Proactive Evaluation of Traffic Safety at An Unsignalized Intersection Using Micro-Simulation

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***Abstract*—Traffic safety is an important area in transportation engineering. Presently, most traffic safety assessment and prediction related work is based on the use of historical accident data that has known drawbacks related to the quality and coverage of data especially in developing countries like India. For the assessment of roadway solutions in the future, it is impractical and unethical to wait for accidents to occur before being able to draw statistically sound conclusions regarding safety impact. Hence there is a need to develop proactive models based on Surrogate Safety Measures (SSMs) for a more effective safety evaluation. The main advantage associated with the use of safety indicators is that they occur considerably more frequently than accidents, thereby implying an efficient and more statistically reliable proximal measure of traffic safety. The objective of this study is to assess the level of traffic safety at an uncontrolled intersection using micro-simulation modeling under mixed traffic condition by devising a unique strategy of measuring proximal safety indicator, Post Encroachment Time (PET).**

***Index Terms*—surrogate safety measures, micro-simulation, uncontrolled intersections, post encroachment time, validation**

I. Introduction

Safety on roads is a major concern in the developing world because of its impact on the global economy and people's welfare. Due to the rising population, the traffic risk has increased especially in developing nations like India, as the infrastructure is unable to cope up with the increasing traffic. In India, 17 lives were lost every hour in 2011 and its increase to 21 lives per hour in 2012 shows the necessity of a reliable strategy to prevent accidents [1].

Intersections pose special safety concerns because of unsafe driver actions and maneuvers. The conflicts at intersections include merging, crossing and diverging conflicts apart from the abrupt changes in vehicle speeds and unexpected lane changes. As the above data amply show drivers as the major cause for accidents, it is essential to further study this from the perspective of infrastructure development to enable drivers take precautionary measures to avoid accidents at intersections in addition to creating social awareness among the driver community.

Studies in general show that speed enforcement led to significant reduction in frequency of accidents [2]. Several studies solely evaluated traffic safety with respect to speed [3], [4]. Experience shows that microscopic simulation is able to predict to a certain extent, the risks within a traffic flow [5]. Microscopic simulation helps to evaluate traffic conditions without having to realize tests in the field. Using these techniques it is very difficult to evaluate accidents and find the cause for it because of the varying trajectories in the real and virtual simulated cases as recognized by Darzentas *et al*. [6].

This lead to a new strategy to approach this problem using Surrogate safety measures (SSMs) [7]. They involve usage of proximal safety indicators that represent the temporal and spatial proximity characteristics of unsafe interactions and near-crashes. The major advantage of such measures is that they occur more frequently than crashes and require short observation periods in order to establish statistically reliable results. As Archer mentioned, these measures include Time-to-collision (TTC), Time extended TTC (TET), Time integrated TTC (TIT), Post encroachment time (PET), Deceleration rate (DR) etc. [8]-[10]. The most commonly used are TTC and PET, which were identified from the study of Gettman and Head [10].

Pirdavani *et al*. presented a safety evaluation of unsignalized intersections using micro simulation and proximal safety indicators. They have applied a micro simulator (S-Paramics) to investigate whether changing speed limits under different traffic volume conditions will affect traffic safety as measured by PET. The results of the simulation show that increasing the traffic volume on both major and minor roadways will lead to a decrease of mean PET values [2].

Klunder *et al*. developed a new micro-simulation model for intersection traffic, which can generate accurate SSMs and which represents driver behavior on intersections more accurately. The results show that as the critical gap value decreases, increasingly unsafe situations can occur at the intersection [11].

Athough these attempts were successful in predicting the future occurrences, the accuracy has always been doubtful because of varying trajectories of different

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vehicles. The objective of the study is to improve the accuracy of findings and also assess the traffic safety under mixed traffic condition. In the current analysis, the safety measure Post Encroachment Time (PET) is used as it is a reliable indicator for both rear-end and transverse collisions which occur frequently at intersections. This measure is used to identify cases in which two road-users pass over a common spatial point or area with a temporal difference. PET is the time between moment t_1 when the first vehicle exits the conflict spot and moment t_2 when the second vehicle enters the conflict spot, defined by $t_2 - t_1$. A smaller PET value implies a greater probability of collision. Micro-simulation modeling software VISSIM 6.0 has been used to evaluate the safety at unsignalized intersections. For the first time in PET studies, a concept of negative PET has been introduced which is detailed in the study methodology section. This will be followed by sections on PET from field and PET from simulations and ended with findings from simulations and conclusions.

