A PROACTIVE APPROACH TO ASSESS SAFETY LEVEL OF AT-GRADE SIGNALIZED INTERSECTIONS

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ABSTRACT

Road safety is a growing concern in emerging countries, and intersections are the major points of concern largely due to complex conflicting movements of vehicles and pedestrians. In order to achieve a safe and sustainable traffic infrastructure at intersections, it is necessary to assess safety level of intersections and suggest safety improvement measures. The present work proposes a pro-active approach to evaluate the safety level of at-grade signalized intersections by identifying design and management deficiencies. The methodology includes (i) identification of unsafe acts and causal factors at signalized intersections, (iii) estimation of the weightage of causal factors (iv) fuzzy evaluation of intersections, (v) calculation of safety levels of intersections, and (vi) validation of the safety levels using crash data. While a combination of Fuzzy Analytical Hierarchy Process (Fuzzy AHP) and Grey Relational Analysis (GRA) was used to estimate the weightage of causal factors, a fuzzy-scoring based expert field investigation was carried out to assess design and management deficiencies at intersections. The methodology was applied to evaluate a few at-grade signalized intersections located along a typical urban corridor in Kolkata city, India. The work presented here is likely to encourage the practitioners to apply the methodology to identify safety deficiencies at intersections and to propose areas of improvement on a priority basis. The study is expected to be of interest to the researchers to adopt similar investigations for improving the safety of facilities in other contexts.

KEYWORDS: Safety Level, Signalized Intersections, Design Deficiencies, Management Deficiencies

INTRODUCTION

Road safety has emerged as a global concern as the world has witnessed an alarming number of accidents in the last few decades *(1)*. While several developed countries have experienced a decreasing trend in road accident through systematic safety improvement programs, emerging countries such as India has experienced an upward trend in road accident during the same period *(1), (2)*. According to the Ministry of Road Transport and Highways (MoRTH), India, 146133 persons were killed, and 500279 were injured in road traffic crashes in India in 2015 *(2)*. These statistics are not only alarming, but also tragic since several of these accidents could be avoided or the severity could be reduced by application of proper safety improvement measures. Therefore, for a greater social benefit, it is necessary to mitigate the road accidents and resulting fatalities by enhancing road safety through systematic safety improvement measures.

Intersections are one of the potential locations of accidents mainly due to complex conflicting movements of vehicles and pedestrians *(3)*. This is clearly reflected in the accident statistics which shows that nearly 42% of the road traffic crashes have occurred at urban intersections in India *(4)*. Safety in and around intersection is a crucial yet neglected aspect in Indian cities. In fact, it is apparent that many of the urban intersection have various design and management deficiencies. While in some intersections design deficiencies such as improper signal design and lack sight distance are predominant, management deficiencies such as lack of enforcement and improper maintenance are predominant at other intersections. Such deficiencies at intersections often lead to vehicle-pedestrian or vehicle-vehicle conflicts and thereby, resulting in accidents of different severity. Therefore, it is necessary to enhance the safety level of intersections by identifying the design and management deficiencies and by providing safe infrastructure and facilities *(3)*. However, owing to the severe financial and institutional constraints prevailing in emerging countries such as India, large scale safety improvement works may not be possible to execute in short span of time *(5)*. Hence, it is important to prioritize the intersections on the basis of safety level to perform safety improvements works in different phases based on priority rankings.

Several studies have been carried out with an aim to assess safety level of urban intersections *(3), (6)*. Poch and Mannering (1996) *(3)* developed a negative binomial model using seven-year accident data from 63 intersections. The estimation was instrumental in quantifying the interactions between geometric and traffic-related elements and crash frequencies. Similarly, Kim and Sul (2009) *(6)* applied a micro simulation model to assess the risk of intersection using accident data. Literature review suggested that a majority of such assessments were focussed on assessing safety level of intersections using the crash data and falls under reactive safety improvement measures. However, in the context of emerging countries, either crash data is not available, or it is not reliable mainly due to improper crash reporting *(5)*. Moreover, the crash data may not always pinpoint all design and management deficiencies which increase the potential for accidents at intersections. In this context, researchers have also used conflict data recorded using video cameras for assessing the safety level of intersections *(7), (8)*. However, the process of collecting the conflicts from intersection influence area is long considering that each intersection needs to be evaluated for a certain period of time to inspect the conflicts that are occurring *(9)*. Moreover, at some intersections, although a low number of conflicts has been recorded, the potential of occurrence of conflicts may be high, due to infrastructure and management deficiencies *(10)*. Therefore, there is a need to develop a proactive approach to assess the safety level of intersections by identifying the design and management deficiencies, even in the absence of crash data or conflict data. With an objective of utilizing the merits of both proactive and reactive approach, the present work aims to develop a methodology to assess safety level of intersections. While the safety assessment is carried out using a pro-active approach, the validation of the method is carried out using crash data analysis (reactive approach). It may be mentioned here that the scope of the present work is limited to the safety assessment of at-grade signalized intersections.

