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A Simulation-Based Approach In Determing Left-Turn Conflicts

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1. Introduction

The traditional models of accident prediction depends heavily on the quality and availability of crash data. Furthermore, because the accidents are rare events, the development of a model requires the collection of a long period of data and a massive effort for their maintenance and update.

However, when the models calibrated on crash data are used to evaluate the safety of a new design solution, the use of innovative equipment or applications in contexts different from those where the models were calibrated (for example, international transferability), the reliability of such models is compromised.

In such situations, the development of surrogate measures with the technique of traffic conflicts is essential for the analysis and prediction of road safety. The traffic conflicts represent a situation observable in which two or more road users will approach each other in space and time in such a way that there is a risk of accident if their movements remain unchanged: for this reason, they are very more frequent and easier to collect compared to the road accidents.

In recent years, several studies have been conducted by researchers in the use of traffic conflicts as surrogate measures of safety (Huang et al., 2013) (Stamatiadis et al., 2015). Generally, the microsimulation is widely used for studies of functioning of traffic (Young et al., 2014), such as travel time and/or estimation of delays in normal traffic safety: drivers and vehicles are well defined and follow certain rules (acceptance of interval, safety distance, reaction times, etc.) for which the occurrence of an accident is excluded from the simulation but the trajectories can be used to evaluate vehicular traffic conflicts.

The main objective of this research is to determine the probability of an accident in a conflict of simulated traffic, randomly assigning drivers and vehicles within a specific conflict and repeating this process for a large number "n" of processing, by using a microsimulation software such as VISSIM and a software developed by the FHWA called SSAM, available as open source from the site of Siemens Energy and Automation. The final result is the development of a simplified model to determine the number of conflict in a two-way signalized intersection based on the opposing and left turn volumes. A nomograph is developed which presents the model in a simple form for the interpretation and application by practicing traffic engineers, when required to determine left-turn phasing options.

2. The Case Study of a Signalized Four-Way Intersection

In the intersections, the traffic signal design is an important tool to order and regulate the movement of vehicles and pedestrians. It consists of a set of light signals governing the advancement, staggered in time, of two or more traffic flows, on one or more branches of an intersection.

There are four basic approaches in treating left turns at a signalized intersection (FHWA, 2004): protected, permitted, protected/permitted and split phasing. Under protected-only phasing, left-turning vehicles have the right-of-way. Under permitted-only phasing, all left-turning vehicles must yield to oncoming traffic before turning. The protected/permitted phasing has both a protected and a permitted movement. Finally, in the split phasing, traffic from two opposing intersection approaches moves during separate phases.

2.1 Methodology

The signalized intersection was simulated through VISSIM, a microscopic, time step and behavior-based simulation model developed to model urban traffic and public transport operations and flows of pedestrians. The program was useful to determine the independent variables necessary for the study of left turn conflicts at signalized intersections (PTV, 2014).

The modeled intersection was a basic four-way intersection with no skewing and normal orthogonal geometrics. Lane width were kept to the standard 12 feet and all left-turning movements were through the use of an exclusive left-turn lane. The phasing of the intersection is a simple two-phase cycle (major and minor). Signalized intersections can be modeled in VISSIM with the indication of cycle times of red, yellow and green; in this case, we considered a red time of 2 seconds and a yellow time of 3 seconds.

A total of 450 simulations, made for a period of 4500 seconds, were performed to collect the data; the modified variables include opposing volume, number of opposing lanes, cycle length and green time with the following conditions:

- Opposing Volume: 500-3000 vehicles per hour with 500 vehicles increments;
- Number of Opposing Lanes: 1, 2, 3;
- Cycle Length: 90, 120, 150, 180, 210 sec;
- Green Split: 30, 40, 50, 60, 70 percent.

The Figures 1, 2 and 3 show the scheme of the three scenarios created with the VISSIM software for turning movements.

The direction to be simulated was chosen arbitrarily and the assignment of the major and minor volumes of crossing vehicles were assigned accordingly. This study referred to vehicles that turn to the left and that are directed northbound (NBL), and vehicles that are opposed to turning left (SBT); the latter are the opposing volumes already mentioned among the input data. Volumes were entered in VISSIM as defined above. Detectors were placed upstream and downstream of the movements to count the passing vehicles and estimate their volumes. These volumes were counted as:

- Left Turn Approach Volume (LT-APP);
- Left Turn Down Volume (LT-DWN);
- Opposing Volumes (OPP).

Vehicle trajectories for each simulations were stored in order to allow for processing through SSAM software (Surrogate Safety Assessment Model), that utilizes several algorithms to identify conflicts.

At a conventional four-leg signalized intersection (FHWA, 2004), conflict points can be categorized as follows (Figure 4):

- Eight merge and eight diverge conflict points. Collisions associated with merging/diverging movements are rear-end and sideswipe collisions, occurring on a particular leg and involving another vehicle on the same leg.
- Sixteen crossing conflict points. Of these, 12 crossing movements are associated with left-turning vehicles (Figure 5). Collisions associated with this crossing movement occur when a vehicle attempting a left turn at a signal is struck by traffic passing through the intersection on another approach. The remaining four crossing movements involve through movements on two adjacent approaches. Angle collisions may occur as a result of this type of conflict.

