ABSTRACT

As the pedestrian’s rapid progress, pedestrian safety has recently assumed greater importance in the research population activities. To assess road user interactions at an unsignalized junctions with heterogeneous traffic complexity, innovative trajectory-based data was used and to make urban intersections safer for road users, the proposed severity levels will be used to test and evaluate numerous infrastructures and control upgrades. Study authors suggests an advanced pattern-based technique to characterize pedestrian-vehicle interactions based on road user behaviors. Surrogate safety measures (SSM) can be estimated more accurately with this study than with the regular grid-based analysis. In order to evaluate SSM (Speed, Time to Collision, Gap Time, Time to pedestrian crossing, Safe Distance and Stopping sight distance with trajectory data are to be estimated. Support Vector Machine (SVM) is used to classify severity grades based on specified indicators generated at an unsignalized junction in India. From the analysis, Severity at the intersection found as 8.12, 8.91 sec respectively, Average gap time, stopping sight distance also calculated. Plots between Time to Collision and Gap Time for pedestrian passing first (PPF), vehicle passing first (VPF) are compared by developing a linear regression model and R²=0.684, 0.656 developed with some independent parameters respectively. Concluded that TTC for PPF is higher than VPF and by considering all the evaluated values this research had improved the methods for analysing and improving the safety of uncontrolled intersections.

Keywords: Un-signalized junctions, Surrogate safety measures, Pedestrians safety, Trajectory data, pedestrian passing first, vehicle passing first, Support Vector Machines.

1. Introduction

More than 1.35 million people have been killed or injured because of road traffic accidents worldwide, according to the Global Status Report on Road Safety 2018, with 90 percent of these deaths occurring in developing nations and 11 percent occurring in India alone. Due to pedestrians’ rapid progression, pedestrian safety has recently assumed greater importance in the research population activities. And use of conflict analysis, surrogate safety measures have proven to be a useful method for studying pedestrian safety because it identifies both quality and quantity issues. Children aged 5-14 and adults between 15 and 29 years of age die most frequently from accident-related causes, according to World Health Organization statistics. Pedestrians, cyclists, and motorcyclists account for 54% of all accident-related deaths worldwide (MORTH, 2019). As pedestrian safety becomes even more critical when traffic is heterogeneous, as it is in India, where different types of vehicles share the same road space without any segregation or lane following behaviour. It is harder to identify accurate conclusions about pedestrian safety based on a limited amount of quality and quantity of collision data. Due to the lack of high-quality accident data, surrogate safety measures (SSM) are important in developing countries like India. Gap Time (GT), Time to collision (TTC), Post Encroachment Time (PET), Deceleration to safety time (DST), and Conflicting Speed are some of the indicators used in the literature [1]. When analysing pedestrian safety, it is critical to choose the best way to indicate evasive actions by other road users. Evasive action is a concept that describes the actions taken by drivers to prevent a collision. If you want to prevent a collision, you can change your direction while crossing the street or increase or decrease your speed to do so. Selected indicators and relevant interactions must be used in order to estimate the severity levels for mixed traffic conditions. A new generation of video processing tools has made it possible to automate pedestrian safety assessments utilizing SSM by applying automated conflict
analysis. Various SSMs have been computed using trajectory data for vehicle to vehicle and pedestrian to vehicle interactions by some researchers. As compared to vehicle-to-vehicle interactions, pedestrian to vehicle interactions are very uneven since pedestrians walk slower and can stop and accelerate quickly. Problems occur when attempting to analyse pedestrian to vehicle interactions in varying traffic conditions and conflict indicators must be used accordingly.

A semi-automated safety analysis will be used in this study to examine pedestrian to vehicle interactions behaviour. Vehicles operating in a mixed traffic conditions will be tracked to evaluate pedestrian interactions. For better comprehension, the study recommends two patterns of road user behaviour. The patterns are based on continuously changing conflict indicators. Conflict indicators are selected and categorized for three types. They are safe passage, critical occurrence and conflict based on the pattern analysis.

