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Surrogate Safety Evaluation at Uncontrolled Intersection in Non-Lane Base Traffic Conditions

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Abstract

Every year, road accidents cost billions of dollars and injure millions of people around the world. The current study implements traffic conflict techniques to examine vehicular safety at three-arm uncontrolled intersections. The traffic conflict technique is designed to be proactive, not solely rely on crashes, and require shorter observation time periods to create acceptable safety assessments. Various surrogate safety measures based on spatial and temporal proximity between road users, like Post Encroachment Time (PET), Time to Collision (TTC), Deceleration Rate (DR), etc., are being used to study road safety. The study focused on crossing conflicts by right-turning and through traffic, as they are considered severe among other conflicts. PET and conflicting vehicle speeds in through traffic are used to determine critical conflicts. However, Delta V and Encroachment Time (ET) are taken as surrogate indicators to identify severity levels of through and right turning movements, respectively, using the clustering technique..

Keywords: Surrogate Safety Measures, Post Encroachment Time, Critical Conflict, Severity Level, Conflict techniques

1. Introduction

Even though technology and infrastructure have improved, road safety has become a major problem in both developed and developing countries. Road traffic accidents are the leading cause of death for children and young people around the world. Each year, they cause about 50 million injuries and about 1.3 million deaths that could have been prevented. As things stand, injuries are predicted to result in around 13 million fatalities and 500 million injuries over the course of the following ten years, as well as obstruct sustainable development, especially in low- and middle-income countries. The Decade of Action for Road Safety 2021–2030 was proclaimed with the goal of "improving word-wide road safety" with the audacious goal of preventing at least half of traffic-related fatalities and injuries by the year 2030 (WHO, 2020). In developing countries, the situation is even worse where traffic conditions are heterogeneous. Road intersections are traffic merging points and hence are prone to accidents. Within the intersection category, three-arm intersections account for the largest share of accidents, deaths, and injuries (MoRTH 2019). As a result, assessing

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current road safety indications, particularly at uncontrolled three arms intersections in mixed traffic, becomes critical compared to other intersections. Previous studies show the majority of traffic safety assessments are based on the analysis of historical accident data, which is reactive in nature; it's as if they're waiting for a road accident to happen before implementing their remedies, which shows this approach has time and efficiency limitations Elvik (2002); Ahmed et al. (2013); Alsop and Langley, (2001); Tarko et al., (2009). Furthermore, researchers suggested a proactive way to solve the above problem with road safety based on traffic conflict techniques using different surrogate safety measures (SSMs) as an alternative way to measure collisions at different types of road geometry (Allen et al. 1978). The main benefit of this method is that it can help predict how often a road accident will happen because of bad road geometry or traffic characteristics caused by the different variables. This makes it a more efficient and reliable measure of traffic safety in the short term. A traffic conflict is defined as "an observable situation in which two or more road users approach each other in time and space to such an extent that there is risk of collision if their movements remain unchanged' (Amundsen and Hyden, 1977). Conflicts occur more frequently than crashes, and they are usually comparable in that conflicts imply proximity to a collision.
This study focuses on the proactive safety evaluation of three-arm intersections in Bhopal city. Suitable SSM parameters have been identified from the literature to assess the safety at uncontrolled intersections for right-turning conflicts. Surrogate safety indicators, namely post-encroachment time (PET) (Allen et al. 1978), conflicting speed (Paul and Ghosh, 2018), relative change in speed of the approaching vehicle (DeltaV) (Gabauer 2006) and encroachment time (ET) (Allen et al. (1978), are considered for the analysis safety of selected intersections. Additionally, several intersection sites have been selected based on the volume of traffic necessary to provide hazardous traffic cond itions. This study main objective is to define the percentage of observed critical conflicts based on PET and conflicting speed. The severity levels of safety measures have been defined using the clustering technique. The study outcomes will be useful for field engineers, planners, and decision-makers to understand the present scenario and provide appropriate safety measures.

2. Literature Review

In a country with a large population, such as India, traffic safety is still a mainly relay on historical crash base assessment. However, such an analysis is typically performed as an "after-thought" rather than proactively. Safety evaluation has historically based on police-reported crash data in order to decrease crashes. The analysis of traffic crash data can be useful to understand the general pattern of crash occurrence and to identify the primary contributory variables that can be useful in implementing necessary countermeasures. However, in addition to the other limitations associated with the traditional technique, non-availability of accident data and inaccurate information about the crash pattern and location are all too typical in developing countries (Alsop and Langley, 2001; Tarko et al., 2009; Salifu and Ackaah, 2012).
Additionally, understanding the diversity in safety analysis has been made possible by big data and network analysis applications. Big Data in the traffic sector made possible by the quick uptake of intelligent transportation systems, are continuously gathered over enormous geographic scales and, analysis using network approach despite appearing to be abstract and disorganized in nature, could be used to improve professional understanding of the transportation system.

