Assessing Countermeasure Effects for Reducing Pedestrian Crash Risk at Urban Intersections: An Experience in Kolkata City, India

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Abstract: Pedestrian safety is a major concern in developing nations. In recent years, several studies have paid attention to the identification and estimation of pedestrian risk factors at the urban road network level in developing nations. Conversely, only a few studies have concentrated on the formulation and field implementation of the countermeasures to improve pedestrian safety. In this background, the present study has utilized fatal pedestrian crash data (2011-2016) obtained from "Kolkata Police", India, and identified a total of 22 risk factors for fatal pedestrian crashes. The study findings are advantageously utilized to formulate suitable countermeasures to reduce pedestrian risk. Three specific countermeasures (i.e., traffic signal, pedestrian signal head with a countdown display, police enforcement) are implemented at three high crash-prone intersections in Kolkata City and found to reduce the likelihood of pedestrian-vehicular conflicts by 13% to 72%. Additionally, pedestrian's perceived risk and crossing difficulty are also declined by 50%.

Key Words: Pedestrian Safety, Risk Factors, Pedestrian Behavior, Perception, Countermeasures

1. INTRODUCTION

Pedestrian safety is a foremost worry all over the world as more than 0.31 million pedestrians die every year in road traffic crashes around the world (WHO, 2018). Among the overall pedestrian fatalities, nearly 90% of death occur in developing countries (Naci et al., 2009). Thus, pedestrian fatalities are an exceptionally serious social concern, particularly in developing countries.

The issues related to pedestrian safety are more severe in urban India as most of the Indian Metropolitans have reported the pedestrian death rate is as high as 50% of the overall road fatalities (i.e., all types of road users) (Mukherjee and Mitra, 2020a). In Indian mid-sized cities also the death rate of vulnerable road users (i.e., pedestrian, cyclist, motorcyclists) varies between 84% and 93% (Mohan et al., 2016). Although in urban India pedestrian volume and density are considerably high, suitable pedestrian-friendly infrastructure is frequently not present (Gupta et al., 2009). It is also imperative to note that motorization and infrastructure development are rather new in urban India. Therefore, there are deficiencies in both infrastructure as well as awareness and safe behavior of pedestrians (Mukherjee and Mitra, 2020a; Mukherjee and Mitra, 2020b; Mohan et al., 2009). Moreover, in India, the enforcement of traffic rules and regulations is often low which also encourages pedestrians to act in an unsafe manner (Mukherjee and Mitra, 2020c; Tiwari et al., 2007). Overall, a combination of poor infrastructure, pedestrians' unsafe acts, and inadequate enforcement lead to a high risk of pedestrian fatalities in Indian cities. In addition, in urban India, road safety improvement projects are usually inclined towards motorized traffic rather than non-motorized transport (Gupta et al., 2009). Consequently, pedestrian safety remains the foremost social distress in urban India.

Successful interventions to protect pedestrians and promote safe walking require an understanding of the nature of risk factors for pedestrians. In recent years, a good number of researchers have focused on the identification of pedestrian risk factors in the context of developing nations (Mukherjee and Mitra, 2020a; Mukherjee and Mitra, 2020b; Mukherjee and Mitra, 2019a; Mukherjee and Mitra, 2019b; Priyadarshini and Mitra, 2018; Rankavat and Tiwari, 2016; Rankavat and Tiwari, 2015). In the former studies, researchers have acknowledged several causes of pedestrian-vehicular crashes such as lack of pedestrian-friendly infrastructure (Mukherjee and Mitra, 2020a), inefficient traffic operations (Mukherjee and Mitra, 2020a), high approaching speed of the vehicle (Mukherjee and Mitra, 2020a), speed inconsistency (Mukherjee and Mitra, 2020a), land use pattern (Mukherjee and Mitra, 2019; Rankavat and Tiwari, 2015), etc. Studies have also shown that pedestrians' risk-taking attitudes such as rolling behavior, sudden path changing behavior, speed changing behavior, also could be significant causes of pedestrian-vehicular crashes (Mukherjee and Mitra, 2020b; Kadali and Vedagiri, 2013). Several studies have reported pedestrian signal violation behavior as the most essential cause for fatal pedestrian crashes at urban signalized junctions in developing countries (Mukherjee and Mitra, 2020b; Tiwari et al., 2007). The researchers have also established a positive correlation between the lower value of post encroachment time and fatal pedestrian crashes at the urban road network level in developing countries (Priyadarshini and Mitra, 2018). Afterward, a few researchers have acknowledged the significance of spatial sociodemographic and socioeconomic characteristics of the road network on pedestrian crossing behavior as well as pedestrian-vehicular crashes (Mukherjee and Mitra, 2020b). For example, it was found that the rate of pedestrian fatality is significantly higher near slum areas (Mukherjee and Mitra, 2020c). The presence of a "pedestrian attraction zone" (i.e., hospital/educational institute/heritage building/shopping mall/heritage building, bar, etc.) without satisfactory pedestrian crossing facilities also increases the risk of pedestrian-vehicular crashes precisely in urban areas (Mukherjee and Mitra, 2020c). Hence, past studies evidently indicate that several interactive factors are primarily responsible for pedestrian crashes at the urban road network level in an emerging nation.

Further, only a few studies have concentrated to formulate appropriate countermeasures to reduce pedestrian risk at the urban road-network level in the context of developing countries (Priyadarshini and Mitra, 2018). To the best of the authors' knowledge, none of these past studies have paid attention to examine the effectiveness of several engineering countermeasures in addressing pedestrian safety at the urban road network level in an emerging nation. Conversely, in the last decade, a good number of researchers have studied and conveyed the usefulness of several engineering as well as non-engineering measures in the context of developed countries such as Canada (Saccomanno et al., 2007), US (Chen et al., 2013; Persaud et al., 2001), etc. Since the road environment and road users' behavior are very dissimilar in these developed countries as compared to Indian cities, the results obtained from these studies and their impact may not be directly transferrable to urban India. Consequently, it is extremely important to formulate and implement suitable countermeasures to improve the overall pedestrian safety at the urban road network level in the context of an emerging nation. Additionally, it is also essential to evaluate the effectiveness of the recommended countermeasures on pedestrian safety.

With this in mind, the present study aims to examine the effectiveness of different countermeasures for reducing pedestrian crash risk at urban intersections in a developing country. In order to achieve the current objective, it is important to identify and prioritize the major risk factors in the context of a developing country. Subsequently, it is required to formulate and implement suitable countermeasures to reduce the risk of pedestrian crashes. To, end it is necessary to study the impact of proposed countermeasures on pedestrian actual risk (i.e., crash frequency), perceived risk, crossing behavior, and pedestrians' satisfaction level.

