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A comparative study of safe and unsafe signalized intersections from the view point of pedestrian behavior and perception

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ABSTRACT

Signalized intersections with marked crosswalks enhance pedestrian safety by providing the designated right of way to pedestrians. However, a significant number of pedestrian fatalities occur at signalized intersections, which may primarily be due to pedestrians' violation behaviors. Since pedestrians' fatalities are not uniform across signalized intersections in a city, it may be expected that violations would also vary across the sites. It is thus worthwhile to investigate if the pedestrian signal violation is a good surrogate for fatal pedestrian crashes at signalized intersections, and if so, what behavioral, spatial, and built environment related factors influence such violations. To this end, present study analyzes pedestrian behavior and perceptions across twenty-four signalized intersections in Kolkata city, India, out of which twelve intersections did not record any fatal pedestrian crashes between 2011 and 2016 and the remaining twelve experienced at least three or more fatal pedestrian crashes over the same period.

Using data from the video-graphic survey at these twenty-four signalized intersections violation behaviors are extracted along with personal attributes at the pedestrian level. Further, pedestrian perception surveys are carried out at each of the twenty-four sites, to obtain a user's perception of safety and satisfaction. Results indicate that pedestrians' signal violations behavior and dissatisfaction are statistically significantly higher at locations with recorded fatal pedestrian crashes. Results from different models and analysis clearly pointed out several planning and design deficiencies such as longer waiting time before crossing, higher pedestrian-vehicular interaction, pedestrian's state of crossing, and a number of personal level attributes such as pedestrian's intended mode of transportation and their state of journey, pedestrian's home location, pedestrian's socio-demographic characteristics as important predictors of pedestrians' violation behavior. The methodology and findings are useful not only for proactive safety improvement at signalized intersections but also to proactively identify potential unsafe sites.

1. Introduction

Pedestrian fatality is a major safety concern all over the world. In urban areas of developing countries such as in India, pedestrian fatalities range between 40% and 60% of the total road traffic fatalities (Mohan et al., 2016; Gosh and Paul, 2013; Mohan et al., 2009; Singh and Misra, 2004). Crash data from Kolkata indicate that on an average 30% of fatal pedestrian crashes occur at the signalized intersections (Kolkata Police Accident Review Report 20111-16). In spite of marked crosswalk with the provision of the pedestrian signal, several signalized intersections consistently witnessed a higher number of fatal pedestrian crashes than other locations. Such high fatality rates could be attributed to the high volume of pedestrian, inadequate pedestrian infrastructure as well as illegal crossing behavior or signal violations, leading to the unsafe interaction between pedestrians and motorized traffic (Gupta et al., 2009). There have been several studies to understand factors influencing pedestrian crash occurrence at signalized intersections (Brde and Larsson, 1993; Lyon and Persaud, 2002; Pulugurtha and Sambhara, 2011), with major focus on influence of traffic and pedestrian volume (Loukaitou-Sideris et al., 2007; Clifton and Kreamer-Fults, 2007) as well as design built environment on pedestrian crash occurrences (Rankavat and Tiwari, 2015a). However, fewer studies if any have focused on pedestrian behavior and crash occurrence (King et al., 2009), even though several studies cited illegal road crossing behavior to be a major problem at both midblock locations (Kadali and Perumal, 2012; Wang et al., 2011; Sisiopiku and Akin, 2003), and signalized intersections (Ren et al., 2011; Zhuang and Wu, 2011; King et al., 2009; Keegan and O'Mahony, 2003). While violation at signalized intersection

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has also been cited as one of the major safety issues in Australia (King et al., 2009) and India (Tiwari et al., 2007), fewer studies have investigated if violation is a good surrogate for pedestrian crashes in general and fatal pedestrian crashes in particular at signalized intersections (King et al., 2009). Further, very few studies if any have focused on how violations vary across signalized intersections with the varied record of pedestrian fatalities; and what pedestrian behavior, spatial factors, and built environment related attributes influence such violations in general and for typical Indian cities in particular. This is important as there needs to be a proactive mechanism to identify sites that may experience fatal pedestrian crashes and identifying associated risk factors is a logical first step.

In order to address this issue, it is essential to compare and contrast sites of a study area and check how pedestrian infrastructure, pedestrian's behavior, and perception have an association with the safety performance across these sites. For this purpose, a group of relatively "safe" (i.e., intersection without recorded fatal pedestrian crashes) and "unsafe" (i.e., intersection with recorded fatal pedestrian crashes) locations may be compared to check what varies across these locations and to what extent. In order to investigate the effect of pedestrian infrastructure and environment on pedestrians' perception and violation behavior this study first compares and contrasts a total of twenty-four signalized intersections in Kolkata which may be categorized in two groups: relatively *"safe"* and relatively *"unsafe"*. Out of these twenty-four signalized junctions, half of them have recorded no fatal pedestrian crashes in a six years' period (i.e., "safe" group of intersection) while the rest of the sites recorded at least three fatal pedestrian crashes over the same duration (i.e., "unsafe" group of intersection). These sites are considered as relatively "safe" and "unsafe" signalized intersections respectively and road inventory surveys, video-graphic surveys, and pedestrian perception surveys were conducted at each of these twenty-four sites. This is essential as police recorded crash data are not easy to be obtained in Indian cities and that there need to be some surrogate measures with appropriate threshold values that may be used to identify unsafe signalized intersections in a proactive manner. In this context, it is important to mention that even though pedestrian's violation behavior is believed to be associated with higher fatality risk; there are limited studies focusing on the impact of the pedestrian violation on the observed safety performance of signalized intersections in general (Guo et al., 2012; King et al., 2009) and especially in the Indian context. Previous research efforts in evaluating pedestrian risk at signalized intersections in typical urban Indian context were primarily concentrated on pedestrians' crossing behavior using various proactive approaches (Marisamynathan and Vedagiri, 2013; Perumal, 2014; Tiwari et al., 2007). However, none of these studies have established an association between pedestrian violation behavior and pedestrian crashes and fatality, which is one of the primary motivations of this study. Using data from Kolkata, a metro city in India, the present study demonstrates a stepwise methodology to test performance across groups of intersections with (i.e., "unsafe") and without (i.e., "safe") fatal pedestrian crash history and checked if pedestrian violation behavior is a good surrogate for fatal pedestrian crashes at signalized intersections. Further, this study compared and contrasted various personal, situational and built environment related factors across study sites to determine what influence pedestrian violation behaviors at signalized intersections in a typical city of a developing country, such as Kolkata in this case. Finally, pedestrians' perception was captured and modeled to identify the possible reasons for their decision of signal violation. In the following sections, the literature review is given first, followed by methodology, results, and discussion.

2. Literature review

Review of literature on pedestrian safety at signalized intersection can be divided into three broad categories: a) with a reactive approach focusing directly on pedestrian crashes or fatalities and intersection level attributes to identify factors affecting pedestrian safety; b) a proactive approach with investigation on pedestrian's signal violation tendency and factors influencing such behavior; and c) analysis of pedestrians' perception and behavior at signalized intersection and its relationship with pedestrian safety. In the following sections, important studies in all three categories are discussed with their findings.

2.1. Reactive approach of pedestrian safety

To assess the safety performance of existing traffic facilities, as well as facilities that have not yet been built, research in road safety has paid attention on the formation of 'Safety Performance Functions' (SPF) that associate the frequency of crashes to a number of traffic operational, circumstantial and built environment related factors (Hauer et al., 1988; Harwood et al., 2000; Gettman and Head, 2003). Existing literature on reactive approach of pedestrian safety assessment can be divided into SPF model for area level and SPFs at road network level, out of which pedestrian crashes at signalized intersections have received much attention due to the fact that a significant number of pedestrian crashes at urban areas occur at these locations, even in the presence of signalization (Ren et al., 2011; Zhuang and Wu, 2011). As the present study focuses on pedestrian risk assessment at signalized intersections, studies focusing on pedestrian crashes at the intersection level are reviewed in depth.

Most of the studies on pedestrian crashes at the transport network level have focused on pedestrian crashes at intersections. These studies mainly looked at the effect of two important exposure variables, vehicle, and pedestrian volumes on pedestrian crash frequency. In an early study, Brüde and Larsson (1993) studied the effect of pedestrian and traffic volumes on pedestrian crashes at intersections (121 signalized, 155 un-signalized, and 9 roundabouts) in Sweden. They found that pedestrian volume has a significant and positive relationship with pedestrian crash frequency. Lyon and Persaud (2002) studied the effect of vehicular volume on pedestrian fatality rate in Toronto, Canada, with data collected from three-legged and four-legged urban signalized and un-signalized intersections. Their findings indicate that not only the total entering traffic volume but also the amount of turning traffic plays an important role in vehicle-pedestrian crashes. They also pointed out that the inclusion of pedestrian volume as an exposure led to a superior model, emphasizing the importance of collecting this information in routine traffic counting programs.

In addition to the vehicle and pedestrian volume, variables such as road geometry, built environment and traffic controls, also play a vital role in pedestrian safety at intersections (Rankavat and Tiwari, 2015b; Harwood et al., 2008). Miranda-Moreno et al. (2011) established a pedestrian crash frequency model to examine the effect of built environment on both pedestrian activity and frequency of pedestrian-vehicular crashes at signalized intersections in Montreal Cities, Canada and concluded that the presence of mix land use significantly affects pedestrian safety. The study in London showed that pedestrian-vehicular crashes are most likely to occur inwards of higher population density and in residential areas (Graham and Glaister, 2003). The type of road, land use as well as the road width, can have an influence on pedestrian safety as well (Rankavat and Tiwari, 2016; Harwood et al., 2008; Morency and Cloutier, 2006).

2.2. Violating behavior

A detailed review of existing studies analyzing pedestrian crashes at signalized intersections reveals that road infrastructure; built environment and traffic operational characteristics significantly influence pedestrian safety. On the other hand, illegal crossing or pedestrian violation behavior could be seen as a proxy measure for the undesirable performance of a signalized intersection (Koh and Wang 2014; Daff and Cramphorn, 2006), in which pedestrians cross in a manner to reduce their crossing time and walking distance. Apart from these basic principles of walking, there are maybe other site-specific as well as pedestrian level factors influencing the risk of signal violation or illegal crossing. The significant findings are summarized in the following sections.

