Safety Enhancement of Unsignalized Intersection Using Microsimulation and Surrogate Safety Measures

Mohamed Hasain Na*, Mokaddes Ali Ahmedb

a PhD Student, National Institute of Technology Silchar, Assam 788010, India
b Professor, National Institute of Technology Silchar, Assam 788010, India

Abstract

Road safety is deteriorating due to the complex driver behaviour in the road network, especially in developing countries like India. Surrogate safety measures for traffic safety assessment are getting attention due to their advantages over traffic accident data. The time-based proximal indicator, Post-Encroachment Time (PET), has been used in this study. Two unsignalized intersections were simulated using VISSIM with proper calibration and validation. The effectiveness of various preventive measures was tested using the simulated model. It was found that implementing a raised table in the major road is increasing the safety of the intersection by increasing the PET value.

Keywords: Microsimulation; Surrogate Safety Measures; Post-Encroachment Time; Unsignalized intersection;

1. Introduction

Traffic safety in the road network mainly depends on the driver’s behaviour. Also, it is deteriorating day by day because of the complex driving behaviour, loose lane discipline and vehicular growth rate of 7.5% per year. This makes traffic safety assessment more critical, especially in developing countries. The usual approach of using the historical accident records for safety assessment is having drawbacks, such as extended observation period, non-reliability of data and reactive nature of evaluation. Also, not all intersections have a significant amount of accident data to make any statistical interpretation, especially in India. However, the traffic safety assessment using surrogate safety measures has more advantages, such as the shorter observation period, proactive nature of the approach, and the availability of a large amount of data for evaluation. In the past, different proximal indicators have been used, namely, Time to Collision (TTC), Post-Encroachment Time (PET), Deceleration Rate to Avoid Collision (DRAC), etc. Mahmud et al. [1] explained all the indicators in a detailed way in their paper. Also, suggestions were made to use Post-Encroachment Time (PET), a time-based indicator, for the unsignalized intersection as they have more traverse collision. In the present study, PET was used as the proximal indicator to assess the safety of the intersection. PET is defined as the time difference between the first vehicle leaving a conflict area and the following vehicle entering the same conflict area.

\[ PET \; (\text{sec}) = t_1 - t_2 \]

Where,
\[ t_1 = \text{time at which the leading vehicle leaves the conflict area}, \]
\[ t_2 = \text{time at which the following vehicle enters the conflict area}. \]

A lower PET value indicates a higher probability of collision. And after evaluating the safety, for deciding the suitable preventive measures, using the microsimulation model to discuss the preventive measures. Recently, microsimulation is getting much attention in traffic studies for its more control over the traffic operations and management benefits. Generally, microsimulation models track individual vehicle movements on a second or sub-second basis. It relies on random numbers to generate vehicles and their vehicular movement with adjustable driving behaviour characteristics. Because of this random nature, it was necessary to run the model

* Corresponding author.
E-mail address: mohamed_rs@civil.nits.ac.in
several times with different random seeds to obtain the desired accuracy. For this study, PTV VISSIM was selected for the microscopic simulation of the intersection.

2. Literature Review

Gettman and Head [2] have stated that microsimulation could be done in a detailed manner compared to manual measurement. They also mentioned various advantages of using microsimulation in the conflict studies, such as the extraction ability of specific data with proper calibration and validation of the model by altering a particular parameter. The use of microsimulation has been effective and is getting much attention in transportation studies. Pirdavani et al. [3] have used S-Paramics to simulate the three-legged intersection and found that the speed influences the safety of the intersection. By increasing the speed of the traffic flow, the PET value is reducing significantly. Also, the higher vehicular speed in the major road makes the minor road users accept the lower gaps, which leads to the collision. Caliendo and Guida [4] used AIMSUN software with vehicular volume as the measure of effectiveness (MOE) and compared the simulated conflicts with the accident crashes and found a good relationship. They have used both PET and TTC separately as the proximal indicator and pointed out that these two indicators cannot be linked directly for the safety evaluation. Killi and Vedagiri [5] have used PET with polygonal shaped grids to measure the PET. They used VISSIM 6.0 software for the simulation and found that increasing the speed, traffic flow and composition of the heavy vehicles in the intersection also decreases the PET value. Ambros et al. [6] have attempted to predict the accidents without the help of any proximal surrogate safety indicators by using microsimulation. They have used the Czech technique to find the observed conflict and compared it with the simulated conflicts and accident data and found a significant correlation. Samir et al. [7] have used VISSIM 7.0 for the modelling of the T-intersection. They used 3.0m × 3.0m as the grid size, with a square shape, made in AUTO-CAD 2007. Vedagiri and Killi [8] have mentioned that most of the studies were done in developed countries, and only less work has been done concerning the heterogeneous traffic countries. They used VISSIM software to simulate the study area and used the model to discuss various preventive measures for the unsignalized intersection. Paul and Ghosh [9] have used critical speed to identify the critical conflicts instead of using a particular threshold value. Mahmud et al. [10] have compared several simulation software in their review article. They compared AIMSUN, VISSIM and S-Paramics software in a detailed manner and found no software superior to others. But the consideration of right-angle collision for the traffic assessment could be done using VISSIM software. Dutta and Ahmed [11] successfully calibrated and validated six T-intersections in various cities around India using VISSIM software with vehicular volume as the measure of effectiveness (MOE). They used one-way ANOVA as the sensitivity analysis to find the sensitive parameters of the model simulated. And the sampling of the sensitive parameters was done using Latin Hypercube Sampling (LHS).