The proposed research work is demonstrated with reference to the metropolitan city Kolkata, India. The recent report of "Kolkata Police" shows that in Kolkata city, in the year between 2011 and 2016 around 4286 fatal pedestrian crashes occurred at intersections (60% of the overall fatal pedestrian crashes). The significant share of pedestrian fatalities at intersections is justifying the need for distinct attention to protect pedestrians and to inspire a safe crossing environment at intersections in Kolkata City.

The rest of this paper is organized as follows - Section 2: describe research methodology, Section 3: explains identification and prioritization of the risk factors, Section 4: explains the formulation of countermeasures to improve pedestrian safety, Section 5: describes the field implementation of several countermeasures and impact analysis of several countermeasures, Section 6: presents the final concussions and recommendations.

2. RESEARCH METHODOLOGY

The proposed research methodology was designed to be simple and easily applicable to different locations (Figure 1).

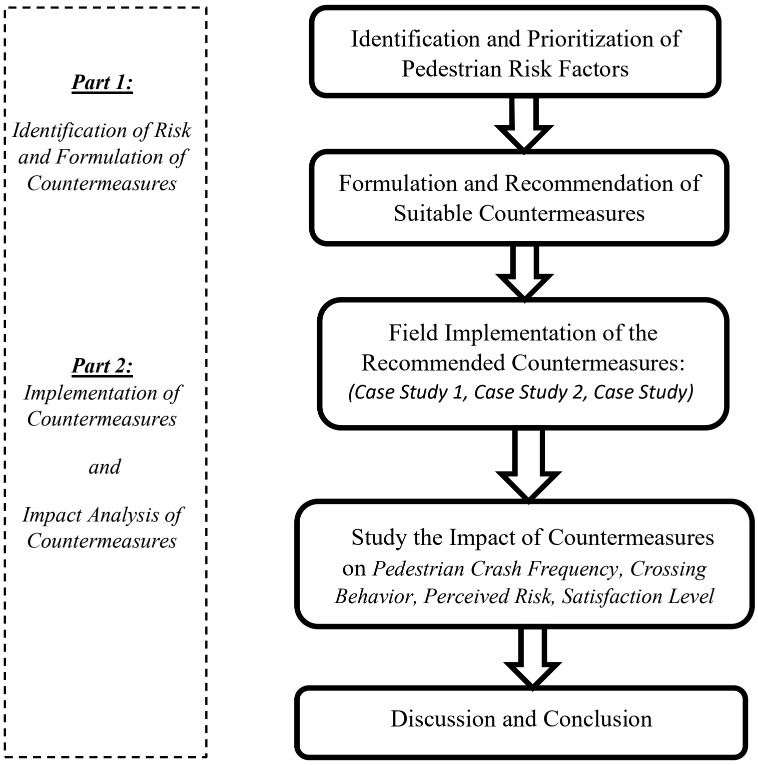

Figure 1. Research design

The present research methodology consists of two major parts, namely, (a) identification of pedestrian risk factors and formulation of the countermeasures, (b) field implementation of the countermeasures, and the impact assessment of different countermeasures.

(a) Identification of pedestrian risk factors and formulation of the countermeasures: With the help of Kolkata Police crash data, 110 major crash-prone intersections were selected for the present study. Further, to identify major risk factors influencing pedestrian fatalities the 'case-control study' was performed and a total of 22 risk factors were identified. Subsequently, the research findings were advantageously utilized to formulate countermeasures to reduce the likelihood of pedestrian crashes, and a total of 15 countermeasures were formulated.

(b) Field implementation of the countermeasures: In the present study, three specific countermeasures, namely, (i) the installation of the traffic signal, (ii) the installation of the *pedestrian signal head, and (iii) assignment of police enforcement were implemented at three major intersections in Kolkata city. Afterward, the impact of each countermeasure was evaluated in terms of (i) pedestrian crossing behavior, and (ii) pedestrian risk perception. Additionally, actual crash data (police-reported crash data) were compared before and after the installation of the countermeasures. The detailed research findings are explained in the following sections.*

3. IDENTIFICATION OF RISK AND FORMULATION OF COUNTERMEASURES

3.1 Identification and Prioritization of Pedestrian Risk Factors

The Kolkata Police provided the "*Monthly Accident Review Report*" for the years 2011 to 2016. *Since in a developing country such as India, the under-reporting of non-fatal crashes is a major issue (Mukherjee and Mitra, 2020a), the scope of the current work is restricted to the investigation of fatal pedestrian crashes only. Based on the police-reported crash data 110 critical intersections were selected for further investigations (Chakraborty et al., 2019). Here it should be mentioned that the crashes were characterized as intersection-related if they occurred within the zone of influence of the intersection (Mukherjee and Mitra, 2020a) (the zone of influence of a junction is defined as the length of approach enclosed by 20 meters along any leg of the junction).*

After identification of study sites, the locations were visited to collect road inventory data. Road inventory data includes information regarding geometric features such as the presence of adequate sight distance, carriageway width, footpath width, type of junction (i.e., three-legged or four-legged crossing), existing infrastructure such as the presence of signalization, pavement condition (i.e., good/excellent or poor), the share of a different land-use type such as residential area, commercial area, educational area, industrial area, etc. (Mukherjee and Mitra, 2020a). The approaching speed of the motorized vehicles was measured using the speed radar gun (Chakraborty et al., 2019). The 'spot speed survey' was cond*ucted for morning 10 am and 11 am, and afternoon 3 pm and 4 pm, so that both peak and off-peak hour vehicle speed could be captured (Chakraborty et al., 2019; Mukherjee and Mitra, 2019c).*

Further, the video-graphic survey was conducted to collect information related to the average daily vehicle and pedestrian volume and pedestrians' crossing behavior. In this study, the entire *pedestrian and classified traffic volume with the turning movement was recorded and extracted for* 24 hours at each of the study sites. Furthermore, pedestrians' behavioral data was extracted for six *hours between morning 10 AM and 1 PM, and evening 3 PM and 6 PM such that both peak and off-peak traffic could be captured (Mukherjee and Mitra, 2019b).*

The factors extracted from the video are primarily of four categories: a) traffic exposures variables such as traffic and pedestrian volume, b) pedestrian's law abidance, such as if the *pedestrian is walking on the zebra crossing, and if he/she is following the signal (if presence), c) pedestrian demographics such as age an*d gender, d) pedestrian's behavioral characteristics such as *walking speed, speed changing characteristics, path changing characteristics, and rolling behavior, using a mobile phone while crossing and waiting time before and while crossing, etc.*

