Investigation of Traffic Conflicts at Unsignalized Intersection for Reckoning Crash Probability Under Mixed Traffic Conditions

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Abstract: The present study aims at assessing traffic conflicts at unsignalized T-intersection under mixed traffic conditions using Surrogate Safety Measure (SSM), namely Post Encroachment Time (PET). The traffic movement data were collected during peak and off-peak hours at an un-signalized T-intersection having a central island using videography survey technique. Traffic characteristics (classified traffic volume) and PET data were extracted manually for the recorded video. To assess safety, primarily, the extracted PET values were tested for its distribution and Generalized Extreme Value (GEV) was found to be the best-fitted distribution for explaining the temporal variations observed in PET values. This was subsequently also extended to estimate the crash probability. Results indicate that the smaller vehicles have higher safety implication at un-signalized T-intersection. Probability of crash was found to vary substantially with respect to vehicle type and their combination based on offending and conflicting vehicle types, traffic volume and composition.

Keywords: Un-signalized intersection, Safety, Post Encroachment Time (PET), Generalized Extreme Value (GEV)

1. INTRODUCTION

Traffic safety is an important and growing concern in the developing world because it affects the nation's economy and people's welfare. Rapid economic development has escalated the demand for travel. Sprawling cities in conjunction with population boom and unavailability of the efficient and effective public transportation system has developed proclivity towards commuting through personalized vehicles. Further, automobile-oriented development with rising income levels among Indian middle-class population has made car and motorcycle ownership more affordable. As per 2011 statistical data, the vehicular population of India is
observed to increase exponentially at a rate of 10%. Extortionate vehicular growth has significantly increased the likelihood of crash and exposure to conflict, as the supportive infrastructure is incapable to sustain such rapid vehicular growth. In developing countries like India, 17 lives are lost, and 55 accidents happen every hour (as per the report from Ministry of Road Transport and Highways; MoRT, 2017), accentuating the necessity to develop a reliable strategy to enhance safety.

A substantial number of intersections on the feeder and local streets, in a city, are un-signalized, primarily because of low-traffic volume on some or all approaches and the cost of installing signals. Large numbers of vehicle-to-vehicle and vehicle-to-pedestrian conflicts are the potential cause for crashes at any given un-signalized intersection. The proportion of conflicts increases under heterogeneous traffic conditions, prevailing in India. To efficiently regulate maneuvering through un-signalized intersections, regulatory signs and priority rules are set to minimize the dilemma faced by the drivers and hence, thereby reducing the likelihood of a crash. However, a lack of compliance by drivers to the aforementioned standards (regulatory signs and priority rules) has increased the probability of crash significantly. As per records of MORTH, 2016, 37% of total accidents took place near the vicinity of the intersection. Within traffic intersections, specifically uncontrolled intersections contributed to a major portion of road accidents underscoring the importance of traffic control mechanism at intersections (MORTH, 2016). Therefore, it becomes inevitable to assess safety levels at un-signalized intersections and further, understand the numerous aspects of roadway geometric conditions, traffic characteristics and road user behaviour, along with vehicular stream characteristics, contributing to crash occurrences.

2. LITERATURE BASE

In India, unsignalized intersections operate quite differently in comparison with their Western counterparts. Be it an all-way stop controlled or two-way stop-controlled one, traffic signs associated with the priority rules such as the stop and yield signs are not respected by the drivers due to the nonexistence of enforcement. The priorities are basically established by the situation’s drivers perceive (Ashalatha and Chandra, 2011; Patil and Pawar, 2014). Because of this undisciplined traffic environment, unsignalized intersections essentially function as uncontrolled ones, where vehicles from all the directions attempt crossing and turning at the same time, therefore increasing the probability of crashes. Traffic conflict studies have been carried out in the past by several researchers to identify hazardous traffic situations by observing instances when drivers took evasive actions to avoid collisions like sudden changing of lanes, hard braking, etc. Some conflict studies have made use of quantitative measurements in terms of time and space proximity between vehicles using video technique. However, for effective implementation of this technique, it is necessary that the conflicts are well-defined and are determined accurately. A unified definition was proposed at the first workshop on traffic conflict to provide some consistency in conflict definition. 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 a risk of collision if their movements remain unchanged’ (Chin and Quek, 1997). Accepting this general definition of conflicts, researchers have projected conflicts as potential collisions of low degree of danger, pre incidents of a collision, and near miss accidents. There are many proximal safety indicators like time to collision (TTC), post encroachment time (PET), and deceleration rate (DR) which are defined as measures of crash proximity, based on temporal and spatial measures that reflect the closeness of road users, in relation to a projected point of collision. Previous research studies
have shown that there is a good correlation between accident rates and conflicts. Gettman and Head (2003) and Gettman et al. (2008) found relatively weak relationship between traffic conflicts and crash rates.