Hereafter the paper is organized into four sections. The methodology to assess the safety level of at-grade signalized intersection is discussed in section termed ‘Methodology’, while the application of the methodology with reference to a few selected corridors is discussed in section ‘Application’. A brief discussion on the worst two and the best two intersections are included in section ‘Discussion and Recommendation’. Finally, the Section ‘Conclusion’ summarizes the outcomes of the present work and the scope of future research.

METHODOLOGY

The methodology to assess the safety level of the at-grade signalized intersection is briefly discussed in this section (Figure 1). The evaluation of the safety level of at-grade signalized intersections is formulated as a Multi Attribute Decision Making (MADM) problem. Researchers have used MADM approach for the evaluation of infrastructure and facilities in various contexts. For instance, Chang and Yeh (2004) *(11)* has used a fuzzy based MADM approach for developing an index for assessing safety level of Airport facilities. The methodology developed for assessing the safety level of at-grade signalized intersection includes (i) identification of unsafe acts and causal factors in and around the intersection, (ii) estimation of weightage of causal factors, (iii) fuzzy evaluation of the intersections by the experts, (iv) calculation of the safety level of intersections, and (v) validation of safety level using crash data.

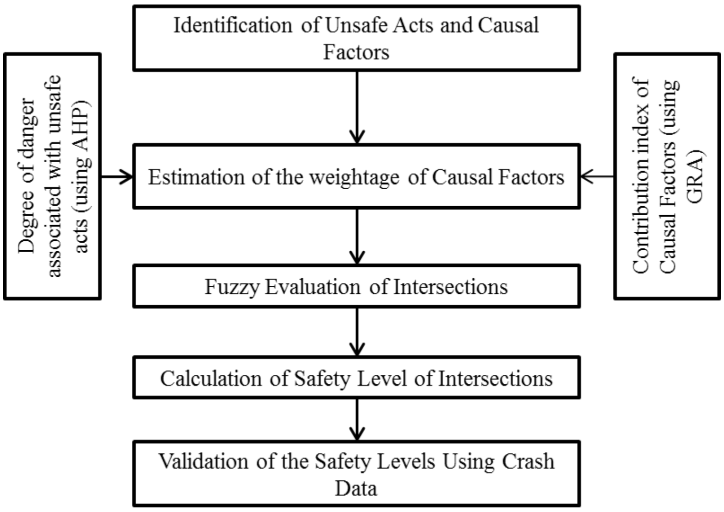

FIGURE 1 Methodology to assess safety level of intersection

Unsafe Acts and Causal factors

Unsafe acts in the context of at-grade signalized intersection may be defined as those actions performed by pedestrians or drivers, which may result in vehicle-vehicle conflicts or vehicle-pedestrian conflicts. Unsafe acts, in general, are the results of design and management deficiencies in and around intersections. Hence, those deficiencies in design and management of intersections which lead to unsafe acts are hereby termed as causal factors. For instance, the vehicles crossing an intersection during red signal is an unsafe act which exposes the vehicle to the traffic/pedestrian flow of subsequent phase and leads to conflicts. The causal factors for the same are the lack of visibility towards traffic lights, insufficient amber indications, etc. As unsafe acts and causal factors are crucial in assessing safety level of intersections, this stage of the methodology deals with the identification of all possible unsafe acts and corresponding causal factors. Additionally, in this stage, all causal factors are classified under design and management deficiencies of intersections.

