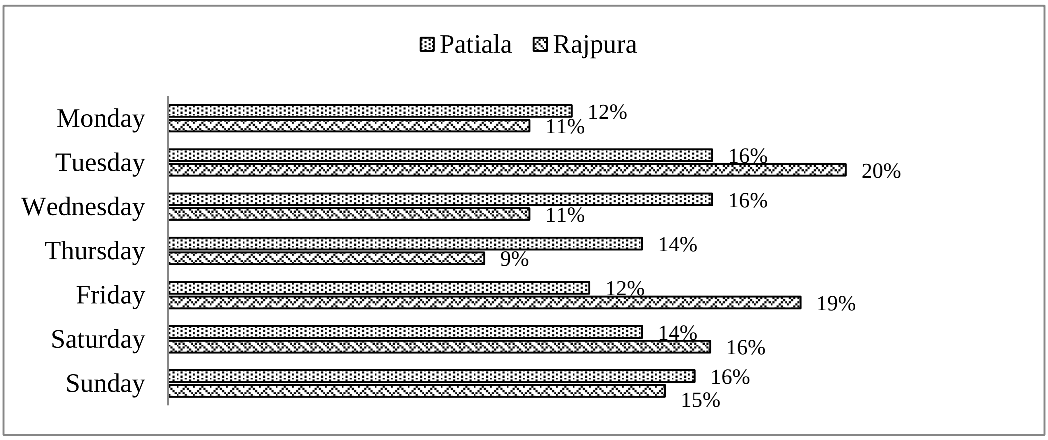

Fig. 6. Road traffic fatalities in Patiala and Rajpura according to road user type.

A comparison of the traffic safety scenario in two small sized Indian cities reveals that the pattern and trend of crashes according to collision type, collision spot, and the proportion of hit and run cases is approximately similar. A substantial percentage of fatalities involving MTW occupants and pedestrians is due to a vehicle hit from the back and hit pedestrian collisions. The findings indicate the need for providing convenient road crossing facilities to the pedestrians and separating slow-moving local traffic along the highways. Is is anticipated that these measures will possibly help curbing such types of crashes by significantly reducing the conflict points.

7. Empirical models and Discussion

The Negative Binomial model for crash frequencies for Patiala and Rajpura are presented in Table 3. All variables have the expected sign. The likelihood ratio test which follows Chi-square distribution has a deviance value of 14.54 and 67.20 for with 1 and 4 degrees of freedom (df) for Rajpura and Patiala respectively. The test is significant at 95% confidence interval with X^2 values equal to 3.841 (df=1) and 9.488 (df=4). It indicates that the null hypothesis that the described model has explanatory power equal to that of a model having only a constant term is rejected. Thus the model shows an overall good statistical fit. One variable in Rajpura model and four variables in Patiala model are found to be statistically significant. The values of p^2 and $\hat{p}^2$ are relatively low as many variables like human factors, lighting, traffic signs are not measured (Jovanis & Chang 1986; Poch & Mannering 1996).

Table 3. Negative binomial model of crash frequency in Patiala and Rajpura

Rajpura, Period (2013, 2014 and 2015)		
Estimates	**Coefficient**	**p-value**
Intercept, β_0	-4.036	0.000*
Number of lanes,β_2	1.660	0.038*
Summary Statistics		
Dispersion parameter		0.754
Number of sections		61
Log likelihood at convergence		-52.359
Deviance value		14.54
p^2		0.122
$\hat{p}^2$		0.0884
Patiala, Period (2013, 2014 and 2015)		
Estimates	**Coefficient**	**p-value**
Intercept	-2.607	0.000*
Segment length	1.497	0.000*
Paved width	0.059	0.053*
ADT	0.025	0.011*
Landuse (base-urban)	-0.559	0.010*
Summary Statistics		
Dispersion parameter		0.496
Number of sections		465
Log likelihood at convergence		-266.912
Deviance value		67.20
p^2		0.112
$\hat{p}^2$		0.0985

*Significant at 5% level

It can also be observed that the dispersion parameter for the models of Patiala and Rajpura is significantly greater than zero indicating the data is over-dispersed. The finding confirms the appropriateness of Negative Binomial model relative to Poisson model for the dataset used here. The number of lanes in a road is found to be significant at 90% confidence interval in the mode for Rajpura. The positive sign on the number of lanes variable implies that with the increase in the number of lanes the crash frequency will also increase. Previous studies have related the number of lane increase to the total increase in lane changing maneuvers and hence increase in conflict between vehicles (Milton & Mannering 1998; Carson & Mannering 2001). Lane changing is not directly applicable to traffic in Indian cities which are dominated by the presence of two-wheelers in traffic stream (Tiwari 2000; Verma 2016). It is possible that additional lanes encourage high speed and pedestrians have difficulty in crossing wider roads.

