Development of A Methodological Framework to Identify Risk of Road Traffic Crashes in Indian Metro Cities Using Police Recorded Crash Data

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Abstract: In India, systematic planning for road safety management is missing in a large scale. In this study, we focus on road traffic safety in urban India with a specific focus on metropolitan cities and show how a framework for road safety management could be developed through which high crash involvement of a particular user group, vehicle class or road location can be identified and addressed. For this purpose, the concept of risk priority number (RPN) and equivalent property damage only (EPDO) measures are adopted. Using these measures a macro level ranking of *black zones* are identified and three distinct groups of zones, e.g., *high risk*, *medium risk*, and *low risk* are obtained for network level studies. The present study is useful to identify the strategies, designing safety treatments and measures and implementing them in an informed manner rather than allocating limited funds with no scientific basis.

Keywords: Road safety management, Road traffic injury, Risk, Risk Priority Number, Equivalent Property Damage Only

1. INTRODUCTION

India is one of the fastest growing and largest emerging market economies in the world. Rapid economic growth is normally associated with high use of personalized vehicles and road transportation. Unfortunately, this is also a leading cause of road traffic crashes, injuries, and fatalities, which Indian cities have been experiencing over the last decade (NCRB 2015). The increasing number of road traffic crashes has imposed considerable social and economic burdens and have degraded public health (Wilson and Purushothaman, 2003; Chakraborty and Roy, 2005). According to the Ministry of Road Transport and Highways report (MoRTH, 2015), in India, a total number of road traffic crashes increased by 12.4% from 439255 in 2005 to 501423 in 2015. The total number of persons killed in road crashes increased by 35% from 94968 in 2005 to 146133 in 2015. Road crash injuries have also increased by 7% from 465282 in 2005 to 500279 in 2015. The severity of crashes, measured in terms of the number of persons killed per 100 crashes has increased from 21.6 in 2005 to 29.1 in 2015.

Further, it has also been observed, in 2015, fifty Million plus Cities accounted for a share of 22.1% in total road crashes in the country, 11.3% in total persons killed and 16.4% in total persons injured in road crashes (MoRTH, 2015), indicating that million plus cities have been the biggest crash victims of India. While the Indian Government has allocated a significant amount of fund for road and infrastructure development, but India is losing more

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than 3% of National 'Gross Domestic Product' each year from road traffic injuries and fatalities. At present in India, we are investing in smart cities, but the current status of road traffic crashes and road safety management is in a dismal state as can be evidenced through several studies (Singh, 2013). These incidents not only hint the serious status of road safety in India but also a signal of a potential threat to public health.

However, in India road safety assessment is broadly missing in urban areas through which high crash involvement of a particular user group, vehicle class or road location can be identified and addressed. Primary reasons for such lack of efforts is that we believe the crashes occur primarily due to human error and that road traffic crashes are not preventable, while in fact, in an emerging country such as India, there exists a host of infrastructure planning, design and operational deficiencies that pose a significant burden on road users. Further, in most metropolitan cities in India, the road use pattern is very different from other high-income countries (Mohan, 2002). For example, Indian cities experience very high interaction between motorized and non-motorized road users, especially due to the absence of appropriate Non-Motorized Traffic (NMT) friendly infrastructure.

While developed countries have experienced a decreasing trend of road traffic crashes through systematic road safety improvement program, road traffic crashes during the same time followed an upward trend in India (Tulu *et al.* 2003). This is primarily due to the fact that a systematic risk management program is missing in India. Road safety management is a methodological framework to prevent the likelihood of crash occurrence. It is also useful to bring a variety of aspects and perspectives to make a multidisciplinary approach to reduce the severity of crashes (Lines, 1996; Quimby *et al.* 2003). The primary goal of road safety management is to be aware of the risk road users and identify the high-risk locations where further safety improvement is obligatory.

Although India has taken various initiatives to improve road safety, most notably, integrating of a formal systematic 'Road Safety Audit' at multiple levels of highway planning and construction, i.e., during planning, and design stage, during construction as well as during operation of major National and State Highways (Ravinder and Nataraju, 2013). However, such effort for urban safety improvement has not been initiated yet. Further, there is no systematic risk assessment framework at a place for urban road safety improvement utilizing crash data. This is primarily due to the fact that road traffic crash data are collected and maintained manually where much important information is not recorded and such data is not easily available. In this background, we focus on road traffic safety in urban India with specific focus on metropolitan cities and show how a risk assessment framework could be developed to identify the temporal and spatial variation of risk; identify the risk of a particular user group or vehicle class such that resources and attention may be utilized in an efficient manner. To demonstrate the methodological framework, Kolkata is chosen as a case study city.

2. LITERATURE REVIEW

In India, the most commonly accessible sources of accident data road traffic crashes are the National Crime Records Bureau (NCRB) and the Ministry of Road Transport and Highways (MoRTH). However, both sources provide aggregate information, with NCRB, provides data on a few basic information such as age, gender, and mode of travel; whereas MoRTH sources provide further details such as the type of highway, type of locality, the cause of the crash, etc. These data sources are good for aggregate level analysis, which can help indicate areas of major safety concerns. However, using these data it is not possible to perform any advanced analysis which will provide meaningful insights into the road safety problems. This has kept down the status and depth of road safety research look into the nation. Furthermore, there is a general conviction that road traffic crashes basically happen because of human blunder (MoRTH, 2015) and which is not escapable. Such reasons are frequently cited in police records, even at locations where road infrastructure related deficiencies are present, but not highlighted in the crash record. Singh and Misra (2004) reported that as per Patna traffic police crash history records in Patna city majority of the crashes were caused by the driver faults during the period of 1996 to 2000, which is probably far away from the reality. This shows that the investigation of the crash site and subsequent diagnosis of crash causation are really lacking in Indian cities. Further, there is no guideline on how the collected crash data may be used to prepare a plan to identify areas requiring further attention and systematic plan for safety intervention. Published literature on road traffic crashes from urban India till date provides mainly descriptive in nature. The existing studies are summarized in the following subsections.