*Subsequently, pedestrian-vehicular conflicts were also examined from the video images and PET value was estimated. The PET can be defined as, the time gap between two road users moving in different directions passing over a common spatial zone (Chandrapp et al., 2016). The decrease in PET will increase pedestrian-vehicular interaction and further increase the possibility of pedestrian-vehicular conflicts, crashes, and even fatalities (Priyadarshini and Mitra 2018). To define the PET and for ease of identification a*nd extraction of PET data, "AVS video editor 5.1" software *was used to place suitable grids on the recorded videotapes (Mitra et al., 2019). As the probabilities* of fatal pedestrian crashes are considerably greater for the conflicts between the "through vehicle" and a pedestrian; in this study, only the PET between the "through vehicle" and a pedestrian was *taken into account (Mitra et al., 2019). A maximum of 2.5 seconds threshold value for PET was* taken into account [i.e., (T2-T1) ≤ 2.5 seconds]. The threshold value for PET estimation was considered based on a study performed by Mitra et al., (2019) in a similar context.

A total of 1,28,854 pedestrians' crossing behavior was extracted across 110 intersections. The method of video-graphic survey and data extraction was adopted by earlier researchers (Mukherjee and Mitra, 2020c).

Table 1. Description of the variables

Variables	**Type of Variable**	**Description**
Road Inventory Survey:		
Signalization	Categorical	Presence =1; Absence = 0
Accessibility of pedestrian crosswalk (Mukherjee and Mitra, 2020c)	Categorical	Presence =1; Absence = 0 *[The "inaccessible pedestrian crosswalk" indicates the lack of connectivity between pedestrian sidewalks and crosswalks]*
On-street parking	Categorical	Presence =1; Absence = 0
Adequate sight distance	Categorical	Presence =1; Absence = 0
Width of the road (meter)	Continuous	Major and minor carriageway width
Zebra crossing	Categorical	Presence =1; Absence = 0
Footpath	Categorical	Presence =1; Absence = 0
Pavement marking and road signage	Categorical	Presence =1; Absence = 0
Type of land use (in %)	Continuous	The share of a certain type of land use such as commercial, residential, office, educational, industrial, park and recreational, hospital, open spaces, etc. (Mukherjee and Mitra, 2020a)
Spot Speed Study:		
Vehicular speed (km/hr.)	Continuous	The average vehicle speed of a junction (uninterrupted approaching speed was only considered) (Chakraborty et al., 2019)
Video graphic Survey:		
Log (average daily traffic volume / ADT)	Continuous	The average daily traffic volume of the intersection (Chakraborty et al., 2019)
Log (average daily pedestrian volume)	Continuous	The average daily pedestrian volume of the intersection (Chakraborty et al., 2019)
The overtaking tendency of vehicles at an intersection (Mukherjee and Mitra, 2020c)	Categorical	Presence =1; Absence = 0
Vehicle on the zebra crossing (Mukherjee and Mitra, 2020c)	Categorical	Presence =1; Absence = 0
Pedestrian is following (using) the zebra crossing: Yes (1) No (0)	Categorical	Whether a pedestrian is crossing the intersection along the zebra crossing or not (Mukherjee and Mitra, 2020b)
Pedestrian signal violation: Yes (1) No (0) [applicable only for 55 signalized junctions]	Categorical	Pedestrian signal violation/illegal crossing is defined as when pedestrians cross the road during the non-green phase; whereas pedestrians crossing during the green phase are considered as legal crossing/non-violation (Mukherjee and Mitra, 2020b)
Path changing behavior of the pedestrians: Yes (1) No (0)	Categorical	Pedestrian changes the path while crossing the road (Mukherjee and Mitra, 2020c)
Speed changing the behavior of the pedestrians: Yes (1) No (0)	Categorical	Pedestrian sudden changes walking speed while crossing the road (Mukherjee and Mitra, 2020c)
Rolling behavior of the pedestrians: Yes (1) No (0)	Categorical	Pedestrian rolls over the available small vehicular gaps (Kadali and Vedagiri, 2013)
Distracted pedestrian: Yes (1) No (0)	Categorical	Pedestrian is using an electronic device while crossing (i.e., using a cell phone, tablet, etc.) (Mukherjee and Mitra, 2020c)

Waiting time before crossing: (seconds)	Continuous	Waiting time of the pedestrian before crossing the road (Mukherjee and Mitra, 2020c)
Waiting time while crossing: (seconds)	Continuous	Waiting time of the pedestrian while crossing the road (Mukherjee and Mitra, 2020c)
Post Encroachment Time (PET) (seconds)	Continuous	Time difference between the end of encroachment of crossing pedestrian and the time that the through vehicle arrives at the potential point of collision (Mukherjee and Mitra, 2020c)
Police personnel (Mukherjee and Mitra, 2020c)	Categorical	Presence =1; Absence = 0

To estimate the pedestrian safety performance at the intersection-level, all the individual level (i.e., pedestrian level) data extracted from the video-graphs were combined across each intersection to obtain the intersection-specific information such as the share of pedestrians following zebra crossing, the average value of pedestrian-vehicular post-encroachment time at a junction, pedestrians average waiting time at an intersection, etc. (Mukherjee and Mitra, 2020c). The description of the variables is shown in Table 1.

To identify the significant impact of a particular factor; the 'case-control study' was carried out to compare the presence and absence of a certain exposure across 'crash-prone' (i.e., case) and 'non-crash-prone' (i.e., control) intersections. In the case-control study the *Odds Ratio* (OR) of the risk factor was calculated as follows (Mukherjee and Mitra, 2019c), (Table 2).

Table 2. Case-Control study

	Case (with a fatal pedestrian crash)	Control (without a fatal pedestrian crash)
Exposed	a	b
Non-Exposed	c	d

$$\text{Odds} = \text{prevalence} / (1 - \text{prevalence})$$
$$\text{Odds Ratio (OR)} = (\text{Odds in cases}) / (\text{Odds in controls}) = (a/c)/(b/d) = \frac{ad}{bc} \quad (1)$$

The risk factors are interpreted as:

- if OR = 1 no association;
- if OR ≥ 1 risk factor;
- if OR ≤ 1 protective factor;

If the 95 % 'Confidence Interval' (CI) range is greater than one, the exposure is a significant risk factor (OR≥1) with a probability of higher than 95%. The significant outcomes obtained from the case-control study are summarized in Table 3. A total of 22 significant risk factors associated with fatal pedestrian crashes was identified. Based on the nature of risk, the identified factors were categorized into *five major groups*, that is (a) traffic operational parameters, (b) land use type, (c) road infrastructure, (d) pedestrian crossing behavior, and (e) pedestrian vehicular interaction. Also, a priority ranking of 22 significant risk factors is presented in Table 3.