Findings from several studies indicate that factors such as age and gender (Dommes et al., 2015; Brosseau et al., 2013) pedestrians' movement characteristics i.e., if they are alone or in-group (Ren et al., 2011; Zhuang and Wu, 2011), walking speed (Ding et al., 2014) and trip purpose (Guo et al., 2012) significantly influence pedestrian's signal violation behavior. Evidence from existing researches also suggests that distraction from electronic devices increase the likelihood of illegal crossing behavior of the pedestrian (Zegeer and Bushell, 2012). Further, Xu et al. (2013) found that previous experience of successful violations at the same location increases the likelihood of violating tendencies.

Beyond the individual characteristics, waiting time at a signalized intersection is another major factor influencing such violation behavior. Based on a survey of pedestrian behavior at signalized intersections in Beijing, China, Wang et al. (2011) found that the likelihood of compliance decreases with longer waiting time and that almost 50% of the pedestrian would not wait more than 40 s. As per HCM (2000) when pedestrians experience more than a 30 s delay, they become intolerant and engage in risk-taking behavior. Further, Ren et al. (2011) and Chen et al. (2011) concluded that time savings and convenience are the most important two factors influencing violation.

Among the traffic operational attributes, vehicle volume (Sun, 2004), speed (Hamidun et al., 2013) and available gaps (Koh and Wong, 2014; Xu et al., 2013) are observed to have a substantial impact on pedestrian risk-taking attitude. Finally, there are also several temporal and seasonal issues such as the time of the day, the day of the week, month and season that influence the pedestrian's crossing behaviour (Wang et al., 2011).

2.3. Risk perception

Although considerable research has been undertaken to address the problem of pedestrian safety but limited studies are available on pedestrian perceptions and attitudes towards the existing facilities (Holland and Hill, 2007; Yannis et al., 2007). Kononov et al. (2007) showed that actual crash data only provide the information related to the crash frequency and the severity comparison, but does not provide any information related to the nature of the problem itself. On the other hand, risk perception is a useful technique to identify the location specific problems and define the proactive countermeasures that take into account pedestrians' needs and behaviors (Schneider et al., 2004; Zegeer et al., 2006). Rankawat (2017) documented the importance of utilizing pedestrians' perceptions about safety, convenience, security and comfort of different crossing facilities and road infrastructure in an urban setup in a developing country.

The association between risk perception and built environmental features can present useful insights to the policy makers and planners to improve pedestrian safety. The literature on pedestrians' risk perception demonstrated a wide variety of outcomes. A study conducted by Tanaboriboon and Jing (1994) reported the attitudes of pedestrians in Beijing, China, towards the satisfactoriness of crossing facilities and the willingness of pedestrians to use them. The study compared between signalized at-grade crossing and grade-separated crossing; and concluded that users preferred the signalized crossings than grade-separated crossings. Rouphail (1984) performed user conformity and preference study on marked midblock crosswalks in the business district of Columbus, Ohio. The study findings showed that users perceived the un-signalized marked midblock crosswalk to be unsafe as compare to the signalized midblock crosswalk.

A study conducted in North Carolina, USA, showed that only about 50% of the crash-prone locations were correctly perceived by the pedestrians (Schneider et al., 2001). Butchart et al. (2000) identified in Johannesburg, South Africa, survey respondents who live close to a freeway (where 10 fatal pedestrian crashes occur per year), perceived the lack of pedestrian crossing facilities as the main reason for pedestrian crashes and survey respondents from other communities pointed out driver intoxication and carelessness as the primary reason for traffic injuries. Further, Cho et al. (2009) showed how perceived risk varies concerning built environment features and concluded that residents who live in low density-single residential localities were more likely to perceive their locality as unsafe compared to the residents of dense and mixed land-use localities. A study conducted in Delhi, India, showed that 70% of the respondents perceived their residential neighborhoods to be riskier than locations where actual crashes occurred (Rankavat and Tiwari, 2016).

A recent study by Marisamynathan and Vedagiri (2017) used pedestrian perception data to model pedestrian level of level of service at the signalized intersection under mixed traffic conditions in Mumbai, India. Marisamynathan and Vedagiri (2018a) also developed a methodological framework to estimate pedestrian perception based safety level at signalized junctions in developing countries. Further, Marisamynathan and Vedagiri (2018b) utilized pedestrians' behavior and safety perception data to evaluate pedestrian safety index value at signalized junctions in Mumbai city, India and validated the proposed modeling methodology.

For a better understanding of the context of the research, Table 1 summarizes the pedestrian risk factors identified in past literature.

Hence, it is evident that a host of different planning, design as well as socio-demographic attributes, influence pedestrians' risk perception, which possibly affects their tendency of signal violation. Despite a wide range of studies on pedestrians' safety, crossing behaviour, and perception, no studies have compared and contrasted the pedestrian violation as well as crossing behavior of pedestrians across signalized intersections in general and across relatively "safe" and "unsafe" signalized intersections, in particular, to identify what systematic differences across these sites influence pedestrians' risk-taking behavior and affect signal violation. It is expected that crossing behavior and violation will be different across "safe" and "unsafe" junctions, and that spatial environment and individual level factors will have a strong effect on pedestrian safety through crossing behavior at a particular site. However, to the best of author's knowledge few studies if any, investigated the components of pedestrians' behavioral differences for which a site may perform safer than others. Further, pedestrians' risk perception also influences their road crossing behavior, including whether or not they use certain pedestrian facilities (Butchart et al., 2000). Hence, it is equally important to investigate if there exists any difference in pedestrians' perception across "safe" and "unsafe" locations due to its importance in promoting safe walking.

This study contributes to the current literature on pedestrian safety by addressing the following research questions: a) *what influences pedestrian fatality at signalized intersections* b) *how pedestrians' behavior and perception are related with the safety performance* c) *what affects violation behavior at a location,* and d) *why pedestrians violate traffic laws at signalized intersections.*

3. Methodology

The methodology includes selection of study locations, data collection, and data extraction, data analysis using various statistical tests and modeling techniques. The overall study methodology is shown in Fig. 1.

3.1. Site selection

In this study, a total of 24 signalized intersections with mixed land use and high pedestrian volume were identified from the Central Business District (CBD) area of Kolkata (as shown in Fig. 2). Out of these 24 intersections, 12 intersections have witnessed at least *three*

Table 1
Identification of pedestrian risk factors.

Research Objective	Author Name	Study Area	Identified Factors
Factors influencing pedestrian crash frequency	Brüde and Larsson, 1993	Sweden	Pedestrian volume
	Miranda-Moreno et al., 2011	Montreal Cities, Canada	Traffic volume, mixed land use
	Lyon and Persaud, 2002	Toronto, Canada	Traffic and pedestrian volume
	Lee and Abdel-Aty, 2005	Washington DC, USA	Traffic and pedestrian volume, demographic characteristics, road geometry, environmental conditions
	Bowman et al., 1995	Atlanta, Phoenix, and Los Angeles/Pasadena, California	median characteristics
	Schneider et al., 2009	Alameda County, CA	Land use type, median type, vehicle turning movement, on-street parking, the presence of commercial activities, the presence of a regional transit station within a 0.1-mile radius of an intersection, total population near the junction
	Rankavat and Tiwari 2015a	Delhi, India	Road width, traffic and pedestrian volume, speed, road width, type of road and type of junction, land use type, transits characteristics
	Harwood et al., 2008	USA	Road width
	Priyadarshini and Mitra, 2018	Kolkata, India	Minor road width, vehicle and pedestrian volume, post encroachment time, width of zebra crossing
	Keall, 1995	New Zealand	Time spent walking, number of roads crossed, presence of zebra crossing
	Boarnet et al., 2005	California	Road network planning
	Matsui, 2014	Japan	Vehicle characteristics
Factors influencing pedestrian's unsafe act and crossing behavior	Guo et al., 2012	China	Age, gender, safety awareness, conformity psychology, trip purpose, red light time, traffic volume, pedestrian flow rate, group number, crossing time,
	Brosseau et al., 2013	Canada	Age and gender, crossing speed, direction of crossing, number of pedestrian crossing together, design built environment
	Ding et al., 2014	China	Walking speed, gap acceptance, pedestrian's delay at a crossing
	Tiwari et al., 2007	Delhi, India	Waiting time before crossing, visual gaze and field of vision
	Ren et al., 2011	China	Time-saving, age and gender, pedestrian crossing alone or in a group, the presence of police enforcement, pedestrian volume
	Chen et al., 2011	China	Time-saving before crossing the road
	Gårder, 1989	Sweden,	Signal timing, waiting time during red phase
	Koh and Wong, 2014	Singapore	Available gap, vehicle type, and volume
	Retting et al., 2002	USA	Vehicle speed, pedestrian stage of crossing, type of junction, gender, rolling behavior of the pedestrian
	Sun, 2004	Beijing	Vehicle volume, waiting time, signal countdown, signal design
	Li and Fernie, 2010	Toronto, Canada	Weather condition
	Zhou et al., 2009	Shanghai, China	Societal conditions
Factors influencing pedestrian risk perception	Diógenes et al., 2010	Brazil	Design built environment, traffic volume, pedestrian volume, the presence of bus bay and bus stop, parking, marked crosswalk,
	Rankavat and Tiwari, 2016	Delhi, India	Demographic characteristics, number of lane, vehicular volume and speed, width of side walk, pedestrian's convince
	Kadali and Vedagiri, 2016	Mumbai, India	Vehicle volumes, vehicle speeds, crossing width and length of traffic signal cycles
	Cho et al., 2009	Montgomery County, Maryland	Built environment, land use
	Petritsch et al., 2005	USA	Demographic characteristics, vehicle volume and speed, the number of traffic lane, the presence of right turning channelization island, pedestrian's delay
	Landis et al., 2001	Pensacola, Florida	The presence of sidewalk and larger lateral separation from vehicles

fatal pedestrian crashes between the year 2011 and 2016 and the remaining 12 intersections had *no* recorded pedestrian fatalities over the same period. The selected signalized intersections could thus represent groups of "unsafe" and "safe" or "crash-prone" and "non-crash prone" intersections respectively in Kolkata city. The selected intersections are all signal operated intersections with marked pedestrian crossing and sidewalk facilities. However, the selected intersections consist of varied road geometrics, traffic volumes, vehicle speeds and pedestrian behavioral characteristics with a wide range of pedestrian-vehicular interaction.