PET is the most suitable and popular proximal safety indicator for determining crossing conflicts (Klunder et al. 2004). Conflicts with low values of PET are potential accidents as there might not be enough time available to the driver of a conflicting vehicle to respond and take evasive actions such as braking or changing lanes, to avoid collision with the offending vehicle. Critical conflicts are judged based on a certain value of PET which is termed as threshold values of PET. However, it is difficult to determine how short the threshold value of PET should be to identify a critical conflict. It is seen that different drivers have different response times and they might also undertake different evasive actions depending upon vehicle’s performance and prevailing traffic conditions (Sultan and McDonald, 2003). PET threshold values used by researchers as 1s (Archer 2000) and as 5s (Caliendo and Guida 2012) where critical conflicts are determined if PET values are less than the threshold value. Conflicts with PET values less than 1 s are generally unsafe (Archer 2000; Klunder et al. 2004). Conflict studies have also been carried out using simulation and the simulated conflicts are compared with actual crash data where the good correlation between conflicts and accidents have been obtained (Ozbay et al. 2007; Dijkstra et al. 2010; Caliendo and Guida 2012). Caliendo and Guida (2012) in their study used SSAM software for determining conflicts at unsignalized intersections. The software generates conflicts based on two surrogate safety measures TTC and PET corresponding to a vehicle to vehicle interaction. The software takes the default threshold values for TTC and PET as 1.5 and 5 s, respectively. Critical conflicts have been identified taking the default threshold values and compared with the actual crash data of the intersections. A good correlation between recorded crashes and critical conflicts computed by SSAM was observed.

Pirdavani et al. (2010) in their study introduced simulation-based method of traffic safety evaluation of unsignalized intersections under different traffic conditions. They used a micro simulator to observe PET values for different traffic volumes and varying speeds on both roadways of the intersection. With an increase in the volume of major roads, the probability of finding large gaps in through traffic becomes smaller and consequently, crossing vehicles from minor roads start accepting smaller gaps, thus low values of PET are recorded. Results show that with the increase in traffic volumes and posted speeds PET values decrease and worsen the safety of the intersection. Babuand Vedagiri(2016) in their study observed that the right-turning LMV (cars, Auto and minibus) are at higher risk as compared to HV (bus and truck) and TW. This may be due to the size of the turning vehicle.Killi and Vedagiri(2014) in their study assessed the level of traffic safety at an uncontrolled intersection using microsimulation modeling under mixed traffic. Authors simulated three different conditions: 1) % increases or decrease in traffic volume, 2) % change in the composition of vehicle and 3) increase or decrease in speed of 5kmph or 10kmph. Vogel (2002) identified that headway and TTC are independent of each other for following vehicles. Due to the fact that TTC values cannot be smaller than headway values, a short headway can be interpreted as potential danger. Samir et al. (2015) identified two major finding: 1) Prospective conflict zone can be identified by using Post Encroachment Time method, 2) Speed enforcement measures can be used to minimize chances of crashes at intersections. Pawar et al. (2019) studied the effect of driving environment on the probability of a crash. Authors observed the lesser probability of crash for divided un-signalized T-intersection was observed to be less than that of undivided un-signalized T-intersection. Paul and Ghosh (2018) in their study understood that right-turning vehicles accept smaller gaps in between the fast moving through vehicles (PTW and LMV) and the conflicts associated with these categories.
are more critical. The percentage of critical conflicts are found to be more when conflicts occur between all right turners and through moving vehicle categories of PTW and LMV.