2.1 Inference

The results of several studies regarding the use of microsimulation in the assessment of traffic safety confirm its effectiveness in modelling the intersection and finding the risk involved in the intersection for vehicular movement. The microsimulation helps extract specific data from the model and discuss effective changes in the field before implementing. The Post-Encroachment Time, a time-based proximal indicator, is preferred for the unsignalized intersection. Thus, the objective of this study was to simulate the unsignalized intersection for the proactive evaluation of traffic safety using Post-Encroachment Time (PET) as the surrogate safety indicator. Also, to calibrate and validate the simulated model for the field conditions using vehicular volume as the measure of effectiveness (MOE). And to discuss various preventive measures using the simulated model for the unsafe intersection.

3. Methodology

3.1. Study Area

As discussed, the unsignalized T-intersection is considered more dangerous due to uncontrolled vehicular movements. So, two three-legged unsignalized intersections were selected for the study purpose in the city of Guwahati, India. Peak hours in the study areas were from 8:00 AM to 10:00 AM and from 4:00 PM to 6:00 PM. BU, only the morning peak hours were selected for the present study due to bad lighting conditions in the evening peak hour. A Video-graphic survey was done in the intersections by placing a camera at the top of the three-story building to get a clear view over the intersection. For the study, six type of vehicles, namely motorized two-wheeler (TW), motorized three-wheeler (Auto), car (C), bus & truck (HV), minivan (MV) and cycle-rickshaw (CR), were considered. The spot speed of the vehicles were collected before 10m of the conflict area for each leg
of the intersection with a radar gun. For each type of vehicle, fifteen vehicle’s speed was collected in each leg of the intersection. Totally, the speed of the 540 vehicles was collected in both intersections. The field PET values were measured by making grids of size 3.5m × 3.5m. This was due to the lane width of 3.5m in the major road and overtaking in the unsignalized intersection is commonly considered unsafe. The grids were made and laid using Adobe Photoshop software and the Adobe After Effect software. The grids made in the intersection (I-2) is shown in Fig. 1. The PET value was measured between every merging and the crossing conflict that occurred in the intersection. There were 1592 conflicts in the intersection (I-1) and 653 conflicts in the intersection (I-2). The average PET value was 0.45 seconds in the intersection (I-1) and 0.72 seconds in the intersection (I-2).

Fig. 1. Snapshot of grids made in the intersection (I-2)

3.2. Input Data and Simulation

VISSIM was selected as the simulation software because of its advantage of considering the right-hand collision. Simulation using VISSIM requires the input data, including the number and width of lanes, vehicular volume, the vehicular composition and the percentage of the turning volume for each approach. They were collected from the video taken in the study area. Flow speed was measured by measuring spot speed for 90 vehicles for each class in both intersections to simulate the models. The 85th percentile speed of the cumulative distribution curve was used during the simulation. The vehicular input volume was given at a specific time interval in the model to get more accurate results. The time interval of 300 seconds was created in the models. The vehicular compositions were also given at the same time interval for each approach in the model. Each leg of the intersection was named as A, B and C leg in both intersections.

3.3. Initial MAPE Value

Modelling the intersection effectively according to the Indian heterogeneous traffic conditions has been a big challenge. In this study, the vehicular volume has been taken as the measure of effectiveness (MOE) for the process of calibration and validation. For checking the validity of the model, the Mean Absolute Percentage Error (MAPE) between simulated flow and actual flow was calculated. Traffic flow at each intersection was measured at the junctions by running the simulation model for five runs with seed increment for each run. The detectors were placed in the model and it gives the flow that exists in the model for every 300 seconds time interval. The initial MAPE value for default driving behaviour characteristics was found for both the intersections. In both the intersection, A and C legs were having an initial MAPE value greater than 15%, which shows the need for calibration.