3.2. Data collection

Crash history records for this study were obtained from the Headquarter of Kolkata traffic police. The police records only contain the information about the accused vehicle type, time of crashes, geographic location of the fatal crashes. However, the data lacks a few significant information such as manner or causes of pedestrian-vehicular collisions, socio-demographic characteristics of the victim, road infrastructure and geometric condition of the site, etc. In the present study, mainly fatal pedestrian crashes are targeted owing to two main reasons— a) the reporting of fatal crashes are better in India, with a very low chance of underreporting compared to the non-fatal crashes (Dandona et al., 2011; Mohan 2009; Dandona et al., 2008; Singh et al., 2018), and b) pedestrian involved crashes tend to be fatal as pedestrians are not confined by any shield (Mohan, 2002; Chong et al., 2010; Anaya et al., 2014; Mitra and Mukherjee, 2017).

After identification of study locations road inventory survey, video graphic survey, questionnaire survey and spot-speed survey were conducted to collect the information regarding road geometry, existing infrastructure, traffic signal details, vehicle and pedestrian volume, traffic movement characteristics, pedestrians' sociodemographic characteristics, pedestrians' risk perceptions and average vehicular speed of a location. Since it was found by Mitra et al. (2016) that in Kolkata, there is no particular season when fatal crashes are significantly higher over a typical year; the relevant data at each site were collected on a weekday with normal weather condition.

3.2.1. Road inventory survey

The road inventory survey was conducted to collect the information

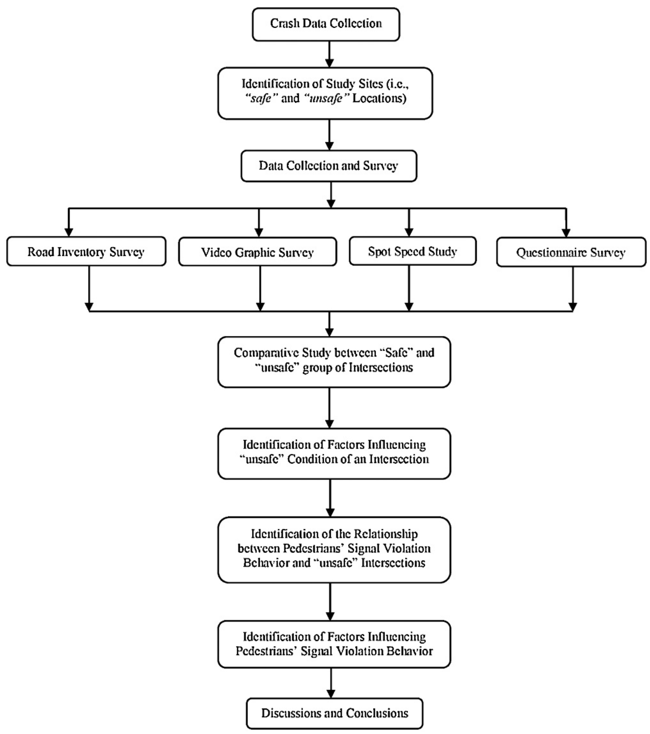

Fig. 1. Study methodology.

regarding road geometry, existing infrastructure, land use type, traffic signal details as per *Indian Roads Congress* specification.

3.2.2. Pedestrian behavioral data collection

In this study, the video-graphic survey was conducted to extract pedestrian's behavioral information while crossing the identified intersections. For the purpose of the video-graphic survey, two or more than two high-resolution video cameras (SONY: Handy-cam, HDR-CX 405) were installed depending on the site conditions, to capture the entire scenario of traffic and pedestrian movement at the intersection. The video cameras were installed beside the road at the height of about 14 m from the road level. Each video camera was used to capture two legs of the intersection. The survey was carried out without disturbing the normal traffic flow. The video recording was conducted for six hours between morning 10 AM and 1 PM, and evening at 4 PM and 7 PM such that both peak and off-peak traffic could be captured. When pedestrian–vehicular interactions are significantly high. The coverage of the video included the waiting area at two ends of the crossing, the zebra crossing, and traffic signal. The position and direction of the video camera installed at these locations are shown in the schematic intersection drawing in Fig. 3 (i.e., Fig. 3A and B), and a few observations obtained during the video-graphic survey are shown in Fig. 4.

The video data was upgraded with millisecond time code using 'AVS video editor 5.1′ software. The traffic data and pedestrian behavioral data were extracted with an accuracy of the millisecond by clicking a step forward option of the video extraction software. Frame by frame progress of videotapes were examined by research assistants manually, and values entered in a pre-designed excel format.

The factors extracted from video are primarily of *six* categories: a) Traffic exposures variables such as traffic and pedestrian volume, b) pedestrian's law abidance, such as if a pedestrian is walking on the zebra crossing, pedestrian is following traffic signal, etc. c) pedestrian demographics such as age and gender, d) pedestrian's behavioral characteristics such as walking speed, speed changing condition, path changing condition, platoon formation, and rolling behavior, and waiting time before and while crossing, etc. e) pedestrian's state of crossing such as carrying overhead load while crossing, distraction from any kind of electronic devices while crossing the road. f) Pedestrian vehicular interaction, such as pedestrian and vehicle volume, Post Encroachment Time (PET), etc. Descriptions of the variables used in this study along with their scales are given in Table 2.

Since it is almost impossible to extract every pedestrian's behavior; out of 6 h' video-graphs, 50 traffic cycles were selected randomly and each pedestrian's crossing behavior was extracted from the selected cycles. The process was repeated for all signalized intersections and the extracted data was subsequently included for detailed analysis.

3.2.3. Pedestrian perceptional data collection

A survey questionnaire form was prepared in a way so that many realistic information could be captured within a short duration (see Fig. 5). The survey periods included both peak hours (10:00 A.M.-12:00 A.M. or 5:00 P.M.-7:00 P.M.) and off-peak hours (12 A.M.-1:00 P.M. and 3:00 P.M-4:00 P.M.) covering the same periods of video-graphic surveys. A number of well-trained interviewers were used to examine the pedestrians' perceptions towards safety and satisfaction level when using a particular signalized intersection. Meaning and importance of question were explained to each pedestrian personally to obtain their responses on a) crossing difficulty b) safety, and c) satisfaction with the overall environment of the intersection on a scale of 1–6 where 1 represents '*excellent*' and 6 represents '*very poor*' condition i.e., most difficult or unsafe or uncomfortable as applicable. Besides, pedestrian's age, gender, trip purpose, trip characteristic, the frequency of using that particular intersection, educational qualification, monthly income, etc. were also asked. Descriptions of the variables associated with the questionnaire survey are given in Table 3. To investigate pedestrian crossing behaviors at signalized intersections and their associated factors, crossing behaviors were classified into two major groups: illegal crossing and legal crossing (Brosseau et al., 2013).

a *Illegal Crossing* (signal violation): Pedestrians committed a violation when crossing during the red phase. They could either had started too early or crossed during the red phase.
b *Legal Crossing* (non-violation): Pedestrians crossing during green phase were considered as legal crossing.

Here it is important to mention that if pedestrian started to cross during the green phase, the crossing was considered as 'legal crossing', even if the end of the crossing was under the red phase. If the pedestrian crossed illegally, a survey expert asked him/her about the reason for such violation behavior, and the reply of the pedestrian was noted down immediately. For each of the study locations, at least 50 pedestrians' responses (both legal and illegal crossing) were collected based on their willingness to participate in the questionnaire survey, and a total of 1452 pedestrians' responses were collected across the 24 signalized intersections. But some of the responses were removed due to incomplete information, which resulted in a total of 1176 complete responses for further analysis and modelling purpose.

3.2.4. Speed data collection

The approaching speed of the motorized vehicles was measured using the speed radar gun. The spot speed survey was conducted for morning 10 AM and 1 PM, and afternoon at 3 PM 6 PM, so that both peak and off-peak hour vehicle speed could be captured. At all study locations, a minimum of 50 samples of a type of vehicle was taken in both peak and off-peak hours to determine the average vehicular speed at the site. Here it should be mentioned that the free flow speed of the operating traffic was only taken into account for further investigations.

The safety performance of an intersection, traffic and pedestrian volume, vehicle speed, and built environmental characteristics, the share of pedestrian signal violation, and pedestrians satisfaction score of the study locations are summarized in Table 4.

Fig. 2. Study locations.

3.3. Modeling methodology and analysis

The statistical assessment in this study started with a correlation analysis using 'Spearman Rank Correlation' test to estimate correlation among the independent variables and that with the dependent variable. Further, for the identification of risk factors, several hypothesis testing was conducted first to compare and contrast pedestrians' perception and behavior across "safe" and "unsafe" sites. After that, several models were developed to identify specific risk factors. To be able to do this, first of all, the individual pedestrian level data collected from the videographic survey and questionnaire survey were aggregated across each site to obtain the share or poprtion or percentage of pedestrian violating the traffic signal, the share of pedestrians having normal walking speed, the share of pedestrian having speed changing condition, the share of pedestrian is crossing in group, the average value of the pedestrians' safety perception at a location, average safety score perceived by the pedestrians, percentage of pedestrians working in different categories, etc. The summary statistics of all observed and collected variables (i.e.,

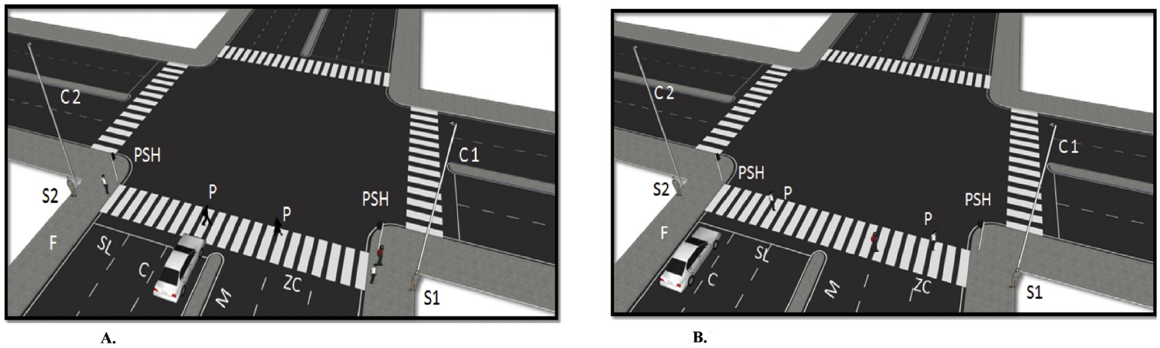

Fig. 3. A. Signal violation / legal crossing (crossing during green phase). Fig. 3 B. Non-violation / illegal crossing (crossing during non-green phase) C1: 'Camera 1′ with stand, C2: 'Camera 2′ with stand, S1: 'Surveyor 1′, S2: 'Surveyor 2′, ZC: Zebra Crossing, PSH: Pedestrian Signal Head, P: Pedestrian, M: Road Median, C: Car, SL: Stop Line, F: Footpath.

road inventory survey, video-graphic survey, questionnaire survey and spot speed survey) are given in Table 5.