2. Literature Studies
To make urban intersections safer for road users, the proposed severity levels will help test and evaluate various infrastructure and improvements. Uncontrolled intersections can be evaluated and improved with the help of this research, which provides a comprehensive framework for doing so [1]. A support vector machine (SVM) classification method has been used to classify severity levels for 1144 events extracted from three intersections in Shanghai. Researchers found that different conflict indicators contributed differently to determining the severity level under various interaction patterns [2]. On specific roads, this paper evaluates the pedestrian vehicle collision risk in order to determine whether pedestrian intervention is needed such as road improvements [3]. From this study it was revealed that the pedestrian will be at higher risk when SD is 1.75 m for VPF case and 19 m for PPF case. This study results can be a supplement to the existing guidelines for pedestrian safety, and provide insight to the practitioners in developing safe and efficient traffic facilities [4]. A six-day traffic flow study was conducted on a small route at a four-way intersection with stop signs. Vehicle headway and TTC were determined to be independent in a car-following condition. While the ratio of short headways is largely consistent across the junction, the percentage of short TTC values fluctuates. Small headways create potentially hazardous circumstances, thus using headway for enforcement is advised. For traffic safety evaluations, TTCs should be utilised instead since they show the actual occurrences of potentially harmful events [5]. In order to predict conflict, a support vector machine model was created. It was then tested against real-world data collected in the field. Unbiased analyses were carried out in order to determine which variables had a significant impact on conflict. Lanes 1 and 2 predict data with a 78% and 85% accuracy respectively [6-10].

3. Methodology
3.1 Study Approach
Researchers have used road crash data and SSM extensively in past to examined and inspected the safety for many different road facilities. A pattern-based approach to pedestrian-vehicle interaction behaviour is examined in this study using trajectory data. Depending on which road user passes the conflict zone first, the interaction behavior will be as follows:

1. Any of the following can be observed when a vehicle passes first (VPF)
   a) A pedestrian withdraws, slows down, or stops until the vehicle passes.
   b) A pedestrian might change their path and move to the end of the vehicle.
   c) A vehicle may accelerate through the conflict point before a pedestrian arrives.

2. Any of the following behaviour can be observed when a pedestrian passes first (PPF)
   a) Stopping or changing the path of a vehicle's brakes.
   b) Prior to the arrival of a vehicle, a pedestrian accelerates and passes the conflict zone.

It is possible to study in detail the above behavior, as well as any evasive action taken by any of the road users, using the trajectory data collected. Road users’ behavior will be categorized into patterns based on their interactions. According to the results of this study, Indicators such as TTC, GT, and Speeds
were used to calculate the pattern in SSM-based systems. The next section explains how the indicators were selected.

3.2 Data collection and Extraction
A literature studies are conducted based on the trajectory data related to vehicle to pedestrian interaction. Then study area selected as High-Tension Junction, Kukatpally, Telangana which is represented in Fig.1, as it is feasible for recording video from elevation. Data was collected using video-graphic method.

![Map of India](image1.png)

**Figure 1:** Study location

At the intersection where the interactions are to be studied, at a certain height, video cameras were put in order to capture the needed crosswalks. Data which gets from video-graphic method is extracted using software. As a result of the study, focus on pair-wise interaction, only interactions between a pedestrian and a vehicle were considered. When vehicles are driving in mixed traffic without lane following, this task can be challenging. Various automatic tracking software is used by the authors to extract the data they need. However, the tracking was not very accurate. If you want to track more than one item, you can utilize a semi-automated tracking software (i.e., data from sky), which offers a good degree of accuracy in the x, y coordinates which is a free source software in the field of traffic analysis, it is commonly used to track commuters and estimate commuters’ speeds.

For the selected intersection, the peak hour volume (PHV) and peak hour factor (PHF) is extracted from 12hours video graphic data and represented in Table 1 and Fig.2. Finalized that from the morning 8.00am to 11.00am is having peak flow and evening 4.00pm to 7.00pm having the peak flow is shown in table 2. So, in these particular times only calculated the vehicle to pedestrian interactions.
Table 1: PHV and PHF

| Time          | PHV (veh/hr) | PHF  |
|---------------|--------------|------|
| 8.30am - 9.30am | 5909         | 0.948|
| 5.30pm - 6.30pm | 5874         | 0.964|

Figure 2: Peak hour volume of 12 hours data.