3.4. Calibration and validation

Usually, adjusting the driver’s behaviour characteristics calibrates the model to the field conditions. Instead of changing every driving characteristics in the model, adjusting the most sensitive parameters would be sufficient for the calibration. The sensitivity analysis was done to find the sensitive parameters in the simulated model. The sensitivity analysis was carried out using the oneway-ANOVA (Analysis Of Variance) test by making one parameter increased by 10% of the default value at a time while keeping all the other parameters default. The level of significance (α) was set as 0.2, with an 80 percent confidence level. Totally eleven parameters were analyzed, and nine were found to be sensitive, whose p-value was less than 0.2. These parameters were
sampled into 150 different sets within the allowable range using Latin Hypercube Sampling (LHS) Technique. For each set of parameters, the models were run with ten random seeds to reduce the effect of stochasticity. The average flow for each leg was collected at 300 seconds time interval by placing the detectors. The set of parameters, which gives the least MAPE value, was taken forward for validation. The other 1-h hour data was used for the validation of the simulated model. For validation, the models were again evaluated for ten random seeds and found that MAPE values were within the limit for both the intersections. The calibrated value of the driving behaviour parameters and each link’s MAPE value for both the intersections is given in Table 1.

| Parameters (Range) | I-1 Intersection | I-2 Intersection |
|--------------------|------------------|------------------|
|                    | Default values   | Calibrated Values| Validated Values | Default values | Calibrated Values| Validated Values |
| \( ax (1-2) \)     | 2.00             | 1.13             | 1.13             | 2.00           | 1.02             | 1.02             |
| \( bx_{add} (0.1-2) \) | 2.00            | 0.13             | 0.13             | 2.00           | 0.26             | 0.26             |
| \( bx_{mult} (0-3) \) | 3.00             | 0.11             | 0.11             | 3.00           | 0.26             | 0.26             |
| \( lad_{min} (10-30) \) | 0.00            | 22.05            | 22.05            | 0.00           | 27.85            | 27.85            |
| \( lad_{max} (250-300) \) | 150.00          | 278.70           | 278.70           | 150.00         | 269.10           | 269.10           |
| \( lb_{min} (10-30) \) | 0.00             | 24.25            | 24.25            | 0.00           | 25.05            | 25.05            |
| \( hw_{min} (0.1-1) \) | 0.50             | 0.33             | 0.33             | 0.50           | 0.19             | 0.19             |
| \( mild_{st} (0.1-3) \) | 0.20             | 0.11             | 0.11             | 0.20           | 0.11             | 0.11             |
| \( mild_dr (0.3-1) \) | 1.00             | 0.41             | 0.41             | 1.00           | 0.41             | 0.41             |
| MAPE (Aleg)        | 56.44%           | 8.66%            | 7.94%            | 57.52%         | 7.76%            | 10.25%           |
| MAPE (Bleg)        | 8.26%            | 1.09%            | 1.32%            | 11.76%         | 2.89%            | 2.83%            |
| MAPE (Cleg)        | 59.93%           | 3.89%            | 5.93%            | 49.04%         | 9.43%            | 9.89%            |

3.5. Extracting PET value from the model

For extracting PET value from the model, grids were made in the model as exactly as in the field by placing the nodes in the conflicting area. The grids size were 3.5m × 3.5m. The number of grids was also made as same as in the field. The pictorial view of the nodes made in the simulated model is shown in Fig. 2. Also, Fig. 2. shows the detectors made in the model and were indicated by orange lines across the road. The raw data for each node was extracted for one hour simulation period with ten random seeds from the model. The raw data was collected in .knr format. The file contains the data such as the type of vehicle, the time at which the vehicle enters and leaves the node, arrival and departure link for each vehicle, etc. and was used for the measurement of PET value. The average PET value was calculated from the model.

4. Results and Discussion

The various preventive measures were discussed using the simulated models. The preventive measures like traffic rotary, traffic control signals, raised tables in the major road, and speed bumps in the minor road were discussed. But, it was found that implementing rotary would require more space than the space available in the study area. Further, installing traffic control signals did not satisfy the warrants given in IRC-93:1985. So, these two were omitted from the discussion of suitable preventive measures. The raised table is generally a hump that runs across the road with 80−100 mm height and 2 m wide. It is more suitable for the road with higher vehicular speed.

On the other hand, the speed bump is ideal for the road with the lower vehicular speed with 150 mm height and 800mm wide. The overview of PET value for the two preventive measures was given in Fig. 3 and it could
be seen that implementing the raised table in the major roads showed more effective results than the other one. This may be due to the reduction in the vehicular speed in the major road, which causes the minor road vehicle to accept comparatively larger gaps for merging in the major road. On the other hand, the speed bump on the minor road also increases the PET values but not as effective as a raised table made on the major road. This may be because the speed bump in the minor road only influences the speed of the minor road vehicles. Thus, the speed of the major road vehicle has more influence over the PET value than the minor road vehicular speed.