Estimation of the Weightage of Causal Factors (w_j)

This stage of the methodology includes estimation of the weightage of causal factors. The weightage of causal factors may be defined as the product of (i) the contribution of the j^{th} causal factor to the i^{th} unsafe act (hereby termed as contribution index, c_{ji}) and (ii) the degree of danger associated with the corresponding unsafe act (d_i). Mathematically, the weightage of the causal factors may be expressed as:

$$w_j = c_{ji} \text{ x } d_i \tag{1}$$

Estimation of the Degree of Danger Associated with Unsafe Acts (d_i)

The degree of danger indicates the relative degree of risk associated with unsafe acts in terms of their potential for conflicts/crashes. In order to estimate d_i, Fuzzy Arithmetic Hierarchy Process (Fuzzy- AHP) is carried out. Fuzzy-AHP is a well-established and widely used scientific technique for the estimation of weightage using expert's pairwise comparison *(12)*. The Fuzzy AHP procedure explained by Ayhan (2013) *(12)* is used in the present work.

Estimation of the Contribution Index of Causal Factors (c_{ji})

The contribution index of the causal factors is estimated on the basis of the contribution of the causal factors to the corresponding unsafe acts. For instance, lack of visibility towards traffic lights (f_1) and insufficient amber indications (f_2) lead to the unsafe act 'vehicles crossing the intersection during red signal (u_1)'. The c_{ji} value of the causal factor 'f_1' is estimated based on the contribution of f_1 to the unsafe act u_1, while that of f_2 is based on the contribution of f_2 to the unsafe act u_1. Unlike unsafe acts, causal factors are large in number. Literature suggests that AHP provides rational results when there is a limited number of factors as it will lead to cognitive burden on the experts otherwise. Therefore, in this stage, the c_{ji} values of causal factors are estimated using Grey Relational Analysis (GRA). It may be mentioned that researchers have extensively used GRA for estimating the weightage of factors in various contexts *(13)*, and the technique is well established in the literature *(14)*. The GRA procedure explained by Wei (2010) *(14)* is used for the estimation c_{ji} in the present work.

Fuzzy Evaluation of Intersections

This stage of the methodology deals with the safety assessment of the intersections with respect to the performance of causal factors. This includes a qualitative assessment of the intersections by experts in the field of traffic safety. The qualitative assessments require subjective judgments of safety experts to reflect the degree to which each intersection satisfies each causal factor. Linguistic terms were found intuitively easy to use in expressing the subjectiveness and imprecision of the decision maker's assessments *(11), (15)*. In order to facilitate the making of qualitative assessments by safety experts, a set of five linguistic terms (Very Poor, Poor, Medium, Good, Very Good) is used *(11)*. Each expert evaluates the performance rating of an intersection with respect each causal factor by using one of these linguistic terms. Each linguistic term is characterized by a triangular fuzzy number for representing its approximate value range between 0 and 10, which is denoted as (t_1, t_2, t_3), where $0 \leq t_1 \leq t_2 \leq t_3 \leq 1$. It may be noted that t_2 is the most likely value of the corresponding term, whereas t_1 and t_3 are the lower and upper bounds respectively to reflect the fuzziness of the term *(11)*. Prior to the fuzzy evaluation of the intersections, each safety expert defines the value range of these linguistic terms for his assessments, for the fact that each safety expert may have a different perception of these linguistic terms. After defining the linguistic terms, experts are asked to assess the safety performance of the intersections with respect to the causal factors. The qualitative assessment of the intersection thus obtained using fuzzy evaluation is termed as fuzzy evaluation matrix which is used in the subsequent calculations.

Calculation of Safety Level of Intersections

The safety level of the intersection is calculated using weightage of causal factor and fuzzy evaluation matrix. The de-fuzzification process proposed by Zheng et al. (2009) *(16)* was used for calculating safety levels of intersections. Although the method is well established in the literature, the procedure of de-fuzzification and calculation of safety level is explained as follows.

Step 1: Calculation of Fuzzy Evaluation Value

The fuzzy evaluation matrix obtained from the previous stage includes performance assessment of causal factors in terms of fuzzy linguistic terms (i.e. very poor (VP), poor (P), medium (M), good (G) and very good (VG)).