Several researchers have carried out conflict study using PET as surrogate measure and critical conflicts are determined by taking a threshold value of PET. Further, a significant number of studies have analyzed traffic conflicts at un-signalized intersections. In addition, the effect of traffic volume and traffic composition on safety is assessed using micro-simulation. However, very limited studies signifying the effect of traffic volume and traffic composition using empirical dataset exists. Further, under heterogeneous traffic conditions, where vehicles with diverse static and dynamic characteristics with loose-lane discipline interact in multiple dimension analyzing traffic conflict becomes even more complicated. With this motivation, the present study attempts to analyze traffic conflicts at un-signalized intersection under mixed traffic conditions, prevailing in India. The scope of the study is strictly restricted to un-signalized T-intersections as they contribute significantly to the total fatalities among uncontrolled intersections.

3. RESEARCH METHODOLOGY

Based on the comprehensive review of the available literature, the research methodology adopted for the present study is systematically illustrated in Figure 1. The research methodology adopted is briefly explained through the following sub-sections.
3.1 Study Location

To assess safety at an uncontrolled intersection, an un-signalized T intersection with a central island located in Surat, India, is selected. The selected intersection is characterized by three different approaches viz. L1, L2, and L3. The L1-approach comprises of the minor road where vehicles are taking right-turn to merge in the major-road traffic stream. L2 approach comprises of the major road where vehicles are taking right-turn to diverge from the mainstream to join the minor road traffic stream. L3 approach comprises of a major road through traffic. Major road and minor road are characterized based on the priority movement defined in INDO-HCM (2018). Road inventory detail and the illustration of different types of conflicting movement is depicted in Figure 2.

![Figure 2. Road inventory detail of the subject study locationalong with different types of conflicting movements](image_url)

3.2 Data collection and Extraction

The traffic data was collected during peak and off-peak hours at the subject un-signalized T-intersection using videography technique. For collecting traffic data, High Definition (HD) camera was placed on top of the high rise building in the vicinity of the study intersection, as a vantage point to capture the traffic movement in all directions. The camera was adjusted such that the naturalistic behaviour of vehicle drivers can be captured. Videography was conducted on a normal working day during peak and off-peak hours (capable of representing entire day scenario) in mid of November 2018 under ideal weather conditions. In the absence of reliable automatic data extractor, traffic characteristics like traffic volume, vehicle composition, vehicle type and Post Encroachment Time (PET) were extracted manually for the recorded video using Avidemux 2.6 software.

To extract PET values, primarily, intersection area boundaries were marked during a road inventory survey to represent the conflict area in the video file with respect to approach legs. This was done during free-flow conditions with the assistance of traffic police. Thereafter, an image of grid, equal size (3.5m×3.5m) to the respective approach leg’s width was drawn in AutoCAD and overlaid in the respective video file at the marked intersection boundary using Corel Video Studio Pro X9 software. Further, Avidemux 2.6 software with 0.04 second accuracy was used for data extraction. Basically, PET is the time gap amid the
completion of encroachment of turning vehicle (T1) and the time that the through vehicle reaches at the potential point of collision (T2) as shown in Figure 3.

\[ \text{PET} = T2 - T1 \]

Where,
T1 = time, when the offending vehicle leaves the conflict zone;
T2 = time, when of the conflicting vehicle enters the conflict zone

Conflicts analogs to PET values less than 6 seconds are considered for further analysis. This threshold value was considered based on the fact that PET values more than 6 seconds have significantly less chance of near-crash occurrence (Vogel, 2003). Further, negative PET values were also noted during data extraction and were considered for analysis (Vedagiri and Killi, 2015; Pawar et al., 2019). The negative values in PET values can be observed because either offending vehicle or conflicting vehicle has accelerated or decelerated while manoeuvring through the conflict area. It was also observed that for one subject vehicle there can be more than one value of PET, therefore, the minimum PET value is considered for further analysis (Mishra et al., 2017; Pawar et al., 2019).

![Figure 3. Methodology to extract PET values from videos (manually)](image)

PET values were extracted for both peak and off-peak hours, to contemplate the effect of traffic volume on the probability of a crash and hence safety at un-signalized intersections. A total of 2637 numbers of conflict during peak hours and 310 numbers of conflict during free flow condition were extracted.