II. Study Methodology

It is known that usage of statistical models based on historical crash data are most common in traffic engineering today. The approach used is considered 'reactive' in nature rather than 'proactive', where a significant number of crashes must occur before a problem is identified and suitable corrective measures can be implemented. Understanding these problems, researchers have recently proposed a framework for 'proactive' safety planning, i.e. planning that is not entirely based on historical crash data, but uses other measures such as the use of safety indicators and predictive models [8]. Also, the use of safety indicators is also a more resource-efficient and ethically appealing alternative for fast, reliable and effective safety assessment.

The method used in this study is to first calculate PET values from the field, then simulate and model in micro-simulation software VISSIM 6.0 and use simulation to identify and predict interdependencies of the vehicle characteristics and evaluate traffic safety at uncontrolled or unsignalized intersections.

Usually PET is calculated on the basis of grids on lanes, assuming vehicles move in a single lane in a straight path, which is not synonymous to the actual case especially in developing nations. Also, traditional method involves using square or rectangular grids of large dimensions on the conflict area at an intersection that may not give reliable conclusions from the study.

Current study involves the concept of area occupancy on the grids, which have an advantage of identifying the grid in which there is highest possibility of collision and also calculate PET values more accurately. A novel geometry of the grid is used for the study, using a rhombus with dimensions as 2.5m x 2.5m and internal angles of 60^0 and 120^0. The advantages of using this geometry compared to the traditional method have been showed in Fig. 1 and Fig. 2. In both the cases, traditional calculation method gives the same value of zero PET at an instant 't', but using the rhombus geometry, one can identify and differentiate relatively safe cases and relatively unsafe cases. In the following figures, it can clearly identified that first case will have a negative PET at that instant 't' as first vehicle is yet to leave and the second case will have a positive PET as first vehicle left already, hence gives accurate predictions.

Figure 1. Relatively unsafe conflict with greater crash possibility.

Figure 2. Relatively safe conflict with lesser crash possibility.

Furthermore, the trajectory of a turning vehicle is never straight and always at an angle that ensures vehicles occupy less number of grids and maximum portion of grids in current case. This will further improve the accuracy of the predictions. Similar method is applied in simulation using the concept of nodes by detecting the time differences when a vehicle enters the defined grids.

III. Post Encroachment Time from Field data

A video based traffic survey was conducted at Central Avenue-Technology St. intersection in Hiranandani Gardens Powai, Mumbai, India for a duration of one hour, on February 19^{th} 2014 from 1700 hours to 1800 hours which is also the peak hour period at that intersection. The roadway characteristics observed from the survey is that, it is an uncontrolled T intersection with three lanes on major road in each direction and two lanes on minor road in each direction. The data set extracted from the video included traffic volume, vehicle composition along each of the directions apart from PET extraction.

The grids have been created manually using Autodesk Maya 3D animation software. These grids were then converted into a transparent picture and then overlaid into the video using Corel VideoStudio Pro X6 software. The grids were numbered lane wise to ease the calculation of PET values. After this, the video is run at frame rate of 6 frames per second. The least count of this is 0.01 seconds, which gives more accurate results. While running frame by frame, when a possible conflict occurs, time t_1 i.e. when a rear end of one vehicle leaves a grid and time t_2 i.e. when a front end of another vehicle touches the same grid are noted, and PET values are calculated as t_2-t_1. Fig. 3 is the snapshot of the overlaid video including the grid numbers. From the data extracted manually from video, the grids 3.4, 3.5, 4.4, 4.5, 5.4, 5.5 had the maximum number of conflicts. In total 944 vehicle-vehicle conflicts have been identified from a total of 3204 vehicles at the intersection. The mean PET value obtained was 4.04 seconds. The frequency distribution of the calculated PET values is tabulated in Table I. The obtained results will be compared to the simulated values in the simulation findings section.

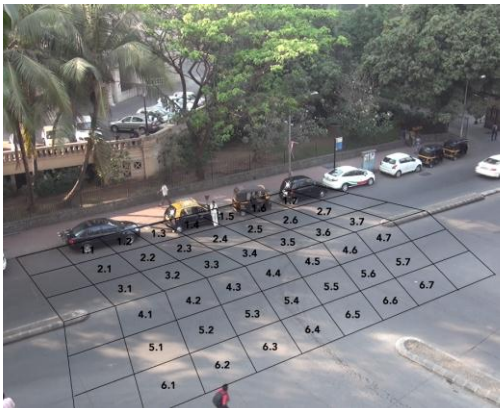

Figure 3. Screenshot of the video with grids.