The fuzzy evaluation vector of jth causal factor of any intersection which is evaluated by k experts was obtained as follows *(16)*.

(2)

V_j is a vector of fuzzy number (set of 3 numbers l_j, m_j, and n_j), which is de-fuzzified using the centre of area method *(7)* to obtain the fuzzy evaluation value f_j for causal factor j.

(3)

Step 2:- Calculation of Safety Level

Safety level for the particular at-grade signalized intersection is calculated using the following equation.

(4)

Where

S is safety level of the intersection

w_j is the weightage of jth causal factor

f_j is de-fuzzified value jth causal factor for the respective intersection

n is the total number of causal factors (including the causal factors of all unsafe acts)

Validation of Safety Levels Using Crash Data

This stage includes validation of the safety level of intersection using crash data obtained from the secondary sources. A correlation analysis is carried out to study whether the safety levels are significantly correlated with crash data at certain significant level.

APPLICATION

The methodology developed to assess the safety level of at-grade signalized intersection is demonstrated here with reference to a traffic corridor in the Kolkata city, India. A corridor of 4.3 km, starting from Alipore Road intersection to Tollygunge intersection via AJC Bose road and Ashutosh Mukherjee road in Kolkata metropolitan city, India, was selected. The corridor includes 8 at-grade signalized intersections, and all intersections are 4-legged except Alipore intersection which is 3-legged. The corridor is a part Central Business District (CBD) and serves high pedestrian and traffic volume.

Unsafe Acts and Causal Factors

There is no universal agreement among the researchers about what exactly constitutes unsafe acts and causal factors. This suggests that intersection safety measures are context dependent, and it must be selected to reflect the concerns of the particular environment or the concerns of emerging countries in the present context. Accordingly, based on field observation and discussion with subject experts, six unsafe acts in and around the intersections were identified. Those includes (i) Vehicle crossing the stop line during red signal (Does not include cases where the vehicle crosses the intersection) (u1), (ii) Vehicle Crossing the Intersection during Red Signal (u2), (iii) Vehicle making unsafe manoeuvre (Does not include cases where intersection is blocked by stopped vehicle) which includes right turning, left turning, U turn, straight movement, etc. (u3), (iv) Vehicle stopping within the intersection block during green time or unable to clear intersection during green signal (u4), (v) Pedestrians crossing road at undesirable location and/or with undesirable interactions with motorized traffic (u5), and (vi) Pedestrian waiting on road/walking by the side of carriageway without using footpath (u6).

Vehicle Crossing the Stop Line during Red Signal (Does not include cases where the vehicle crosses the intersection) (u1)

The drivers often stop the vehicle ahead of the stop line causing inconvenience to pedestrian and vehicles in subsequent phases. In the process, vehicles may fully/partially occupy the crosswalk causing discomfort to the pedestrian while crossing the road. Also, it was observed that stopping the vehicle ahead of the stop line often partially blocks the natural path of the vehicle in subsequent phases. The factors contributing to this unsafe act includes (i) No stop line or stop line is not visible to the driver (u1f1), (ii) traffic light is not visible to the driver (u1f2), (iii) insufficient/no amber indication (u1f3), (iv) inadequate lighting (u1f4) and (v) unruly behaviour of drivers (u1f5).

Vehicle Crossing the Intersection during Red Signal (u2)

Vehicles may cross the intersection during red signal resulting in conflicts with the vehicle/pedestrian in subsequent phases. This often leads to intersection blockage which in turn disturbs the overall traffic flow and lane discipline. The factors contributing to this unsafe act includes (i) no stop line or stop line is not visible to the driver (u2f1), (ii) traffic signal light is not visible to the driver (u2f2), (iii) insufficient/no amber signal indication (u2f3), (iv) inadequate lighting (u2f4), and (v) unruly behaviour of drivers (u2f5). It may be mentioned that although the causal factors of u2 are same as that of u1, the degree of danger associated with u1 and u2 are likely to be different. This was the reason for considering the u1 and u2 separately for the study.