Table 2: Percentage Frequency and Percentage Cumulative Frequency w.r.to Speeds

| Speed Range | Mid Speed | No. of Vehicles | No. of Pedestrians | Frequency | %Frequency | Cum Frequency | % Cum Frequency |
|-------------|-----------|-----------------|-------------------|-----------|------------|--------------|----------------|
| 0-10        | 5         | 7064            | 441               | 7505      | 48.18000899| 7505         | 48.18000899    |
| 10-20       | 15        | 4208            | 11                | 4219      | 27.08480452| 11724        | 75.26481351    |
| 20-30       | 25        | 3457            | 0                 | 3457      | 22.19297682| 15181        | 97.45779033    |
| 30-40       | 35        | 382             | 0                 | 382       | 2.452333569| 15563        | 99.9101239     |
| 40-50       | 45        | 13              | 0                 | 13        | 0.083456378| 15576        | 99.99358028    |
| 50-60       | 55        | 1               | 0                 | 1         | 0.006419721| 15577        | 100            |

Table 3: Percentile speeds at the HT Junction

| Percentile speeds | HT Junction (kmph) |
|-------------------|--------------------|
| Design Speed (98th) | 26                 |
| Safe Speed (85th)  | 18.5               |
| Median Speed (50th) | 6                  |
3.3 Data Analysis

3.3.1 Selecting and calculating the surrogate safety measures

This understanding led to a selection of surrogate safety indicators including Speed, TTC, Gap Time to classify road user interactions. Events were classified based on their speed (explained below) as shown in Fig. 3 and Table. 3, while their severity was assessed using the TTC, GT.

Speeds of each vehicle and pedestrian are calculated by considering the entry and exit time when they crosses the intersection after installation of the gates in the software and with known dimensions of junction i,e., north-south direction 34m, east-west direction 20m.

Calculation of the indicators can be as follows:

Here $D_v(t)$ is the distance from the conflicting zone to the front of the vehicle at time(t). The $D_p(t)$ is the distance from the conflicting zone to the front of the pedestrian at time(t). All kinds of each conflicting vehicles length and widths are given as (L) and (W) respectively. Speeds of vehicles and pedestrians at time (t) are given as $V_v(t)$ and $V_p(t)$ respectively.

Table 4: Shows the Length and Width of each vehicle

| Vehicle Type | Vehicles Included       | Size (m) |
|--------------|-------------------------|----------|
|              |                         | Length (L) | Width (W) |
| 2W           | Motorcycles, Scooters   | 1.72      | 0.7       |
| 3W           | Autos                   | 2.2       | 1.2       |
| 4W           | Cars, LCV               | 4.2       | 1.7       |
| HV           | Std Bus                 | 11        | 2.44      |

Each indicator is estimated using two scenarios: the scenario where the pedestrian passes before a motor vehicle does, as well as a scenario where the motor vehicle passes before the pedestrian (all the indicators are calculated in seconds). TTC, GT are as follows:

3.3.2. Time to Collision

Hayward was the first to propose the idea of computing a time to collision (TTC). If they continue at their current speed and on the same path, he defined it as "the time required for two vehicles to collide." According to Hyden, lower TTC values are termed as higher conflict severities.

A change to the calculation of TTC was recommended in the latest report. By looking at the numerator of Equation, you can see that the different widths of the vehicles are taken into account with a factor W.
The concept of varying widths should be taken into consideration when studying pedestrian interactions with several kinds of vehicles. Pedestrian to vehicle interaction has been examined in the past only with one type of vehicle i.e., car. As part of this study, other pedestrian-vehicle interactions were also examined and is given in Fig.6 and Fig.7. Changes in vehicle type affect the conflict zone width, which has an impact on TTC calculation when a pedestrian crosses the junction first (as shown in Equation), and the same is applicable for GT estimation.

Time to collision when pedestrian passes first,

$$\text{TTC} (t) = \text{Maximum} \left( \frac{D_p + W}{V_p(t)} \frac{D_v(t)}{V_v(t)} \right)$$

In Eq.1 the reason for considering the maximum will give you the safe TTC rather than the Critical TTC and similar is the case for Eq.2.

