

INFLUENCE OF SIGHT DISTANCE CHARACTERISTICS ON SAFETY OF INTERSECTIONS USING SURROGATE SAFETY MEASURES

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Abstract

Recent road accident statistics indicate that more than 30% of accidents occur at intersections. Whereas, total percentage of intersections present in the entire road network is less than 2%. From design point of view, one way to ensure reduction of accidents at intersections is to provide sufficient sight distance and clear sight triangles. However, it was observed that even when minimum sight distance is provided, it does not ensure non-occurrence of accidents because available sight distance at intersection changes with time. Hence there is a need to understand the effect of sight distance characteristics on safety at uncontrolled intersections. From safety studies, it was observed that crash data is highly unreliable as it is generally underreported. Hence in the present study, surrogate safety measures were used instead of crash data. To accomplish the study objectives, six uncontrolled three-legged intersections were selected. Geometric data such as sight distance was measured as per IRC SP 41 (1994) guidelines. Traffic data collection at each intersection was carried out using videography method. From the recorded videos, volume data, speed data, and Post Encroachment Time (PET) data were extracted manually. The effect of various geometric and traffic factors on the critical conflict rate was studied using correlation and regression analysis. From the models developed, it is observed that for every 1 unit increase in logarithm of major and minor road sight distance, critical conflict rate decreased by 18.14% and 33.56%, respectively. Also, it was found that, the available sight distance is far shorter than the design/minimum sight distance specified by IRC SP 41 (1994).

Keywords: Critical conflicts; Critical speed; Intersection sight distance; Post Encroachment; Time; Uncontrolled Intersections

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Introduction

The rapid economic development of India's cities has resulted in a corresponding increase in travel demand. The expansion of cities into sub-urbans and the non-availability of efficient, economical, and adequate public transportation services around Indian cities have led people to use their own vehicles to go about. At the same time, rising middle-class income levels in India have made automobile and motorcycle ownership more attainable. According to 2021 statistics, India's car population is over 190 million, and it is growing at a rate of more than 10% per year. This rapid growth of the vehicle population has increased traffic risk and has put road safety in jeopardy. Road user safety is one of the major areas of concern in the field of Transportation engineering. But as of now, India is lacking in the aspect of road user safety. As per World Road statistics (2019), India is ranked 1st in the number of road accident deaths across the 199 countries followed by China and US. According to Ministry of Road Transport and Highways (2019) of India statistics, a total of 2, 81, and 811 road accidents have been reported by States and Union Territories in the calendar year 2019, out of which 1, 25, and 498 accidents (44.5%) took place at intersections. Among intersections, uncontrolled intersections account for a more significant number of accidents. Out of 1, 25, and 498 accidents occurred at intersections, 92,654 accidents occurred at uncontrolled intersections. The statistics indicating the total number of accidents at intersections are presented in Table 1.

It can be observed that, out of total accidents that happen at intersections, 74% occurred at uncontrolled intersections. At uncontrolled intersections, as no control is levied, drivers passing through uncontrolled intersections are supposed to yield the right-of-way. However, it is observed that majority of the drivers are not aware of right-of-way laws or often force their way into intersection which leads to accidents. AASHTO has also determined that 50% of accidents occurring on urban roads and 30% of those that happen in rural areas occur at an intersection. Whereas, total percentage of intersections present in the entire road network is less than 2%. Hence there is a need to analyze situations that are resulting in accidents and implement necessary safety measures at intersections.

One of the ways to reduce these accidents at uncontrolled intersections is by providing proper sight distances. Intersection sight distance (ISD) provided will enable driver to perceive the hazard and take necessary action. Along with providing

intersection sight distance, areas (sight triangles) along intersection approach legs and across including corners should be clear of obstructions there by providing a sufficient view for the driver to avoid conflicts. ISD is calculated based on time required by the driver on the minor road to perceive the traffic conditions on the intersection, evaluate the gaps in the vehicle stream, take a decision about actual crossing, and finally to accelerate the vehicle to complete the maneuver.

From the road accident statistics, it is observed that on comparing the percentage of accidents occurring at intersections and the proportion of intersections present in the total road network, the intersections are the most critical points where the majority of accidents take place. The Indian traffic condition is mixed traffic condition without lane discipline, which consists of several vehicle categories with different physical and dynamic characteristics. It is not easy to understand the causes for these accidents under mixed traffic conditions. Hence there is a need to analyse causative factors that result in accidents and implement necessary safety measures at intersections under mixed traffic conditions. Among the causative factors, insufficient sight distance is one of the important factors. These accidents cannot be reduced only by providing minimum intersection sight distance because sight distance provided at an intersection may vary with time due to development/ growth of land parcels around the intersection which obstruct line of sight at intersections. Hence there is a need to understand the influence of sight distance characteristics on safety at uncontrolled intersections. So, the aim of the present research work is to evaluate the safety of selected intersections by quantifying critical conflicts using surrogate safety measure 'Post

Table 1. Road accident statistics at intersections (Road accident statistics in India 2019, MORTH)

Type of control	Total number of accidents	Number of people killed	Number of people injured
Signal	9,719	2,839	8,890
Police	10,425	3,501	9,254
Stop sign	6,461	2,439	5,458
Flashing signal	6,239	2,222	5,494
Uncontrolled	92,654	28,727	87,489
Overall	125,498	39,728	116,585

Encroachment Time' and to model critical conflict rate and determine effect of sight distance and vehicle composition on critical conflicts.