Vehicle Making Unsafe Manoeuvre (Does not include cases where intersection is blocked by stopped vehicle) which includes right turning, left turning, U turn, straight movement, etc. (u3)

The drivers sometimes make unsafe manoeuvres for the following reasons. (i) Insufficient clearance time (u3f1) (ii) inadequate or improper signage (u3f2) (iii) inadequate sight distance to conflicting vehicle (u3f3) (iv) inadequate lighting (u3f4), (v) absence of pavement markings (other than crosswalk/ stop line) (u3f5), (vi) inadequate auxiliary lanes (acceleration and de-acceleration lane for left turn, storage lanes and de-acceleration lane for right turn) (u3f6), (vii) Inadequate number of signal phases (leading to conflicts) (u3f7), and (viii) unruly behaviour of driver (u3f8).

Vehicle Stopping within the Intersection Block During Green Time or Unable to Clear Intersection During Green Signal (u4)

The drivers may stop the vehicle within the intersection block during green signal for the following reasons. (i) Queue spill over from downstream intersection preventing entering vehicle to clear the intersection (u4f1)**,** (ii) roadway width and capacity at exit is lesser than the width and capacity at entry (u4f2)**,** (iii) capacity at exit is reduced due to local blockage, such as bus stop, bus not stopping at curb lane/left lane, parking, temporary encroachment) (u4f3), and (iv) unruly behaviour of drivers (u4f4).

Pedestrians Crossing Road at Undesignated Location and/or with Undesirable Interactions with Motorized Traffic (u5)

Field investigation revealed that pedestrian crosses the road at undesignated locations at intersections for various reasons. This unsafe act exposes the pedestrian to vehicular stream resulting in vehicular-pedestrian conflicts. It may be mentioned that designated crosswalk facility includes crosswalk with pedestrian signal, foot-over-bridge, and pedestrian under pass. If designated crosswalk facility is available within walking distance, then following causal factors are considered. (i) Access to designated crossing facility is not proper (u5f1), (ii) designated crossing facility is occupied by vehicles/hawkers, etc. and is not available for use by pedestrians (u5f2), (iii) designated crossing facility is not well maintained (u5f3), (iv) designated crossing facility does not provide adequate opportunity for crossing road (u5f4) and, (v) unruly behaviour of pedestrians (u5f5). On the other hand, in the absence of a designated crossing facility, the following causal factors are considered. (i) The location used for crossing is unsafe (u5f6), (ii) adequate opportunity for crossing is unavailable (u5f7),

(iii) Inadequate lighting facility (u5f8) and (iv) pedestrian entry/ exit (bus stop/ subway/ market etc.) is located away from the designated crosswalk (u5f9).

Pedestrian Waiting on Road/Walking by the Side of Carriageway without Using Footpath (u6)

Pedestrians may encroach upon the roadway when they walk by using carriageway instead of using the sidewalk or wait for the bus on the carriageway rather than at the waiting area. Field investigation revealed that even if the pedestrians are at the shoulder of the carriageway the chances of conflicts are not negligible. The factors contributing to this unsafe act includes (i) inadequate width /absence of footpath (u6f1) (ii) footpath is present but encroached by hawkers, temporary establishment, parked vehicle, etc. (iii) (u6f2), footpath is not well maintained (u6f3), (iv) inadequate capacity of the waiting area, (v) no designated bus stop but buses are making unauthorized stops within intersection block (u6f5), (vi) inadequate lighting on footpath/ designated bus stop waiting area (u6f6), and (vii) unruly behaviour of pedestrian (u6f7). After identifying the causal factors, these are further classified under design and management deficiencies as shown in Table 1.

TABLE 1 Design and Management Deficiencies of Intersections

Design Deficiencies	**Management Deficiencies**	
	Enforcement deficiencies	**Maintenance Deficiencies**
Insufficient/no amber indication	Unruly behavior of drivers	Stop line is not visible
Insufficient clearance time	Queue spill over from downstream intersection preventing entering vehicle to clear the intersection	Traffic light is not visible to the driver
Inadequate or improper signage		
Inadequate sight distance to conflicting vehicle		Access to designated crossing facility is not proper
Absence of pavement markings (other than crosswalk/ stop line)	Footpath is present but encroached by hawkers, temporary establishment, parked vehicle, etc.	
Inadequate auxiliary lanes (acceleration and de-acceleration lane for left turn, storage lanes and de-acceleration lane for right turn)		Designated crossing facility is not well maintained
Inadequate number of signal phases	Adequate opportunity for crossing is unavailable	Footpath is not well maintained
Roadway width and capacity at exit is lesser than the width and capacity at entry	Designated crossing facility is occupied by vehicles/hawkers, etc.	
Designated crossing facility does not provide adequate opportunity for crossing road	Capacity at exit is reduced due to local blockage	
Inadequate/absence of footpath	Buses are making unauthorized stops within intersection block	
Inadequate/absence of footpath		
Inadequate lighting	Unruly behavior of pedestrian	
Inadequate capacity of the waiting area		