Once such data were aggregated, the proportions of these variables or the means of the variables as applicable were compared across the two different groups to check if there exists any difference across these two groups (i.e. "safe" and "unsafe" locations). For this purpose, a statistical technique, such as independent sample *t*-test was used to compare means of continuous variables such as waiting time, vehicle and pedestrian volume, perceived satisfaction level, etc. across "safe" and "unsafe" groups. The null hypothesis and the alternate hypothesis of the test are stated as follows.

$$H_0: \mu_1 - \mu_2 = 0 \,[\text{the two population means are equal}] \quad (1)$$

$$H_a: \mu_1 - \mu_2 \neq 0 \,[\text{the two population means are not equal}] \quad (2)$$

However, for comparing between population proportions, such as the percentage of the pedestrian violating traffic signal, the proportion of male and female pedestrian, the percentage of the pedestrian following zebra crossing, etc. *t*-test is not suitable. In such case, the sampling distributions of the sample proportions p_1 and p_2, and their difference p_1–p_2 are approximately normally distributed; and the competing hypotheses for the difference between population proportions are (Washington et al., 2003)

$$H_0: P_1 - P_2 = 0 \,[\text{the two population proportions are equal}] \quad (3)$$

$$H_a: P_1 - P_2 \neq 0 \,[\text{the two population proportions are not equal}] \quad (4)$$

The test statistics follow a normal distribution and is given as

$$Z = \frac{(p_1 - p_2) - 0}{\sqrt{p(1-p)\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}} \quad (5)$$

Where, $p_1 = x_1/n_1$ is the sample proportion of "safe" group; $p_2 = x_2/n_2$ is the sample proportion of "unsafe" group, Where, n_1 and n_2 are the sample size obtained from an intersection under "safe" and "unsafe" group, x_1 and x_2 are the sizes of a particular observed variable out of n_1 and n_2 observations, and p is computed as follows

$$p = \frac{x_1 + x_2}{n_1 + n_2} \quad (6)$$

Subsequently, to estimate the probability of "unsafe" condition from a certain behavior or perception related factor, Binary Logit (BL) model was developed, such that factors influencing "unsafe" condition at a specific site could be identified. The binary logistic regression model establishes the relationship between a binary dependent and a set of independent or explanatory variables. The dependent variable was considered as a binary variable indicating if a particular location is "unsafe" or "safe", whereas the independent variables are considered as volumes of pedestrian and vehicles, % of pedestrian violation, the average speed of the vehicle, road width, perceived satisfaction level, etc. To avoid the problem of multi-co-linearity among the independent variables, only a few selected independent variables were used for model building, which had lower correlations among them. The probability of occurrence of an alternative ("unsafe" versus "safe") was estimated based on a linear combination function (utility function) expressed as Eq. (8):

$$Y_i = \alpha_i + \beta_{i1}X_1 + \beta_{i2}X_2 + \beta_{i3}X_3 \ldots\ldots\ldots\ldots + \beta_{in}X_n \quad (8)$$

Where, Y_i = the utility of alternative i at a particular location; i = the alternative [Y = 1 (*unsafe*: at least three pedestrian fatalities occurred in between 2011 and 2016); Y = 0 (*safe*: no recorded pedestrian fatalities in between 2011 and 2016)]; n = number of independent variables; α is a constant; β_{i1} to β_{in} are the coefficients. The utility of alternative 'i' has to be transformed into a probability in order to predict the probability of a particular alternative occurring at a location and the probability of alternative 'i' occurring could be calculated using the following function:

$$\text{Prob}(i) = \frac{1}{1 + e^{-Y_i}} \quad (9)$$

Further, the percentage of pedestrian violation behavior at each signalized intersection was modeled using Multiple Linear Regression (MLR) technique to identify what factors affect pedestrian violation behavior at a site. As the '% of pedestrian violation behavior' is a continuous variable and normally distributed, with a value of Anderson–Darling test statistic 0.295, $p = 0.568 > 0.05$ (Anderson and Darling, 1954) the MLR model is the most suitable modeling technique to build a association between independent variables and dependent variable (i.e., share or the proportion of pedestrian signal violation). The model framework is given below:

$$Y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_{i3}X_3 + \ldots\ldots + \beta_nX_n \quad (10)$$

Where, Y = % of Violation Behavior at a particular location; X_i = Explanatory variables (for i = 1 to n); β_i = Estimated parameters from the model (for i = 1 to n); β_0 = y-intercept of regression line.

Finally, the cause of pedestrians' violation behavior, which was obtained from the questionnaire survey, was modeled using a Multinomial Logit Model (MNL). MNL is a discrete choice modeling framework, where various causes of pedestrian violation behavior (i.e., 'Not accessible'/ 'Walking distance is more'/ 'Hurry'/ 'Pedestrian does not know the traffic rules', etc.) was expressed as a function of pedestrian's personal characteristics, trip purpose, state of journey, waiting time, perceived safety, crossing difficulty and satisfaction level, etc. The linear function Y_{in} that determines the outcome i of observation n may be written as (Washington et al., 2003)

$$Y_{in} = \beta_i X_{in} + \varepsilon_{in} \quad (11)$$

Where β_i is the vector of estimable parameters for discrete outcome i; X_{in} is a vector of observable characteristics that determine a

Sealdah Big Bazar Crossing: Illegal crossing behavior, Pedestrians are not using footpath and not following designated crossing facility

CR Avenue & MG Road: Pedestrians are not following traffic signal

Shyambazar Crossing: Pedestrians are not following zebra crossing

CR Avenue & MG Road Crossing: Pedestrians are not following designated crossing facility, pedestrian using cell phone while crossing

Chiriamore Crossing: Pedestrians are not following designated crossing facility

CR Avenue & BB Ganguly Street: Pedestrians are following zebra crossing and traffic signal

JL Neheru Crossing: Pedestrians are running across the road)

EM Bypass Chinrihata Crossing: Pedestrians are not using footpath

MG Road & Strand Road Crossing: Distracted Pedestrian: using electronic devices while walking

CR Avenue & MG Road Crossing: Pedestrian carrying Overhead Load

Fig. 4. Pedestrian crossing behavior.

dichotomous outcome for observation n; ε_{in} is the random error term, and it follows Gumbel distribution. The probability of observation 'n' having discrete result is calculated as follows:

$$\text{Prob}_n^{(i)} = P(Y_{in} > Y_{in}) \ \forall \ I \neq i \tag{12}$$

Where, $\text{Prob}_n^{(i)}$ is the probability of observation n having discrete outcome i(i∈ I), where, i denotes all possible outcomes for observation.

4. Results and discussion

In order to understand the effect of several variables obtained from video-graphic survey and questionnaire survey on the fatal pedestrian crash occurrence, one-dimensional co-relation (i.e., 'Spearman rank correlation') test between the fatal pedestrian crash frequency and other independent variables was performed and summarized in Table 6. A number of observations can be made from the correlation test. First of all, the fatal pedestrian crash frequency at a signalized intersection is found to be highly correlated with pedestrians' 'signal violation' behavior ($\sigma = 0.660$; $\rho < 0.01$) and 'running behavior' ($\sigma = 0.752$; $\rho < 0.01$). Beyond the crossing behavior, pedestrians' state of crossing [i.e., pedestrian carrying the overhead load while crossing ($\sigma = 0.794$; $\rho < 0.01$) or any distraction ($\sigma = 0.869$; $\rho < 0.01$)] is also linked with pedestrian fatality risk in Kolkata. Findings from correlation also indicate that pedestrians' signal violation tendency increases with the 'longer waiting time' before crossing ($\sigma = 0.607$; $\rho < 0.01$). Pedestrian-vehicular interaction in terms of PET is also found to be negatively

Table 2
Descriptions of the variables extracted from thee video graphs.

Variable type	Name of the variable	Description
(a)Traffic Exposures Variables	Log(Average Daily Traffic Volume)	Average daily traffic volume of the study location
	Log(Average Daily Pedestrian Volume)	Average daily pedestrian volume of the study location
	Pedestrian vehicular ratio	Pedestrian and vehicle volume ratio of a location
(b) Pedestrian law abidance	Pedestrian violating (illegal crossing/violation) the traffic signal: Yes (1) No (0)	Illegal cases are defined in this study as when pedestrians cross the road during the non-green phase (i.e., violation), whereas pedestrians crossing during a green phase are considered as legal crossing (non-violation)
	Pedestrian crossing along the zebra crossing: Yes (1) No (0)	Whether pedestrian is crossing along the zebra crossing or not
(c) Pedestrian demographic	Age: Gender:	Minor: up to 16; Young: 16 to 49; Elder: 50 and Above Male (1), Female (0)
(d) Pedestrian behavioral characteristics	Walking speed:	Normal, Fast, Running;
	Speed Changing condition: Yes (1) No (0)	Pedestrian changes speed while crossing the road
	Path Changing condition: Yes (1) No (0)	Pedestrian changes crossing path while crossing the road
	Platoon Formation: Single (1) Group (0)	Pedestrian is in a group (number of pedestrians ≥ 3)
	Group Size:	Total number of pedestrian crossing in a particular group
	Presence of Rolling Behavior: Yes (1) Else (0)	Pedestrian rolls over the available small vehicular gaps (Kadali and Vedagiri, 2017)
	Waiting Time before Crossing: Sec	Waiting time of the pedestrian before crossing the road
	Following Footpath: Yes (1) No (0)	Pedestrian is using the footpath
	Stage Crossing: Yes (1) No (0)	Pedestrian is crossing the road in a single stage or multiple stages
	Number of stages while crossing	Total number of stages while crossing the road
(e) Pedestrian's State of Crossing	Distracted Pedestrian: Yes (1) No (0)	Pedestrian is using an electronic device while crossing (i.e. using a cell phone, tablet, etc.)
	Carrying overhead loads: Yes (1) No (0)	Pedestrian is carrying a load on his/her head that exceeds the standard or ordinary legal size that really obstruct visibility of the pedestrian
(f) Pedestrian vehicular Interaction	Post Encroachment Time (PET)	"Time difference between the end of the encroachment of crossing pedestrian and the time that the through vehicle actually arrives at the potential point of collision" (Gettman and Head, 2003; Killi and Vedagiri, 2014)