4. DATA ANALYSIS

Preliminary analysis revealed that the traffic composition at the subject intersection is dominated by motorized two-wheeler (59%) followed by three-wheelers (29%) and cars (3%). The combined composition of LCV, HCV and Bus was observed to be 9%. Such consistency was observed for both peak and off-peak hours. The traffic volume (through traffic) was observed to vary from 980veh/hr to 3000veh/hr. Further, the right turning volume was observed to vary from 550veh/hr to 2000veh/hr.
4.1 Traffic Conflict Assessment

Traffic conflict is defined as an observable situation in which two or more road users approach each other in space and time to such an extent that there is a risk of collision if their movements remained unchanged (Hyden, 1977). Due to lack of quality traffic accident database, researchers have adopted the use of traffic conflict techniques to assess safety. For the present study, traffic conflicts were assessed using post encroachment time (PET) as it is most suitable surrogate safety measure to analyse crossing conflicts (Gettman and Head, 2003; Klunder et al., 2004; Archer and Young, 2010; Peesapati et al. 2013). At any un-signalized T-intersections, right-turning (RT) movements are more severe as compared to left-turning and through (straight) movements. Therefore, only RT interactions were considered to assess safety at the subject study location (Pawar et al., 2019).

To evaluate safety at an intersection, extreme value theory is applied to estimate the probability of crash values as the theory deals with the estimating rare occurrence of an event, i.e., crash for the present case. Towards this purpose, PET dataset for different vehicle types and their combinations based on conflicting and offending vehicle type as per approach leg was checked for its potential statistical distribution. Based on the goodness-of-fit indices, Generalized Extreme Value (GEV) distribution was observed as the best-fitted distribution among different potential statistical distributions. Disaggregating dataset by offending-conflicting vehicle type combination provides microscopic information regarding traffic conflicts and therefore can facilitate the assessment of safety at microscopic levels. Figure 4 represents a sample frequency distribution plot for different vehicle types for both peak and off-peak conditions.
Based on the principle that PET value less than zero represents critical conflict conditions (Mishra et al., 2017), the menace of undergoing a crash in a one-hour interval is corresponding to the probability of PET between -1 and 0 (Hyden, 1996; Archer, 2005). Because if the PET value is greater than -1 there is enough time available to the driver to control their manoeuvring and pass safely at an intersection. The obtained probability of a crash, and hence prevailing safety-level, were analyzed for four different aspects:

1. Effect of vehicle type and its combination
2. Effect of Traffic volume
3. Effect of Traffic composition
4. Effect of queueing at the intersection

### 4.2 Effect of Vehicle Type and its Combination

The probability of crash was obtained for a different vehicle type and its combination based on offending-conflicting vehicle type, to comprehend the effect of vehicle characteristics on safety. Four combinations of offending-conflicting for each type of offending vehicle were bifurcated to calculate the probability of crash at microscopic levels based on vehicle type. Table 1 and Table 2 summarizes the probability of crash during forced flow (peak hour) and free-flow (off-peak) condition of the day respectively.
Table 1. Probability of crash for peak hours by approach leg and offending-conflicting vehicle type combination

<table>
<thead>
<tr>
<th>Offending Vehicle</th>
<th>Offending-Confliction vehicle combination</th>
<th>Probability of Crash</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>L1</td>
</tr>
<tr>
<td>2w</td>
<td>2w-All</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>2w-2w</td>
<td>0.26</td>
</tr>
<tr>
<td></td>
<td>2w-3w</td>
<td>0.23</td>
</tr>
<tr>
<td></td>
<td>2w-4w</td>
<td>0.22</td>
</tr>
<tr>
<td></td>
<td>2w-other</td>
<td>0.17</td>
</tr>
<tr>
<td></td>
<td>3w-All</td>
<td>0.21</td>
</tr>
<tr>
<td></td>
<td>3w-2w</td>
<td>0.20</td>
</tr>
<tr>
<td></td>
<td>3w-3w</td>
<td>0.30</td>
</tr>
<tr>
<td></td>
<td>3w-4w</td>
<td>0.38</td>
</tr>
<tr>
<td></td>
<td>3w-other</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>4w-All</td>
<td>0.24</td>
</tr>
<tr>
<td></td>
<td>4w-2w</td>
<td>0.24</td>
</tr>
<tr>
<td></td>
<td>4w-3w</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>4w-4w</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>4w-other</td>
<td>*</td>
</tr>
</tbody>
</table>