Literature Review

In this section, various past studies conducted in the subject area of the present study are discussed in detail in various sub-sections.

Studies on Intersection Sight Distance (ISD)

Himes *et al.* (2018) analysed effect of intersection sight distance on safety at unsignalized intersections. Crash data was obtained from highway informatic systems. Geometric and traffic data was obtained from road inventory data, GIS Maps, Google earth, and field surveys. Exploratory data analysis, correlation and multivariate regression analysis were performed and final regression equation was obtained. One of the important variables considered in this study was ISD quality (based on obstructions present in sight triangle). From the data analysis, it was observed that crash frequency varies logarithmically with intersection sight distance. Himes *et al.* (2022) evaluated safety aspect of intersection sight distance at unsignalized intersections. Crash data was obtained from highway informatic systems. Geometric and traffic data was obtained from road inventory data, GIS Maps, Google earth, and field surveys. The model was developed by performing exploratory data analysis, correlation, and multivariate regression analysis. From the study it was found that the sensitivity of the expected number of target crashes to changes in ISD is highest when ISD is shorter and decreases as ISD increases i.e., the safety benefit of increasing ISD from 300 to 600 ft is substantially larger than the safety benefit of increasing ISD from 1,000 to 1,300 ft. It was also found that crash frequency is more sensitive to changes in intersection sight distance when both speed limit and traffic flow increases. Zirkel *et al.* (2018) analysed relationship between sight distance, crash frequency, and operating speed at single lane roundabouts. In this study at each approach, 4 sight distances were measured they are intersection sight distance, upstream approach sight distance, circulating approach sight distance and circulating sight distance. Sites were classified into two categories based on posted speed limit of 40kmph and study was carried out separately for these. Category two sites exhibited larger number of crashes than category one. Crash prediction model was developed with crash rate as dependent and speed and various sight distance as independent variables. It was determined that as approach

upstream sight distance increased, crash rate decreased logarithmically.

Studies on Reduced Visibility

Chandra *et al.* (2021) devised a methodology which employs aerial photogrammetry to identify obstructions in intersection sight triangles. Obstruction was identified using three-dimensional models created from imagery collected from unmanned aerial surveys. Imagery of the intersection was taken from different positions. All the imagery were corrected for distortion and combined to form an Orthomosaic image. Orthomosaic image is stitched image present in a uniform scale to measure horizontal distances between features present on the image. 3-dimensional model of intersection is then developed by overlapping Digital Elevation Model and Orthomosaic image. This model was used to identify obstructions present in the sight triangles of intersection.

Achtemeier *et al.* (2019) studied the influence of restricted sight distance on driver stress and behaviour at a rural intersection using a driving simulator. The study was carried out on a total of 36 participants out of which 19 were men and 17 were women. Three scenarios were simulated by changing the intersection sight distance (400ft, 600ft, 1000ft) and effect of these scenarios on stress level and intersection crossing judgment was evaluated. Results indicated a significant relationship between stress experienced by drivers and sight distance. It was also found that a significant relationship exists between TTC (Time Taken to Collision) and sight distance. TTC at 400ft and 600ft was found to be significantly shorter than the TTC at 1000ft.

Studies on Critical Gap

Mohan *et al.* (2012) investigated influence of heavy vehicles in conflicting traffic on the critical gap under mixed traffic situations was explored. For the purpose of analysis, proportion of conflicting flow was classified as Small, medium, and large sized vehicles. Two- and three-wheeled vehicles were deemed to be of small size, while small and large car were of medium size, and all other vehicles were of large size. Critical gap was evaluated using occupancy time method. Critical gap increases logarithmically as the proportion of large-sized vehicles in conflicting flows increases. There was no correlation between critical gap and the percentage of medium and small-sized vehicles.

Abhigna *et al.* (2017) studied the how major road vehicles are impacted by gap acceptance behaviour of right turning vehicles from minor road under mixed traffic conditions. The study was

carried out on two three legged intersections (one from Kozhikode and other from Karimnagar). Traffic volume was divided into 6 categories Two wheelers, Three Wheelers, Four Wheelers, LCV, HCV and bus. It was concluded that the critical gap is largely influenced by combination of major stream vehicles which are offering gap. Smaller gap offered by combination of heavier vehicles were rejected, whereas same gap offered by combination of smaller size vehicles were found to be accepted.