Indian Institute of Technology Kharagpur
Department of Civil Engineering
Transportation Engineering Section
Pedestrian Questioner Survey

Gender: M/F
Age: up to 18 / 18 to 50 / above 50
Educational Qualification: Nil / Primary / Secondary /Graduation /Post Graduation
Employment Status: Unemployed / Office Worker / Industrial Worker / Business / Student / others
Monthly Income: up to 1000 / 1001 - 5000/ 5001-15000 / 15001-30000 /30001-50000/Above 50000
Daily User: Yes / No (If 'No', Frequency of Use? Once in a Week / Month / Year / 1st Time user)
Location of Home: Walking distance /Other Location
Purpose of Trip: Education / Business / Job / Entertainment / Shopping / Medical Treatment/ Others
Pedestrian's Intended Mode of Transport: Public Transport / Others
The pedestrian is going / returning to the work: (going [i.e., onward trip] / returning)
How do you perceive the crossing?

Scale
Not Difficult 1 2 3 4 5 6 Highly Difficult

How do you perceive the road safety?

Scale
Highly Safe 1 2 3 4 5 6 Not Safe

Your satisfaction of the road service:

Scale
Excellent 1 2 3 4 5 6 Very Poor

Is the pedestrian following traffic signal? (Yes / No)
If, 'No'- Major reason of such signal violation behavior:
1. Existing facilities are not convenient (e.g. Not accessible / Walking distance is more / Not visible)
2. The pedestrian does not know the rules
3. Hurry
4. Other reasons (……………...)

Fig. 5. Sample questionnaire form.

and significantly correlated with fatal pedestrian crash count (σ = -0.730; ρ < 0.01). On the other hand, pedestrians' socio-demographic characteristic such as age (σ = -0.312; ρ > 0.10), gender (σ = -0.023; ρ > 0.10), monthly income (σ = -0.335; ρ > 0.10), educational qualification (σ = 0.202; ρ > 0.10), and home location (σ = 0.093; ρ > 0.10) were not found to be significant; but pedestrians' trip

Table 3
Variable description of questionnaire survey form.

Characteristics	Variables	Descriptions
(a) Pedestrians' Perceptions	Pedestrian's perceived satisfaction level	Based on the pedestrian perception: Excellent = 1 to Very Poor = 6;
	Pedestrian's perceived difficulty	Not Difficult = 1 to Highly Difficult = 6;
	Pedestrian's perceived safety	Highly Safe = 1 to Not Safe = 6;
(b) Demographic Characteristics	Gender	if, Male = 1; Female = 0
	Age of the pedestrian	a) up to 16; b) Young : 16 to 49; c) Elder: 50 and Above
(c) Frequency of use	Daily user	if, Yes = 1; No = 0 if, No, Frequency of use a) Once in a Week b) Month c) Year d) 1 st Time
(d) Home Location	Pedestrian's home location	Walking distance (i.e. Local Pedestrian) = 1; Other location = 0
(e) Trip Purpose	Pedestrian's trip purpose	a) Education b) Business c) Job d) Entertainment e) Shopping f) Medical Treatment g) Others
(f) Mode of Transport	Pedestrian's Intended Mode of Transportation	a) Public Transport = 1; b) Others = 0
(g) The pedestrian's state of Journey	Pedestrian is going or returning for the work purpose	Pedestrian is going to the work purpose (onward trip) = 1 Pedestrian is coming back from the work = 0
(h) Socio economic characteristics	Educational qualification	a) Nil b) Primary Level c) Secondary level d) Graduation Level e) Post Graduation and above
	Employment status	a) Unemployed b) Office Worker c) Industrial Worker d) Business e) Student f) others
	Monthly income	a) up to 1000 b) 1001- 5000 c) 5001-15000 d) 15001-30,000 e) 30001-50,000 f) Above 50,000
(h) Crossing Behavior and law abidance	Pedestrian following traffic signal	if, Yes = 1; No = 0
	Possible reason of signal violation behavior of the pedestrian	a) Existing facility or facilities are not convenient to the pedestrian (it may be due to lack of accessibility or walking distance is more form the pedestrian's destination or signal is not clearly visible to the pedestrian) a) The pedestrian does not aware of the traffic rules a) Pedestrian is in hurry and ready to take risk of signal violation a) Other reasons

purpose and state of journey were found to have a good correlation with the pedestrian fatality risk. For example, the pedestrian who is either going to work (σ = 0.346; ρ < 0.10) or to catch public transport (σ = 0.392; ρ < 0.05) are more likely to involve in a crash. Further, it was observed that several external exposures and operational parameters such as pedestrian volume (σ = 0.548; ρ < 0.01) and vehicle volume (σ = 0.602; ρ < 0.01), and vehicular speed (σ = 0.727; ρ < 0.01) are highly significant with fatal pedestrian crash frequency at the signalized intersection level.

Further, to compare and contrast across "safe" and "unsafe" groups of intersections an 'independent sample *t*-test or z-test' was performed to check if the means (*t*-test) or percentages (z-test) of the certain attribute is different across the relatively "safe" and "unsafe" intersections. The result in Table 7 shows that at "unsafe" locations the mean of 'share of pedestrian violation behavior' is 1.90 times higher than safe locations, which is also statistically significant. Similarly, the mean of 'percentage of running behavior' is 3.75 times more at "unsafe" locations; whereas, the average value of the variable 'percentage of distracted pedestrian' is five times higher at "unsafe" locations. The mean of the variable 'percentage of pedestrian carrying overhead load' is 2.33 times higher at "unsafe" locations. Further, it was observed that the mean value of pedestrian perceived safety and satisfaction are more than 1.3 times higher at "safe" locations as compared to "unsafe" locations. At "unsafe" locations pedestrians' average waiting time before crossing is 1.5 times higher than "safe" sites. The mean value of the 85th percentile PET of "safe" group is significantly higher (1.6 times) than "unsafe" group. It was also observed the average vehicle speed (1.19 times) and the average road widths (1.27 times) of "unsafe" sites are statistically and significantly higher (at 5% level of significance) than "safe" sites. Finally, the comparison also indicated that several other factors associated with pedestrians' socio-economic and socio-demographic characteristics, trip purpose and state of the journey, mode of transport, pedestrian volume are not statistically dissimilar across the "safe" and the "unsafe" group.

To develop an understanding of the variables significantly affecting the probability of the "unsafe" condition of a signalized intersection, a set of binary logit models were formed (as shown in Table 8). In these models, several attempts were made to associate the built environment (Model 1), traffic exposures and operational parameters (Model 2), pedestrian behavior and perception (Model 3) with a dichotomous dependent variable (i.e., "unsafe" or "safe"). Once this preliminary investigation was carried out, for each major risk categories, a combined model with several independent variables was developed (Model 4–6 in Table 8).

The model finding shows that the approaching speed of the motorized vehicle significantly increases the likelihood of "unsafe" condition of a signalized junction. It is obvious that the possibility of a pedestrian fatality will increase with higher operating speed (Eluru et al., 2008). Ewing and Dumbaugh (2009) also found that vehicular volume determines the crash frequency, whereas operating speed determines the crash severity. Further, the model findings indicate that road width and traffic volume positively influence pedestrian risk at 90% confidence interval. Consequently, it can be concluded that intersections with a high traffic volume and wide road width are likely to have more pedestrian crashes leading to fatalities. In this perspective, Zegeer and Bushell (2012) showed that road environments with high volume traffic without adequate facility could be a significant reason for pedestrian-vehicular crashes. Further, it was observed that hourly pedestrian volume of an intersection, the presence of designated bus stop facility, and inaccessibility of pedestrian crosswalk don't have any significant impact on pedestrian safety, at least for the present case study. Interestingly, it was found that pedestrian's risk perception and crossing difficulty captured through "pedestrian satisfaction level" has a strong association with the likelihood of an "unsafe" intersection.

Finally, the variable "share of pedestrians' signal violation behavior" emerged to be the most significant factor for "unsafe" condition of a signalized junction in Kolkata. A similar conclusion was postulated by several studies conducted in developed countries (Ren et al., 2011; Zhuang and Wu, 2011) as well as in developing countries (Tiwari et al., 2007); where pedestrians' signal violation or illegal crossing behavior was identified as the predominant factor of pedestrian-vehicular crashes at signalized junctions. Therefore, it became essential to identify factors influencing the high share of *pedestrians' violation behavior*. To investigate that, a linear regression model was developed to model "*percentage of violation*" across "safe" and "unsafe" sites. Results from this model are shown in Table 9.

The results obtained from the MLR model indicate that a host of risk factors ranging from the pedestrians' personal level attribute to planning, design, and traffic operational attributes of the intersection influence pedestrian's signal violation behavior. The model finding shows

Table 4
Description of study area.