TABLE I. FREQUENCY DISTRIBUTION OF FIELD PET

Lower Class Limits	Upper Class Limits	Mid point	Conflicts Frequency	Percentage Relative Frequency	Cumulative Percentage Frequency
-5	0	-2.5	196	20.76	20.76
0	5	2.5	488	51.69	72.45
5	10	7.5	136	14.41	86.86
10	15	12.5	80	8.47	95.33
15	20	17.5	22	2.33	97.66
20	25	22.5	12	1.27	98.93
25	30	27.5	6	0.64	99.57
30	35	32.5	4	0.42	100

IV. POST ENCROACHMENT TIME FROM SIMULATION

As mentioned earlier, micro-simulation modeling software VISSIM 6.0 has been used. In developing the model of the existing situation in VISSIM, the first step was to create a road network with the background of the intersection extracted from Google maps. The dimensions of the road and channelization have been obtained using wheel meters and the same have been applied in the simulation model. VISSIM has inbuilt features that can be partially considered as assumptions of the simulation model for real time data. It follows Poisson's distribution for the arrival process with exponential inter arrival times. It uses a psychophysical car following model and a rule-based algorithm for lateral movements.

A. Calibration

After building the road network, the model is calibrated by assigning vehicle inputs from all the three directions from the values obtained in field data. Speed ranges are assigned to vehicles by conducting a spot speed survey of 15 vehicles in each vehicle type. Reduced speed areas have been used at the intersections when the average speed of all the vehicles was reduced by 5 kmph to 10 kmph depending on the vehicle type. The vehicle dimensions are also adjusted according to the Indian traffic with the inclusion of a three-wheeler called Auto-rickshaw and a Light commercial vehicle (LCV). Priority zones are given in accordance to the real movement of traffic from the field data collected. A total of 6 vehicle types are considered under study, which conforms to the requirement of mixed traffic condition.

B. Validation

After calibrating the model and running the simulation a couple of times, driver behavior characteristics were changed in order to get the simulated values comparable to the field values. The shapes of connectors are also adjusted for better outputs. The final model was then re-validated with secondary data from another one-hour period and the results obtained were satisfactory. Hence, the simulation model was calibrated and validated.

C. Calculation of PET

Polygon nodes of rhombus shape have been placed exactly at the same positions as in the video based method. Fig. 4 is the screenshot of the intersection during simulation.

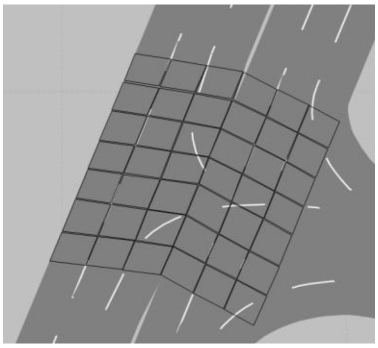

Figure 4. Screenshot of the modeled intersection.

TABLE II. FREQUENCY DISTRIBUTION OF BASECASE SIMULATED PET

Lower Class Limits	Upper Class Limits	Mid point	Conflicts Frequency	Percentage Relative Frequency	Cumulative Percentage Frequency
-5	0	-2.5	221	23.31	23.31
0	5	2.5	432	45.57	68.88
5	10	7.5	160	16.88	85.76
10	15	12.5	91	9.6	95.36
15	20	17.5	28	2.95	98.31
20	25	22.5	12	1.27	99.58
25	30	27.5	4	0.42	100
30	35	32.5	0	0	100

The nodes are numbered in the same manner as the case of field data and raw data from the nodes is collected in a Microsoft Excel sheet. The raw data contains the details of time when a vehicle enters the node, time when a vehicle leaves the node, type of vehicle and path of vehicle. From this PET values are calculated using Excel functions and this can also be generalized using a computer program to save some time for data analysis. For the existing case, a total of 948 vehicle-vehicle conflicts have been identified from a total of 3204 vehicles at the intersection. The mean PET value obtained was 4.11 seconds. The frequency distribution of the calculated PET values is tabulated in Table II. Similar procedure was followed with some changes in inputs to test their influence on PET values, which is discussed in the upcoming findings from simulation section.

V. Findings from Simulation

A. Comparision with Field Results

After obtaining both the field and simulated PET values, they were compared with relative frequency and cumulative frequency curves. The graphs are plotted as shown in Fig. 5 and Fig. 6 respectively. From the figures, it is obtained that field and simulated values are almost same and model is accurate. This is also an indicator that the model has been calibrated and validated. The next step was to assess these values with varying vehicle characteristics as discussed in the following subsections.