Numerous areas are covered in studies on traffic safety, including modelling of real-time safety, crash frequency, human factors, economic evaluation, before and after analysis of safety evaluations, and modelling of injury severity. Analysis of big data in traffic safety that includes an evaluation of recent real-time crash prediction studies. Miaou and Lum (1993) investigated different linear and poisson regression models for defining relationships between vehicle accidents and geometric design characteristics. The author found that linear regression models are not accurate for estimating the probability of accidents. On the other hand, poisson regression models have the preponderance of favourable characteristics for describing the probability of accidents. Gua et al. (2019) looked at the correlations between intersections on corridors at two levels. In a conditional autoregressive model, the size of correlations is based on the distance between intersections, while a corridor-specific random effect was used to model the effect at the corridor level. With non-informative priors, Poisson and negative binomial Bayesian models were constructed, and the Deviance Information Criterion was used to check the performance of the model. It was found that the poisson spatial model provides the best fit. Russo & Vitetta (2006) proposed quantitative risk analysis models for risk analysis in the transportation system in an Italian city. For risk analysis purposes, the authors propose various evacuation techniques for medelling and designing the urban road network system under emergency conditions. Russo and Rindone (2021) examine regional transportation plans in a European city by assessing basic contents and comparing deepening the public transportation-related contents. However, other researchers like Marciano and Vitetta (2011) concentrate on model user characteristics and environmental conditions. The authors estimated an individual risk model of the driver and pedestrian involved in a crash scenario and the probability of pre-assigned conditions. The probability of the involved pedestrian being a particular age and sex was estimated using the aggregate model. The estimated model validated with crash data shows 95% significance. Where application of big data in road safety Klauer et al. (2014) evaluated the relationship between engaging in side tasks, such as using a cell phone, and the risk of collisions and near-collisions, author found that novice drivers were more likely to experience a collision or near-collision when engaging in side tasks like texting and using a cell phone. According to Hassan and Abdel-Aty (2013), the traffic factors that cause visibility-related crashes vary slightly from those that cause clear visibility crashes. Whereas analysis of safety in short interval, indirect traffic safety measures using conflict techniques that are 'proactive' in character and can be utilized instead of historical collision data for a more reliable and faster safety assessment Allen and Cooper (1978). Perkins & Harris (1968) stated traffic conflict as an operational tool based on evasive action taken by road users to avoid collision on the site to analyze road user behavior in accident situations concerning safety. Alhajyaseen (2015) studied proximal safety measures obtained from observation and video analysis and found to be beneficial in assessing safety at target locations based on their threshold values. PET readings were examined at an uncontrolled intersection with varying traffic volumes and speed on major and minor roads by taking PET threshold of 1.5sec. Babu and Vedagiri (2016) in their study recorded PET values and the speeds of their related conflicting through traffic to observe conflicts. Considering mixed traffic into account, Critical conflicts were discovered by Paul and Ghosh (2018), Babu and Vedagiri (2018) utilized critical speed, which was established using two surrogate safety indicators, speed of conflicting vehicles and PET. Paul and Ghosh (2019) estimated a suitable PET threshold for classifying critical conflicts in a highly heterogeneous traffic environment. and correlated PET values with crash data for considering different class of vehicles and observed PET threshold is 1 s. The intersections were ranked based on the cumulative number of PETs and accompanying crash data. Babu and Vedagiri (2016) proposed critical speed to identify critical conflicts which are calculated based on the braking distance concept for the particular critical value. They found that right-turning light motorized vehicles (LMVs) such auto-rickshaws, cars, and minibuses are more vulnerable than large vehicles (buses and trucks) and 2W. According to Reddy et al. (2019) traffic volume and operating vehicle speed have significant effects on crash probability at uncontrolled intersections, with an increase in vehicular speed resulting in a lower PET threshold frequency because the spatial gap between moving vehicles increases. Another study by Goyani et al. (2021) suggested the percentage of two-wheelers has a considerable impact on the percentage of critical conflict. The majority of research is carried out in developed countries with homogeneous traffic flow patterns. However, in developing countries, traffic characteristics and driving behaviour vary due to vehicle operational conditions and driver performance. Apart from that, there is currently no clear guidance on the use of surrogate safety measures to assess road safety. Very few works have been identified applying surrogate safety assessment to analyze vehicle conflicts nor have the safety implications on rural roads been explored. The current advancement in identifying technologies and in statistical methodologies makes possible to develop valid and practical surrogate-based methods of estimating and modeling safety. In the Indian context majority of SSM study has been conducted on PET, and speed of vehicles. So, other parameters like TTC, PSD, DeltaV, and ET need to be studied and reviewed. Need for an approach for the selection of safety indicators for different field conditions like type of intersection. The influence of Geometric, traffic, and operational characteristics on SSM indicators can be studied to identify influencing factors and can suggest counter measures accordingly.