Category	Intersection Name	Safety Performance	Traffic Exposures			Behavior and Perception		Built Environment		
		Number of Pedestrian Fatalities *(2011-16)*	Pedestrian Crossing Volume per Hour	Vehicle Volume per Hour	Speed of Vehicle (kmph)	(%) of Pedestrian Violation	Average Satisfaction Score of the Location	Type of Intersection	Accessibility of Crosswalk	Designated Bus Stop
UNSAFE GROUP	Ruby Intersection	11	8180	10374	62	70	4.85	4-Legged	Absence	Presence
	EM Bypass & Chingrighata	8	2470	5619	55	75	4.73	4-Legged	Absence	Presence
	Chiria More Crossing	7	2479	5204	60	47	4.69	4-Legged	Presence	Presence
	Sealdah Bigbazar	6	2970	3631	45	66	4.60	3-Legged	Absence	Absence
	EM Bypass Panchanna gram	6	751	2619	55	61	2.42	4-Legged	Presence	Absence
	EM Bypass Mandir Para Road	5	2040	4160	60	32	4.52	4-Legged	Absence	Presence
	Apollo Gleneagles Hospitals	5	1277	3944	50	43	4.20	3-Legged	Presence	Presence
	APC Rajabazar Crossing	4	2216	3137	55	77	5.02	3-Legged	Presence	Presence
	Shyambazaar Crossing	3	2235	4129	40	57	3.30	5-Legged	Absence	Absence
	Strand Rd & MG Road	3	2417	5673	35	70	2.84	4-Legged	Absence	Absence
	CR Avenue and MN St	3	2826	5239	45	33	4.04	4-Legged	Absence	Absence
	MG Road & CR Avenue	3	2350	5075	35	49	4.33	4-Legged	Absence	Absence
SAFE GROUP	AJC Bose and Cathedral road	0	2745	1939	40	62	2.20	4-Legged	Presence	Absence
	Amhesrst St. & Surya Sen. St	0	1236	2279	35	16	2.71	4-Legged	Presence	Presence
	BB Avenue & JM Avenue	0	1903	3402	45	14	2.50	4-Legged	Absence	Absence
	East and Esplanade Row	0	1113	4313	45	09	2.33	4-Legged	Absence	Absence
	CR Avnu. Ganesh Talkies	0	1035	3965	40	26	2.87	4-Legged	Absence	Presence
	JL Nehru Rd & AJC Bose Rd	0	1273	3747	45	32	5.02	4-Legged	Presence	Absence
	Bk Paul & R Sarani	0	1118	5189	35	26	4.89	4-Legged	Absence	Presence
	AJC Bose Rd & Lenin Sarani	0	2357	3826	40	47	2.35	3-Legged	Presence	Presence
	AJC Bose Rd & SN Banerjee	0	3640	3118	45	40	2.33	3-Legged	Presence	Presence
	CR Avenue & BB Ganguly St	0	2580	3748	40	30	3.44	4-Legged	Presence	Presence
	JL Nehru Rd & Shakespeare Sarani	0	1982	4357	50	41	3.92	4-Legged	Absence	Absence
	Cathedral Rd & Queens Way	0	1349	4010	40	21	2.24	4-Legged	Absence	Absence

Table 5
Descriptive Statistics.

Characteristics	Variable Names	Minimum	Maximum	Mean	Std. Deviation
Safety Performance	Fatal Pedestrian Crash Count	0.00	11.00	2.67	3.21
	Unsafe Intersection = 1; Safe Intersection = 0	0.00	1.00	0.50	0.51
Pedestrian Crossing Behavior	% of Signal Violation	0.09	0.77	0.44	0.20
	% of Pedestrian Crossing Alone	0.30	0.90	0.62	0.16
	% of Fast Walking	0.05	0.70	0.24	0.16
	% of Running Behavior	0.01	0.38	0.10	0.10
	% of Speed Changing Condition	0.09	0.67	0.34	0.15
	% of Path Changing Condition	0.13	0.63	0.35	0.13
	% of Rolling Behavior	0.01	0.90	0.16	0.20
	% of Pedestrian Not Following Zebra Crossing	0.13	0.63	0.35	0.13
Pedestrian Perception	Average Perceived Crossing Difficulty (Highly Difficult = 6; Not Difficult = 1)	2.25	4.98	3.53	1.04
	Average Perceived Safety (Not Safe = 6; Highly Safe = 1)	2.20	5.02	3.50	1.02
	Average Perceived Satisfaction (*Very Poor* = 6; *Excellent* = 1)	2.20	5.02	3.60	1.06
Traffic Exposures	Pedestrian Crossing Volume per Hour	751.00	8180.00	2272.58	1455.36
	Vehicle Volume Per Hour	1939.00	10374.00	4279.04	1632.50
	Speed (km/h: Kilometer per hour)	35.00	62.00	45.71	8.41
Pedestrian Vehicle Interaction	PET (Sec)	2.02	4.14	2.90	0.76
Setae of Crossing	% of Pedestrian Carrying Overhead Load	0.06	0.28	0.15	0.07
	% of Distracted Pedestrian	0.01	0.17	0.06	0.05
Pedestrian's Delay	Waiting Time Before Crossing (sec)	3.65	30.23	14.65	6.33
Built Environment	Road Width (meters)	16.76	42.98	24.78	6.91
	Presence of Accessibility of Crosswalk (Yes = 1; No = 0)	0.00	1.00	0.46	0.51
	Presence of Designated Bus-stop (Yes = 1; No = 0)	0.00	1.00	0.50	0.51
	Length of Pedestrian Phase (sec)	0.00	81.00	11.00	22.26
	Traffic Cycle Length (sec)	92.00	216.00	136.67	26.73
Pedestrian's Intended Mode of Transportation	Pedestrian using Public Transport (in %)	0.03	0.39	0.21	0.10
Educational Qualification	Up to Primary Level (in %)	0.00	0.06	0.03	0.02
	Primary to Graduation Level (in %)	0.69	1.00	0.84	0.08
	Post-Graduation and Above (in %)	0.00	0.30	0.13	0.07
Working Status	Unemployed (in %)	0.00	0.20	0.11	0.05
	Office Worker (in %)	0.09	0.43	0.26	0.09
	Industrial Worker (in %)	0.04	0.28	0.14	0.06
	Business (in %)	0.06	0.39	0.25	0.10
	Student (in %)	0.05	0.30	0.17	0.07
Monthly Income	Up to 30,000 NIR (in %)	0.52	0.87	0.74	0.10
	30001-50,000 NIR (in %)	0.05	0.39	0.21	0.10
	Above 50,000 NIR (in %)	0.00	0.09	0.03	0.03
Frequency of Road Use	Daily Users: Yes = 1; No = 0	0.50	0.91	0.68	0.12
Pedestrian's Home Location	Walking distance = 1; else = 0	0.00	0.69	0.25	0.17
Trip Purpose	Education (in %)	0.09	0.27	0.15	0.05
	Business (in %)	0.15	0.67	0.38	0.13
	Job (in %)	0.00	0.39	0.13	0.08
State of journey	Onward Trip	0.00	0.92	0.28	0.22
Demographic Characteristics	Age up to 16 (in %)	0.02	0.34	0.12	0.08
	Age (16-49) (in %)	0.27	0.88	0.68	0.14
	Age (≥50) (in %)	0.08	0.40	0.20	0.09
	% of Male Pedestrian	0.62	0.89	0.73	0.07

that the share of pedestrian signal violation significantly reduces with a higher volume of traffic. A number of researchers also documented similar findings, in which pedestrians' risk-taking attitudes was highly linked with the traffic environment of the site. For example, a study conducted in Beijing, China, by Guo et al. (2012) showed that pedestrian risk of signal violation and traffic volume are inversely associated. Wang et al. (2011) also studied the influence of traffic volume on pedestrian's crossing behavior in Beijing, China, and concluded that the rate of pedestrian violation is significantly high when traffic volume is very less. Further, Kho and Wong (2014) found that the traffic volume and the available gaps between two consecutive vehicles are two predominant factors of pedestrian's decision of signal violation. The model outcome also suggests that a longer waiting time encourages the probability of signal violation. Several studies have documented that longer waiting time, which probably makes a pedestrian impatient, and lack of safety consciousness are external and internal factors for pedestrian violations (Guo et al. 2012; Wang et al., 2011; Van-Houten et al., 2007; Tiwari et al., 2007).

A very unique finding from this study hints that pedestrians carrying oversized loads have more tendencies to disobey the traffic signal; probably due to the inconvenience to wait with an oversized load on their heads, which force them to violate traffic signal. Interestingly, it was observed that distraction from any kind of electronic devices such as cell phone, electronic tab also significantly increases the pedestrian's signal violation probability. In general, mobile phone users pay less attention while crossing, which leads to a more unsafe road crossing (Stavrinos et al., 2011; Nasar et al., 2008).

Interestingly, it was observed that the share of signal violation behavior is also affected by the pedestrians' intended mode of transportation. For example, a pedestrian who is going to catch a public bus is more likely to disobey traffic signal, primarily due to the fear of missing a public bus and waiting for a long time. Pedestrians' such unsafe behavior is also affected by the lack of information on the arrival of next bus, and the absence of designated bus stop facility, compelling them to take unnecessary risk of signal violation. This is a very important result, probably capturing the implications of wider planning and design level issues on pedestrians' crossing behavior and risk-taking attitude.

The findings from this study indicate that the likelihood of traffic

Table 6
Correlation with crash frequency.

Characteristics	Variables	Correlation Coefficient
Crossing Behavior	% of violation	0.660***
	% of Running Behavior	0.752***
	% of Fast Walking	0.163
	% of Path Channing Condition	−0.531***
	% of Speed Changing Condition	0.158
	% of Rolling Behavior	0.131
	% of Pedestrian using Footpath	−0.802***
	% of Pedestrian Following Zebra Crossing	−0.310***
	% of Pedestrian Alone	0.409**
State of Crossing	% of Pedestrian carrying Overhead Load	0.794***
	% of Distracted Pedestrian	0.869***
Waiting Time	Average Waiting Time (Sec.)	0.499***
Pedestrian Vehicle Interaction	85^{th} Percentile PET (Sec.)	−0.730***
Pedestrian's Intended Mode of Transportation	Pedestrian using Public Transport (%)	0.392*
Trip Purpose	Office Work (%)	0.414**
State of the journey	Onward Trip (%)	0.346*
Perceived Safety and Satisfaction	Crossing Difficulty	0.830***
	Perceived Safety of the Intersection	0.856***
	Perceived Satisfaction Level	0.521***
Traffic Exposures	Average Hourly Traffic Volume	0.602***
	Average Hourly Pedestrian Volume	0.548***
	Speed (Km/h)	0.727***
Built Environment and road Infrastructure	Road Width (meter)	0.434**
	Cycle Length (sec)	0.230
	Length of Pedestrian Phase (sec)	−0.179
	Presence of Designated Bus stop	−0.181
	Presence of Accessibility of Crosswalk	−0.181

* Significant at 95% Confidence Level.
*** Significant at 99% Confidence Level.

signal violation by younger pedestrian (16 to 49) is significantly higher than the older pedestrian (50 and above). A comparable finding was documented by Zhang et al. (2016), where the authors showed that in Guangdong, China the age group between 25 and 59 has a high risk-taking attitude compared to the other age groups. Further, there is some evidence that the risk-taking tendency of the local pedestrian is significantly higher. This is a very unique finding which indicates the share of pedestrian signal violation is also affected by the home location of the pedestrian. Subsequently, it was found that office workers are less likely to violate traffic rules. The findings of the statistical assessments clearly explain that there are other major risk factors than waiting time which affects pedestrians' violation behavior significantly.