*data insufficient for estimation
Other: LCV, truck and bus dataset combined

Table 2. Probability of crash for off-peak hours by approach leg and offending-conflicting vehicle type combination

<table>
<thead>
<tr>
<th>Offending Vehicle</th>
<th>Offending-Confliction vehicle combination</th>
<th>Probability of Crash</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>L1</td>
</tr>
<tr>
<td>2w</td>
<td>2w-All</td>
<td>0.11</td>
</tr>
<tr>
<td></td>
<td>2w-2w</td>
<td>0.12</td>
</tr>
<tr>
<td></td>
<td>2w-3w</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td>2w-4w</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>2w-other</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td>3w-All</td>
<td>0.17</td>
</tr>
<tr>
<td></td>
<td>3w-2w</td>
<td>0.17</td>
</tr>
<tr>
<td></td>
<td>3w-3w</td>
<td>0.21</td>
</tr>
<tr>
<td></td>
<td>3w-4w</td>
<td>0.26</td>
</tr>
<tr>
<td></td>
<td>3w-other</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>4w-All</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td>4w-2w</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>4w-3w</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>4w-4w</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>4w-other</td>
<td>*</td>
</tr>
</tbody>
</table>

*data insufficient for estimation
Other: LCV, truck and bus dataset combined
From the above tables, it can be concluded that the probability of crash varies with respect to offending-conflicting vehicle type combinations, approach of an intersection and traffic volume. Probability of crash was observed to be higher when minor road vehicle performs right turn operation to merge into a major stream. This can be attributed to poor yielding behaviour of vehicles in major stream and as a result, vehicles in minor stream accepts smaller gaps, thereby, increasing the probability of crash significantly. Therefore, driving behaviour significantly influences safety at un-signalized intersection. Consistency in observation was noted for both peak and off-peak periods. Further, the probability of crash was higher when 2w and 3w were conflicting vehicle for both peak and off-peak periods. Based on combinations of conflicting and offending vehicle types, 2w-2w, 2w-3w, 3w-2w and 3w-3w were identified as critical cases for both peak and off-peak conditions, with respect to their probability of crash values. Therefore, it can be concluded that 2w and 3w exhibit risky behaviour compared to cars. Further, for a given combination of offending-conflicting vehicle type, probability of crash was higher for peak periods compared to off-peak periods, highlighting the effect of traffic volume on crash probability and hence safety at unsignalized intersections.

4.3 Effect of Traffic Volume

To contemplate the effect of traffic volume on the probability of crash, traffic volume (volume of conflicting vehicle) was aggregated at every 5-minute interval. Considering heterogeneous traffic conditions, vehicular volume was normalized using PCU values reported in INDO-HCM (2018). Thereafter, traffic volume was clustered into three flow levels, i.e. flow level 1 (< 100PCU/5min), flow level 2 (100-200PCU/5min) and flow level 3 (>200PCU/5min). To comprehend the effect of traffic volume, probability distribution plots of PET values for different flow levels were laid on the same set of axes as represented in Figure 5.

![Figure 5. Probability distribution plot of PET values for varying flow levels.](image)

What can be observed from the graph is that, the location (mean) of the distribution shifts towards the left side with an increase in volume levels. This signifies that the number of conflicts increases with an increase in traffic volume. This can be attributed to the fact that at a lower volume, larger gaps are available, and a result driver accepts larger gap values to merge into traffic stream. However, with an increase in traffic volume, gap size decreases.
Further, poor-yielding behaviour forces the drivers to accept smaller gaps to merge into traffic stream at higher volume, thereby, increasing the probability of crash. Therefore, the volume of through traffic significantly influences safety at un-signalized intersections.