3. Methodology

The methodology of a research project outlines the complete work process and plan for achieving the research objectives. The adopted methodology for the study is shown in Figure 1. From the collection of existing literature, various surrogate safety measures have been implemented and evaluated. In this research, safety assessment included surrogate safety indicators such as post-encroachment time, encroachment time, Speed conflicting vehicle, Delta V. This is a quantitative method for determining the state of a conflict while moving vehicles. Because traffic moving characteristics such as stop and yield signs are frequently absent at uncontrolled intersections, drivers have little control over their approaching speed. At intersections, the higher approaching speed of vehicles contributes to the severity of conflict that results in a collision. However safety assessment, Surrogate indicator PET alone cannot judge, severity of a conflict, the approaching conflicting speed of through traffic, is considered in determining the severity and frequency of a conflict and evaluating the intersection's safety. The extracted data is used for analysis, from which critical conflicts and clustering were defined to define the severity level of different intersections.

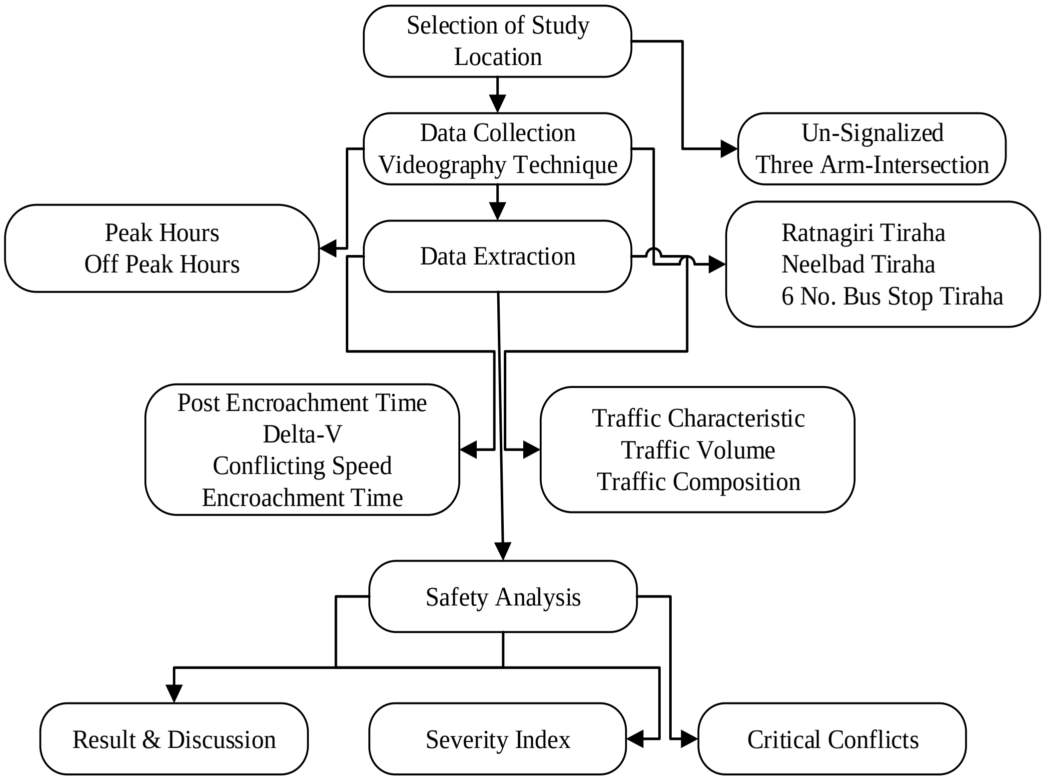


Figure 1: Methodology Flow Chart.

3.1 Data Collection and Extraction

The traffic data was collected using a video-graphy technique on a working day in October 2021 under fair weather conditions at the different three arm-uncontrolled intersections. Road inventory and traffic volume details of selected intersections are also collected and shown in Table.1 and Figure 3.

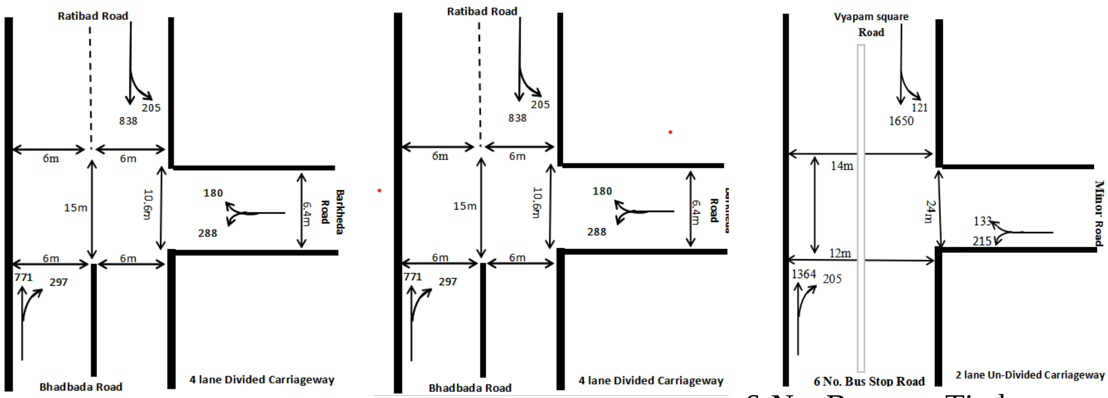
Table 1: Road Inventory and volume details at the intersections