Finally, to identify the reasons for pedestrians' illegal crossing or signal violation behavior from pedestrians' perspective, a multinomial logit model was developed. As previously discussed, it was assumed that a pedestrian may violate traffic signal due to reasons such as (a) the pedestrian is in a hurry, or (b) existing facility is inconvenient, or (c) the pedestrian is ignorant about the traffic rules or something else other than these three reasons. The responses are summarized in Fig. 6, which indicates almost an even distribution of reasons (a) and (b), and a lesser share of reason (c). However, there may be different groups of pedestrians with different backgrounds and requirements with different reasons for violation. Hence, obtaining such insight is important for specific intervention.

To identify why pedestrians', choose a certain reason for violation, an MNL model was developed, where reasons of violations are modeled as ordered variables such that '0 = the pedestrian is ignorant about the traffic rules'; '1 = existing facility is inconvenient'; '2 = pedestrian is in a hurry', with a host of factors or covariates collected through questionnaire survey. Results from this model are shown in Table 10, where 'the pedestrian is ignorant about the traffic rules' was taken as the base variable. Results show the young pedestrians (age below 16 years) are more likely to violate due to lack of knowledge regarding traffic rules, whereas pedestrians between age 16 and 49 years were found to violates traffic signal to *save time*, which is 3.3 times more likely than their perception of "inconvenience with the facility". On the other hand, results indicate that pedestrians above 50 years of age are more likely to violate due to inconvenience with the facility, but not due to time-saving. While, waiting time is one of the major reasons for pedestrians' signal violation, several other factors related to the pedestrians' trip purpose and state of the journey, their home location, their socio-demographic characteristics are also found to be highly significant with their "*time saving*" behavior.

Interestingly, it was observed that pedestrians who are either *going to work (i.e., onward trip)* or to *catch public transport* are more likely to violate signals to save time and the odds of violation is more than three times higher than "inconvenience with the facility". However, local pedestrians don't care about the "*convenience of the existing facilities*"; and they violate signals primarily to minimize the waiting time. Office workers are found to violate traffic signal due to the inconvenience of the existing facilities, which is linked to a longer walking distance or due to inaccessibility to their destination.

On the other hand, industry workers' violation behaviors are found to be associated with waiting time as well as inconvenience. Finally, a striking finding emerged from this study is the effect of pedestrians' education on their signal violation behavior. Findings indicate that pedestrians with higher educational qualification are less likely to violate signals—probably indicating their better perception of risk from the signal violation.

Overall, the model outcomes with McFadden ρ^2 value of 0.351 and a significant χ^2 value suggest that the model adequately fits to explain causes of pedestrians' violation behavior based on the explanatory variables.

5. Conclusion

Pedestrian fatalities constitute a significant percentage of road traffic-related fatalities in Indian cities. While faulty-design built environment poses a high risk to pedestrians; pedestrians' violation behavior is also a major risk factor, which is often influenced by faulty facility planning, road design, and traffic operational characteristics. By comparing and contrasting pedestrians' behavior and perception across

Table 7
Significant contrast between "safe" and "unsafe" group.

Variables	Mean Value of "safe" Group	Mean Value of 'Un-Safe' Group	t-Value/z-Value	Null Hypothesis#
Crossing Behavior				
% of Violation	30	57	5.678***	Reject
% of Running	4	15	2.652***	Reject
% of Speed Changing Condition	31	37	0.895	Cannot Reject
% of Pedestrian Following Zebra Crossing	41	28	−1.933***	Reject
% of Path Changing Condition	27	41	2.089***	Reject
% of Rolling Behavior	29	35	0.909	Cannot Reject
The state of Pedestrian While Crossing				
% of Distracted Pedestrian	2	10	2.381***	Reject
% of Carrying oversize loads	9	21	4.687***	Reject
Demographic Characteristics				
% of Age Group up to 16	10	15	1.069	Cannot Reject
% of Age Group 16-49	63	73	1.515	Cannot Reject
% of Age Group Above 50	22	17	−0.892	Cannot Reject
% of Male Pedestrian	72	74	0.318	Cannot Reject
Waiting Time				
Waiting time before Crossing (sec.)	11.71	17.58	2.523***	Reject
External Exposures				
Pedestrian Volume	1861	2684	1.416	Cannot Reject
Vehicle Volume	3658	4900	1.979*	Cannot Reject
Pedestrian Vehicle Ratio	0.57	0.52	−0.392	Cannot Reject
Pedestrian Vehicular Interaction				
85th Percentile PET (sec.)	3.56	2.23	−1.113***	Reject
Traffic Operational Characteristics				
Average Speed of Vehicle (Km/h)	41.67	49.75	2.643**	Reject
Educational Qualification				
Up to Primary (%)	2	3	0.452	Cannot Reject
Up to Graduation (%)	86	81	−0.952	Cannot Reject
Post-Graduation (%)	12	14	0.047	Cannot Reject
Employment Status				
Unemployed (%)	9	10	0.241	Cannot Reject
Office Worker (%)	30	22	−1.289	Cannot Reject
Industrial Worker (%)	14	12	−0.420	Cannot Reject
Business (%)	24	26	0.326	Cannot Reject
Student (%)	14	19	0.952	Cannot Reject
Monthly Income				
Up to 30,000 (%)	71	76	0.801	Cannot Reject
Above 30,000 (%)	22	18	−0.707	Cannot Reject
Daily Users	72	65	−1.065	Cannot Reject
The share of Local Pedestrian	23	28	0.811	Cannot Reject
Trip Purpose				
Education (%)	13	16	0.602	Cannot Reject
Job (%)	10	15	1.069	Cannot Reject
Business (%)	44	32	−1.748**	Cannot Reject
Pedestrian's Intended Mode of Transportation				
Public Transport (%)	26	17	−1.549*	Cannot Reject
Perceived Safety and Satisfaction				
Average Crossing Difficulty	2.66	4.40	7.924***	Reject
Average Safety	2.64	4.36	7.918***	Reject
Average Satisfaction	3.06	4.12	2.783***	Reject
Built Environmental Characteristics				
Cycle Length (sec)	129.83	143.5	1.269	Cannot Reject
Road Width (meter)	21.80	27.76	2.307**	Reject

* Significant at 95% Confidence Level.
*** Significant at 99% Confidence Level.
\# Null Hypothesis: means are equal in two groups.

relatively "safe" and "unsafe" signalized intersections in Kolkata, this study came to several distinct conclusions.

- The study outcomes indicate that pedestrians' signal violation tendency, running behavior, post-encroachment time, waiting time before crossing, pedestrian dissatisfaction level, trip purpose and trip characteristics, pedestrians' state of crossing, state of journey are significantly correlated with the fatal pedestrian crash frequency either in a positive or negative manner. Further, it was observed from the '*t*-test' that the operating speed of these two groups is very different, with the "unsafe" group having an average speed of 49 km/h, and "safe" group having an average speed of 41 km/h. Interestingly, it was found that higher traffic and pedestrian volume did not emerge to be major risk factors for the fatal pedestrian crash occurrence, which is intuitive. However, pedestrian-vehicular interaction measured in term of PET (for illegal crossings) was found to be dissimilar across two groups of signalized intersections, with the "unsafe" group having significantly lower values of PET. There is also some evidence that pedestrian fatal crashes are higher on wider roads than on narrow roads; however, with weak correlation. Interestingly, it was found that pedestrian sociodemographic and socioeconomic characteristics don't have any significant influence on the pedestrian fatal crash frequency. These findings provide answer to the very first research question of interest identified in section 2.3 *(i.e., what influences pedestrian fatality at signalized intersections)*.
- The findings to support the answer to the research *question 2* (i.e., *how pedestrians' behavior and perception are related with the safety performance*) are explained below:
- The study outcomes indicate that pedestrians' behavioral characteristics such as pedestrian signal violation behavior, running behavior, pedestrians' path changing characteristics, waiting time before crossing and pedestrians' risk perception are significantly different across the "unsafe" and "safe" group of intersections.
- Interestingly, it was observed that pedestrian's state of crossing such as the share of distracted pedestrian or pedestrian carrying the oversized load on their head while crossing is considerably higher at "unsafe" locations.
- From the results of the binary logit models, the variable "pedestrians' signal violation" behavior emerged to be a major factor for "unsafe" condition of an intersection (at 5% level of significance), along with variables road width, traffic volume, speed and pedestrian satisfaction level (all at 10% level of significance).
- To answer the third question (i.e., *what affects violation behavior at a location)*, findings from the pedestrian signal violation behavior model (i.e., MLR model) are referred.
- The model results indicate that a host of broad-ranged spatial and individual level factors such as pedestrian's state of crossing (i.e., pedestrian carrying overhead load, distracted pedestrian), pedestrian's intended mode of transportation (i.e., pedestrian going to catch public transport or not), pedestrian's home location (i.e., share of local pedestrian) as well as pedestrian's socio-demographic characteristics (i.e., age, education level, working status) and pedestrian's state of journey (i.e., onward trip or not) are significantly associated with pedestrians' violation behavior.
- Interestingly, it was found that the probability of a pedestrian signal violation is relatively low at intersections having high vehicular volume. This finding indicates pedestrians are actually afraid to take a risk at high volume roads.
- The MLR model outcome also suggests that if the pedestrians experience a longer waiting time before crossing, they become impatient and engage in signal violation. This finding indicates the deficiencies in signal design and planning.
- To answer the *last question*, *why pedestrians violate traffic laws at signalized intersections, a* pedestrian questionnaire survey was conducted across the study locations. Interestingly, it was observed that

Table 8
Evaluation of "unsafe" condition of signalized intersection using binary logit model.