Estimation of the Weightage of Causal Factors (w_j)

A panel of experts including researchers, safety experts, and other professionals in the field of traffic and transportation engineering were approached for conducting Fuzzy-AHP and GRA. The panel included more than 30 experts which were satisfying the required sample size for conducting AHP or expert surveys *(17).*

Degree of Danger Associated with Unsafe Acts (d_i)

As mentioned in the methodology, the degree of danger associated with the unsafe acts was estimated by conducting Fuzzy-AHP survey. A Fuzzy-AHP questionnaire was developed to facilitate a pairwise comparison. SAATY's 9 point scale was used to compare the unsafe acts *(17).* The consistency of the responses was checked, the responses with consistency ratio less than 0.1 was accepted *(18).* Table 2 shows the d_i values obtained from the fuzzy AHP study.

TABLE 2 Degree of Danger with Unsafe Acts

Unsafe Acts	Degree of danger (d_i)
Vehicle crossing the stop line during red signal (Does not include cases where the vehicle crosses the intersection) (u1)	0.04
Vehicle Crossing the Intersection during Red Signal (u2)	0.29
Vehicle making unsafe maneuver (Does not include cases where intersection is blocked by stopped vehicle) which includes right turning, left turning, U turn, straight movement, etc. (u3)	0.17
Vehicle stopping within the intersection block during green time or unable to clear intersection during green signal (u4)	0.12
Pedestrians crossing road at undesirable location and/or with undesirable interactions with motorized traffic (u5)	0.28
Pedestrian waiting on road/walking by the side of carriageway without using footpath (u6)	0.10

It was interesting to note that, according to the experts, 'vehicle crossing the intersection during red signal (u1)' (0.29) has the highest degree of danger, which is closely followed by 'Pedestrians crossing road at undesirable location and/or with undesirable interactions with motorized traffic (u5)' (0.28). 'Vehicle crossing the stop line during red signal (u1) (0.04)' has the least degree of danger.

Contribution Index of Causal Factors (c_{ji})

The contribution indices of causal factors were estimated using GRA technique as shown in Table 3. The experts were asked to give the rating (on a scale of 1-7) based on the contribution of the causal factors to the respective unsafe act. It may be mentioned that the contribution indices of causal factors of each unsafe acts are normalized to one.

TABLE 3 Contribution Index of Causal Factors

Causal Factors	Contribution Index (c_{ji})	Causal Factors	Contribution Index (c_{ji})	Causal Factors	Contribution Index (c_{ji})
u1f1	0.203	u3f4	0.102	u5f5	0.203
u1f2	0.237	u3f5	0.100	u5f6	0.255
u1f3	0.198	u3f6	0.126	u5f7	0.282

u1f4	0.161	u3f7	0.139	u5f8	0.235
u1f5	0.201	u3f8	0.134	u5f9	0.227
u2f1	0.170	u4f1	0.241	u6f1	0.156
u2f2	0.269	u4f2	0.250	u6f2	0.164
u2f3	0.180	u4f3	0.277	u6f3	0.142
u2f4	0.171	u4f4	0.231	u6f4	0.125
u2f5	0.210	u5f1	0.157	u6f5	0.159
u3f1	0.127	u5f2	0.244	u6f6	0.112
u3f2	0.137	u5f3	0.220	u6f7	0.141
u3f3	0.134	u5f4	0.176		

After estimating the degree of danger values and contribution indices, the weightage of the causal factor is estimated using equation 1, and the results are presented in Figure 2.