The overall test results indicate that pedestrian-vehicular interaction, the share of pedestrians not following zebra crossing, inaccessible pedestrian crosswalk, absence of adequate pavement marking, lack of sight distance, waiting time before crossing, and the absence of police enforcement are the foremost factors influencing fatal pedestrian crashes at urban intersection level in the context of a developing nation.

Subsequently, it was recognized that pedestrian fatality risk is 3.2 times higher at the intersections having an average vehicular speed of more than 42 km/hr. Besides, the overtaking behavior of the vehicle driver (OR = 3.9) and the absence of police enforcement (OR = 4.5) increase the risk of fatal pedestrian crashes. The sites with a high commercial activity increase pedestrian fatality risk by 2.6 times. The other variables associated with the built environment and road infrastructure such as the inaccessible pedestrian crosswalk (non-standard marking of the pedestrian crossing) (OR =8.3), on-street parking (OR = 3.2), inadequate sight distance (OR = 5.1), the absence of footpath (OR =3.4) significantly increase the risk of fatal pedestrian crashes. Afterward, it was observed that the absence of pavement marking such as zebra crossing (OR = 2.2), the absence of stop line (OR = 6.5), the lack of road signage (OR = 2.8), the absence of traffic signal (OR = 3.3) and the presence of vehicles on the pedestrian crosswalk (OR =2.4) positively increase the likelihood of fatal pedestrian crashes. The wider at-grade crossing (greater than 11 meters) also rises the pedestrian fatality risk by 2.3 times.

Pedestrians' unsafe crossing behavior such as a high share of pedestrians not following zebra crossing at a junction is likely to increase fatality risk by 8.4 times. The path-changing behavior by pedestrians also affects pedestrian safety (OR = 4.2). An extensive waiting time before crossing (more than 3.44 seconds) increases the odds of fatal pedestrian crashes by 3.9 times; whereas a longer waiting time while crossing (more than 0.812 seconds) increases the odds of fatal pedestrian crashes by 4.8 times. Pedestrian fatality risk is likely to increase by 9.2 times when the average PET value of a junction is lower than 1.78 seconds. A high share of pedestrians' signal violation (greater than 35%) at a signalized junction is likely to increase pedestrian fatality risk by three times. Similarly, a high proportion of distracted pedestrians (more than 8%) at an intersection also increases pedestrian fatality risk by 3.5.

Table 3. Outcomes of the case-control study

Risk Category	**Variables**	**Odds Ratio**	**95% Confidence Interval**		**Priority Ranking of the Risk Factor**
			Lower Limit	Upper Limit	
(a) Traffic operational parameters	Speed > 42 kmph	3.20	1.28	7.99	15
	Overtaking Tendency of Vehicles	3.92	1.65	9.31	10
	Absence of Police Personal	4.58	1.82	11.51	8
(b) Land use	Commercial Area	2.61	1.37	4.96	19
(c) Road infrastructure	Inaccessible Pedestrian Crosswalk	8.33	2.95	23.48	3
	On-Street Parking	3.20	1.11	9.22	15
	Inadequate Sight Distance	5.18	1.81	14.82	6
	Road Width > 11 meters	2.39	1.29	4.43	21
	Absence of Zebra Crossing	2.21	1.00	5.11	22
	Absence of Footpath	3.48	1.10	10.99	13
	Absence of Pavement Marking	6.00	2.22	16.19	5
	Absence of Stop Line	6.50	2.50	16.89	4
	Absence of Traffic Signal	3.35	1.25	8.94	14
	Absence of Road Signage	2.83	1.21	6.61	18
	Vehicles on Zebra Crossing	2.41	1.35	4.29	20
(d) Pedestrian crossing behavior	Share of Pedestrians Not Following Zebra Crossing > 68%	8.46	4.39	16.28	2
	Share of Pedestrians having Path Changing Behavior > 12%	4.23	1.64	10.90	9
	Waiting Time before Crossing > 3.44 Seconds	4.80	1.33	17.27	7
	Waiting Time While Crossing > 0.812 Seconds	3.91	1.24	12.30	11
	Share of Signal Violation > 35%	3.08	1.70	5.58	17

	Share of Distracted Pedestrian > 8%	3.56	1.42	8.87	12
(e) Pedestrian vehicular interaction	The Average Post Encroachment Time (PET) at a Junction < 1.78 Seconds	9.26	3.22	26.68	1

3.2 Formulation and Recommendation of Countermeasures

To promote safe walking facilities for pedestrians, it is essential to identify appropriate countermeasures that will reduce pedestrian risk of fatalities and injuries, and enhance walkability. The selection of several engineering and non-engineering countermeasures was primarily accomplished based on the former literature available in this context. Table 4 summarizes various countermeasures.

Table 4. Recommendation of the countermeasures

Risk Category	Risk Factor	Countermeasures
(a) Traffic operational parameters	Overtaking and overspending tendency of the vehicle	• Speed management by installing appropriate "**Speed limit**" sign and monitoring speed with "**speed camera**" or other forms of enforcement should be of high priority • **Traffic calming measures** could also be a viable alternative (Mukherjee and Mitra, 2020a)
(b) Land use	Commercial area	• Adequate pavement marking (zebra crossing, stop line, edge line) and road signage (i.e., warning sign, informatory sign, etc.) should be provided to guide the pedestrian as well as the driver (Matsui et al., 2016) • An off-street parking facility should be provided • At signalized junctions, the **special pedestrian signal phase** should be provided considering pedestrian demand (Mukherjee and Mitra, 2020b) • At un-signalized junctions, police personnel must be assigned to control pedestrian and vehicular movement (Mukherjee and Mitra, 2019a)
(c) Road infrastructure	Absence of zebra crossing	• **Marked pedestrian crosswalks** must be provided near the junction (Mukherjee and Mitra, 2019b)
	Absence of pavement marking (i.e., stop line, edge line, and centerline)	• Adequate **pavement marking** should be provided • To improve visibility **retroreflective pavement markers** may be provided (Mukherjee and Mitra, 2019a)
	Absence of road signage	• **Road signage** such as an informatory sign, mandatory sign, and warning sign should be provided at suitable locations (Aidoo et al. 2013)
	Inaccessible pedestrian crosswalk	• Marked pedestrian crosswalk (**zebra crossing**) should be provided • Zebra crossing must be well connected with the pedestrian sidewalk facility (footpath) (Mukherjee and Mitra, 2020b)
	Absence of traffic signal	• Un-signalized junctions with a high pedestrian-vehicular interaction (lower PET) should be upgraded by providing **signalization** (Mukherjee and Mitra, 2019b) • Additionally, the **pedestrian signal head** with an adequate pedestrian phase should be provided • A **countdown display** for pedestrians should be provided (Lee and Abdel-Aty, 2005)