Attributes	Model 1 (Built Environment)	Model 2 (Traffic Exposure and Operational Characteristics)	Model 3 (Behavior and Perception)	Model 4 (Combined)	Model 5 (Combined)	Model 6 (Combined)
	Model Coefficients (t-stat)					
Constant	−5.482 (2.003)**	−20.747 (2.035)**	−13.865 (1.950)**	−21.142 (2.167)**	−14.117 (2.213) **	−24.494 (1.873) *
Road Width (meter)	0.200 (1.86)*			0.205 (1.454)		
Presence of Designated Bus-Stop	−0.410 (0.209)					
Presence of Accessibility between Crosswalk and Sidewalk	−0.930 (0.480)					
Average Hourly Traffic Volume		2×10^{-3} (1.741)*				
Average Hourly Pedestrian Volume		1×10^{-3} (1.145)				
Speed (Km/h)		0.265 (1.920)**			0.192 (1.803) *	0.172 (1.460) *
Average Satisfaction Level			1.864 (1.707)*	2.251 (1.840)*		2.086 (1.384)
% of Violation			15.985 (2.058)**	18.230 (2.167)**	12.864 (2.222) **	20.676 (1.850) **
	Goodness of Fit					
ρ^2	0.257	0.425	0.536	0.593	0.527	0.595
Model Accuracy (in %)	66.7	81.70	83.33	91.70	83.30	87.50
Sample Size	24	24	24	24	24	24

* Significant at 90% Confidence Level.
** Significant at 95% Confidence Level.

the time-saving is the primary motivation of the pedestrian signal violation in Kolkata, and nearly 40% of the pedestrian violates traffic signal to reduce their waiting time before crossing. On the other hand, nearly than 31% of the pedestrian violate traffic signal owing to inconvenience with the facility. Surprisingly, it was observed that in Kolkata around 22% of the pedestrian signal violation occurs due to the lack of awareness and knowledge, at least from the survey findings.

- Finally, when investigated to gain plausible insights related to causes of pedestrians' violation behavior using MNL model, it was found that factors such as pedestrians' age, their educational qualification, trip purpose, state of the journey, and their home locations are the significant determinants. Interestingly, it was observed that young pedestrians mainly violate traffic rule to save time; whereas the older pedestrians are more expected to violate traffic rule due to inconvenience with the facility, instead of time-saving. Another unique finding of the present study is that the pedestrian who is going to catch public transport is more likely to violate signal due to the fear of missing a public bus and waiting for a long time. This is also influenced by the lack of information on the arrival of next bus, the absence of designated bus stop facility and proper access to the bus stops, absence of marked pedestrian crosswalk and the absence of pedestrian signal head near the intersection forcing pedestrians to take unnecessary risk and violate traffic signal. This is again a very important finding, probably capturing the implications of broader planning and design level issues on pedestrians' behavior and risk-taking attitude. In the end, a remarkable finding was obtained from the study is that pedestrian with higher educational qualification is less likely to violate traffic signal, at least based on the data obtained from the survey of pedestrians at the study intersections in Kolkata City.

The overall study outcome suggests that signalized intersections with marked crosswalk facilities are strongly linked to pedestrians' violation tendency, which in turn is highly associated with planning and design issues as well as risky human behaviors. While improvement in the design of the built environment and signal settings to facilitate pedestrians' convenience and confidence are must, there is a crucial need to incorporate innovative safety management techniques to address spatial and temporal needs of an intersection. Based on several unique findings obtained from this study following immediate measures are recommended.

- Signalized junctions having high pedestrian and traffic volume should be upgraded by providing an exclusive pedestrian phase or pedestrian scramble type signal to accommodate pedestrians' demand.
- The sites with high commercial activities producing high volume of

Table 9
Factors affecting pedestrian violation behavior (*location specific*).

Characteristics	Variables	Coefficients	t-statistics	P-Value
	Constant	−0.301	−3.951	0.001***
Traffic Exposures	Vehicle Volume Per Hour	-2.530×10^{-5}	−4.601	0.000***
Pedestrian Delay	Average Waiting Time before Crossing (sec.)	0.005	2.814	0.013***
The State of Pedestrian while Crossing	Pedestrian Carrying Overhead load (in %)	0.814	3.632	0.002***
	Share of Distracted Pedestrian (in %)	0.932	3.701	0.002***
Pedestrian's Intended Mode of Transportation	Pedestrian going for Public Transport (in %)	1.290	12.821	0.000***
Demographic Characteristics	Share of Age Group (16-49, in %)	0.210	3.317	0.005***
Pedestrian's Home Location	Share of Local Pedestrian (in %)	0.330	4.683	0.000***
Trip Purpose	Share of Pedestrian Going for Job (Office Workers, in %)	−0.366	−2.955	0.010***
Model Summary	Total Observations	24		
	Adjusted R^2 Value	0.970		
	Model Accuracy (in %)	95.64		

*Significant at 90% CI.
** Significant at 95% CI.
*** Significant at 99% CI.

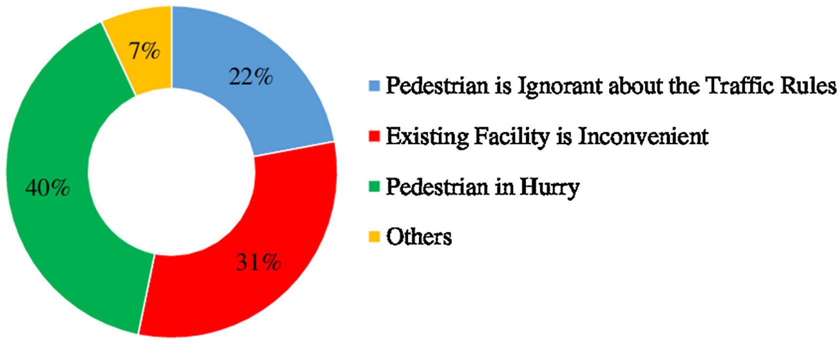

Fig. 6. Possible Reason for Pedestrian Violation Behavior.

pedestrians carrying overhead goods, demand special pedestrian phase with countdown signals or at least increased intervention from traffic police at certain hours of a day to ensure the safety. The same is applicable to intersections with higher pedestrian vehicular interactions, which requires the redesign of the signal cycle and phase timing to cater to the pedestrians' needs.

- Additionally, to reduce jaywalking of pedestrian, marked pedestrian crosswalk must be provided near the junctions, keeping in mind that pedestrian sidewalk and crosswalk facilities should be well connected.
- In order to control the high approaching speed of vehicles "speed limit", "speed camera", "no overtaking" sign should be implemented along with strict enforcement. In addition to these, at the intersections with high approach speed, sufficient pedestrian green time and clearance time are required along with the enforcement to reduce illegal crossing. Further, for better safety management use of an appropriate informatory sign, a warning sign is to be provided at several "unsafe" locations.
- As it was identified that the chance of signal violation is significantly higher for the public bus user, locations with more number of bus routes should be prioritized for interventions to reduce pedestrian risk-taking attitude.
- Additionally, there is a critical need for strict enforcement and regulations to prevent traffic signal violations and punish offenders. The traffic enforcement and control devices shall be set up effectively to decline signal violations behavior of the pedestrians at several "unsafe" locations or the key spots that record pedestrian-vehicular crashes regularly.
- Moreover, in order to enhance compliance with traffic signals, road safety campaigns, education, and awareness programs are must for better and safer road use, especially for young pedestrians.

Similar to other studies, the present study is not without its limitations. Based on the current study several risk factors were identified concerning pedestrians' behavior and perceptions. However, drivers' behavior was not taken account into account; whereas, some studies

Table 10
Cause of pedestrian signal violation tendencies (individual level).

Characteristics	Variables	Coefficients	t-statistics	Coefficients	t-statistics
		P (Y = 1) Existing Facility is not Convenient		P (Y = 2) Pedestrian in Hurry	
	Constant	−2.780	−3.395***	−2.059	−1.545*
Pedestrian's Delay	Waiting Time Before Crossing	0.016	0.660	0.221	6.616***
Pedestrian's Perception	Crossing Difficulty	0.375	2.791***	0.073	0.391
	Safety	0.203	1.501*	0.150	0.983
	Satisfaction Level	0.380	2.990***	0.425	2.371**
Demographic Characteristics	Male	−0.907	−0.200	0.441	0.640
	Age < 16	0.299	1.231	0.093	0.173
	Age 16 to 49	0.822	1.552*	2.710	2.909***
	Age ≥ 50	1.850	5.527***	−3.413	−4.982***
Education & Employment status	Graduation Level	−1.100	−3.659***	−1.804	−2.715***
	Industrial Worker	0.833	3.657***	2.154	3.868***
	Office Worker	1.074	3.639***	0.159	0.529
	Student	0.269	1.008	1.082	3.189***
Home Location	Walking Distance (i.e. Local Pedestrian)	−0.436	−1.935**	1.542	4.238***
Frequency of Use	Daily Users	−0.453	−2.243**	2.087	8.256***
State of journey	Onward Trip	0.282	1.558*	1.097	4.082***
Trip Purpose Pedestrian's Intended Mode of Transport	Job	0.192	0.524	2.853	7.281***
	Public Transport (i.e., Bus)	1.053	4.863***	2.993	10.277***
Model Summary	Total Observation	1176			
	Log Likelihood	−805.123			
	DOF	18			
	Pearson χ^2	2188.871 (Sig: p < 0. 000)			
	Deviance χ^2	1598.615 (Sig: p < 0.000)			
	Cox and Snell ρ^2	0.530			
	Nagelkerke ρ^2	0.600			
	McFadden ρ^2	0.351			
	Model Accuracy	61.78%			

* Significant at 90% Confidence Level.
*** Significant at 99% Confidence Level

have reported that pedestrian, vehicular collisions are significantly influenced by the driving behavior as well (Gårder, 2004; Boarnet et al., 2005). Hence, incorporation of drivers' behavior in the present analyses would assist in a better understanding of the pedestrian safety-related issues. Other than these, the sample size can be increased by incorporating more number of signalized junctions in the study. The geographical stability of the present findings is yet to be validated but has served to give us important insights regarding pedestrians' safety of urban signalized intersections in a major city such as Kolkata. Although there is a vast scope for advance research in this field, findings from this study hold high potential for safety management in urban signalized junctions of developing and emerging countries where similar road environment and behavior are present.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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