Time to collision when vehicle passes first,

$$\text{TTC} (t) = \text{Maximum} \left( \frac{D_p}{V_p(t)} \frac{D_v(t)}{V_v(t)} \right)$$

TTC min = minimum (TTC(t))

For each collision, the TTC is calculated, and a set of values are obtained. To determine the maximum severity of this interaction, the TTC minimum (sec) is extracted from this set.

3.3.3. Gap Time

Gap time when pedestrian passes first,

$$\text{GT} (t) = \left| \frac{D_p(t) + W}{V_p(t)} - \frac{D_v(t)}{V_v(t)} \right|$$

Gap Time when Vehicle passes first,

$$\text{GT} (t) = \left| \frac{D_p(t)}{V_p(t)} - \frac{D_v(t) + L}{V_v(t)} \right|$$

GT min = minimum (GT(t))

For each collision, a pair of values are extracted for the GT between the conflicting vehicles and pedestrians. To determine the maximum severity of this interaction, the GT min (sec) is extracted.

3.3.4. Evaluation of safe distance

From the tables 4,5, all vehicles were divided into four categories and it shows the vehicle composition at the study location. Two-wheelers and four-wheelers make up the majority of the traffic, heavy vehicles accounted for only 3.3 percent of the total. It is extremely rare for a heavy vehicle to collide with a pedestrian. For all 241 & 271 cases the trajectory data was used to calculate the safe distance, speed of vehicles and pedestrians, stopping sight distance.

| Vehicle Category | Vehicle Composition (%) | Type Interaction | Total Samples | Safe Distance | Mean Speed of Vehicle/ Pedestrian (kmph) | Stopping Sight Distance |
|------------------|-------------------------|------------------|---------------|---------------|------------------------------------------|------------------------|
| 2W               | 40.25                   | PPF              | 39            | 3             | 61.9 16.83 6.33 14.122 16.83             |
|                  |                         | VPF              | 58            | 0.5           | 24.3 7.8 6.71 7.32 24.69                 |
| 3W               | 16.6                    | PPF              | 14            | 1.81          | 104 24.83 6.44 16.8 24.18               |
|                  |                         | VPF              | 26            | 0.59          | 24 7.59 7.592 4.9 23.5                   |
| 4W               | 39.83                   | PPF              | 52            | 0.35          | 61 14.24 6.27 11.99 14.24               |
|                  |                         | VPF              | 44            | 0.125         | 7.15 21.5 5.48 5.73 17.44               |
| HV               | 3.32                    | PPF              | 5             | 3.1           | 26.2 17.5 6.75 9.81 17.57               |
|                  |                         | VPF              | 3             | 1.33          | 27.3 16.72 8.2 4.85 39.8                |
### Table 6: Summarizes the Descriptive Statistics of Morning Flow on Wednesday of a Week

| Vehicle Category | Vehicle Composition (%) | Type Interaction | Total Samples | Safe Distance | Mean Speed of Vehicle/Pedestrian (kmph) | Stopping Sight Distance |
|------------------|-------------------------|------------------|---------------|---------------|-----------------------------------------|------------------------|
|                  |                         |                  |               | Min | Max | Mean | Standard Deviation |                               |                        |
| 2W               | 42.44                   | PPF              | 48            | 2.66 | 52.4 | 14.32 | 5.81                  | 13.89                     | 21.22                   |
|                  |                         | VPF              | 67            | 0.81 | 23.8 | 6.6   | 6.43                  | 7.16                      | 20.86                   |
| 3W               | 17.34                   | PPF              | 18            | 2.1  | 92.7 | 19.55 | 5.98                  | 18.81                     | 23.53                   |
|                  |                         | VPF              | 29            | 0.46 | 26.8 | 6.24  | 7.12                  | 4.6                       | 22.71                   |
| 4W               | 34.69                   | PPF              | 36            | 0.38 | 54.9 | 12.89 | 7.86                  | 10.65                     | 16.79                   |
|                  |                         | VPF              | 58            | 0.125| 7.15 | 21.5  | 6.21                  | 4.91                      | 20.82                   |
| HV               | 5.54                    | PPF              | 9             | 2.65 | 18.5 | 14.4  | 6.59                  | 6.72                      | 13.8                    |
|                  |                         | VPF              | 6             | 1.1  | 24.6 | 17.1  | 7.67                  | 6.58                      | 28.64                   |

### 4. Results and Discussion

From this figure 4, PPF having very high time to collision and very less critical points for pedestrians so they can be safe if they pass first before the vehicle crossing them with safety. Overall 110 cases are observed from that just 8 cases are very critical.