4.4 Effect of Traffic Composition

It is well articulated that; traffic composition has a significant effect on traffic operations at un-signalized intersection. Therefore, it can affect safety at un-signalized intersection. The following section analyses the effect of traffic composition on safety at un-signalized intersections. Since the traffic composition was dominated by 2w (average 59%), it was deemed appropriate to consider 2w proportion for analysing the effect of traffic composition on safety at un-signalized intersection. To comprehend the effect of traffic composition, the proportion of 2w was cluster into different ranges. The effect of traffic composition on safety was analysed for both cases (a) varying proportion of 2w in conflicting volume (b) varying proportion of 2w in offending volume.

4.4.1 Varying proportion of 2w in conflicting volume

Primarily, proportion of 2w in conflicting volume was cluster into three groups (a) <45% (b) 45-60% and (c) >60%. For the considered proportion of 2ws, probability distribution plots of PET were plotted on the same set of axes as shown in Figure 6.

![Figure 6. Probability distribution plot of PET for a different proportion of 2w in conflicting stream](image)

It can be noted from Figure 6 that, with an increase in the proportion of 2w in the conflicting stream, the mean of the distribution shifts towards the left side, which indicates that the critical conflict increases with increase in two-wheeler proportion. The mean value of PET was 1.5sec when the proportion of 2W was lesser than 45%, while the same reduces to -1.5sec when the proportion of 2w is greater than 60%. As the average PET values reduced with increase it proportion of 2w in the conflicting stream, it is apparent that the probability of crash would increase with an increase in the proportion of 2w in a traffic stream.
4.4.2 Varying proportion of 2w in offending stream

Similarly, to the previous section, the proportion of 2w in conflicting volume was cluster into three groups (a) <45% (b) 45-60% and (c) >60%. For the considered proportion of 2ws, probability distribution plots of PET were plotted on the same set of axes as shown in Figure 7.

A similar observation is also noted, when the proportion of 2w in offending stream decreases, the mean value of PET shift towards the right side, indicating a reduction in crash probability values. However, an increase in proportion of 2w in offending stream has marginally lesser values of probability of crash compared to the proportion of 2w in a conflicting stream. This can be attributed to the fact that if the proportion of 2w increases in conflicting stream, chances of them yielding to right turning vehicle decreases, as a result, the right turning is forced to accept smaller gaps to merge into the traffic stream.

4.5 Effect of Queueing with Varying Traffic Volume and Vehicle Types

At an intersection, it is apparent that one conflicting vehicle may interact with multiple offending vehicles and vice-versa. Under such conditions, it becomes imperative to examine how vehicle (either conflicting or offending) with different level of interaction (one-one or one-many) have effect on the probability of crash, hence, the safety of the intersection. Since the number of samples for one offending and many conflicting vehicles were very less for drawing conclusion, only interactions of one conflicting with multiple offending is studied comprehensively. Towards this purpose, cases of one-to-one interaction and one-to-many interactions were bifurcated. A total of 8 cases (one conflicting to multiple offending) were identified and were coded as 1V to 8V. To analyze these cases, the probability distribution of PET values for different cases were plotted on the same set axes.
From the above Figure, it can be noted that as the conflicting vehicle interacts with more than one vehicle, the mean value of PET shifts towards the right side. This signifies that the number of critical conflicts reduces with an increase in the level of interaction (one-to-many interaction). Therefore, the probability of crash decreases with an increase in the level of interaction (one conflicting interacting with many offending). The probability of collision was found to decrease from 0.22 for 1V to 0.08 for 8V. This can be attributed to the fact that, as the number of interacting offending vehicle with one conflicting vehicle increase, the offending vehicle gets more time to take its decision to either to move or wait for some acceptable gap. For the present study, a substantial difference in crash probability is noted when more than three offending vehicles are interacting with one conflicting vehicle. To probe further, this phenomenon was analysed in detail by bifurcating conflicting vehicle based on its vehicle type. Towards this purpose, again probability distribution plots of PET for a different type of offending vehicle having multiple interactions with conflicting vehicle was plotted as shown in Figure 9.
Figure 9. Probability distribution plot of PET for a different level of interaction cases when conflicting vehicle types are (a) 2w (b) 3w (c) car (d) other.
From Figure 9, it can be concluded that, for different category of conflicting vehicle, if the conflicting vehicle interacts with a greater number of offending vehicles, the probability of crash decreases. However, the magnitude of decrease in crash probability is dependent on the category of conflicting vehicle. For the same number of interactions i.e., 1V or 2V, the crash probability is higher when the conflicting vehicle type is 2w or 3w. Because of smaller dimension size of 2w and 3w, drivers in the offending stream exhibit aggressive behaviour. However, the driver in the offending stream exhibits less aggressive behaviour when the conflicting vehicle is a car. Therefore, it can be concluded that smaller vehicle types like 2w have significant implications on safety at un-signalized intersections.