The use of traffic lights in a road intersection is aimed at reducing conflict points between vehicles in order to obtain adequate conditions of safety and fluidity allowing a faster and more secure flow.

The model in SSAM considered three different types of simulated conflicts, including rear-end, lane-change and crossing conflicts. On the basis of the angle α of conflict, the software SSAM defines three types of conflict (Figure 6):

- REAR END $\alpha < 30°$;
- CROSSING $\alpha > 85°$;
- LANE CHANGE $30° < \alpha < 85°$.

If link and lane information is available, that information is utilized for classification in the case that the vehicles both occupy the same lane (of the same link) at either the start or end of the conflict event. If the vehicles both occupy the same lane at the start and end of the event, then it is classified as a rear-end event. If either vehicle ends the conflict event in a different lane than it started (while having not changed links), then the event is classified as a lane-change.

A conflict is recorded in SSAM when the minimum time to collision (TTC) and the minimum post encroachment time (PET) values exceed the predetermined threshold values.

The TTC value is the minimum time-to-collision value observed during the conflict. This estimate is based on the current location, speed, and trajectory of two vehicles at a given instant. The maximum value is infinity and the minimum is zero and represents the accident. In general, a TTC <1.5 s is considered critical by most authors and is therefore often used as a threshold value.

The PET value is the minimum post encroachment time observed during the conflict. Post encroachment time is the time between when the first vehicle last occupied a position and the second vehicle subsequently arrived at the same position. A value of 0 indicates a real collision; generally a PET <5 s is used as a threshold value.

SSAM can show conflicts in the map view section without loading a map file as a background, the Figure 7 shows some points of conflict obtained with the software.

2.2 Result

The resulting left-turn conflicts for each of the 450 cases examined were reviewed in order to identify a prediction model of conflicts useful to improve safety at four–way signalized intersections.

The regression model in this case is linear-logarithmic:

$$Y_i = \beta_o + \beta_1 \ln(X_i) + \varepsilon_i \quad i=1, \ldots, n$$

where a variation of 1% of X is associated a variation of Y equal to 0.01*β1.

In this model, we are considered as independent variable X the combinations of input variables and output obtained with the VISSIM microsimulation, and as the dependent variable Y the number of crossing conflicts obtained with the software SSAM.

The regression model obtained is the following:

$$Y = -\ln(X) + 138{,}55$$

where:

X = TOT. OPPOSING VOLUMES * LT-DOWN ^{2} * CYCLE^3/OPPOSINGLANES^2

Y = number of crossing conflicts

It is evident that the independent variables LT-DOWN (number of vehicles in left turn) and TOT. OPPOSING VOLUMES (total number of vehicles that are opposed to the left turn) cannot be studied separately because the number of conflicts is influenced by the combination of vehicles engaged in the left turn and those who oppose the operation, and not isolated from a study of each of them as they are, one consequence of the other.

It was important to study the cross product of the variables, because thanks to it has been possible to derive the effects of the conflicts for the lanes; from this product is clearly not possible to study left turn and through volumes individually but the effect of the combination of them.

Based on this simplified model it is then possible to develop simple nomograph that relate the number of crossing conflicts with the cross product of TOT.

OPPOSING VOLUMES * LT-DOWN. Figure 8 shows that the increase of the cross product between the TOTAL OPPOSING VOLUME and the LEFT TURN DOWN produces a decrease of the number of conflicts when there is a greater number of opposing lanes, so when there is only one opposite lane the number of conflicts is higher. This result is explained by the fact that with a greater number of lanes increases the number of gaps and therefore the vehicles have more spaces to turn left and consequently the possibility of having accidents is clearly lower.

3. Conclusions

Signal phasing is a critical component of signalized intersections that allows for safe and efficient operations. However, this is clearly a decision of the traffic engineers that can evaluate and determine the best scheme to be utilized at a signalized intersection in order to improve safety.

Since crash frequency is a direct measure of traffic safety, the development of crash prediction models is able to give policy-makers, planners and traffic engineers a clear insight into past, current and future safety. Hence, crash prediction models play a very important role in safety study and need to be carefully examined to ensure their accuracy and reliability. However, most crash prediction models are statistically-based methods requiring significant efforts on crash data collections. Moreover, the statistical-based prediction methods may not be applied in particular traffic environments due to the limitation of data sources.

Therefore, it is necessary to find surrogate metric instead of traffic crashes. Compared to traffic crash that is an infrequent incident in real world, traffic conflict is considered to be a more frequent incident type and share the similar distribution to traffic crash. The studies on traffic conflicts have been conducted for years with the purposes of developing a qualified safety surrogate. Traditional traffic conflict studies are mostly field-based studies depending on manual counting, which is also labor-intensive and inaccurate. The video-techniques can help eliminate the work on field observation but still difficult to extract accurate data due to its two-dimensional nature. Nowadays, simulation tools are more and more utilized in traffic studies. With the development of computer science, they are capable of establishing a simulated traffic environment similar to the real world. Moreover, due to its automatic recording mechanism, the data can be derived easily and more accurate.

Result of this study is the identification of a simplified model to calculate conflicts at two-way signalized intersections: it can then be useful both to reduce the number and consequences of accidents, and to determine, in existing intersections, the possibility of taking a protected phase useful to improve road safety if its appearance somewhat conflicting conditions and unsolvable with a permitted phase.

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