A study by Ghosh and Paul (2013) reported that a total of 7217 road traffic crashes occurred in Kolkata between the year 2007 and 2009. Further, they reported that bus and truck were involved 21% of overall road crashes in Kolkata. In Bhubaneswar city, the motor cars represented 37% of total crashes whereas trucks were involved in 19.1% of total crashes as was reported by Kar *et al.* (2015). A study conducted by Kajzer *et al.* (1992) also showed that in India buses and trucks were involved in a greater proportion of crashes than any other vehicles. Further, Rankavat and Tiwari (2013) confirmed in Delhi pedestrian fatalities at arterial road intersections involving car and buses were 27% and 14% of overall fatalities involving cars and buses respectively. The results from involvement of trucks or buses are also very similar, i.e., between 8% and 15%, in Indian medium-sized cities (i.e., Agra, Amritsar, Bhopal, Ludhiana, Vadodara, and Vishakhapatnam) as pointed out by Mohan *et al*. (2016). They have also reported that the risk of road traffic injuries for vulnerable road users such as pedestrians, bicyclists, and motorized two-wheeler riders was highest in such cities and it varies in the range as high as 84% to 93%. When two-wheelers were considered alone, their involvement rate was between 70% and 75% in fatal road crashes in these cities. Singh and Misra (2004) reported similar statistics of pedestrian fatality for Patna city. Further, Ghosh and Paul (2013) claimed pedestrians were the major victim group of road user in fatal (60% to 64%) and injury (73% to 78%) crashes among all the vulnerable road users. Pathak *et al.* (2008) also identified that pedestrians were involved in 32.91% of total road crashes in Jaipur City, India. As per Hyderabad police records in the year 2002, 40.3% of pedestrians were the victim of road traffic fatalities (Dandona and Mishra, 2004). In Mumbai city also, the pedestrian’s fatality rate was more or less 57% (Singh, 2013). On the other hand, in Manipal, South India, the majority of the victims were two-wheeler occupants (35%) followed by pedestrians (23%) as reported by Shetty *et al*. (2012). In Delhi, the national capital of India, also the fatality rate of vulnerable road users was about 84% as reported by Mohan (2009).

Findings from temporal variation of crash risk from studies across India indicate that a relatively high number of crashes occur between 8 p.m. and 11 p.m. in midsize Indian cities as was reported by Mohan *et al*. (2016). Similar findings were reported by Ghosh and Paul (2013) for Kolkata city, a time frame between 6 p.m. and 11 p.m., was at high risk, with especially the time period between 8 p.m. to 10 p.m. being the highest risk prone. In Jaipur city too, 22.78% crashes occurred between 9 p.m. and 12 a.m. (Pathak *et al.* 2008). Such temporal distribution was also confirmed by Mohan (2009), who pointed out that in million-plus cities (population > 1 million) in India, the majority of crashes occurred in between 6 p.m.

and 9 p.m. However, in Patna city, there is some evidence that 70% of crashes occurred during daytime (Singh and Misra, 2004).

In India, in many cases, crash reports do not include socio-demographic characteristics of the crash victim. As per NCRB 2012 report in Indian cities, approximately 90% of the vulnerable road users were between the age group 15 and 60. Singh and Misra, (2004) also reported that in Patna city, the age group between 18 and 60 years was the major victim. Ghosh and Paul, 2013 reported in Kolkata 25% of the crash victims were between the age group 18 and 30. Kakkar *et al.* (2014) identified in Ujjain city, the age group of 25 to 34 with male road users were the major victim of road crashes. In Chandigarh city, also young adults of the age group of 21 to 30 year were the foremost victim of road crashes (Sharma *et al.* 2002). In Mangalore city, major two-wheeler victims were in between age group 18 and 44, as reported by Jain *et al.* (2009). However, in Indian cities share of child fatality is emerged to be low (Mohan *et al.* 2016). Therefore, overall literature suggests that in Indian urban areas young adults are the major victim of the road traffic crashes.

The summary of various crash statistics across Indian cities suggests that there exists a clear pattern of road crashes in most of the metro and midsize cities across the entire county. While these studies provide an excellent overview of the current status of road traffic safety; however, none of these studies provide any guidelines how the available crash data from police records could be used in a meaningful way to formulate a risk management plan, and how the data collection should further be improved to help in risk management. Since, the critical component of the risk management framework is identification of high-risk sites on road network such as intersections or mid-blocks, identification of factors associated with high crash counts and severities as well as identification of user and vehicle groups overrepresented in crash data, crash data collected and maintained by police should include pertinent details. While the available literature based solely on crash data provide information on road users and vehicles involved in crashes, they do not provide any guidance as to which locations on road network in these cities pose a high risk of road traffic crashes to different road users and vehicles. Further, there is no guidance as to which network locations and which group of road user suffer from the highest risk of road traffic crashes in India, which is foremost importance to engineers and researchers working to improve the safety of transport infrastructure. In identifying such locations, it is also important that two aspects of safety are considered. For example, it is possible that some locations on a road network record a high number of crashes, but with low severity as opposed to locations where crashes are recorded in low numbers but with very high severity. Thus two aspects of safety i.e., a) crash frequency, which is the likelihood of crash occurrence, and b) crash severity which is the expected consequence of the crash should be considered to identify crash risk. Since these two factors capture two different aspects of safety, it is important that an assessment of risk, an approach combining both aspects of safety should be considered. To do that estimation of *'Risk'* across various locations in a city should be estimated first such that the following research questions or research gaps can be addressed:

- Is there any temporal and spatial variation of risk?
- Which road users are at high risk?
- What are the key factors associated with the high risk zones in a typical Indian Metropolitan?

3. METHODOLOGY

There are primarily two major approaches to road safety management: a) proactive and b) reactive. While proactive approach should always be preferred to prevent crashes from occurring, it requires scanning for hazards at planning, design and operational level, which is suitable for new facilities for which records of road traffic crashes may not be required. In most of the Indian cities, road traffic crash records are maintained even though it is not publicly available. Using these records it is possible to perform significant analysis, which is reactive in nature and finds the answer to the research questions identified in the previous section.

To get the answers of these research questions, first '*Risk*' should be defined such that it could be estimated with help of crash data. The risk is defined as the probability of damage, injury, fatality, or any other negative consequence that is caused by external or internal vulnerabilities, and that may be prevented through pre-emptive action. Risk estimation is the process of assigning values to the probability and consequence of the risk, which in this case is a road traffic crash. While a comprehensive method of risk estimation would involve identification and collection of all possible factors that may affect crash occurrence and severity, it is still possible to obtain a relative measure of risk with the help of crash data collected from the police. For this purpose, the concept of 'Risk Priority Number' (RPN), which is a popular method in 'Failure Modes and Effects Analysis' (FMEA) could be used (Dhillon, 2011). As per this, the RPN, is a numeric assessment of risk assigned to a process, or steps in a process, in which numeric values could be assigned to quantify the possibility of occurrence, the likelihood of detection, as well as the severity of impact as given below:

$$RPN = P \times C \times D \tag{1}$$

Where P is the probability of crash occurrence; C is the consequence or severity of the crash; D is the detectability of the crash occurrence. If the consequence or severity of a crash can be used on a KABCO scale, then an Equivalent Property Damage Only (EPDO) estimate could be done. However, in the context of India, often injuries are recorded in four scales: fatal, grievous injury, minor injury and no injury or Property Damage Only (PDO) crashes, with a very high rate of underreporting for a minor injury and PDO crashes. Hence this clearly indicates that the detect-ability is low in case of minor injury and PDO crashes. The equivalent property damage is the weighted crash severity index, which measures the seriousness of a crash. It is calculated to assign different weight factors for each type of crashes as follows: 33.05 for the fatal crash, 14.98 for grievous injury, 1.16 for a minor injury, and one for property damage case (Bandyopadhyaya and Mitra, 2011). RPN is very similar to that of the Equivalent Property Damage Only (EPDO) score, except there is a parameter captures the variation in reporting or detecting a crash. This RPN, when arranged called detect-ability which in a descending order, could indicate the locations with descending risk. However, one needs to remember that RPN is not a measure of risk, but of risk priority, which is a measure for comparison within different analysis zones or investigation groups based on the ranking method with the presence of limited information with higher RPN score indicating higher priority.

While RPN score is a valuable tool for setting priority, it does not provide any information about the significant variation of risk across a city. For this purpose, t-test or ANOVA should be used for comparison between two groups or more groups respectively. ANOVA tests the null hypothesis that the means for several groups in the population are equal by comparing the sample variance estimated from the group means with that estimated within the groups. Specifically, it tests the null hypothesis:

$$H_0: \mu_1 = \mu_2 = \mu_3 = ... = \mu_k \quad (2)$$
$$H_A: \mu_i \neq \mu_j \text{ for at least one pair of } i\text{-}j$$

Where, H_0 = null hypothesis, H_A = alternative hypothesis, μ = group mean and k = number of groups. If ANOVA returns a significant result, we accept the alternative hypothesis (HA), which is that there are at least two group means that are significantly different from each other.

If the risk is not uniformly distributed throughout a city, it is recommended to divide the city is at least three clusters, namely, 'high risk', 'moderate risk', and 'low risk'. To do that it is important to follow an appropriate distribution of risk data. For this purpose, use of EPDO is more appropriate as it converts the count nature of crash data to a continuous scale, which can be approximated to a normal distribution. After that, it will be required to perform a relative assessment of risk for the three clusters to gain an understanding of the safety problem and decide suitable countermeasures. A methodological framework of the present study is shown in Figure 1.

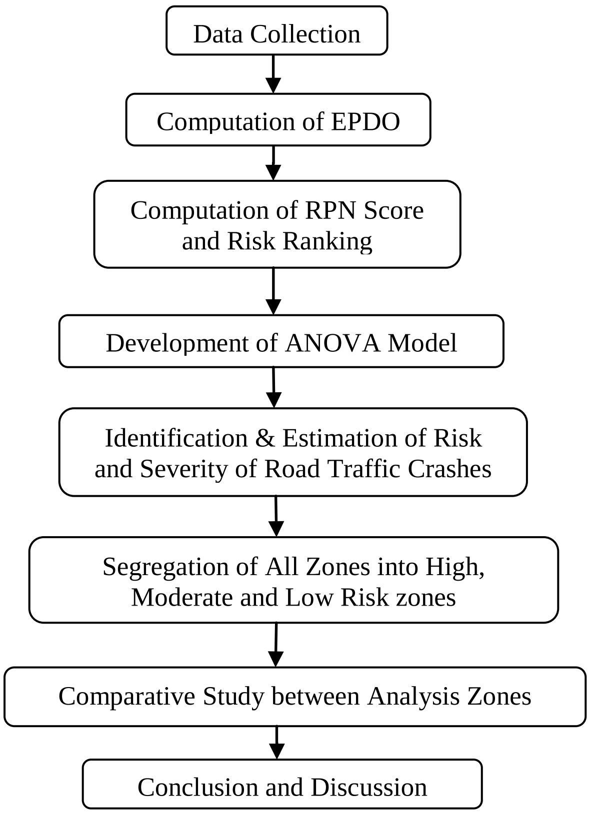

Figure 1. Research methodology

4. DESCRIPTION OF THE STUDY AREA AND CRASH DATA

Kolkata is a premier metropolitan city of India, which is suited in the Gangetic plain of West Bengal on the eastern bank of river Hooghly. Kolkata, which is under the jurisdiction of the Kolkata Municipal Corporation (KMC), has an area of 187.33 km^2 with a population density around 24,252/km^2 or 62,810/mi^2 (Government of West Bengal, 2015). In Kolkata, overall road space allocation is only 6%, which is extremely lesser than other metropolitan cities of India (Chakrabartty and Gupta, 2015). For ease of road traffic management, Kolkata police have divided the entire city into twenty-five 'Traffic Guards', eight 'Divisions' and sixty-nine 'Police Stations'. The names of the traffic guards and the divisions are shown in Table 1 and a typical map of traffic guard is shown in Figure 2.

Table 1. Name of the traffic guards and divisions

Traffic Guard						Division
1.	Vidyasagar	10.	East	19.	Thakurpukur	1. North
2.	Ultadanga	11.	Kasba	20.	Tiljola	2. Central
3.	South West	12.	South East	21.	Head Quarters	3. Port
4.	South	13.	Park Circus	22.	Beliaghata	4. Eastern suburban south
5.	Shyambazar	14.	Howrah Bridge	23.	Bhowanipur	
6.	Sealdah	15.	Regent Park	24.	Purba Jadavpur	6. SED
7.	Jorabagan	16.	Diamond Harbor Road	25.	Metiabruz	7. SWD
8.	Tollygunge	17.	Jadavpur			8. SSD
9.	Garia	18.	James Long Sarani			