To probe further, the effect of traffic volume on one-to-many interaction was comprehended. Towards this purpose, probability distribution plots of one-to-many interactions under varying traffic flow levels were plotted as shown in Figure 10.

![Graph showing probability distribution plots for 101-200 PCU/5 MIN](image)
It can be noted that as the conflicting vehicle interacts with more offending vehicles the probability of crash decreases. However, the magnitude of the same is dependent on traffic volume. If the volume is low then there is large gap available to the driver so that they can move safely but, with an increase in traffic volume, the probability of crash for one conflicting multiple offending vehicle cases increases. One conflicting vehicle interacts with more than three offending vehicles than there is a decrease in the probability of crash because they have enough time to take a decision either they go or wait for some suitable gap.

To probe further, for a given interaction level 1v or 2v, probability distribution plot of PET for varying traffic flow levels were plotted to contemplate the effect of traffic volume on safety. The probability distribution plot is presented in Figure 11.
Figure 11. Probability distribution plot of PET for different level of interaction cases (a) 1V (b) 2V (c) 3V (4V)
As shown in the above figures, it can be clearly noted that, for a given level of interaction, variation in traffic volume, causes variation in the mean value of PET and hence, crash probability. For a given level of interaction, higher probability of a crash is observed for higher traffic volume. This corroborates the observation that traffic volume has a significant effect on safety at un-signalized intersection. Further, as the level interaction increases, the probability of crash decreases.

5. FINDINGS AND CONCLUSION

Driver’s acceptance or rejection decision for the available gap plays an important role while manoeuvring through the intersection. Irrespective of vehicle type, drivers risk themselves, if they accept small gaps in through traffic, which is found to be consistent with observations reported by researchers (Babu and Vedagiri, 2016). The present study attempts additionally to assess safety at un-signalized intersection using safety surrogate measure, named PET under mixed traffic conditions for estimating crash probability. Towards this purpose, un-signalized T-intersection with Central Island is selected. Safety evaluation of the subject intersection was assessed based on vehicle type, traffic volume, traffic compositions and level of interactions. Some of the important findings drawn from the study are as follows:

1. A minor street offending vehicle while performing right running operations are at higher risk compared to vehicles in major stream performing right turning operations.
2. Probability of crash was observed to vary with respect to vehicle type and their combination based on offending and conflicting vehicle. Therefore, vehicle type and their characteristics have an influence on the safety of traffic operations at un-signalized intersection.
3. Traffic volume significantly influences probability of a crash. Higher probability of crash is observed for higher traffic volume ranges.
4. Traffic composition similarly influences crash probability at un-signalized intersections. The higher proportion of 2ws in the conflicting or offending stream, higher is the crash probability.
5. The study analyses the effect of level of interaction (one conflicting vehicle interacts with one or more than one offending vehicle). It was noted that, as the number of offending vehicles interacting with conflicting vehicle increases, the crash probability decreases.
6. Smaller size vehicles have a significant impact on safety implications at un-signalized intersections.

The present study presents a detailed investigation into traffic conflict analysis at un-signalized T-intersections under mixed traffic conditions. The study corroborates the effect of traffic volume, traffic composition on safety implication at un-signalized intersections. It is apparent that safety at un-signalized intersection is greatly influenced by road geometry. The study provides significant insights that extensive studies on safety at un-signalized intersections under varying roadway geometry and traffic control is required to develop appropriate safety measures.
REFERENCES