	Inadequate sight distance	• To improve the sight distance and visibility of an intersection, banning of hoardings and temporary stalls are must to have clear sight distance at the intersections (Mukherjee and Mitra, 2019a)
	On-street parking	• On-street car parking close to intersections should be prohibited • **Off-street parking facility** needs to be provided at several junctions where parking demand is considerably high (Congiu et al. 2019)
	Absence of footpath/encroachment of footpath	• The street vendors and hawkers can be shifted further away from the *zone of influence* of the junction • An **adequate sidewalk facility** should be provided for the pedestrian • Pedestrian sidewalk and crosswalk facilitates must be well connected • Additionally, a **pedestrian guard rail with a designated opening** should be provided along the footpath to minimize the pedestrian-vehicular interactions and to control the pedestrian's movement (Mukherjee and Mitra, 2020a; (Mukherjee and Mitra, 2019c; Stevenson et al. 1995)
	Wider road width leading to high exposures to pedestrians	• An **exclusive pedestrian phase** or **grade-separated crossing facility** should be provided • Wider unsignalized junctions with high pedestrian and vehicle volume should be promoted by providing signalization with exclusive pedestrian phase • Police personnel should assign to assist the pedestrian to cross the intersection safely • The **pedestrian refuge island** is a must (Mukherjee and Mitra, 2020a; Zhuang et al. 2020; Priyadarshini and Mitra, 2018)
	Presence of vehicle on zebra crossing	• Vehicles should not allow stopping on the zebra crossing • Vehicles should not allow stopping ahead of the stop line • Strict enforcement is required to punish the offenders
(d) Pedestrian crossing behavior	Signal violation	• The major junctions where traffic cycle length is too long, the **grade-separated facility** should be constructed • **Police personnel** should be assigned (i.e., police enforcement) to decline the road users' violation behavior • Pedestrian signal head with a countdown display and marked pedestrian crosswalk should be provided (Mukherjee and Mitra, 2020b; Mukherjee and Mitra, 2019b, Koh et al., 2014; Tiwari et al., 2007)
	Pedestrian is not following zebra crossing	• Marked pedestrian crosswalk (i.e., zebra crossing) should be well connected with the sidewalk facility • **Raised pedestrian crosswalk** may be provided near a junction • To improve visibility during nighttime retroreflective pavement marker (**RRPM**) may be used along the zebra crossing (Rankavat and Tiwari, 2016)
	Distraction while crossing and jaywalking, path changing behavior of the pedestrians	• Severe **police enforcement** should be assigned • **Road safety campaigns**, **education, and awareness programs** are necessary • A marked pedestrian crosswalk must be provided near the junction (Mukherjee and Mitra, 2019b)
	Longer waiting time before crossing	• **A grade-separated crossing facility** for the pedestrian should be constructed • Police personnel should be assigned for better safety management • At the signalized junction, redesign of the traffic signal accommodating pedestrians' demand is needed (Mukherjee and Mitra, 2020b; Tiwari et al., 2007)
(d) Pedestrian vehicular interaction	High pedestrian-vehicular interaction (lower PET value)	• Unsignalized junction should be promoted by providing **signalization with an exclusive pedestrian signal phase**

		• Signalized junctions without an **exclusive pedestrian phase** should be upgraded by providing a **special pedestrian signal phase** accommodating pedestrians' demand • **Flexible poles** may be used to separate motorized and non-motorized traffic • **Police personnel** must be assigned to reduce pedestrian-vehicular conflicts (Mukherjee and Mitra, 2020a; Mukherjee and Mitra, 2020b; Mukherjee and Mitra, 2019c; Priyadarshini and Mitra, 2018)

4. FIELD IMPLEMENTATION AND IMPACT ANALYSIS OF COUNTERMEASURES

The countermeasures evaluated in this research study are
(a) installation of a traffic signal at an un-signalized junction
(b) installation of the pedestrian signal head (with countdown display) at a signalized junction, (c) assignment police enforcement.

The selected countermeasures were deployed at three major intersections in Kolkata City, namely, (a) Strand Road and Raja Wood Mount Street crossing, (b) BBD Bagh crossing, and (c) MG road and CR Avenue crossing. The evaluations were based on field observations of pedestrian crossing behavior, their risk perception, and their perceived satisfaction level towards existing facilities, before and after the installation (application) of the countermeasures. Subsequently, the police reported fatal pedestrian crash records were also compared, before (2011-2016) and after (2017-2020 March) the installation of countermeasures. The following subsections provide a detailed description of three different case studies.

4.1 Case Study 1: Strand Road and Raja Wood Mount Street Crossing

In this case study, two specific countermeasures, namely (a) traffic signal, (b) police enforcement, were implemented or assigned at a major intersection in Kolkata city (i.e., Strand Road and Raja Wood Mount Street Crossing, where a total of four fatal pedestrian crashes occurred between the years 2011 and 2016).

The video-graphic and questionnaire survey were conducted for both the before and the after installation of the countermeasures on weekdays during morning 10 AM to 1 PM and afternoon 3 PM to 6 PM. Several well-trained interviewers were assigned to examine the pedestrians' perceptions towards (i) *risk of road traffic crashes*, (ii) *crossing difficulty*, and (iii) *satisfaction level* while a pedestrian was using the particular crossing. The meaning and importance of each question were explained to each pedestrian personally to obtain their responses on a scale of 1 to 6; where 1 represents "least risk/ not difficult/ highly satisfied" and 6 represents "highest risk/ extremely difficult / least satisfied" condition (Mukherjee and Mitra, 2020c). For the questionnaire survey, at least 100 pedestrians' perception data were collected before and after the installation of the countermeasures. In the case of *after condition* (after installation of the countermeasure), data were collected no earlier than one month after the installation of the countermeasures. This interval in the data collection process was expected to reduce any novelty effects. Subsequently, a host of statistical tests were performed to examine the usefulness of the proposed remedial measures. The police-reported fatal pedestrian crash records were also compared, before (2011-2016) and after (2017-2020 March) the installation of countermeasures. The descriptions of the case study with the substantial findings are summarized in the following sections. At this study intersection, pedestrians' crossing behavior and perception were examined under four different scenarios (Figure 2). A brief descriptive statistic of the selected variables has been shown in Table 5.