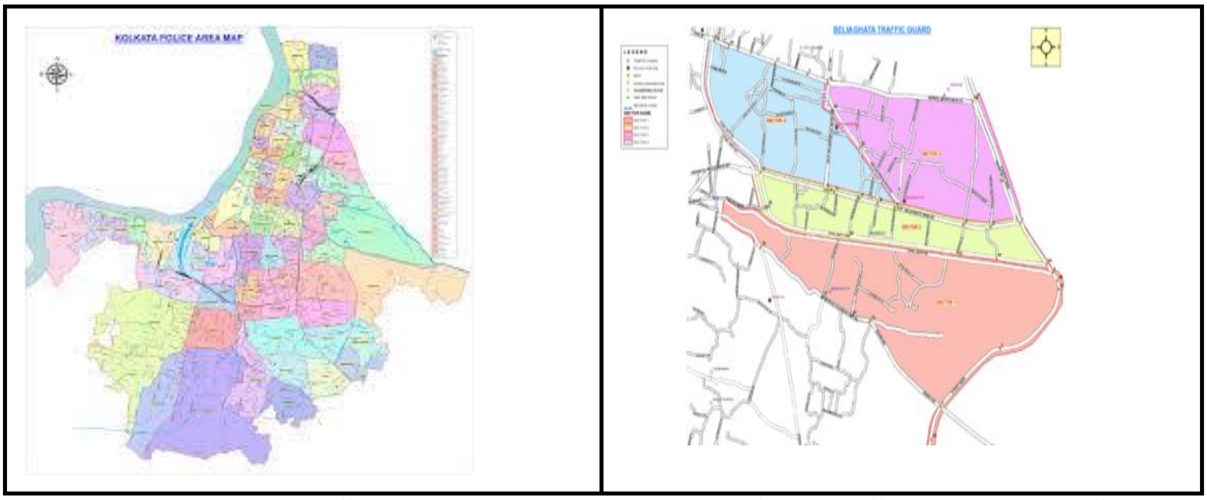

Figure 2A. Kolkata Traffic Guard Map Figure 2B. Map of a typical traffic guard (Beliaghata Traffic Guard)

In this study, road traffic crash data are collected from Head office of Kolkata traffic police, Lal Bazar, Kolkata for the years 2011 to 2016. Only the following variables are available in police data which is used for analysis:

- Place of occurrence with reference to the traffic guard
- The severity of the crash
- Gender and age of the victim
- Month and time of the crash
- Road user type and accused vehicle type for the fatal crash only
- Place of the crash occurrence of the fatal crash only

While some of the important information is missing from the data, such as the geographic location, the type of road where the crash occurred, the manner of collision, weather condition, pavement condition, land use type, type of road users involved for minor injury crashes etc., a representative analysis can still be performed to identify those vulnerable road users and locations on road network. A brief representation of the available data on road traffic crashes in Kolkata is presented in Figure 3. From the police data (2009-16) data, it can be seen that in Kolkata city, the total number of crashes increased by 34.8% from the year 2009 to 2016. However, for the first time in two consecutive years, i.e., 2014 and 2015, witnessed a decline in the number of road crashes, fatalities and injuries despite considerable increase of private car ownership and motor vehicles, at least as per police record.

Figure 4 shows the share of different types of registered vehicles in Kolkata. As per Kolkata police record, private cars and two-wheelers are the major shares of the transport mode of the city. In Kolkata, personalized automobile ownership growth rates are in the order of 15%-20% per annum (Indiastat.com, 2008). The trend in personalized vehicle ownership highlights a continuing shift from slow modes to fast modes. Particularly, the growth of private cars and two-wheelers has been much higher than the growth of other vehicles (Chakrabartty and Gupta, 2015). However, in Kolkata, non-motorized transport such as the bicycle, cycle rickshaw, hand pull rickshaw, still remains an important mode of transportation in the city. This indicates the ascendancy of both motorized and non-motorized transportation mode causing distortion in a modal mix and resulting in unsafe and uneconomical travel conditions. Figure 7 presents the frequency of road crashes shared by vehicle types. Motorized vehicles accounted for 99% of the total road traffic crashes between the calendar year 2013 and 2016. Amongst the vehicle categories, cars accounted for the highest share in total road crashes (36%) in between 2011 and 2016, followed by goods vehicles (20%) and two-wheeler riders (20%).

Figure 5 shows the percentage of road crash shared by different types of road users. Pedestrians were the most vulnerable and unprotected road users killed in road traffic crashes in Kolkata between the year 2011 and 2016. The crash statistic indicates, in Kolkata, pedestrian contributes to 43% of the overall crashes. Further, investigation shows in the year between 2011 and 2016, pedestrians represented for 51% of road traffic fatalities of the overall fatalities (Figure 6).

The age group 31-50 is the major victim of road traffic crashes which shares 42% of the overall crashes as shown in Figure 8. The accident statistic indicates that the age group ‘up to 12’ is the least affected group (less than 3%). As per the police report most of the cases, buses, and goods vehicles are the major offending vehicles involved in the fatal crashes in Kolkata (see Figure 9). The crash data also reveal that in Kolkata, the majority of the fatal crashes occurred at night time, especially with a high risk between night 11 p.m. and morning 6 a.m. (Figure 10). The gender wise comparison in respect of male and female in road traffic crash victims reveals that 77% of the overall crash victims are male. The crash records obtained from the Kolkata police show a very similar type of statistics as documented in the past literature for other cities across India.

5. RESULTS AND DISCUSSION:

In the following results from risk estimation and ANOVA are given first, followed by a comparative study across high, medium and low-risk zones.

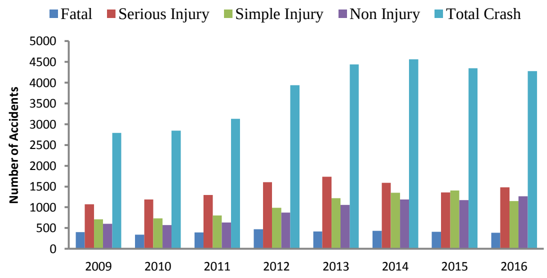

Figure 3. Road accident scenario in kolkata (2009-16)

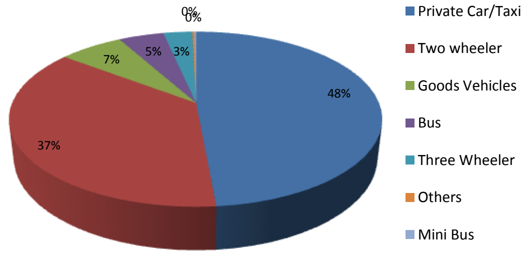

Figure 4. Different types of registered vehicles in Kolkata, 2013 (Kolkata police – review report, 2013)

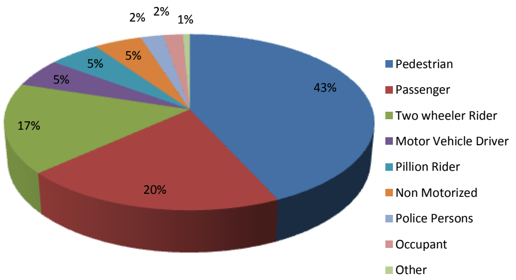

Figure 5. Percentage shared in road crashes by the different types of road user 2011-16

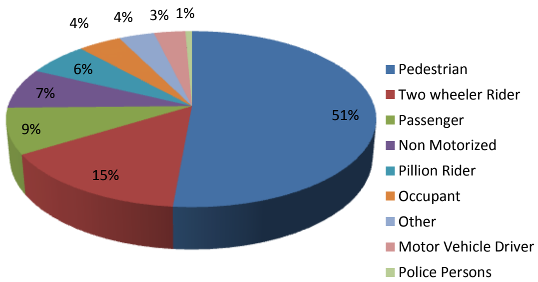

Figure 6. Percentage shared in fatal crashes by the different types of road user 2011-16