Study Location	No. of lanes in approachess		Width of approaches (m)		Traffic volume (veh/hr)		
	Major	Minor	Major	Minor	Through	Right Turn	Left Turn
Ratnagiri Tiraha	6	6	3.5	3.5	2311	1126	512
Neelbad Tiraha	6	2	3	3.5	1609	477	493
6 No. Bus stop Tiraha	4	2	3	3	3014	338	336

Three uncontrolled intersections were selected based on having different geometric and traffic characteristics, including the presence of high-rise buildings near the location to capture data effectively, variable traffic demand at a different site to get more variations in safety indicators, vehicles travelling at the desired speed with less obstruction to flow, and both commercial and residential land use showing in figure 2. Further, to track the movement of turning vehicles, the conflict area is divided into grids of 3.5m x 3.5m squares, with a lane width of 3.5m, then overlaid with Kinovea software. Data extraction of 1hr (10 am to 11 am) has been performed at selected study locations to evaluate safety in this study. The time delay between the offending vehicle (turning vehicle) leaving the conflict grid and the conflicting vehicle (opposite through vehicle) entering the respective conflict grid is used to calculate PET values. The speeds of conflicting vehicles are also calculated by recording the time it takes to travel the distance between grids three to four grids. PET values and the speeds of related conflicting vehicles along with the type of right turning and conflicting vehicles are noted. Similarly, DeltaV, and ET have been also extracted from video using Kinovea.

Ratnagiri Tiraha Neelbad Tiraha 6-No. Bus Stop Tiraha

Figure 2: Camera views of intersections site



Ratnagiri Tiraha Neelbad Tiraha 6-No. Bus stop Tiraha

Figure 3 Road Inventory details of Intersections

3.1.1 Extraction of surrogate safety measures.

The use of different conflict indicators in the past has been explored in the literature. F or the purpose of analyzing the safety of road user interaction, some studies either selected a single indicator or incorporated multiple indicators. In order to classify the interactions between road users, the current research chose the four surrogate safety indicators of PET, conflicting speed vehicle, ET, and Delta V. Below is a process showing how the indicator are extracted

i. *PET*

PET data is traditionally taken from extracted using video by creating a grid topinpoint the area of conflict. The grid size for this experiment was established using sources from previous studies. By placing a grid in the same dimension as the intersection approach leg, PET data was extracted. For example, in Kinovea 8.27. Software (Kinovea, 2019), a perspective grid with a size 3.5x3.5 m (width of the approach legs) is produced and overlaid on the relevant video. Since unavailability of a reliable automaticdata extractor, parameters such as categorized traffic volume, PET, and vehicular speed were manually extracted using

Kinovea software by playing the recorded video at a rate of 20 frames per second. PET is the time differential between when the subject (right- turning) vehicle left the conflict area and when the opposing (straight-moving) vehicle enters. In this study, a total of 896, 404, and 450 vehicle-vehicle interactions were observedat Ratnagiri Tiraha, Neelbad Tiraha, and 6 No. Bus Stop Tiraha respectively The mean PET value obtained was 1.43s, 4.07s and 1.83s at Ratnagiri Tiraha, Neelbad Tiraha, and6 No. Bus Stop Tiraha respectively.

i. Speed of conflicting Vehicle

The speeds of conflicting vehicles before entering and after entering the conflict area are calculated by recording the time it takes to travel the distance between grids (threeto four grids). The mean conflicting speed observed at Ratnagiri Tiraha, Neelbad Tiraha, and 6 No. Bus Stop Tiraha are 18.43km/h, 20.33km/h, and 18.79 km/h respectively.

ii. Delta V

It is a change in speed over collision duration (Gabauer2006). Defined as the change in velocity between conflict velocity, and post-collision velocity.

Delta V = ‖V(aftercol) – V(beforecol)‖

The mean Delta V and unsafe vehicle type observed at Ratnagiri Tiraha, Neelbad Tiraha, and 6 No. Bus Stop Tiraha are shown in Table 2.

iii. Encroachment Time (ET)

Encroachment time was extracted from video-graphic data using Kinovea software as the time difference between entering and leaving time stamps in through traffic path by right-turning vehicles (as given in Eq.2). Which indicates time spend by right-turning traffic in a through traffic path (Allen1978).

ET(Rt) = texit (Rt) - tentry (Rt)

Where ET(Rt) is Encroachment of Right turning (Rt) vehicle
The mean Encroachment Time (ET) and unsafe vehicle type observed at Ratnagiri Tiraha, Neelbad Tiraha, and 6 No. Bus Stop Tiraha are shown in Table 2.