Scenario 1: *Un-signalized intersection*
Scenario 2: Intersection with *flashing yellow light*
Scenario 3: Signalized intersection with *pedestrian signal head*
Scenario 4: Signalized intersection with *police enforcement* (where the pedestrian crossing was controlled by the police personnel)

To determine the significant difference between two proportions (e.g., the share of pedestrian signal violation behavior, path changing behavior) obtained under the two different scenarios the "z-test" was performed (Washington et al., 2010).

H_0 (Null hypothesis): P_1 - P_2 = 0 [the two population proportions are equal] (2)
H_a (Alternative hypothesis): P_1 - $P_2 \neq 0$ [the two population proportions are not equal] (3)

The test statistics follow a normal distribution and is given as

$$Z = \frac{(p_1 - p_2) - 0}{\sqrt{p(1-p)(\frac{1}{n_1} + \frac{1}{n_2})}} \tag{4}$$

Where, $P_1 = \frac{x_1}{n_1}$ is the sample proportion of "sample 1"; $P_2 = \frac{x_2}{n_2}$ is the sample proportion of "sample 2". Where, n_1 and n_2 are the sample size obtained from the study intersection under "sample 1" and "sample 2" groups, 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:

$$p = \frac{x_1 + x_2}{n_1 + n_2} \tag{5}$$

For the continuous variables such as post-encroachment time (measured in second), an "independent sample t-test" was applied (Washington et al., 2010). Additionally, for the ordinal data such as pedestrians' perception data which was collected on a Likert scale (i.e., 1 to 6), the Mann-Whitney test (U-statistics) was executed to recognize the significant differences between before and after installation/assignment of countermeasures (Washington et al., 2010). In this test, the null hypothesis and alternative hypothesis are as follows:

H_0: The two sample distributions are drawn from the same population (6)
H_a: the sample distributions are drawn from two different populations (7)

Further, U-statistics is defined as follows:

$$U_1 = (n_1)(n_1) + \frac{n_1(n_1+1)}{2} - \sum R_1 \tag{8}$$

$$U_1 = (n_1)(n_1) + \frac{n_2(n_2+1)}{2} - \sum R_2 \tag{9}$$

Where, n_1 = size of sample 1; n_2 = size of sample 2; $\sum R_1$ = the sum of sample 1 ranks; $\sum R_2$ = the sum of sample 2 ranks

In the case of large sample size (i.e., first or second or both the sample size is more than 20), it is assumed that 'U' approaches a normal distribution, and so the null hypothesis can be tested by a Z-test. Compute the standard deviation of U:

$$Std\ Dev = \sqrt{\frac{(n_1)(n_2)(n_1 + n_2 + 1)}{12}} \tag{10}$$

Compute z

$$Z = \frac{U - \left(\frac{n_1 n_2}{2}\right)}{Std\ Dev} \tag{11}$$

Further, the obtained Z value compares with the critical Z value to decide whether to retain or reject the null hypothesis. If the absolute value of the obtained Z is less than the critical Z value, then retain the null hypothesis. Alternatively, if the absolute value of the obtained Z is greater than the critical Z value, then reject the null hypothesis (Washington et al., 2010).

Table 5. Descriptive statistics of 'case study 1'

Variable Name	Mean	Standard Deviation	Maximum	Minimum
Scenario 1				
Share of Conflicts (in %)	36	5.65	30	38
Average PET (seconds)	1.765	0.14	1.656	1.846
Jaywalking (in %)	11	5.65	06	14
Share of Path Changing Characteristics (in %)	60	21.92	50	81
Signal Violation (in %)	-	-	-	-
Crossing Difficulty (Likert Scale)	4	3.5	2	5
Crossing Difficulty (Likert Scale)	4	3.5	2	5
Satisfaction Level (Likert Scale)	4	3.5	2	5
Scenario 2				
Share of Conflicts (in %)	27	11.31	19	35
Average PET (seconds)	1.910	0.14	1.838	2.045
Jaywalking (in %)	10	2.12	8	11
Share of Path Changing Characteristics (in %)	25	6.36	21	30
Signal Violation (in %)	90	12.02	81	98
Crossing Difficulty (Likert Scale)	4	3.5	2	5
Crossing Difficulty (Likert Scale)	4	3.5	2	5
Satisfaction Level (Likert Scale)	4	3.5	2	5
Scenario 3				
Share of Conflicts (in %)	23	4.24	20	26
Average PET (seconds)	2.090	0.10	2.052	2.196
Jaywalking (in %)	9	1.41	8	10
Share of Path Changing Characteristics (in %)	17	6.36	14	23
Signal Violation (in %)	67.5	20.05	59	88
Crossing Difficulty (Likert Scale)	3	1.41	2	4
Crossing Difficulty (Likert Scale)	3	1.41	2	5
Satisfaction Level (Likert Scale)	3	1.41	2	4
Scenario 4				
Share of Conflicts (in %)	10	2.82	8	12
Average PET (seconds)	1.976	0.15	1.876	2.095
Jaywalking (in %)	5	3.53	3	8
Share of Path Changing Characteristics (in %)	12	2.84	9	13
Signal Violation (in %)	28	21.92	12	43
Crossing Difficulty (Likert Scale)	2	1.62	1	4
Crossing Difficulty (Likert Scale)	2	1.62	2	5
Satisfaction Level (Likert Scale)	4	2.09	2	5

Scenario 1: Un-signalized junction

Scenario 2: Intersection with flashing yellow light

Scenario 3: Signalized junction with the pedestrian signal head (pedestrian phase)

Scenario 4: Signalized junction with police enforcement [police personnel is controlling pedestrian movement with a manually operated barricade]

Figure 2. Pedestrians' crossing behavior under different scenarios

The outcomes obtained from the present case study are summarized in Table 6. The significant findings are as follows:

- The study findings show that after the installation of traffic signals the share of pedestrian-vehicular conflict was decreased by 36% (z-Statistics = 2.76; $p<0.05$). Further, it was found that due to the presence of police enforcement the share of conflict was declined by 72% (z-Statistics = 3.99; $p<0.01$).
- The test result shows that after installation of a traffic signal with police enforcement, the average PET value of the junction was increased by 12% (t-Statistics = -2.18; $p<0.10$) (Figure 4 b), and the share of the distracted pedestrian (Jaywalking) was also reduced by 54% (z-Statistics = 2.47; $p<0.05$).
- After the installation of the traffic signal with police enforcement pedestrians' path changing characteristics was significantly declined (z-Statistics = 4.43; $p<0.01$).
- Interestingly, it was detected that due to the presence of police enforcement (i.e., scenario 4) pedestrian signal violation rate was decreased by 59% (z-Statistics = 4.64; $p<0.01$).
- The outcomes of the pedestrians' questionnaire survey indicate that pedestrians' perceived risk and crossing difficulty were reduced by 25% owing to the installation of the traffic signal. Further, there is evidence that police enforcement is beneficial to reduce pedestrians' perceived risk, and the test result shows that pedestrians' crossing difficulty was reduced by 50% (Mann-Whitney z-statistics = -4.613; $p<0.01$) after assignment of police personnel.
- However, pedestrians' overall satisfaction level doesn't improve after the junction treatment (Mann-Whitney z-statistics = -1.57; $p>0.10$).
- Lastly, it was noticed that there was no recorded fatal pedestrian crash, after the installation of the traffic signal with police enforcement (2017 January to 2020 March).

Table 6. Summary of the study outcomes for case study 1

Characteristics	**Variables**	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
		Un-signalized intersection	**Intersection with flashing yellow light**	**Signalized intersection with pedestrian signal head**	**Signalized intersection with police enforcement**
Pedestrian-vehicular Interaction	Share of Conflicts (in %)	36	27	23	10
	Average PET (seconds)	1.765	1.910	2.090	1.976
Pedestrian Crossing Behaviour	Jaywalking (in %)	11	10	9	5
	Share of Path Changing Characteristics (in %)	60	25	17	12
	Signal Violation (in %)	-	90	67.5	28
Perception	Crossing Difficulty (Likert Scale)	4	4	3	2
	Perceived Safety (Likert Scale)	4	4	3	2
	Satisfaction Level (Likert Scale)	4	4	3	4

4.2 Case Study 2: Strand Road and Hare Street Crossing

This is a major signalized intersection in Kolkata City located near BBD Bagh Railway station. At this location, pedestrians' crossing behavior and perception were examined under the following scenarios:

Scenario 1: Signalized Junction *without pedestrian signal head*
Scenario 2: Signalized junction *with the pedestrian signal head (with countdown display)*

For the present case study, pedestrians' behavior and perception data were collected before and after the installation of the pedestrian signal head. The video recording was conducted for six hours between morning 10 AM and 1 PM, and afternoon at 3 PM and 6 PM. The coverage of the video included the waiting area at two ends of the crossing, the zebra crossing, and the traffic signal. In addition to this, a survey questionnaire form was prepared in a way so that much realistic information could be captured within a short duration (Mukherjee and Mitra, 2020c). A total of 159 pedestrians' perception data was collected *before the installation of the pedestrian signal head*; whereas 129 pedestrians' perception data were collected *after the installation of the pedestrian signal head*. Pedestrians' behavior under two different scenario is shown in Figure 3.

An "independent sample t-test or z-test" was applied to recognize the significant improvement in pedestrian crossing behavior *after the installation of the pedestrian signal head* (Table 7). Since pedestrian risk perception data were collected on an ordinal scale, the *Mann-Whitney* test was performed to compare pedestrian risk perception before and after installation of the pedestrian signal head (Table 8).

(a) Presence of pedestrian signal head

(b) Absence of pedestrian signal head

Figure 3. Case Study in Strand Road and Hare Street

The outcomes of the "independent sample t-test" indicate that pedestrians' behavioral characteristics such as signal violation (37%), and speed changing characteristics (62%) were significantly reduced after installation of the pedestrian signal head (Table 7). It was also observed that due to the presence of the *pedestrian signal head* the share of conflicts between vehicles and pedestrians was decreased by 29%, and the PET value was increased by 13.35%. The Mann-Whitney test results confirmed that after the installation of the pedestrian signal head, pedestrians' perceived satisfaction level was not significantly improved; however, the perceived risk and crossing difficulty were reduced at a reasonable level (Table 8).

Table 7. The test result of “independent sample t-testor z- test” –case study 2

Characteristics	Mean Difference	Std. Difference	95% Confidence Level		t-Statistics/ Z-Statistics	Sig.
			Lower	Upper		
Share of Signal Violation (in %)	-0.254	0.058	-0.376	-0.131	-4.352	0.000
Post Encroachment Time (seconds) [t-test, as PET is a continuous variable]	0.265	0.094	0.068	0.463	2.825	0.011
Share of Speed Changing Condition (in %)	-0.149	0.0358	-0.073	-0.224	-4.167	0.001
Share of Conflict (in %)	-5.416	3.064	-11.854	1.020	-1.768	0.094

Table 8. The test result of “Mann-Whitney test” – case Study 2

Characteristics	Z-value	Significance Level	Null Hypothesis
Crossing Difficulty	-9.606	0.000	Reject
Perceived Safety	-5.383	0.000	Reject
Satisfaction Level	-0.904	0.366	Accept

4.3 Case Study 3: CR Avenue and MG Road Crossing

This is a major signalized junction located in central Kolkata. At this intersection, pedestrians' crossing behavior and perception were examined under two different scenarios.

Scenario 1: Signalized Junction *without police enforcement*
Scenario 2: Signalized junction *with police enforcement*

For the present case study, pedestrians' behavior and perception data were collected in the presence and the absence of police enforcement. The video recording was conducted for six hours between morning 10 AM and 1 PM, and afternoon at 3 PM and 6 PM. A few observations obtained during the site visit and data collection are presented in Figure 4. A total of 160 pedestrians' perception data was collected in the absence of police enforcement. Another set of 160 pedestrians' perception data was collected in the presence of police enforcement.

An “independent sample t-test and/or z-test” was performed to identify the significant differences in pedestrian crossing behavior due to the presence of police enforcement, and test results are presented in Table 9. The test result shows that the pedestrian signal violation behavior was reduced by 31%; whereas the share of pedestrian-vehicular conflicts was declined by 44%. Further, it was observed that pedestrian-vehicular PET value was also improved by 16%. Interestingly, it was found that after the assignment of police enforcement, the share of pedestrians' rolling behavior was reduced by 88%.

To recognize the significant difference in pedestrian risk perception, the Mann-Whitney test was performed, and test outcomes are summarized in Table 10. The test outcomes indicate that pedestrian's perceived risk and crossing difficulty were significantly declined after the assignment of police enforcement. Though, pedestrian's overall satisfaction level doesn't improve adequately after the assignment of police enforcement.