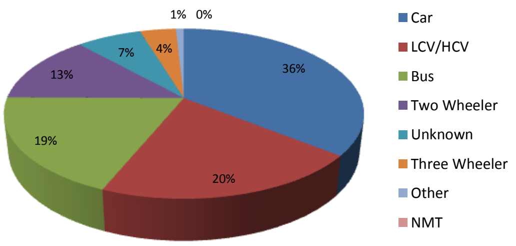

Figure 7. Percentage share of crash frequency by different types of vehicles 2013-16

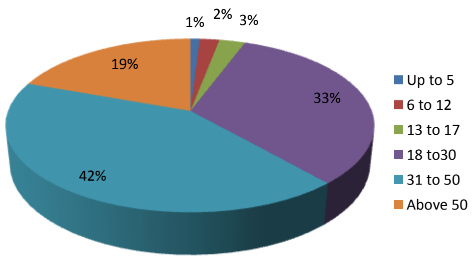

Figure 8. Percentage shared in road accidents by different age groups 2013-16

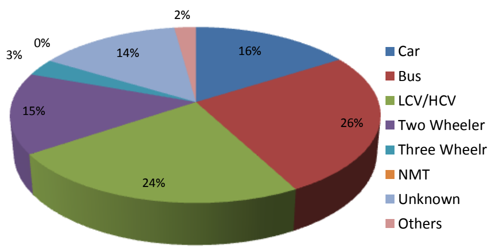

Figure 9. Percentage share of offending vehicles types associated with fatal accidents 2013-16

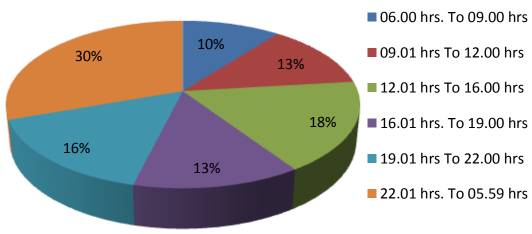

Figure 10. Temporal variation of fatal crashes (2013-16)

5.1 Results from Risk Priority Number

Initially, traffic guard wise RPN was estimated and presented in Figure 11. Figure 11 indicates that the risk of road traffic crashes is not consistent with the entire city and there exists high variation even across crashes of different severity levels both within and across traffic guards. Hence, in this study, a focus was given to macro level risk investigation such that high crash prone zones can be identified. Results obtained from risk estimation across traffic guards for the year 2013 to 2016 are presented in Figure 11. While Figure 11 indicates that risk of road traffic crashes in several traffic guards such as ‘Ultadanga’, ‘Shyambazar’, ‘Jorabagan’, ‘Vidyasagar’, ‘South West’, ‘South’ are very high; whereas, traffic guards like ‘Jadavpur’ ‘James Long Sarani’, ‘Garia’, ‘Metiabruz’, etc have experienced of low risk.

Further, Figure 11 indicates that in most of the traffic guards, the risk has increased in 2016 as compared to 2015; however, there are few traffic guards, such as, ‘Bhowanipur’, ‘Park Circus’, ‘Garia’, and ‘James Long Sarani’ etc. have experienced a lower risk compared to 2015. Further, a risk ranking table was also prepared which shows the ranking of traffic guards based on two important parameters, namely, a) severity of crashes (EPDO) and b) RPN. Subsequently, the ‘Wilcoxon-Sum-Ranked' test was performed to check if there exists any significant difference between these two methods of ranking. The z value was obtained as -0.188 and $p = 0.849 > 0.05$ (at 95% of confidence level) which indicates that there is no significant difference in ranking obtained from these two methods. However, it can be identified that ‘Ultadanga’, ‘Shyambazar’, ‘Jorabagan’ are the high-risk traffic guards and ‘James Long Sarani’, ‘Garia’, ‘Metiabruz’ are relatively low-risk traffic guards, in the year 2016. The ranking based on RPN provides a valuable measure for setting priority in terms of improvement measures. However, using this ranking, it is not possible to recognize if the risk of any traffic guard is significantly different from the other. Further, to compare the risk level across the traffic guards ANOVA technique was applied.

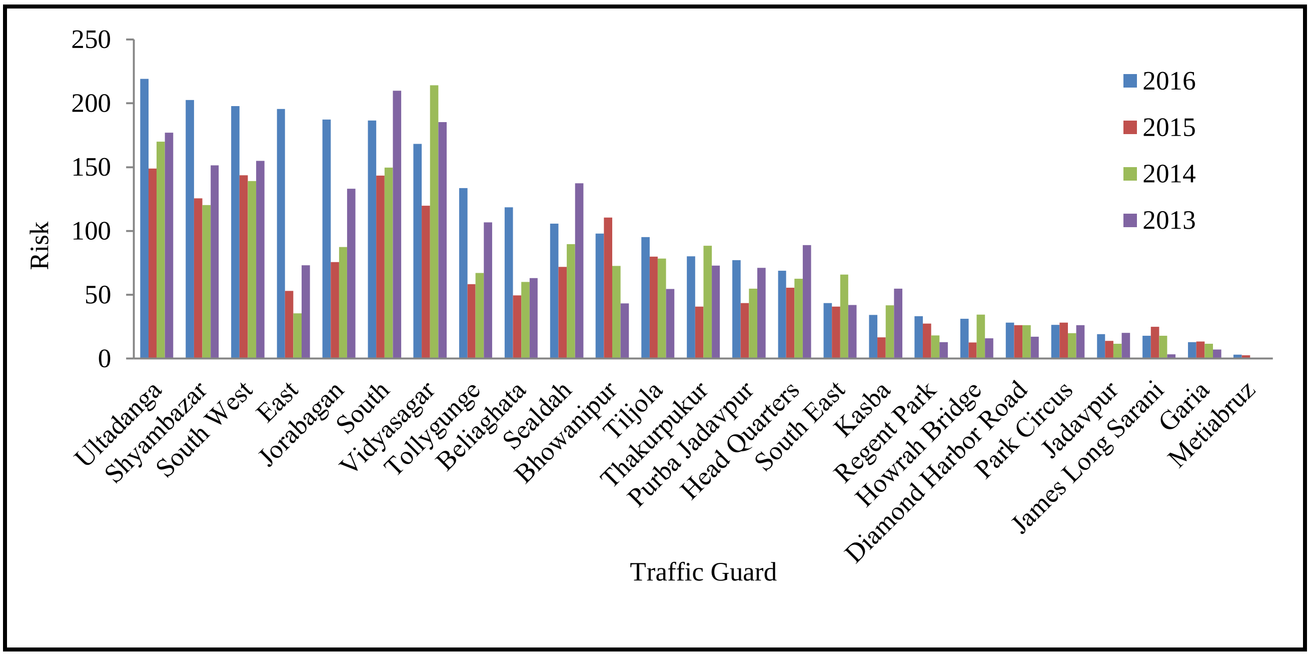

Figure 11. Traffic Guard wise accidents in kolkata (2013-16)