Table 2: Mean DeltaV and ET values at study locations

Study Location	Mean Delta V (Km/h)	ET(Sec)
Ratnagiri Tiraha	5.58	6.15
Neelbad Tiraha	3.79	4.28
6 No. Bus Stop Tiraha	5.58	4.27

4. Data Analysis

PET and conflicting speeds of through traffic are used to determine critical conflicts for right turning and through traffic conflicts. Further, Delta V, and Encroachment Time (ET) are taken as surrogate indicators to identify severity level of through and right turning movements respectively using the clustering technique.

4.1 Descriptive Statistics.

The following Table 3 shows the descriptive statistics of the extracted data at three study locations namely Ratnagiri Tiraha, Neelbad Tiraha, and 6 No. Bus stop Tiraha.

The aggregate mean, standard deviation, variance of the SSM indicators evaluated to assess the safety of 3-arms uncontrolled crossings in Bhopal City are shown in the descriptive statistics.

Table 3: Descriptive statistics of SSM parameters at study locations

Parameter	Total conflict	Range	Mean	Standard Deviation	Variance
Ratnagiri Tiraha					
PET	896	10.4	1.4	1.2	1.5
Conflicting Speed	896	42.0	18.4	6.9	47.8
DeltaV	440	46.5	5.6	5.7	32.8
ET	662	33.1	6.2	3.5	12.1
6 No. Bus Stop Tiraha					
PET	450	18.00	1.82	1.92	3.70
Conf. Speed	450	65.87	18.79	8.06	65.01
Delta V	394	40.35	5.98	6.17	38.14
ET	365	33.91	4.27	3.35	11.25
Neelbad Tiraha					
PET	404	18.00	4.06	3.56	12.71
Conf. Speed	404	39.58	20.32	6.57	43.17
DeltaV	404	23.81	3.78	4.03	16.28
ET	396	29.40	4.28	3.52	12.39

4.2 Distributions of conflicts for all right-turning vehicles with through traffic.

For a conflict with such PET value and speed of the conflicting vehicle, when right-turning vehicle just left the conflict area, the conflicting through vehicle is at a distance equal to PET times the conflicting vehicle's speed (PET × conflicting vehicle's speed). The conflict is not critical if this distance exceeds the stopping distance required for conflicting vehicle's speed. Conflict is critical if distance is shorter than stopping distance required Paul and Ghosh (2018), Babu and Vedagiri (2016). To distinguish between critical and non-critical conflicts, the distanceavailable is equated to braking distance. Because opposing vehicle drivers have already reacted to crossing manoeuvre, theperception distance was neglected. The formula v2/2gf is used to compute the braking distance 'd,' where v is the opposing vehicle's speed in m/s, g is gravity acceleration in m/s^2, and f is the coefficient of friction between the road surface and tyre. The critical speed for that PET value is computed using PET* 2 gf, which is calculated by multiplying the available distance by the braking distance. Using this method, critical speeds for specific PET levels are computed using g = 9.81 m/s^2, and coefficient of friction = 0.35. Table 4 shows critical speeds for various PET values. Table 4 shows the critical speeds for each PET group.

Available distance = Braking distance

$V \times PET = V^2/2gf$

Critical speed, $V = 2gf \times PET$

Table 4. Critical speed values for different PET value

PET(sec)	Speed (m/sec)	Speed (km/h)
0	0	0
0.5	3.44	12.4
1	6.86	24.7
1.5	10.3	37.1
2	13.73	49.4
2.5	17.16	61.8
3	20.6	74.2
3.5	24.03	86.5
4	27.46	98.9
4.5	30.9	111.2
5	34.33	123.6

conflicts found critical at Ratnagiri Tiraha, Neelbad Tiraha, and 6 No. Bus stop Tiraha respectively. At Ratnagiri Tiraha and 6 No. Bus stop Tiraha conflicts involving cars are found to be at a higher risk with 51.2%, and 30.7% conflicts involving cars are critical. Whereas, at Neelbad Tiraha two-wheelers are at higher risk with 24.66% conflicts involving two-wheelers are critical. While earlier studies by Babu and Vedagiri, Gupta et al. (2021), found that 20.3% and 71% of unsignalized intersections had critical at various intersections, Paul and Ghosh (2018) observed conflict varied from 32.57% to 83.21%, and Paul and Ghosh (2019) observed ranged from 18.7% to 29.5% as critical conflicts

Table 5. Distributions of conflicts for right-turning with through traffic at Ratnagiri Tiraha