Studies on Surrogate Safety Measures

Gastaldi *et al.* (2021) analysed safety at unsignalized intersections using bivariate extreme value theory. In this study, researcher modelled multiple Collision types using extreme value theory with help of multiple extreme variables. Two extreme value methods namely component wise maxima and excesses over a threshold method. These methods were applied to perform safety analysis under two different perspectives: 1. Single surrogate measure with two conflict points. 2. Single conflict point with two surrogate safety measures. The results for both perspectives were obtained using bivariate approaches and then compared with results of univariate approach. It was observed that in case first perspective, number of predicted collisions by bivariate approach were like collisions predicted by univariate approach. In case of second perspective, bivariate method predicted number of collisions when compared to univariate method.

Paul and Ghosh (2020) determined threshold value of post encroachment time for right turn related crashes at uncontrolled intersections. In this study, researchers employed both quantitative and qualitative methods of analysis. In quantitative analysis, the correlation between cumulative PET values below the assumed threshold and intersection crash data was identified. In qualitative study, intersections were rated according to cumulative PET less than the assumed threshold and crash-related data. Both approaches found a 1 second PET threshold. This threshold can be used to determine which conflicts are critical. Srinivasula *et al.* (2020) analysed safety of an unsignalized intersection by developing proximal safety indicators (surrogate safety measures). The safety indicators were developed for an uncontrolled intersection in Surat City. The safety indicator that was considered in the study was post encroachment time. Speed bumps were constructed at intersection so video of the same intersection was captured again after construction to analyse effect of speed bumps. Statistical tests indicated that speed bumps constructed had a significant effect on PET values. Crash frequency was estimated using extracted PET data.

Lakshmi *et al.* (2018) studied whether Post encroachment time can substitute intersection characteristics in crash prediction models. In this study, crashes predicted using PET data were compared with crash data available from crash records. For predicting crashes, different GLM models developed using PET data as independent variables crash frequencies obtained from the models were compared with actual crash frequencies. The results were mixed it was observed that at some intersections model was over estimating crashes. Second set of models was developed by considering both PET and traffic data. From this it can be concluded that, *PET alone* cannot completely represent crash scenario. Ma *et al.* (2018) used conflict probability and severity to develop safety heatmap for an uncontrolled intersection. In this study, along safety of entire intersection distribution of safety with in intersection is determined. Distribution of safety with in intersection is termed as safety heatmap. Safety index of entire intersection (safety map) is determined by considering safety level of each cell within intersection. In safety heat map developed, green indicates safe, yellow indicates marginally safe, orange indicates dangerous and red indicates seriously dangerous.

Paul and Ghosh (2020) developed a speed based proximal indicator to identify critical right turn conflicts at uncontrolled intersections. The study aimed to build a proximal indicator by analysing the speeds of through-moving vehicles and PET. Based on braking distance and PET, a speed parameter, critical speed, was computed and utilised to identify critical conflicts. The correctness of the method was determined by comparing it to intersection crash data. It was noted that when conflict speed increased, the number of critical conflicts also increased, and that there were more critical conflicts involving through-moving two-wheeler and other minor road vehicles.

Astarita *et al.* (2019) evaluated safety of intersections by simulating them using traffic simulation models. Three intersections (Complex Unsignalized, signalized and roundabout) were simulated using three simulation software's namely Aimsun, Vissim and Tritone and safety was evaluated using surrogate safety measure (Time to collision). Traffic and geometric data were used in modelling intersection. In case of VISSIM and Aimsun, only basic car following models i.e., Gipps and Wiedemann 99 were used and in case of Tritone, Gipps, Fritzsche, Gazis and Herman, IDM 2000, Wiedemann 99 were used. In case of unsignalized intersection, percentage of conflict varied from 9.02 to 24.63. Out of three intersections, it can be observed that Signalized intersection ranks

1st in terms of safety followed by unsignalized and roundabout.

From the literature review it is observed that, crash data is highly unreliable as it is generally underreported and using crash data is a reactive approach. In the present study, surrogate safety measures are used instead of crash data. Very limited number of studies have been carried out to determine influence of ISD quality on safety and even majority of these studies are driving Simulator Studies. Studies also did not consider the effect of difference in design and available intersection sight distance, ISD quality on safety. The present study considers all these measures instead of using crash data.

Study Area

The present study was conducted at a total of six different intersections. Out of six intersections, four are in the Warangal and other two are in Hyderabad.

The names of the intersections are Dargah intersection, Erragattu intersection, Madikonda intersection, Hunter-road intersection, NTR Circle and Ramnagar intersection. These intersections were selected after careful consideration of the geometric and traffic conditions that are typical at intersections, specifically the variations in sight distance along major and minor roads, traffic flow, vehicle proportions, turning movements, median presence, width of median, and length of median opening on major road. The Google Earth images of the study intersections are shown in Figures from 1 to 6.

All the study intersections three-legged intersections.