Table 2. Traffic Guard wise severity and risk ranking (2016)

Traffic Guard Wise Severity Ranking			**Traffic Guard Wise Risk Ranking**		
Traffic Guard	**EPDO**	**Rank**	**Traffic Guard**	**RPN**	**Rank**
Ultadanga	2564.83	1	Ultadanga	219.03	1
Shyambazar	2407.80	2	Shyambazar	202.60	2
Jorabagan	2367.70	3	South West	197.83	3
South West	2351.19	4	East	195.64	4
South	2215.66	5	Jorabagan	187.33	5
East	2194.13	6	South	186.43	6
Vidyasagar	2170.50	7	Vidyasagar	168.32	7
Tollygunge	2047.06	8	Tollygunge	133.68	8
Sealdah	1922.30	9	Beliaghata	118.44	9
Beliaghata	1895.70	10	Sealdah	105.62	10
Tiljola	1569.39	11	Bhowanipur	98.03	11
Thakurpukur	1567.67	12	Tiljola	95.09	12
Head Quarters	1469.20	13	Thakurpukur	80.22	13
Purba Jadavpur	1453.92	14	Purba Jadavpur	77.14	14
Bhowanipur	1328.65	15	Head Quarters	68.73	15
South East	1217.80	16	South East	43.58	16
Park Circus	1064.74	17	Kasba	34.20	17
Regent Park	976.62	18	Regent Park	33.11	18
Diamond Harbor Road	892.96	19	Howrah Bridge	31.24	19
Howrah Bridge	880.79	20	Diamond Harbor Road	28.31	20
Kasba	864.71	21	Park Circus	26.40	21
Jadavpur	720.64	22	Jadavpur	19.23	22
James Long Sarani	621.81	23	James Long Sarani	17.96	23
Garia	515.63	24	Garia	12.78	24
Metiabruz	319.74	25	Metiabruz	3.11	25

Table 3. ANOVA table

Null Hypothesis	**Factors**	**Comparing Group Numbers**	**Sample Size**	**F-Statistic**	**F-Critical**	**P-Value**	**Remarks**
Severity of *Overall* road traffic crashes is consistently distributed across the city	Traffic Guard	25	12	24.22	1.56	0000	Reject
	Division	8	12	18.72	2.11	0000	Reject
	Police Station	69	12	7.57	1.31	0000	Reject
Severity of *Pedestrian* crashes is consistently distributed across the city	Traffic Guard	25	12	9.47	1.55	0000	Reject
Severity of fatal *Pedestrian* crashes is consistently distributed across the city	Traffic Guard	25	12	2.26	1.55	0000	Reject
Severity of *Overall* road traffic crashes does not vary by age	Age Group	6	12	264.16	2.35	0000	Reject
Severity of *Overall* road traffic crashes does not vary by the gender of the victim	Gender	2	12	395.27	4.30	0000	Reject
Severity of *Pedestrian's* road traffic crashes does not vary by the age	Age Group	6	12	465.62	2.35	0000	Reject
Severity of *Overall* road traffic crashes does not vary by vehicle type	Vehicle Type	16	12	57.50	2.11	0000	Reject
Severity of *Overall* road traffic crashes is consistently distributed across to the time variation	Month	12	25	0.89	1.82	0.550	Accept
	Time of a Day	6	12	12.71	2.35	0000	Reject
Severity of *Pedestrian* crashes is uniformly distributed across the time variation	Month	12	25	1.60	1.82	0.097	Accept
	Day Type	7	25	0.572	2.15	0.752	Accept
	Time of Day	6	12	2.26	1.82	0.011	Reject
Severity of *Overall* road traffic road crashes does not vary by road user type	User Type	9	12	186.00	2.03	0000	Reject
Severity of *Two Wheeler* crashes is consistently distributed across the time	Time of a Day	6	12	14.67	2.21	0000	Reject
Severity of *Passenger's* crashes is uniformly distributed across the time	Time of a Day	6	12	2.48	2.35	0.040	Reject
Severity of *Pedestrian* crashes doesn't vary by the accused vehicle type	Vehicle Type	9	12	32.91	2.03	0000	Reject

5.2 Results Obtained from ANOVA

In the previous section, it was recognized that the risk of road traffic crashes is not uniform across the city. If ANOVA outcome gives a significant p-value which indicates severity (EPDO) of road crashes is not consistently distributed across the entire city (results are shown in Table 3). Similarly, the ANOVA technique was also applied to identify the mean difference of crash severities among the different demographic characteristics. The outcome indicates that the severity of road crashes altogether varies with age and gender. The severity of crashes is higher for peoples coming under the working group (31-50) followed by the age group of 18-30, and the age group of above 50. Subsequently, it was observed that crash severity of the age group 18-30 is very high due to two-wheelers, followed by private cars. Likewise, the severity of crashes for the age group 31-50 is very high due to private cars followed by private buses and the severity of crashes for the age group 50 above is high due to private cars followed by buses and motorcycles. In Kolkata, men are over-represented in severe crashes than women. The risk of men is nearly two times higher than women road user. Although at present, in Kolkata, male and female population ratio is 1.1, (www.census2011.co.in, Census of India, 2011). This difference between male and female can be partly explained that in Kolkata, the number of women road user is comparatively lesser than men road user

To recognize the temporal variations of crash severity, the month wise crash data converted into EPDO and ANOVA technique applied. This result exposed that there is no particular season when crashes, fatalities, and injuries are high over a typical year. However, the severity of crashes is not uniform across the day. Although, the details of the crash data are not easy to available, but it is clear the fatality rate was higher at night time, and in 2016, 31% of the overall fatal crashes occurred in between 7:00 p.m. and 1:00 a.m. It could be due to the low traffic volume, vehicles drive faster at night, insufficient street lighting, the absence of traffic police and drunk-driving problem, etc.