PET (sec)		Cri. Speed	Ratnagiri Tiraha		Two-Wheeler		Three- Wheeler		LCV		Car	
LL	UL		PC	PCC	PC	PCC	PC	PCC	PC	PCC	PC	PCC
0	0.5	0.0	18.9	18.9	15.6	15.6	1.9	1.9	3.1	3.1	7.3	7.3
0.5	1	12.4	29.1	24.6	26.1	22.2	3.8	3.4	2.4	2.2	10.5	8.5
1	1.5	24.7	18.5	3.6	16.0	3.5	3.5	0.2	4.4	0.0	13.1	5.4
1.5	2	37.1	10.7	0.2	9.3	0.1	0.8	0.0	1.5	0.0	4.3	1.1
2	2.5	49.4	9.1	0.0	7.8	0.0	0.9	0.0	1.3	0.0	4.1	0.0
2.5	3	61.8	4.4	0.0	3.7	0.0	0.7	0.0	0.5	0.0	1.7	0.0
3	3.5	74.2	2.9	0.0	2.5	0.0	0.5	0.0	0.3	0.0	0.8	0.0
3.5	4	86.5	2.7	0.0	2.7	0.0	0.5	0.0	0.0	0.0	0.9	0.0
4	4.5	98.9	0.8	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.2	0.0
4.5	5	111.2	0.7	0.0	0.7	0.0	0.1	0.0	0.0	0.0	0.3	0.0
5	5.5	123.6	0.7	0.0	0.5	0.0	0.0	0.0	0.1	0.0	0.3	0.0
5.5	6	135.9	1.7	0.0	0.5	0.0	0.0	0.0	0.3	0.0	0.1	0.0
			100	**47.3**	85.9	**41.3**	12.5	**5.5**	13.9	**5.4**	43.6	**22.3**

Table 6. Distributions of conflicts for right-turning with through traffic at Neelbad Tirah

PET (sec)		Cri. Speed	Neelbad Tiraha		Two-Wheeler		Three-Wheeler		LCV		Car	
LL	UL		PC	PCC	PC	PCC	PC	PCC	PC	PCC	PC	PCC
0.0	0.5	0.0	9.9	9.9	8.7	8.7	2.0	2.0	1.7	1.7	2.5	2.5
0.5	1.0	12.4	8.3	7.9	8.2	7.9	0.7	0.7	0.5	0.5	2.7	1.5
1.0	1.5	24.7	8.2	1.0	7.7	1.0	8.2	0.5	8.4	0.0	16.8	0.3
1.5	2.0	37.1	7.8	0.3	7.7	0.3	0.7	0.0	1.5	0.0	1.2	0.0
2.0	2.5	49.4	7.5	0.0	5.7	0.0	1.2	0.0	1.0	0.0	1.5	0.0
2.5	3.0	61.8	6.3	0.0	6.2	0.0	0.7	0.0	0.3	0.0	2.2	0.0
3.0	3.5	74.2	7.2	0.0	6.7	0.0	0.5	0.0	0.5	0.0	1.7	0.0
3.5	4.0	86.5	7.5	0.0	7.7	0.0	0.5	0.0	0.7	0.0	1.2	0.0
4.0	4.5	98.9	4.0	0.0	3.0	0.0	0.3	0.0	0.5	0.0	0.3	0.0
4.5	5.0	111.2	4.3	0.0	4.5	0.0	0.5	0.0	0.3	0.0	0.7	0.0
5.0	5.5	123.6	4.2	0.0	3.5	0.0	0.3	0.0	0.5	0.0	1.0	0.0
5.5	6.0	135.9	25.0	0.0	3.0	0.0	0.7	0.0	0.0	0.0	1.0	0.0
			100	19.1	72.3	17.8	16.4	3.2	15.9	2.2	32.9	4.2

Table 7. Distributions of conflicts for right-turning with through traffic at 6 No. Bus Stop Tiraha

PET (sec)		Cri. Speed	6 No. Bus stop Tiraha		Two-Wheeler		Three- Wheeler		LCV		Car	
LL	UL		PC	PCC	PC	PCC	PC	PCC	PC	PCC	PC	PCC
0.0	0.5	0.0	19.3	19.3	16.2	16.2	2.2	2.2	1.8	1.8	9.1	9.1
0.5	1.0	12.4	21.6	17.1	19.1	16.0	3.1	2.2	0.9	0.4	8.7	7.1
1.0	1.5	24.7	15.8	3.6	12.9	3.3	5.1	0.4	4.0	0.0	17.6	4.4
1.5	2.0	37.1	14.2	0.4	12.9	0.4	0.9	0.0	1.3	0.0	6.0	1.3
2.0	2.5	49.4	8.4	0.0	7.6	0.0	0.9	0.0	0.9	0.0	4.2	0.0
2.5	3.0	61.8	4.0	0.0	3.6	0.0	0.7	0.0	0.2	0.0	1.1	0.0
3.0	3.5	74.2	3.6	0.0	3.6	0.0	0.2	0.0	0.2	0.0	1.8	0.0
3.5	4.0	86.5	4.7	0.0	4.7	0.0	1.1	0.0	0.0	0.0	0.9	0.0
4.0	4.5	98.9	1.1	0.0	1.1	0.0	0.2	0.0	0.0	0.0	0.4	0.0
4.5	5.0	111.2	1.6	0.0	1.1	0.0	0.7	0.0	0.0	0.0	0.7	0.0
5.0	5.5	123.6	0.7	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.4	0.0
5.5	6.0	135.9	5.1	0.0	1.1	0.0	0.0	0.0	0.4	0.0	0.2	0.0
			100	40.4	68.4	19.7	12.9	2.6	7.9	0.4	42	12.8

Note: Cri. Speed = Critical Speed, PC = Percentage of Conflicts, and PCC = Percentage of Critical Conflicts.