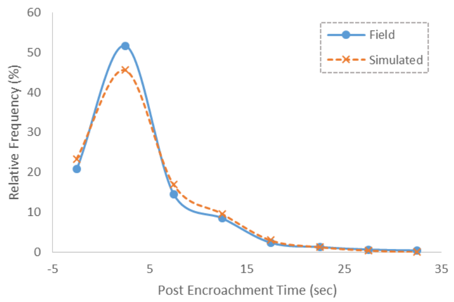

Figure 5. Relative frequency curves for field and simulated PET

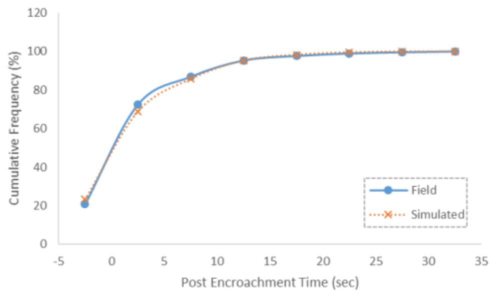

Figure 6. Cumulative frequency curves for field and simulated PET.

B. Effect of Change in Major Road Volume

The first part of assessment involved changing the volumes of vehicles on the major roads in both the directions with respect to the existing major road volumes. With about 10% increase every year in total number of vehicles, it is essential to evaluate the facility by changing the volumes to future values. It is also essential to see for any reductions in case of lesser volumes as the incoming traffic can be diverted through some other route or a new facility can be created as an alternative means for some incoming traffic.

Keeping all the other characteristics constant, volumes on major roads were increased by 10%, 20% and also decreased by 10%, 20%. One can easily predict that total number of conflicts would obviously increase when volume is increased and total conflicts would decrease when volume is decreased.

The total number of conflicts was 1147, 1267 for 10% and 20% increase respectively. The conflicts were 837 and 726 for 10% and 20% decrease respectively. To do a comparative analysis, relative frequency curve is plotted as in Fig. 7 and it was clearly observed that a huge proportion of about 88% of conflicts had PET values less than 5 seconds in case of 20% increase in volume and about 53% of conflicts in case of 20% volume decrease compared to the existing 69%. The results are comparable with the results from previous studies but with more reliable and foolproof technique [5].

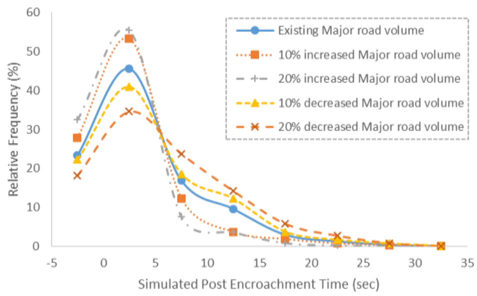

Figure 7. Frequency curves for change in Major road volume.

C. Effect of Change in Vehicle Composition

The second part of assessment involved changing the vehicle compositions on roads along all the directions. This is a crucial step of evaluation as the entry of heavy vehicles can be restricted in cities up to an extent, at least during the peak hours on the roads. The analysis was done changing the total number of heavy vehicles and commercial vehicles i.e. buses, LCVs and HCVs which form a major source of obstruction and also increase the collision probability.

Keeping all the other characteristics constant, heavy vehicle compositions were increased by 10%, 20% and also decreased by 10%, 20%. In this case, surprisingly, the total number of conflicts was not much higher compared to the previous case with only change in volumes on major roads. This is possibly because speeds vary for different type of vehicles and this being a mixed traffic condition with 6 different vehicle types.

The total number of conflicts was 1169, 1278 for 10% and 20% increase respectively. The conflicts were 822 and 652 for 10% and 20% decrease respectively. To do a comparative analysis, relative frequency curve is plotted as in Fig. 8 and it was clearly observed that a huge proportion of about 93% of conflicts had PET values less than 5 seconds in case of 20% increase in heavy vehicle composition and about 43% of conflicts in case of 20% heavy vehicle composition decrease compared to the existing 69%.

This means that although, in case of 20% increase there is not much difference in the number of conflicts, in case of excess heavy vehicles a greater proportion of conflicts have PET values less than 5 seconds, which is unsafe. But, in case of lesser heavy vehicles which is possible by restricting heavy vehicle movement along such routes by only allowing public transport, less than half of the conflicts came under 5 seconds PET value.

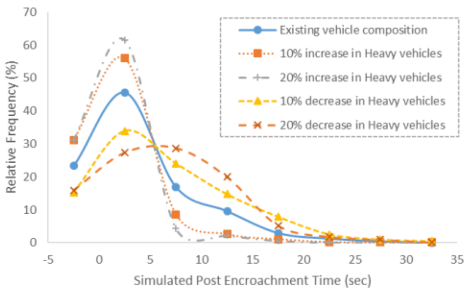

Figure 8. Frequency curves for change in heavy vehicle composition.