Fig. 3. PET comparison from the different source

5. Conclusion

Attempts were made to evaluate the unsignalized intersection proactively and also to simulate and discuss suitable preventive measures. The PET was measured for the crossing and the merging conflicts. There were 1592 conflicts in the intersection (I-1) and 653 conflicts in the intersection (I-2). The lower number of critical conflicts in the intersection (I-2) may be due to the lower vehicular volume lesser than the intersection (I-1). The average PET value was less than 0.75 seconds in both intersections, which shows a higher probability of collision between the road users. This shows a lower safety prevails in both intersections. During the calibration of the simulated model, the sensitivity analysis was done using one-way ANOVA. Instead of altering every driving behaviour characteristics, the sensitivity analysis helps to find sensible parameters, which could be modified. Most of the previous studies used vehicular volume as the measure of effectiveness (MOE). The nodes were placed exactly the same way and used the raw data from the nodes to extract the PET value. Because of the non-availability of space and the unfulfillment of warrants, two of the four preventive measures were omitted. The raised table in the major road was effective in both the intersections. This may be due to the speed control of the major road vehicles, which causes the minor road vehicles to accept the larger gaps for the manoeuvres.

But still, the PET values were below 2.5 seconds after the implementation of the suitable preventive measures. So, the PET values may be affected by some other parameters like geometric characteristics of the road, vehicular composition and percentage of fast-moving vehicles in the intersection, etc. Hence, further work is needed to understand the nature of Post-Encroachment Time in heterogeneous traffic conditions. The calibration was done manually in this study, which consumes much time. In future, the manual part of the study could be done automatically using COM-interface. The research could also be extended to the four-legged intersection with other proximal indicators. But, the unsignalized three-legged intersection is commonly considered more dangerous than the four-legged intersection and the Post-Encroachment Time (PET) is more suitable for the unsignalized intersection.

References

[1] S. M. S. Mahmud, L. Ferreira, M. S. Hoque, and A. Tavassoli, “Using a surrogate safety approach to prioritize hazardous segments in a rural highway in a developing country,” IATSS Res., vol. 44, no. 2, pp. 132–141, 2020, doi: 10.1016/j.iatssr.2019.11.002.
[2] D. Gettman and L. Head, “Surrogate Safety Measures from Traffic Simulation Models,” Transp. Res. Rec., no. 1840, pp. 104–115, 2003, doi: 10.3141/1840-12.
[3] A. Pirdavani, T. Brijs, T. Bellemans, and G. Wets, “Evaluation of traffic safety at un-signalized intersections using microsimulation: A utilization of proximal safety indicators,” Adv. Transp. Stud., no. 22, pp. 43–50, 2010.
[4] C. Caliendo and M. Guida, “Microsimulation approach for predicting crashes at unsignalized intersections using traffic conflicts,” J. Transp. Eng., vol. 138, no. 12, pp. 1453–1467, 2012, doi: 10.1061/ASCE/TE.1943-5436.0000473.
[5] D. V. Killi and P. Vedagiri, “Proactive Evaluation of Traffic Safety at An Unsignalized Intersection Using Micro-Simulation,” *J. Traffic Logist. Eng.*, vol. 2, no. 2, pp. 140–145, 2014, doi: 10.12720/jtle.2.2.140-145.

[6] J. Ambros, R. Turek, and J. Paukrt, “Road Safety Evaluation Using Traffic Conflicts : Pilot Comparison of Micro-Simulation and Observation,” *Int. Conf. Traffic Transp. Eng. Novemb. 27-28, 2014*, no. November 2014, pp. 221–227, 2014.

[7] A. Samir, S. Thorat, and B. Godboley, “Assessment of Traffic Safety Performance At Unsignalized T-Intersection Under Mixed Traffic … Assessment of Traffic Safety Performance At Unsignalized T-Intersection Under Mixed,” vol. 8354, no. April 2015, pp. 127–132, 2016.

[8] P. Vedagiri and D. V. Killi, “Traffic safety evaluation of uncontrolled intersections using surrogate safety measures under mixed traffic conditions,” *Transp. Res. Rec.*, vol. 2512, pp. 81–89, 2015, doi: 10.3141/2512-10.

[9] M. Paul and I. Ghosh, “Speed-based proximal indicator for right-turn crashes at unsignalized intersections in India,” *J. Transp. Eng. Part A Syst.*, vol. 144, no. 6, 2018, doi: 10.1061/JTEPBS.0000139.

[10] S. M. S. Mahmud, L. Ferreira, M. S. Hoque, and A. Tavassoli, “Micro-simulation modelling for traffic safety: A review and potential application to heterogeneous traffic environment,” *IATSS Res.*, vol. 43, no. 1, pp. 27–36, 2019, doi: 10.1016/j.iatssr.2018.07.002.

[11] M. Dutta and M. A. Ahmed, “Calibration of VISSIM models at three-legged unsignalized intersections under mixed traffic conditions,” *Adv. Transp. Stud.*, vol. 48, pp. 31–46, 2019, doi: 10.4399/9788255254723.