Similarly, it was identified from the ANOVA test; the severity of pedestrian crashes was not uniform across the city. Further, it was found in the year between 2013 and 2016, 25% of the overall pedestrian crashes was shared by signalized intersections, and 35% of the crashes were shared by un-signalized intersection. However, the majority (40%) of the pedestrian crashes occurred at midblock road segments. Moreover, it was found at 95% confidence interval, the severity of pedestrian crashes was consistent throughout the year 2016. Conversely, pedestrian crash severity varies across the day and pedestrian deaths are relatively higher between 10 p.m. and 11 p.m. It was also recognized that in the year 2016, private cars were the major offending vehicle for pedestrian’s crashes, which was involved in 36% of the overall crashes, followed by buses. Afterward, it was identified in the year 2016 during evening 7 p.m. to midnight 12 a.m. most of the pedestrian fatalities (39% to 48%) occurred due to private cars; whereas, at morning and afternoon season majority of the pedestrian fatalities occurred due to buses (30% to 35%).

ANOVA outcomes additionally suggest the crash severity of two-wheeler riders and passengers is not uniform across the day. Risk of two-wheeler riders is significantly higher between night 10 p.m. and morning 6 a.m. However, the risk of a passenger of public transport remains higher and almost constant during working hours and after evening 7 p.m. risk of passengers is significantly lower as compared to other road users. As per police reports in the year 2016, fatalities associated with two-wheeler riders (45%) were mainly concentrated in between night 10 p.m. and morning 6 a.m. whereas, passenger’s fatalities (64%) mainly ensued between 9 a.m. and 7 p.m.

5.3 Comparative Study between Risk Zones

As the risk of road crashes is not consistently distributed across the entire city; thus, it is important to cluster zones into at least three different categories, namely, 'High Risk', 'Moderate Risk' and 'Low Risk', such that further sampling can be done to study crashes at network level. For this purpose, EPDO of the most recent crash data (2016) was used. Since EPDO data follows a continuous scale, a normal distribution may be approximated and tested to fit this data. To check if the data followed a normal distribution, a suitable test, i.e., Anderson-Darling (AD) test was performed. The null hypothesis in AD test assumes that the data does not follow normal distribution under a pre-specified significance level (Anderson and Darling, 1954). The AD test statistics for this data was obtained as 0.295 with $p = 0.568 > 0.05$, which evidently shows that the data can be approximated as Normal distribution. The probability-probability plot is shown in Figure 12. The descriptive statistics of this EPDO analysis was performed using 'Minitab 15' software package and presented in Table 4. The normal density function is given by the following equation (3):

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\frac{(x-\mu)^2}{\sigma^2}} \quad - \infty < x < +\infty \tag{3}$$

$$f(x) = \frac{1}{\sqrt{2\pi}} e^{\frac{-z^2}{2}} \quad - \infty < x < +\infty \tag{4}$$

Where the parameters of the distribution are σ (standard deviation) and μ (mean). The equation of the function, in terms of standard normal variate, is shown in equation (4). The relationship between the variable x and the standard normal variate z is given by the equation (5).

$$z = \frac{x-\mu}{\sigma} \tag{5}$$

$$x = \mu \pm z\sigma \tag{6}$$

Table 4. Descriptive Statistics of Severity of Crash data (Traffic Guard Wise, 2016)

Count (Number of Traffic Guards)	25
Mean	1504.04
sample standard deviation	676.80
Minimum	319.74
Maximum	2564.83
Range	2245.09
Sum	37601.14
upper threshold value	1788.26
lower threshold value	1219.78

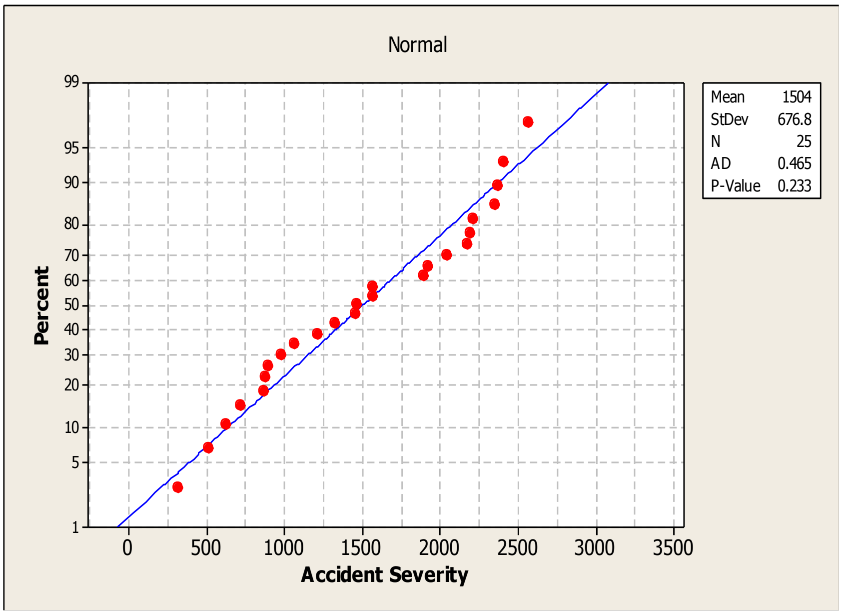

Figure 12. Probability plot of crash severity 2016

The mean (μ= 1504) and standard deviation (σ = 676) of the EPDO data used in this study were computed and the entire data was divided into three clusters such that equal weights are assigned to all these zones. Following this logic, Z value corresponding to 33.33% share of the cumulative density function, φ(z) was obtained as 0.42. The upper and lower threshold value is obtained from the equation (6); based on which the zones are segregated into three equal clusters, namely, 'Low Risk', 'Moderate Risk', and 'High Risk' respectively. Subsequently, a comparative study had been conducted between three risk zones for which the results are shown in Table 5. The outcome reveals that pedestrians are the major victim in all kinds of risk zones. In the case of low and moderate risk zones, private cars and buses are the major victims of road crashes. However, in case of high-risk zone goods vehicles are also significantly affecting road safety. Results also indicate that most of the crashes occurred between 22:01 hrs and 5:59 hrs. When looked at the road network level, it was found that in Kolkata, intersections are more unsafe than a road segment (Table 5). The shares of fatal crashes by intersections and mid-block are 59% and 41% on an average. However, in case of high-risk zones, it was found that intersection-related crashes (68%) are more than mid-blocks (32%). Further, it was found from the police records the share of crashes at signalized intersections is more compared to un-signalized intersections due probably too the high volume of traffic. Once the distribution of the risk of road traffic crashes in Kolkata city is obtained, a suitable sampling scheme is devised to sample network locations from the city for further study.