Table 8. Brief Summary of critical conflicts

Location	Severity Level	Total	Two-Wheelers	Three-Wheelers	LCV	Car
Ratnagiri Tiraha	Conflicts	896	770	112	124	391
	Critical Conflicts	424	370	49	48	200

	Percent of Critical Conflicts in overall conflicts	47.3	48.05	43.75	38.7	**51.2**
Neelbad Tiraha	Conflicts	404	292	66	64	133
	Critical Conflicts	77	72	13	9	17
	Percent of Critical Conflicts in overall conflicts	19.06	24.66	19.70	14.1	**12.8**
6 No. Bus Stop Tiraha	Conflicts	450	307	58	36	189
	Critical Conflicts	182	89	12	2	58
	Percent of Critical Conflicts in overall conflicts	40.44	29.00	20.69	5.55	**30.69**

Where, UL = Upper Limit of PET, LL = Lower Limit of PET and LCV = Light Commercial Vehicle.
Note: Percent of Critical Conflicts in Total conflicts = (Critical conflicts of that particular vehicle category)/(conflicts of that particular vehicle category).

4.3 Severity level categorization using indicators.

Encroachment time and Delta V are chosen as safety indicators to define severity levels of right turning and through traffic respectively at three intersections.Encroachment time was extracted from video-graphic data using Kinovea software as time difference between entering and leaving time stamps in through traffic path byright-turning vehicles (as given in Eq.1). Which indicates time spend by right-turning traffic in through traffic path (Allen1978). DeltaV is the is the change in speed over collision duration (as mentioned in Eq.2) and widely used in collision databases, whereit is typically calculated from post-collision measurements (Gabauer2006). Introducedin the late 1970s (Carlson1979), it uses the difference in speed to estimate the probability of a severe injury or fatality. Velocity before entering conflict is and after entering conflict are taken as velocities to determine Delta V which are extracted from Kinovea Softwareby drawing grids of 3.5m x 3.5m.

$$ET(Rt) = t_{exit}(Rt) - t_{entry}(Rt) \quad (1)$$

Where ET(Rt) is Encroachment of Right turning (Rt) vehicle

$$DeltaV = \|V(aftercol) - V(beforecol)\| \quad (2)$$

The severity of probable road crashes will increase with an increase in the value of DeltaV for through and ET for right turning. In order to classify the severity of probable road collision based on the DeltaV and ET, all the values are grouped using the clustering techniques. Cluster analysis is the process of categorizing itemsbased on data in the data set that describes their relationships. Clusters developed through an effective clustering technique tend to have a significant inter-cluster distance and a small intra-cluster distance Boora et al. (2017). In this study, K-means, 2 step clustering are used to classify severity levels based ET and Delta V. Both clustering techniques are well-known hard partitioning approaches that are particularly useful for forming small clusters from large datasets Lloyd (1982), Boora et al. (2017). After classifying the data, the silhouette index was used to validate the results of each clustering technique Spector (2011). This silhouette value, which represents the complete data set, demonstrates how well and precisely the data have been clustered. The cluster analysis and validation were carried out using Matlab software. A lower global silhouette value denotes weak clustering, while a larger value denotes a strong structure. Researcher Spector (2011) suggested that a cluster of high quality has a global silhouette value between 0.71 and 1.0. A value in the range of 0.51-0.70 denotes an acceptable structure, a value in the range of 0.26-0.50 denotes a weak structure, and a value of less than 0.25 denotes the absence of any significant structure. For 3 clusters, both approaches gave statistically significant good values. In the 2-step and K-mean clustering procedures, the silhouette range for the three clusters is between 0.6 to 0.8 (Table 9) which is thought to constitute a good cluster. Framework of ET and Delta V ranges of both clustering techniques threshold analysis for selected sites is shown in Table 9. However, the ET and Delta V ratio's range of values for each cluster shows that both strategies produce results that are identical. Therefore, the grouping values produced from the k-mean clustering technique have been taken into account in the current study to propose safety characteristic (severity level) at uncontrolled intersection of likely road crashes, as shown in Table 10 and Table 11. Severity level (SL) A, B, and C which denotes Safe, Moderately Safe, and Unsafe conditions of road users at uncontrolled intersections in mixed traffic conditions. The frequency of probable road crashes for unsafe condition based on their ET and DeltaV for selected intersections using K-means arepresented in Table 12. The results from Table 12 show that the percentage of unsafe right turn vehicles is more at Ratnagiri Tiraha with 5.65% whereas unsafe through is more at 6 No. Bus stop Tiraha with 6.19%.