In the model for Patiala city, four explanatory variables - segment length, ADT, paved width and land use characteristic are significant at 90% level. Both section length and ADT are observed to have positive correlation with crash frequency. This finding concur with the results of the studies conducted in India (Dinu & Veeraragavan 2011; Chikkakrishna et al. 2013). The positive sign on the variable paved width indicates that with the increase in paved width the crashes increase as it leads to higher speeds and ultimately higher number of overtaking maneuvers, leading to greater crash frequency (Jacob & Anjaneyulu 2013). Landuse is an indicator variable with urban signifying the roads within the municipal corporation boundary of Patiala, whereas the rural refers to mainly the intercity highways outside the municipal corporation boundary entering Patiala city. The negative sign signifies that intercity highways passing through rural areas experience higher crash frequency than roads in the urban area. It may be because the congestion in the city resulting in slower speeds and hence fewer crashes.

To obtain a better understanding of the relative effect of the variables included in the model on crash frequencies, average elasticity has been computed and expressed in Table 4. It is imperative to note that elasticity estimates can only be applied to determine the effect of a small change of independent variable on the expected crash rate.

Table 4. Elasticity estimates for crash occurrence in Patiala.

Variable	**Elasticity (Patiala model)**
Segment length	0.239
Paved width	0.706
ADT	0.436
Landuse (urban)	-1.177

Table 4 describes the elasticity values of the explanatory variables in the model for Patiala. It has been observed that none of the continuous variables are elastic. For example, the value of elasticity of paved width is 0.706. It implies that 1% increase in paved width will increase the crashes by 0.706% in Patiala. Further 1% increase in ADT will result in 0.44% increase in crashes in Patiala. The indicator variable land use is elastic with a value of -1.177 indicating a negative correlation with crash frequency in urban areas relative to intercity highways.

8. Summary and Conclusions

The study presents the results of preliminary data analysis of fatal road traffic crashes as reported in police first information reports in Patiala and Rajpura in the 3-year time period from 2013 to 2015. It has been observed that the pattern of crashes according to collision type and collision spot is similar in both the cities. The study shows MTWs and pedestrians, have the highest percentage of fatalities accounting for 67% to 73% of the total fatalities in Patiala and Rajpura with vehicle hit from back and hit pedestrians as the most predominant collision types in small cities.

The second part of the study presents a negative binomial model of crash occurrence. The impact of geometric and traffic characteristics with fatal crashes has been analyzed. The explanatory variables include ADT, number of lanes, road category, divided or undivided highway, metalled width on a segment and number of fatalities per segment as the dependent variable.

Number of lanes positively impacts crash occurrence in Rajpura. However, in Patiala, both traffic and geometric parameters significantly impact the crash occurrence. Metalled width, ADT and segment length significantly positively impacts the crash occurrence in Patiala. The landuse characteristic highlights that highways close to the city have been experiencing highest crash occurrences indicating their geometric standards and designs need to be relooked as the city activities are overlapping over these corridors. Thus constructing separate service lanes to separate the local slow moving traffic might prove effective in reducing fatal crashes as the number of conflict points will reduce.

Further elasticity analysis gives the true marginal effect of the variable on the crash occurrence. The elasticity analysis highlights that wider metalled width, higher ADT, and larger segment length will lead to the higher crash frequency in Patiala. However, in Rajpura, higher number of lanes will lead to increase in the crash frequency. Correlating the trend of vehicle hit from back and hit pedestrian collisions with mainly MTW and pedestrian victims respectively with the model findings and elasticity estimates convey that infrastructural improvements like road widening will substantially increase the crash occurrence in the two cities. This highlights that infrastructural improvement strategies are not considering the safety requirements of the vulnerable road users- pedestrian and MTW riders. If with road widening, the pedestrian crossing facilities, footpaths and separation of traffic lanes for local slow moving traffic, facilities are provided simultaneously, such traffic issues can be possibly resolved. Thus the primary cause possibly is the skewed distribution of road space with geometric road designs in favour of motorized vehicles.

The study conveys that infrastructural improvement, especially in small cities, like road widening, increasing number of lanes increases the potential for crash occurrence. This is consistent with the finding of the study Moeinaddini et al. 2014. Thus future scope of work can include further analysis of the prevalent pattern of road networks in the two cities and effort can be made to incorporate safer designs in planning the cities to enhance road safety.

It is important to highlight the limitations of this study. The study is primarily based on data recorded by police in first information reports. The crash locations are based on the description available in the FIRs which might have an error associated due to the inappropriate description on the part of the person describing the incident or there might as well be some miscommunication while recording it and there can be possibly an error associated in marking the exact latitude-longitude locations. Speed measurements and traffic counts could not be done as part of this study due to time constraints. Detailed documentation of traffic activities-counts, speeds, presence of other activities on the road may provide better insights.

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