![Figure 4](image-url)

**Figure 4:** A plot between the comparison of obtained TTC w.r.to PPF for Pedestrian and Vehicle

From this figure 5, VP are taking very less time to collide with pedestrians and very high critical points compared to PPF. So, pedestrians will be in critical position when VPF. Overall 131 cases are observed from that 24 cases are very critical.

![Figure 5](image-url)

**Figure 5:** A plot between the comparison of obtained TTC w.r.to VPF for Pedestrian and Vehicle

#### 4.1 Severity of the Junction

In order to evaluate the severity, time which is minimum as to be consider
Table 7: Showing the severity of the junction

| Type | Time  | PPF   | VPF   | Severity |
|------|-------|-------|-------|----------|
| TTC  | Morning | 9.61  | 8.12  | 8.12     |
|      | Evening | 10.88 | 8.91  | 8.91     |
| GT   | Morning | 5.21  | 2.65  | 2.65     |
|      | Evening | 6.33  | 3.82  | 3.82     |

Table 8: Showing Severity of the intersection at different times

| TTC (sec) | Severity |
|-----------|----------|
| PPF & VPF | 2 <      |
|           | Critical |
|           | 2 to 6   |
|           | Nominal  |
|           | > 6      |
|           | Safe     |

Figure 6: The plot between Max TTC and Gap Time of High Tension Junction for PPF of morning and evening

Table 9: Testing the accuracy of goodness of fit for PPF

| Goodness of Fit | Results |
|-----------------|---------|
| R-square        | 0.6841  |
| MAE             | 0.438   |
| MAPE            | 11.32   |
| RMSE            | 2.176   |
| MSPE            | 1.208   |
| CHI-SQUARE      | 59.735  |
| CRITICAL CHI-SQUARE | 79.082 |
Figure 7: The plot between Max TTC and Gap Time of High Tension Junction for VPF of morning and evening

Table 10: Testing the accuracy of goodness of fit for VPF

| Goodness of Fit | Results         |
|-----------------|-----------------|
| R-square        | 0.632           |
| MAE             | 0.761           |
| MAPE            | 50.07           |
| RMSE            | 2.596           |
| MSPE            | 3.165           |
| CHI-SQUARE      | 147.73          |
| CRITICAL CHI-SQUARE | 177.39        |

5. Conclusion

Trajectory has the advantage of being able to track both the pedestrian and the vehicle in both the longitudinal and lateral directions, which or else difficult. As part of this study, pedestrians and motor vehicles were compared in terms of how they interacted while crossing unsignalized intersections. Pedestrian Passing First (PPF) and Vehicle Passing First (VPF) have been used to quantify the interaction between pedestrian and vehicle. Surrogate safety measures like

1. TTC and GT is good in case of PPF compared to VPF, because pedestrians having more time to cross the intersection before the vehicle arrives.

2. Safe Distance (SD) has been introduced in the present study. This measure is based on a thorough analysis of 241, 271 pedestrian-vehicle interactions. According to the study findings, Mean SD is more for all PPF than VPF with consideration of size of vehicles and speeds.

3. And after comparing all the pedestrians to vehicles in tables (5), (6) pedestrians speed is much more when they passes first w.r.to two wheeler, having less speed when pedestrian passes first w.r.to three wheeler.

4. From the tables (5), (6) I can conclude that SSD is greater than the SD for VPF compared to PPF so it very critical to pass safely when VPF.

5. Severities are evaluated from the trajectory data and severity levels are analysed based on the severities of the junction as shown in the tables (7), (8).
6. In both cases, obtained Chi-square is less than the critical chi-square as shown in Table.10, so developed model is best fit.

From all the above points concluded that there is no much risk for the pedestrians who uses the unsignalized intersection and having less risk too when pedestrians passes first w.r.t to vehicle.

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