(a) Pedestrians movement is controlled by the police personnel during the red phase

(b) The intersection is controlled by the traffic police personnel

(c) Pedestrians movement during the green phase

Figure 4. Case Study in MG Road and CR Avenue

Table 9. Test result of "independent sample t-test or z-test" –case study 3

Characteristics	Mean Difference	Std. Difference	95% Confidence Level		t / z-Statistics	Sig.
			Lower	Upper		
Share of Signal Violation (in %)	-0.114	0.062	-0.241	0.012	-1.833	0.076
Post Encroachment Time (seconds) [t-test, as PET is a continuous variable]	0.289	0.090	0.106	0.473	3.206	0.003
Share of Rolling Behavior (in %)	-0.024	0.010	-0.045	-0.030	-2.328	0.026
Share of Conflict (in %)	-10.916	3.876	-18.785	-3.038	-2.816	0.008

Table 10. The test result of "Mann-Whitney test" –case study 3

Characteristics	Z-value	Significance Level	Null Hypothesis
Crossing Difficulty	-4.613	0.000	Reject
Perceived Safety	-4.561	0.000	Reject
Satisfaction Level	-1.577	0.115	Accept

In this section, the effectiveness of several countermeasures was examined across three major intersections of Kolkata City. The outcomes obtained from the field observations indicate that the share of pedestrian-vehicular conflicts, pedestrians' risk-taking attitudes such as signal violation, path changing characteristics were significantly declined after installation of the countermeasures. On the other hand, it was found that the average value of pedestrian-vehicular post encroachment time (PET) was considerably enhanced after the installation of the countermeasures. To end, it was observed that there were no recorded fatal pedestrian crashes, after the installation of the countermeasures at these junctions (2017 to 2020 March). The significant outcomes obtained from these three case studies are summarized in Table 11.

Table 11. Summary of the effectiveness of countermeasures

Variables	Type of Countermeasures		
	Installation of Traffic Signal	**Installation of Pedestrian signal Head with Countdown Display**	**Assignment of Police Enforcement**
Share of Conflicts	-36%	-29%	-44% to -72%
PET	+19%	+13%	+16%
Share of Distracted Pedestrian	-19%	-35%	-29% to -54%
Path Changing Characteristics	-72%	Not Improved	-88%
Share of Signal Violation	Not Applicable	-37%	-32% to -68%
Crossing Difficulty	-25%	-25%	-50%
Perceived Safety	-25%	-25%	-50%
Perceived Satisfaction Level	Not Improved	Not Improved	Not Improved
Fatal Pedestrian Crashes (2011-2016)	2	4	3
Fatal Pedestrian crashes (2017-2020 March)	0	0	0
- Decreased + Increased/Improved			

5. CONCLUSION

Pedestrian fatalities constitute a major share of road traffic-related fatalities in developing countries. In recent years, several studies have paid attention to the identification of pedestrian risk factors and formulation of countermeasures in the urban setup in developing countries. On the other hand, very few studies have concentrated on examining the effectiveness of the proposed countermeasures. In this background, the present study has identified twenty-two major risk factors associated with fatal pedestrian crashes. The findings are utilized advantageously to formulate countermeasures to reduce pedestrian risk at the urban intersection level. Three specific countermeasures are successfully implemented at three major intersections in Kolkata city and found to reduce pedestrian-vehicular conflicts by 13% to 72%. The key contributions of the present study are as follows:

- The study finding indicates that pedestrian fatality risk at an intersection is significantly and positively associated with the average post encroachment time indicating a lower value of PET at an intersection raises the possibility of fatal crash incidence.
- The presence of inaccessible or non-standard marking of the pedestrian crosswalk is a common problem in Kolkata, and the presence of a poorly designed pedestrian crosswalk encourages pedestrians to cross the road from anywhere. It was found that pedestrian fatality risk substantially increases due to the presence of an inaccessible pedestrian crosswalk at an intersection. The lack of pavement marking was also found to have a significant impact on fatal pedestrian crash incidence.
- The lack of sight distance also positively increases pedestrian fatality, which justifies the need for priority attention for removing objects causing visibility obstruction at a
- junction. The study outcome reveals that the presence of police personnel is extremely beneficial to improve pedestrian safety and to recover pedestrian crossing behavior. The findings obtained from three specific case studies have confirmed that due to the presence of police

enforcement, the share of pedestrians' signal violations (32%-68%), jaywalking (29%-54%) and rolling behavior (88%) were significantly declined. Moreover, the average PET value was increased by 16%, and the likelihood of a pedestrian-vehicular conflict was declined by 44% to 72% owing to the presence of police enforcement.

- Interestingly it was observed that pedestrian-vehicular conflict was reduced by 36% after installation of a traffic signal at an unsignalized junction which designating installation of traffic signal could be a good solution to reduce pedestrian-vehicular conflicts at an unsignalized junction where pedestrian density is substantially high. Pedestrian's path-changing behavior (72%) and jaywalking (19%) were also considerably declined after the installation of the traffic signal.
- Finally, it was witnessed that there were no recorded fatal pedestrian crashes, after the installation of the countermeasures at these junctions (2017 to 2020 March) which is the most vital contribution of the present study.

Similar to any other study, this study is also not without limitation. The limitations of the present work and future scope are mentioned below:

- In this study, a total of 15 countermeasures was formulated and the effectiveness of three specific countermeasures was assessed. The impact of other countermeasures needs to be verified in the future.
- Further, it is agreed that the impact analysis of several countermeasures only three sites is not very rigorous and that needs to perform at a good number of sites to quantify the benefit of the treatment. Subsequently, it was assumed that all other parameters related to the built environment and traffic features of the sites were consistent during the evaluation period (i.e., before: 2011-2017 and after: 2018-2020 March). This is one of the major limitations of the present study. Although, in Kolkata city, the built environment features and traffic parameters were not significantly transformed in the last few years (Priyadarshini and Mitra, 2018); in the upcoming studies, the effects of transformation of the built environment and traffic parameters must be addressed while measuring the impact of any intervention.
- As it was recognized that pedestrians' satisfaction level does not improve after the installation or assignment of infrastructure-based or enforcement-based countermeasures, in upcoming research, it is important to recognize the significant factors related to the built environment and traffic operational parameters that influence pedestrians' satisfaction level or level of service.

Even though there is scope for further improvement in the current context, observations obtained from the present study provide clear directions to the policymaker, and engineers to recover pedestrian safety in urban areas of India and similar other developing countries.

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