D. *Effect of Change in Vehicle Speeds*

The third part of assessment involved changing the speeds of vehicles with respect to the speeds along the existing facility. This part of study evaluates and identifies the safe speed at the intersections that will be different from the design speed of the road. The results of this part of study can be used to have restrictions on vehicle speeds in order to provide a safe road for commuters by preventing accidents. The analysis was done by changing the speeds of vehicles in all the directions irrespective of the vehicle type.

Keeping all the other characteristics constant, speeds were increased by 5 kmph (kilometers per hour), 10 kmph and also decreased by 5 kmph, 10 kmph. In this case, the total number of conflicts was much lesser compared to both the previous cases where there was change in volumes on major roads and change in vehicle compositions. This is possible because of many factors such as:

- Vehicles might follow a completely different trajectory in order to maintain their speed and avoid stoppages.
- The duration of vehicles on the conflict spots is less than before in case of faster movement.
- The vehicles may start queuing in case of slower movement and hence PET values would automatically increase.

The total number of conflicts was 1020, 1083 for 5 kmph and 10 kmph increase respectively. The conflicts were 881 and 750 for 5 kmph and 10 kmph decrease respectively. To do a comparative analysis, relative frequency curve is plotted as in Fig. 9 and it was clearly observed that a huge proportion of about 76% of conflicts had PET values less than 5 seconds in case of 10 kmph increase in vehicle speeds and about 62% of conflicts in case of 10 kmph decrease in vehicle speeds compared to the existing 69%.

From the observed values, we can clearly notice that there is not much dependence of vehicle speeds on PET values apart from the fact that overall conflicts would increase with increase in vehicle speeds which increases the total accident probability, but the relative risk in each of the case is almost same with similar pattern of frequency distribution for different PET values.

The intersection selected in the study was a typical uncontrolled intersection inside city premises with limited speeds. This can be one of the reasons for observing a similar pattern for all the speeds. But, if the overall speeds increase, which occurs usually when volume decreases, there is a possibility of observing a varied pattern of relative frequency distribution.

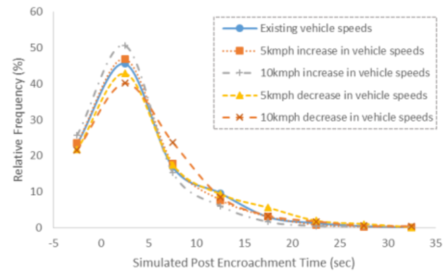

Figure 9. Frequency curves for change vehicle speeds.

VI. Conclusion

This paper presented a proactive safety evaluation of an unsignalized intersection using proximal safety indicator Post Encroachment Time (PET) and micro-simulation modeling. This new method of calculating PET can provide useful comparisons for evaluating safety by studying the effect of roadway and traffic characteristics under mixed traffic condition.

A few conclusions specific to the intersection under study can be drawn as follows:

- The PET values obtained are very small, with 25-40% values in the negative range and 40-50% values in the range of less than 5 seconds.
- It can be inferred that the intersection is highly unsafe and there is a need of precautionary measures such as using signals, decreasing the overall vehicle volumes etc.
- A couple of minor transverse end crashes were observed during the short study period, which supports this conclusion.

The practical merits of micro-simulation were demonstrated with varying conditions of speeds, volumes and compositions. The application shows how the changes in certain parameters effect the safety situation, as measured by the Post Encroachment Time (PET). The promising results found in this new study methodology pointed out an opportunity of expanding the research to a more complex, comprehensive and extensive traffic safety evaluation with different combination of assessment apart from traffic policy measures.

From the three phases of assessment, change in the traffic volumes resulted in a proportional change in relative frequencies whereas change in heavy vehicle compositions had a higher impact on relative frequencies. On, the contrary, change in speeds did not have great effect on these values. Hence, the best and first precautionary method is decreasing the number of heavy vehicles on the road during peak hours.

However, it is necessary to point out that this study is limited to the use of PET as a proximal safety indicator, which is predominantly useful to investigate transverse collisions. The use of other safety indicators, like TTC and its derived sub-indicators are more useful in rear-end collisions. Nevertheless, since most of the collisions at unsignalized intersections are transverse collisions, the use of PET for this type of intersection is appropriate.

The outcome of our study and its future scope promises an accurate and reliable method to identify unsafe intersections and prevent accidents by applying necessary precautionary methods.

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