Table 9. Results of Clustering Techniques along with Silhouette Index

Study Location	Threshold Values for ET	Severity Level	safety characteristic
Ratnagiri Tiraha	<6.435	A	Safe
	6.435 - 17.635	B	Moderately Unsafe
	> 17.635	C	Unsafe
Neelbad Tiraha	<5.089	A	Safe
	5.089 - 14.88	B	Moderately Unsafe
	> 14.88	C	Unsafe
6 No. Bus Stop Tiraha	<6.448	A	Safe
	6.448 - 16.82	B	Moderately Unsafe
	> 16.82	C	Unsafe

Table10. Classification of DeltaV (km/h) for severity of through traffic

Study Location	Parameter	Range		Thresholds	Silhouette Value	
		Min	Max		K-means	2-Step
Ratnagiri Tiraha	DeltaV	0.00	56.47	6.435, 17.635	0.7	0.7
	ET	0.80	33.85	6.525, 12.5	0.6	0.6
Neelbad Tiraha	DeltaV	0.00	23.81	5.089, 14.88	0.8	0.7
	ET	0.48	29.88	5.68, 16.14	0.7	0.8
6 No. Bus Stop Tiraha	DeltaV	0.00	40.35	6.448, 16.82	0.7	0.6
	ET	0.60	34.52	7, 27.76	0.7	0.6

Table 11: Classification of Encroachment Time (sec) for severity of Right Turning traffic

Study Location	Threshold Values for Delta V	Severity Level	safety characteristic
Ratnagiri Tiraha	<6.525	A	Safe
	6.525 - 12.5	B	Moderately safe
	> 12.5	C	Unsafe
Neelbad Tiraha	<5.68	A	Safe
	5.68 - 16.14	B	Moderately safe
	>16.14	C	Unsafe
6 No. Bus Stop Tiraha	<7	A	Safe
	7 - 27.76	B	Moderately safe
	>27.76	C	Unsafe

Table 12. Percentage of vehicles fall under unsafe conditions

Surrogate Indicators	Ratnagiri Tiraha	Neelbad Tiraha	6 No. Bus Stop Tiraha
Delta V	1.67	2.72	6.19
ET	5.65	1.52	0.27

5. Conclusion

This research provided a study that developed a methodology for evaluating a surrogate safety indicator, PET, and conflicting speed to measure traffic safety at three-arm uncontrolled intersections. Further, developed severity levels to assess the safety of through and right turning movement using DeltaV and ET. PET threshold values are used to determine critical conflicts. However, at intersections with mixed traffic and varying speeds, relying solely on PET to assess safety is insufficient. As a result, conflicts are observed in the current study employing two surrogate indicators PET, and related conflicting vehicle's speed. However, determination critical conflicts at intersections, the critical speed is used. The braking distance concept is used to find out the critical speed for a certain PET value. There is a substantial percentage of observed conflicts at the intersection are critical at intersections. This demonstrates that right-turning vehicle drivers are willing to take chances and accept short gaps in through traffic paths, which is unsafe. At Ratnagiri Tiraha, and 6 No. Bus stop Tiraha, conflicts involving cars are found to be at a higher risk with 51.2% and 30.7% of conflicts involving cars being critical. Whereas, at Neelbad Tiraha two-wheelers are at higher risk with 24.7% of conflicts involving Two- wheelers being critical. This could be owing to their high proportion of volumes and high speed. Moreover, surrogate safety indicators namely Encroachment Time (ET) and Delta-V are used to define severity levels of right turning and through movements. Three unsafe severity levels were developed namely less unsafe, moderately unsafe, and highly unsafe using the K-means clustering technique. Among three intersections Ratnagiri Tiraha found it unsafe for right-turning traffic with 5.65% of vehicles falling under severity Level C, and 6 No. Bus stop Tiraha found it highly unsafe for through traffic with 6.19% of vehicles falling under severity level C. The proposed approach provides a dependable method to identify unsafe crossings, unsafe movements, and reducing accidents by executing preventive management measures that exist in developing nations. The chosen surrogate indicator has been demonstrated to be useful for safety evaluation at uncontrolled intersections, especially for right-turn-related crashes, which are the most serve crashes of all crash types. These surrogate indicators can help proactive traffic engineers and safety experts choose the best traffic calming and management techniques to increase safety at uncontrolled intersections. Several counter measures like providing speed brakers, speed humps, and speed tables can be provided to reduce DeltaV which will eventually reduce ET and results in safer movements. The estimated crash probability, which is verifiable using field-reported crash data, could determine the direction of the research moving forward. This can be expanded to include more traffic facilities for research purposes, such as signalized intersections, four-arm uncrontrolled intersections, and the effects of various traffic calming measures on road safety in urban areas through the application of simulations. Future studies must incorporate detailed analysis of driver behavior along with the use of naturalistic driving studies and driving simulations.

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