FIGURE 2 Weightage of causal factors

It may be noted that, as u1f1 and u2f2 are same causal factors resulting in different unsafe acts (u1and u2), the weightages are combined, and for the same reason, weightages of u1f2 and u2f2; u1f3 and u2f3; u1f4, u2f4 and u3f4; u1f5 and u2f5; were also combined. According to the experts, 'traffic signal not visible to the driver' is the causal factor with highest weightage, followed by 'in adequate opportunity for crossing is unavailable' and 'location used for crossing is unsafe'. On the other hand, 'inadequate lighting on footpath/designated waiting area' is the causal factor with least weightage. This may be because inadequate lighting in the foot path or waiting area will not force the pedestrian to the middle of the carriageway and exposes less to the vehicular traffic. On the other hand, 'in adequate lighting in the crosswalk facility' will force the pedestrian to cross the road at undesignated locations and exposes more to the vehicular traffic, which justifies the higher weightage of this causal factor.

Fuzzy Evaluation of Intersections

As discussed in the methodology section, prior to the evaluation of the intersections, the experts were asked to define the linguistic variables, Very Poor (VP), Poor (P), Medium (M), Good (G) and Very Good (VG) in terms of triangular fuzzy numbers on a scale 1-10. The linguistic variables defined by three field experts are shown in Table 4.

TABLE 4 Defining Fuzzy Linguistic Variables by Three Experts

Linguistic Variable	VP			P			M			G			VG		
Expert 1	0	0	2	2	3	4	4	5	6	6	7	8	8	10	10
Expert 2	0	0	2	2	3	4	4	5	6	6	7	8	8	10	10
Expert 3	0	0	2	2	3	4	4	5	6	6	7	8	8	10	10

After defining the fuzzy variables, the experts were asked evaluate each approach of the intersection in terms of the causal factors. The evaluation was carried out separately during peak and off-peak hours. Table 5 shows the fuzzy evaluation matrix of the east approach of Alipore intersection during off peak hours. Similarly, fuzzy evaluation was carried out for all approaches in every intersection during peak and off-peak hours and average safety level was calculated.

TABLE 5 An Example of Fuzzy Evaluation of Intersection

Causal Factor	Expert 1	Expert 2	Expert 3	Fuzzy Evaluation Value (f_j)	Weightage of Causal Factor (w_j)	w_j*f_j
u1f1	G	G	VG	7.778	0.008526	0.066315
u1f2	M	M	M	5	0.009954	0.04977
u1f3	M	M	P	4.333	0.008316	0.036033
u1f4	M	G	G	6.333	0.006762	0.042824
u1f5	G	P	M	5	0.008442	0.04221
u2f1	G	G	VG	7.778	0.04811	0.3742
u2f2	M	M	M	5	0.076127	0.380635
u2f3	M	M	P	4.333	0.05094	0.220723
……	………	………	……..	…………	………	………
u6f6	P	M	M	4.333	0.011424	0.0495
u6f7	G	VG	G	7.778	0.014382	0.111863
Safety Level of east approach of Alipore intersection ,						**5.94**

Safety Levels of Intersections

The safety levels of intersections were calculated using the weightage of causal factors and fuzzy evaluation matrix. Initially, the safety levels of each approach were calculated for peak and off-peak hours as shown in Table 6 and the same were averaged out to calculate the safety level of intersections. Table 6 summarizes the safety levels of eight at-grade signalized intersections in the selected corridor in the order of priority. Prioritization of the intersections was performed based on the fact that 'lower the safety level, higher the priority for improvement'. While DL Khan intersection was best in terms of safety level (5.81), Hazra intersection was the worst in terms of safety level (3.95).

TABLE 6 Safety Levels of At-grade Signalized Intersections

Priority Order	Intersection Name	North	East	South	West	Safety level
1	Hazra	3.78	3.81	3.67	4.55	**3.95**
2	Rash Behari	4.24	4.20	4.20	4.18	**4.20**
3	Exide	4.26	4.18	4.19	4.26	**4.22**
4	Tollygunge P.S	5.00	5.11	5.09	5.36	**5.14**
5	Rabindra Sadan	5.13	5.54	4.92	5.00	**5.15**
6	Alipore	N.A	5.78	5.55	5.68	**5.67**
7	Elgin	5.84	5.65	5.74	5.72	**5.74**
8	DL Khan	6.08	5.66	5.69	5.82	**5.81**