Data Collection

In the present study, geometric data, traffic data and sight distance quality were collected.



Figure 1. Dargah Intersection



Figure 2. Erragattu Intersection



Figure 3. Madikonda Intersection



Figure 4. Hunter road Intersection



Figure 5. NTR Circle



Figure 6. Ramnagar Intersection

Geometric Data

Geometric data such as sight distance along major and minor road, number of lanes, lane width, shoulder width, approach width, and length of median opening were measured in field using measuring wheel and tape. Geometric data of six intersections is tabulated in Table 2.

Sight Distance Data

For measuring sight distance, eye height and object height of 1.2 m. and 0.15 m. were considered. At a height of 1.2 m. and 0.15 m., markings were created on ranging rods, which were then utilised to simulate eye level and object height in field for measuring sight distance. At each intersection, three sight distances are measured i.e., sight distance along two major legs (towards left and right) and one minor leg as shown in Figure 7.

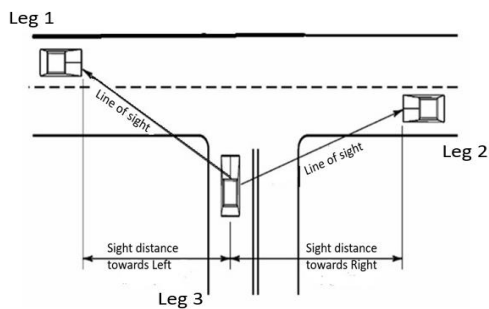


Figure 7. Sight distance along major road (leg 1 and leg 2)

Sight distances measured at six intersections are given in Table 3.

At six intersections, the sight distance along major roads varied from 8 to 32 metres, whereas it varied from 7 to 15 metres along minor roads. The available sight distance is far shorter than the design/minimum sight distance. According to IRC SP 41 (1994), the sight distance along major roads is 60 m and along minor roads it is 45 m.

Intersection Sight Distance Quality

ISD quality was obtained using Google earth image. In the present study, ISD quality is defined as percentage of sight triangle free of obstructions. Its value ranges from 0 to 100. A value of 80% indicates 20% of sight triangle is obstructed by buildings etc. At each intersection, major and minor roads are categorised according to the IRC functional classification, and the design speed of the roadways was obtained. For the obtained design speed, required sight distances were measured using IRC SP 41 (1994). As depicted in Figure 8, these sight distances were projected over Google earth images to generate sight triangles. After sight triangles are plotted, obstructions within the sight triangles are found, as depicted in Figure 8, and the area covered by these obstructions within the sight triangles was measured using Google earth. ISD quality was measured based on the area obscured and the area of the complete sight triangle. ISD quality measured is shown in Table 4.

Table 2. Geometric details of study intersections

Intersection	Approach	Number of entry lanes	Lane width (m)	Presence of median on (Yes/No)	Length of median opening (m)	Median width (m)
Dargah	Major	2	3.5	Yes	16.4	1.4
	Minor	1	5	Yes	—	1.4
Erragattu	Major	2	3.3	Yes	47	1.2
	Minor	1	4.5	No	—	—
Madikonda	Major	2	4	Yes	68	4
	Minor	1	4	No	—	—
Hunter-road	Major	2	3.3	Yes	15.4	1.2
	Minor	2	3	No	—	—
NTR Circle	Major	2	3.3	Yes	25	1.0
	Minor	1	5	No	—	—
Ramnagar	Major	1	4.75	No	—	—
	Minor	1	4.75	No	—	—

Table 3. Sight distances measured in field

Intersection	Sight distance along major road (m)		Sight distance along minor road (m)
	Towards left	Towards right	
Dargah	29	24	13
Erragattu	20	22	11
Madikonda	25	27	18
Hunter-road	11	32	16
NTR Circle	17	21	12
Ramnagar	10	8	7

It can be observed that ISD quality varied from 63.46% to 83.55%. Lowest quality was observed at Ramnagar intersection and highest quality was observed at Dargah intersection.

Volume data

Volume data was extracted manually by playing the recorded video in MPC-HC media player. While extracting, vehicle types are categorised into Two-wheeler, Three-wheeler, Car, Bus, Light commercial vehicle (LCV), Heavy commercial vehicle (HCV), and Tractor. These classified volume counts were extracted for each 5-minute interval. These 5-minute volume count data were utilised to identify peak hours at each intersection. Each intersection's peak hour flows and peak hour factor are listed in Table 5. Peak hour flows at the intersections varied between 2669.5 pcu/hr and 3288.5 pcu/hr. Peak hour factors at all intersections are close to 1, indicating uniform flow of traffic.

The percentages of different vehicle types at selected intersections are shown in Table 6.