Table 5. Comparative studies between risk zones

Subjects	**Low Risk**	**Moderate Risk**	**High Risk**
Number of Traffic guards	9	6	10
Mean value of Crash Severity in 2016	761	1434	2213
Total number of crash in 2016	650	1023	2441
Number of Fatal crash in 2016	43	87	251
Number of Serious Injury in 2016	225	340	826
Number of Minor Injury in 2016	177	263	649
Number of Collision cases	175	333	715
Avg. Risk Score (*RPN*)	25	77	172
Major Victim	Pedestrian	Pedestrian	Pedestrian
Major Accused Vehicle for Fatal Crashes	Private Car (30%) Buses (24.78%)	Private car (41%) Buses (24.21)	Private car (27.5%) Goods vehicles (25.73%) Buses (21.48%)
Critical crash Timing for Fatal Crashes	22:01-5:59 hrs.	22:01-5:59 hrs.	22:01-5:59 hrs.
Critical crash Timing for Serious Crashes	22:01-5:59 hrs.	22:01-5:59 hrs.	22:01-5:59 hrs
Locations of Fatal Crashes			
a) *Intersection* b) *Midblock*	52% 48%	59% 41%	68% 32%
Locations of Serious Crashes			
a) *Intersection* b) *Midblock*	66% 34%	69% 31%	72% 28%
Number of Locations where ≥ 5 fatal crashes occurred in between 2011 and 2016	7	19	34
Number of Locations where ≥ 4 fatal crashes occurred in between 2011 and 2016	16	35	51
Number of Locations where ≥ 3 fatal crashes occurred in between 2011 and 2016	25	55	78

6. DISCUSSION AND CONCLUSION

The study aims to demonstrate a methodological framework using which a systematic crash investigation and treatment can be performed using reactive methods in Indian cities. For this purpose, Kolkata city is used. The result from this study clearly indicates that crash occurrence is not uniform across a city and it is thus important to identify high-risk zones such that interventions could be targeted to them. However, in doing that it is also not preferable to collect data from high-risk locations only, rather data from all representative locations in a city so that exposures and factors influencing crashes have a representative variation. Hence, the traffic zones are divided into three groups, i.e., low, medium and high-risk zones for further study at the network level. In doing such studies, it is important to collect network level data in addition to crash data and a systematic management plan can provide a meaningful direction for that.

The study also recognized the temporal variation of risk and reveals months have no significant effects on the severity of the crashes. However, some Indian (Singh 2017) and foreign studies (Bijleveld and Churchill, 2009) have confirmed the seasonal variation of road traffic crashes. Further, it was found that there is a substantial variation in road crashes across the day. The fatalities remain relatively high during night time, low during the early morning, and follow a constant rate during working hours. The study outcome clearly reveals that driving during night-time is riskier than daytime.

Further, it was observed the total number of vulnerable road user's (pedestrian, bicyclist, and two-wheeler rider) deaths in Kolkata ranges between 79% and 83%; passengers and car occupant deaths between 9% and 15%. These crash patterns are very similar to the other Indian cities (Mohan *et al.* 2016). The reason behind such high fatalities of vulnerable road users may be due to the fact the absence of adequate facilities for vulnerable road users on arterial roads in Kolkata and most of the times they have to share the same road space with motorized vehicles. The provision of separate and adequate pedestrian and bicycle lanes in all cities is an essential measure to control road traffic fatalities and injuries.

Among the vulnerable road user's pedestrian risk is extremely high (51%). As the pedestrian constitute such a large proportion of road traffic fatalities, it is clear that Kolkata needs to give priority to improve the safety of pedestrians. The pedestrian fatalities are relatively high between 10 p.m. and 11 p.m., a time frame when one would expect traffic volumes to be relatively low but vehicle speed is higher. Other possible factors include insufficient street light, drinking driving, the absence of traffic police, etc. (Mohan and Bhalla, 2016; Malhan, 2014). Unavailability of data restricts us to identify the exact cause of crashes, especially at night-time. Moreover, it was identified; the severity of pedestrian crashes for the age group above 50 and the age group 31-50 is very high due to buses. One of the possible reasons could be in Kolkata, due to the absence of a designated bus stop facility, most of the time pedestrian has to wait for buses on the road; which gives us an insight about the critical interaction between the pedestrians and buses. Hence, the absence of such basic requirements of pedestrian often increases the exposure of pedestrian crashes. In Kolkata, nearly 10% of the overall pedestrian's fatalities are unknown, which point out the loopholes in the crash recording system and further documentation process.

The age group 31-50 comprises only 26% of the total population (www.census2011.co.in), but faces almost 42% of total fatality. Therefore, age group 31-50 years, the economically active age group, is the most vulnerable age group in Kolkata. Almost half of the road traffic crash fatalities are faced by this group of the population, which accounts for less than one-third of the total population. This could be because people in this age group are in their prime working years and thus are more likely to be present on the roads. Subsequently, it has been observed the crash severity of the age group 18-30 is just next to the age group 31-50. The crash severity of 18-30 age group is very high due to the motorcycle, one of the major causes of its lack of hamlet use (Sharma *et al.* 2016; Pruthi *et al.* 2010; Mallikarjuna and Krishnappa, 2009; Mahajan *et al.* 2013; MoRTH, 1988). In Kolkata, the involvement of children in fatal crashes appears to be low. The underlying reason for these situations is not very clear; however, it suggests advanced studies are essential to determine the reliability of these findings.

In Kolkata, the largest proportion of road fatalities are associated with a collision with private cars and buses, followed by two-wheelers. The same holds true for the other Indian metro cities. As per MoRTH (2013) report, drivers' fault is the unique important factor accountable for road traffic crashes; followed by the fault of drivers of other vehicles, the imperfection of vehicles, poor road conditions and disobedient behavior of the road users. Further, it is suggested, enhancement of vehicular safety additionally plays an important role to lessen the severity of crashes. A broader scope of vehicle safety must be included as a part risk management (Crandall and Graham, 1984).

At the end of this study, result reveals that in most of the traffic guard risk of road crashes followed an increasing trend from 2015 to 2016. However, there has been a slight decline in the number overall crashes from the year 2015 to 2016. In addition, there is some evidence that in about 102 locations at least four fatal crashes occurred in the past six years and likewise a total of 55 locations where at least five fatal crashes occurred in the last six years. These findings clearly indicate that there is scope for safety improvement. The findings also suggest that intersections rather than mid-block segments are more risk-prone and the crash occurred at intersections are higher in high-risk zones, which provide some indications that intersections are risky locations in the road network. This also directs that safety studies should be conducted for intersections; both for signalized and un-signalized to identify the elements associated with high risk. Even though crash data are not easily available in Indian cities; they provide important insight which is otherwise unknown for safety improvement. Thus, there should be an effort to better collect and maintain crash data, such that evidence from both proactive and reactive studies could be used for efficient risk management.

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