Validation of Safety Levels Using Crash Data

The proactive approach discussed here may be applied to assess the safety level of intersections even in the absence of crash data. In order to evaluate the rationality of the methodology and validate the safety levels, crash data obtained from the authorities were used. Initially, accidents occurred at the influence areas of the intersection were filtered out from the database and were located on the corridor map to obtain accident concentration map. Subsequently, the accident concentration map was overlaid on intersections to obtain the cumulative number of accidents (from the year 2011 to 2014). Then the safety level computed from the present work was plotted against the cumulative number of accidents occurred at the intersection as presented in Figure 3. A correlation analysis between the safety levels and cumulative accidents shows a correlation of 0.628 which was significant at 5% significance level. Moreover, safety assessment model being a non-predictive model, a correlation value greater than 0.6 is acceptable to validate the model *(19).*

FIGURE 3 Validation safety levels using crash data

DISCUSSIONS AND RECOMMENDATIONS

Although detailed discussions and recommendations were made to improve the safety levels of eight intersections, owing to the space constraints, analysis of two best and two worst intersections are discussed here. It may be mentioned that major deficiencies and corresponding recommendations are highlighted here with reference to these intersections.

Analysis of the Worst Two Intersections

Hazra (3.95) (Figure 4a) and Rash Behari (4.20) (Figure 4b) intersections were the worst two in terms of the safety level. It was found that street vendors have occupied a major portion of the footpath and have blocked the access to the designated crosswalks. This is ultimately forcing the pedestrians to encroach upon the carriage way. A large number of pedestrians in these intersections demand a pedestrian signal. At present, the opportunity for crossing the road is very less and pedestrians are crossing the road in an unsafe manner resulting in conflicts. It was also found that buses and taxis are making unauthorized stops at these intersections resulting in severe blockage, especially during peak hours. Therefore, in order to enhance the safety level of the at grade signalized intersections, it is recommended to (i) relocate the street vendors away from the influence area of intersection, (ii) redesign the traffic signal providing adequate conflict free pedestrian phase, and (iii) strengthen the enforcement to prevent buses and taxis making unauthorized stops at intersection.

Analysis of the Best Two Intersections

DL Khan road (5.81) (Figure 4d) and Elgin intersections (5.74) (Figure 4c) were the best in terms of safety levels. In order to improve the safety levels of these intersections further, it is recommended to shift the vendors away from the intersection and strengthen the enforcement against on-street parking.

(a) (b) (c) (d)

FIGURE 4 (a) Hazra intersection; (b) Rash Behari intersection; (c) Elgin intersection; (d) DL Khan Rd intersection

CONCLUSION

The paper presents a proactive approach for assessing the safety level of at-grade signalized intersection by identifying the existing infrastructure and facilities. The safety levels obtained using proactive approach was also validated using crash data obtained from a secondary source. The methodology includes identification of unsafe acts and causal factors, estimation of the of the weightage of causal factors, fuzzy evaluation of the at-grade signalized intersections, calculation of the safety levels of intersections, and validation of the safety levels using crash data.

The approach was applied successfully to evaluate the safety levels of eight at-grade signalized intersections located along a typical urban corridor in the Kolkata metropolitan city, India. The fuzzy evaluation of the intersection was conducted for each approach of the intersections during peak and off-peak hours. The causal factors were identified in terms of design and management deficiencies, safety levels of intersections were assessed, prioritization of the intersections was carried out, and appropriate recommendations were made to improve the safety levels of the unsafe intersections. The calculated safety levels of the intersections are successfully validated using crash data available for the intersections. Safety levels of the intersections ranged between 3.95 to 5.81 (10 being the best and 0 being the worst). The recommended measures are expected to improve the safety deficiencies of these intersections.

The methodology provides a deep insight to the safety deficiencies related to the design and management deficiencies of the intersections, and the findings are expected to be instrumental in formulating appropriate improvement measures for enhancing the safety level. While the methodology developed in this study is expected to be of interest to the researchers in the field of public transport safety, the application of the methodology as demonstrated in this paper is likely to encourage the practitioners to apply a similar approach to identify safety lacunas at other intersections and take appropriate measures for improvement.

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