It can be observed that the percentage of two-wheeler is more at all the intersections when

compared to other categories of vehicles. Proportion of two-wheeler is varying from 55% to 71%, which is more than half of the total traffic at the intersections. The proportion of car ranges from 15% to 20%, followed by the proportion of three-wheeler vehicle, which ranges from 8% to 14%. The proportion of light commercial vehicle varies between 2 and 6 percent. The percentage of heavy vehicle at intersections ranges from 1 to 6.

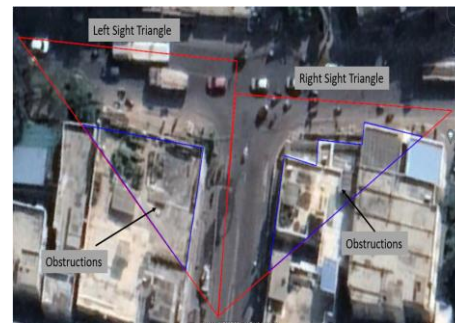


Figure 8. Intersection sight distance measurement at Ramnagar intersection

Table 4. ISD quality measured

Intersection	Area (sq. m) of		ISD quality of left sight triangle %	Area (sq. m) of		ISD quality of right sight triangle %
	Left sight triangle	Obstructions in left sight triangle		Right sight triangle	Obstructions in right sight triangle	
Dargah	1611	265	83.55	1292	265	79.49
Erragattu	838	163	80.53	682	160	76.53
Hunter-road	912	277	69.63	668	112	83.22
Madikonda	1619	365	77.47	1269	373	70.57
NTR Circle	1515	460	69.62	1296	242	81.27
Ramnagar	761	278	63.46	664	225	66.07

Table 5. Peak hour flows and peak hour factor

Intersection	Leg wise peak hour flow for each movement (pcu/hr)						Peak hour volume (pcu/hr)	Peak hour factor
	Leg 1		Leg 2		Leg 3			
	TH	RT	LT	TH	LT	RT		
Dargah	1630	106.5	175.5	1094	75	207.5	3288.5	0.93
Erragattu	1065	262	104	950	304	86.5	2771.5	0.94
Madikonda	933.5	296	112	966.5	383	81.5	2772.5	0.84
Hunter-road	1330.5	187	188.5	1120	202.5	141	3169.5	0.87
NTR Circle	610	524	245	608.5	456.5	319.5	2763.5	0.88
Ramnagar	735	212	266.5	976	216	264	2669.5	0.89

Table 6. Percentages of different vehicle types at study intersections

Intersection	TW%	3W%	Car%	LCV%	HV%
Dargah	62	17	15	2	3
Erragattu	56	14	20	4	5
Madikonda	55	13	20	6	6
Hunter-road	66	9	19	4	1
NTR Circle	71	8	15	3	3
Ramnagar	62	14	18	4	2

Post Encroachment Data

Post encroachment time is defined as the time difference between a vehicle leaving an encroachment zone and conflicting vehicle entering the same zone. For extracting PET data, time at which first vehicle leaves conflict zone (t_1) and time at which second vehicle enters conflict zone (t_2) were noted. Difference between these two times was noted as PET. First vehicle exiting the conflict zone is referred to as the offending vehicle, while the second vehicle ready to enter the conflict zone is referred to as the conflicting vehicle. Process of PET extraction is shown in Figure 9.

In order to extract PET data, grids were laid over the conflict area of the intersections. Process of laying grids over the conflict area is as follows: Firstly, grid of required size was drawn in AutoCAD software and then grid was exported as a PNG file. PNG file with a grid was superimposed on the video using Corel studio video editor. The grids were oriented in such a way that size of grid and distance marked on road are equal. After the grids were superimposed, the same software was used to process the video. The processed videos were

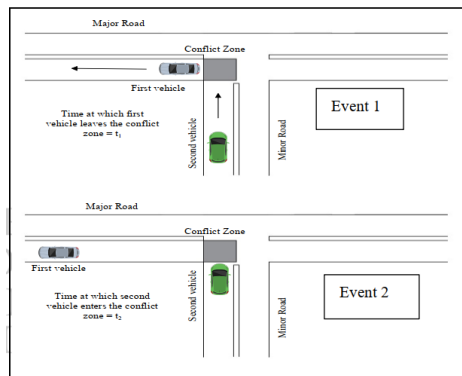


Figure 9. Intersection sight distance quality measurement at Ramnagar intersection

played using the MPC-HC media player, and timestamp at which first vehicle i.e., offending vehicle exits the grids in the conflict zone and timestamp at which second vehicle i.e., conflicting vehicle enters the same grid were recorded; post encroachment time was then calculated as the difference between these two times.

In the present study, PET data was extracted for two types of conflicts i.e., major through movement - minor right turn conflict and major right turn- minor right turn conflict. These two conflicts were only studied because sight distance at an intersection has major effect on these two conflicts. The average PET values for each study intersection are shown in Table 7.

Speed Data

In this study, speed data was required to determine whether a conflict is critical or not. The speed of each conflicting vehicle (second vehicle about to enter conflict zone) was utilised to decide whether a conflict is critical or not. Using grids designed for the extraction of PET data, speed was retrieved. The number of grids a conflicting vehicle crossed prior to reaching the conflict point and the time it took to traverse the grids were recorded. The number of grids traversed was used to calculate the distance travelled by the vehicle, from which the vehicle's speed was derived. Approaching speed of each type of vehicle at Dargah intersection are plotted in Figure 10.

Where, 2W = Two wheeler, 3W = Three Wheeler, Car = Passenger car, LCV = Light Commercial Vehicle, and HV= Heavy Vehicle. It can be observed that the average approaching speed of two-wheelers is higher compared to other vehicle types.

Modelling Critical Conflict Rate

In this section, the effect of various geometric and traffic factors on critical conflict rate was

Table 7. Average PET values

Vehicle combination	Average PET (sec)					
	Dargah	Erragattu	Madikonda	Hunter-road	NTR Circle	Ramnagar
2W-3W	2.40	2.32	2.42	2.62	2.54	2.21
3W-3W	2.54	2.39	2.69	2.89	2.79	2.29
Car-3W	2.98	2.71	2.81	3.51	3.44	2.75
LCV-3W	3.23	3.19	3.12	3.93	3.53	3.53
2W-Car	2.83	2.40	2.48	2.79	2.67	2.33
3W-Car	2.88	2.76	2.89	3.46	3.52	2.79
Car-Car	3.58	3.59	3.65	3.98	3.87	3.59
LCV-Car	3.53	3.01	3.02	3.96	4.01	2.98
2W-LCV	3.05	2.87	3.01	3.15	3.15	2.65
3W-LCV	3.13	3.11	3.09	3.95	3.56	3.59
Car-LCV	3.59	3.12	3.15	3.91	3.99	2.98

studied and models were developed with critical conflict rate as dependent variable and various geometric and traffic parameters as independent variables. Sight distance along major roads, sight distance along minor roads, intersection sight distance quality, right-turning vehicle percentage, vehicle composition, etc. were considered as independent variables. Correlation analysis was performed to determine the significance of variables. Based on Pearson's correlation coefficient, significance level, and t-statistic, significant variables were identified. Four intersections' data was used to develop the model, while two intersections' data was used to validate the model. The developed model was then used to determine the effect of various geometric and traffic variables on safety. Correlation and Regression analysis were performed for developing models for critical conflict rate.

Correlation analysis

Pearson correlation test was performed on various traffic and geometric parameters to check for correlation and identify significant variables. Significant variables were identified based on correlation coefficient, t-statistic, and p-value. The correlation matrix developed for the chosen variables is shown in Table 8.

Where, CCR = Critical conflict rate (conflicts/hr), S_{maj} = Sight distance along a major road in meters, S_{min} = Sight distance along a minor road in meters, I_q = Intersection sight distance quality in %, A_w = Approach width of a minor road in meters, A_s = Average speed of conflicting of conflicting vehicle in kmph, V = intersection volume in PCU/hr, P_{2w} = Percentage of two-wheeler in conflicting flows, P_{3w} = Percentage of three-wheeler in conflicting flows, P_{Car} = Percentage of car in conflicting flows, P_{LCV} = Percentage of LCV

in conflicting flows. It can be observed that critical conflict rate has a negative correlation with sight distances, ISD quality, and the percentage of car and LCV, and a positive correlation with the average speed of conflicting vehicles, intersection volume, the percentage of two-wheeler, and the percentage of three-wheeler. No correlation was observed between critical conflict rate and approach width. Multi-collinearity was also observed between speed, sight distance and ISD quality.

Regression analysis

Regression analysis was performed to develop model with critical conflict rate as explained variable and other geometric and traffic parameters as explanatory variables. Significant variables were identified by performing correlation analysis were used in development of models. Four intersections were used for modelling and two intersections were used for validation purposes. Out of the six intersections chosen for this study, Dargah

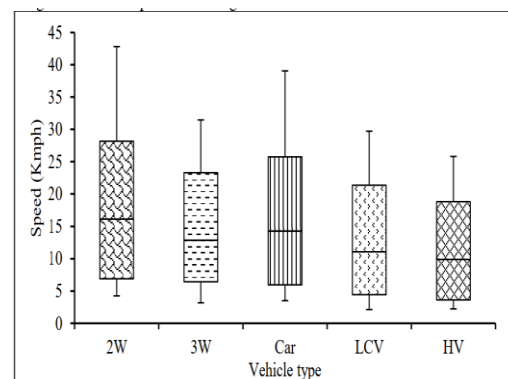


Figure 10. Speeds of conflicting vehicles with respect to vehicle type

Table 8. Correlation matrix indicating coefficient of correlation

	CCR	S_{maj}	S_{min}	I_q	A_s	V	P_{2w}	P_{3w}	P_{car}	P_{LCV}
CCR	1.00									
S_{maj}	-0.71	1.00								
S_{min}	-0.82	0.39	1.00							
I_q	-0.56	0.87	0.57	1.00						
A_s	0.55	0.57	0.27	0.59	1.00					
V	0.41	0.53	0.34	-0.14	-0.46	1.00				
P_{2w}	0.89	-0.61	-0.75	-0.75	0.51	0.68	1.00			
P_{3w}	0.75	-0.76	-0.44	-0.88	0.65	0.52	0.39	1.00		
P_{car}	-0.78	0.77	0.68	0.82	-0.45	-0.48	-0.47	-0.32	1.00	
P_{LCV}	-0.26	0.54	0.34	0.44	-0.57	-0.56	-0.50	-0.46	0.23	1.00

intersection, Madikonda intersection, Hunter-road intersection, and NTR circle are the intersections used for modelling. Erragattu and Ramnagar intersection are employed for validation. Various linear and nonlinear models were tried using a various combination of exploratory variables. Some of the logically valid models are discussed below.

Model 1: The relation between critical conflict rate, sight distance along major and minor roads, presence of median on major road and intersection sight distance quality is presented in Equation 1.

$$\text{CCR} = 103.383 - 0.364 \times S_{\text{maj}} - 1.822 \times S_{\text{min}} - 7.929 \times \text{POM} - 0.339 \times I_q \quad (1)$$

Where, CCR = Critical conflict rate (conflicts/hr), S_{maj} = Sight distance along major road in meters, S_{min} = Sight distance along minor road in meters, I_q = Intersection sight distance quality (%) and POM = Presence of median on major road (1 if exists, 0 otherwise).

The R^2 value of model is 0.722 and the standard error is 2.024. MSE, RMSE and MAPE values of model are 4.098, 2.024 and 3.003 respectively. The t-statistic and p-value of the variables present in model at a significance level of 5% are presented in Table 9.

Model 2: The relation between critical conflict rate, sight distance along major and minor roads, presence of median on major road and percentage of two-wheeler, percentage of car is presented in Equation 2.

$$\text{CCR} = 18.36 - 0.37 \times S_{\text{maj}} - 1.28 \times S_{\text{min}} - 5.28 \times \text{POM} + 0.77 \times P_{2w} - 0.28 \times P_{\text{car}} \quad (2)$$

Where, CCR = Critical conflict rate (conflicts/hr), S_{maj} = Sight distance along major road in meters, S_{min} = Sight distance along minor road in meters, P_{2w} = Percentage of two-wheeler in conflicting flow, P_{car} = Percentage of car and POM = Presence of median on major road (1 if exists, 0 otherwise).

The R^2 value of model is 0.799 and the standard error is 1.400. MSE, RMSE and MAPE values of model are 1.960, 1.400, and 2.037 respectively. The t-statistic and p-value of the variables present in model at a significance level of 5% are presented in Table 10.

Model 3: The relation between critical conflict rate, logarithm of sight distance along major and minor roads, presence of median on major road and intersection sight distance quality is presented in Equation 3.

$$\text{CCR} = 172.56 - 7.06 \times \ln(S_{\text{maj}}) - 32.81 \times \ln(S_{\text{min}}) - 11.25 \times \text{POM} - 0.31 \times I_q \quad (3)$$

Where, CCR = Critical conflict rate (conflicts/hr), S_{maj} = Sight distance along major road in meters, S_{min} = Sight distance along minor road in meters, I_q = Intersection sight distance quality (%) and POM = Presence of median on a major road (1 if exists, 0 otherwise)

The R^2 value of the model is 0.785 and the standard error is 1.865. MSE, RMSE, and MAPE values of the model are 3.479, 1.865, and 2.770 respectively. The t-statistic and p-value of the variables present in a model at a significance level of 5% are presented in Table 11.

Model 4: The relation between critical conflict rate, logarithm of sight distance along major and minor roads, presence of median on major roads

Table 9. p-value and t-statistic values of model 1

	Coefficient	t- statistic	p-value
Intercept	103.383	10.135	0.000
Sight distance along major road (m)	-0.364	-2.021	0.048
Sight distance along minor road (m)	-1.822	-6.226	0.000
POM (1 if exists, 0 otherwise)	-7.929	-3.859	0.003
ISD quality (%)	-0.339	-2.041	0.046

Table 10. p-value and t-statistic values of model 2

	Coefficient	t- statistic	p-value
Intercept	18.358	6.669	0.000
Sight distance along major road (m)	-0.370	-3.623	0.005
Sight distance along minor road (m)	-1.277	-5.603	0.000
POM (1 if exists, 0 otherwise)	-5.277	-3.861	0.003
Percentage of two-wheeler in conflicting flows	0.767	2.299	0.044
Percentage of car in conflicting flows	-0.284	-2.106	0.041

and percentage of two-wheeler, percentage of cars is presented in Equation 4.

$$\text{CCR} = 80.01 - 6.85 \times \text{Ln}(S_{\text{maj}}) - 24.57 \times \text{Ln}(S_{\text{min}}) - 8.11 \times \text{POM} + 0.70 \times P_{2w} - 0.28 \times P_{\text{car}} \quad (4)$$

Where, CCR = Critical conflict rate (conflicts/hr), S_{maj} = Sight distance along major road in meters, S_{min} = Sight distance along minor road in meters, P_{2w} = Percentage of two-wheeler in conflicting flow, P_{car} = Percentage of car and POM = Presence of median on major road (1 if exists, 0 otherwise)

The R^2 value of model is 0.856 and the standard error is 1.241. MSE, RMSE and MAPE values of model are 1.542, 1.242 and 1.784 respectively. The t-statistic and p-value of the variables present in model at a significance level of 5% are presented in Table 12.

Out of all models, model 4 which was developed by considering logarithm relation between sight distance and critical conflict rate gave highest R^2 value compared to other models.

Validation of model

The models developed were validated to determine the degree to which they represent the real system. Model 4 was validated using two intersections data: Erragattu and Ramnagar intersection. A graph was plotted between observed critical conflict rate values on the x-axis and predicted/expected critical conflict rates values on the y-axis. The data points proximity to the 45-degree line implies that the model is valid. Predicted critical conflict rate values are close to those observed from real field data, as shown in Figure 11. Between the expected and

observed critical conflict rate values, there is a high level of confidence ($R^2 = 0.86$).

Conclusions

The following are the conclusions from the present research work:

1. For a given conflicting vehicle (second vehicle entering conflict area), the average PET went up as the size of offending vehicle (first vehicle leaving the conflict area) increased. This is because when first vehicle leaving the conflict area is large, driver of second vehicle who is approaching the conflict area is found to be more careful and less aggressive.
2. Models developed with logarithmic relation between sight distances and critical conflict rate exhibited better prediction capabilities compared to models developed with linear relation. It is observed that for every 1 unit increase in logarithm of major and minor road sight distance, critical conflict rate decreased by 18.14% and 33.56% respectively. It

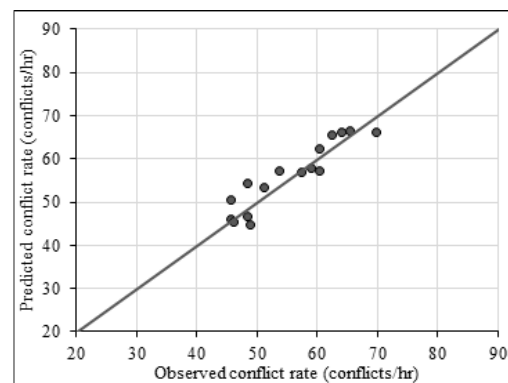


Figure 11. Validation of model 4

Table 11. p-value and t-statistic values of model 3

	Coefficient	t- statistic	p-value
Intercept	172.564	20.967	0.000
Ln(Sight distance along major road (m))	-7.056	-2.514	0.029
Ln(Sight distance along minor road (m))	-32.815	-8.730	0.000
POM (1 if exits , 0 otherwise)	-11.248	-5.650	0.000
ISD quality (%)	-0.312	-2.048	0.045

Table 12. p-value and t-statistic values of model 4

	Coefficient	t- statistic	p-value
Intercept	80.012	2.706	0.022
Ln (Sight distance along major road (m))	-6.854	-4.374	0.001
Ln (Sight distance along minor road (m))	-24.570	-7.613	0.000
POM (1 if exits, 0 otherwise)	-8.114	-5.788	0.000
Percentage of two-wheeler in conflicting flows	0.704	2.352	0.041
Percentage of car in conflicting flows	-0.281	-2.350	0.041

can be inferred that critical conflict rate is more sensitive towards minor road sight distance.

3. There is a decrease in critical conflict rate with an increase in intersection sight distance quality. It is observed that for every 5% increase in intersection sight distance quality, the critical conflict rate decreased by 2.13%.

4. There is a decrease in critical conflict rate when there is a median on major roads. It is observed that the critical conflict rate decreased by 8 conflicts/hr or 11.08% when the median is present on major roads. Even in the presence of a median opening, the critical conflict rate increases with an increase in the median opening. This is because the larger the median opening, larger the conflict area, which results in a higher number of conflicts.

5. There is an increase in critical conflict rate with an increase in percentage of two-wheelers in conflicting flow. This is because two-wheelers tend to approach intersections at faster speeds, thereby increasing the likelihood of critical conflict. It is observed that, for every 5% increase in the percentage of two-wheelers, the critical conflict rate increased by 4.81%.

6. There is a decrease in critical conflict rate with an increase in the percentage of cars in conflicting flow. It is observed that, for every 5% increase in percentage of cars, the critical conflict rate decreased by 1.92%.

7. The available sight distance is far shorter than the design/minimum sight distance specified by IRC SP 41 (1994).

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