Evaluation of traffic safety
at un-signalized intersections using microsimulation:
a utilization of proximal safety indicators

A. Pirdavani   T. Brijs   T. Bellemans   G. Wets

Transportation Research Institute (IMOB), Hasselt University, Science Park – Building 5
B-3590 Diepenbeek, Belgium
email: ali.pirdavani@uhasselt.be

Abstract

In many cases crashes at intersections account for over 50% of all urban road crashes. The need to reduce these crashes has fostered considerable research on the development and evaluation of traffic safety at intersections. This paper introduces a micro-level behavioral approach for estimating the crash potential at unsignalized intersections for different traffic conditions. To this end, proximal safety indicators which represent the temporal and spatial proximity characteristics of unsafe interactions and near-accidents are explored and a practical implementation of post-encroachment time (PET) is carried out in the safety evaluation process. Simulation results demonstrate the sensitivity of PET to changes in the speed limit on roads and show that it can be used to carry out safety evaluations of uncontrolled intersections. More generally, the ability of microsimulation to evaluate safety effects of policy measures like speed limit is demonstrated.

Keywords – microsimulation, proximal safety indicators, safety evaluation and unsignalized intersection

1. Introduction

Intersections present special safety concerns because of unsafe driver actions and maneuvers that result in traffic conflicts with a potential for preventable crashes. These include conflicts in vehicle trajectories for different intersection approaches, pedestrian conflicts, abrupt changes in vehicle speeds, unexpected lane changes, etc. A number of recent studies of crashes for North American urban roads suggest that over 50% of reported road crashes take place in the proximity of intersections [8]. Speeding is recognized as a major contributing factor in traffic crashes, specifically for intersections. Numerous studies have been conducted to elucidate the relationship between speed and safety: detailed reviews of which are provided elsewhere [20, 25]. Three of the most important elements of this study were (a) controls for speed conditions in models of crash counts, (b) use of disaggregate roadway data permitting tight control of design factors, and (c) specification and evaluation of various count models for panel data. The results of several studies that examine the effect of speed enforcement programs on safety and speed have confirmed that it is evident that a driver's speed is one of the most important factors affecting crash severity, owing to the relationship between vehicle velocity, kinetic energy, and energy absorption upon impact.

Studies in general show that speed enforcement programs lead to a significant reduction in speed and crash frequency. Several studies solely evaluated the effect of speed enforcement on speed [5, 23] or on traffic safety [13, 17], while others evaluated both speed and safety [4, 6, 7, 15, 16, 18, 24]. In an evaluation study, the effects on mean speed, the percentage of speed limit violators, the number of injury accidents, and the number of serious casualties were assessed by comparing the development on the roads that were subject to targeted speed enforcement with the development on similar roads without targeted enforcement. Both the mean speed and the percentage of speed limit violators decreased during the targeted enforcement program [15]. Another research presents the results of a comprehensive analysis of the impact of a speed enforcement program on speeding behavior, crashes, and the economic impact of crashes. The impact on speeding behavior was estimated using generalized least square estimation, in which the observed speeds and the speeding frequencies during the program period were compared to those during other periods [24].

On the other hand the relationship between traffic flow and traffic safety should also be considered. Benedetto et al. [3] verified the variability of probability and severity of an accident for different traffic flows.

Experience shows that microscopic traffic simulation is able to improve the knowledge of risks within a traffic flow. Thus, microsimulation can potentially contribute to a better understanding and evaluation of road safety. In fact, microscopic traffic simulation helps to evaluate and optimize different routing strategies, without having to realize tests in the field. Traditionally, ,microscopic traffic simulation tools are mainly used to estimate the performance level of road networks in terms of flow, speed or travel time. However, research on the possibilities offered by these tools to estimate the safety level remain limited. In a related research a new safety indicator was proposed which is called the "unsafe density" (UD). The concept of the unsafe parameter is based on the direct interaction between a couple of vehicles, which seem to be appropriate for treating safety problems. The UD parameter takes into account only potential for rear-end collision and is therefore particularly suited for highway network assessments. The indicator allows highlighting the difference in safety level between a free flow and a congested traffic situation, which cannot be shown by using traditional macroscopic outputs like speed, flow or occupancy [19,21]. In another study a new microsimulator was developed, called "ValSim", which allows researchers to relate the skewed angle at intersections (merging or crossing) to the driver's angle of visibility for both direct vision and indirect vision through rearview mirrors. ValSim aims to allow designers to evaluate, by dynamical analysis in the geometric design process, the configuration and geometry of an intersection, and to verify possible conflicts at merging as well as at skewed crossings due to lack of visibility. The software simulates the driver's behavior while carrying out the entry or crossing maneuver. For each moment, it calculates the blind spot zones and a possible visibility conflict is highlighted [21].

The potential benefits of adopting a micro-level simulation approach were initially recognized by Darzentas et al. [10]. Yet, the use of micro-level simulation in safety work has found some resistance due to the inherent problems of accurately representing a complex crash situation, which may require a more comprehensive in-depth "Nanoscopic" view of the various relationships involved [1]. This can require a great amount of computer power and capacity. Researchers have attempted to overcome these limitations by using surrogate safety measures within the context of a more aggregate micro-level approach. Arguably, it is a more effective safety assessment strategy which involves the use of proximal safety indicators that represent the temporal and spatial proximity characteristics of unsafe interactions and near-crashes.

The main advantage of such measures is related to their resource-effectiveness given that they occur more frequently than crashes and require relatively short periods of observation in order to establish statistically reliable results. Such surrogate measures include, time-to-collision (TTC), time extended TTC (TET), post-encroachment time (PET) and deceleration rate (DR), etc. [12, 14, 19, 22]. Gettman and Head [14] described a project which has identified surrogate measures that can be collected from commercial simulation models for evaluation of the relative safety of intersection design alternatives or existing facilities. It was pointed out in their study that the surrogate indicators that are proposed as the best measures are TTC, PET, and DR. It was emphasized that TTC, PET, and DR can be used to measure the severity of the conflict [14]. Mouzon et al. have reported a study carried out for assessing risk associated to traffic situations through surrogate safety indicators. The findings show that these safety indicators enable proactive actions without waiting for accidents to occur [12].

Recently, a procedure was presented for calibrating and validating a microscopic model of safety performance at signalized intersections, using the above mentioned indicators [9]. More specifically, a systematic procedure was presented for calibrating and validating a microscopic model of safety performance. The context in the model application is the potential for rear-end crashes at signalized intersections.

2. Methodology

While the use of statistical models based on historical crash data are most common in traffic engineering today, there are availability and quality problems associated with the data on which they are based. This approach is also considered "reactive" in nature rather than "proactive", where a significant number of crashes must occur before the 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 [2].

An alternative and/or complementary approach to safety prediction is to measure the more frequent occurrence of near-crashes using proximal safety indicators where these are believed to have an established relationship to crash occurrence [11]. Proximal safety indicators have been suggested as an alternative to the use of crash data. These are defined as measures of crash proximity, based on the temporal and/or spatial measures that reflect the "closeness" of road-users (or their vehicles), in relation to a projected point of collision. The actual measure of crash proximity depends on the safety indicator concept or technique used.

A key advantage (and prerequisite) of proximal safety indicators is that they occur considerably more frequently than crashes. This suggests the need for a significantly shorter study period to establish statistically reliable results. Furthermore, the use of proximal safety indicators is also a more resource-efficient and ethically appealing alternative for fast, reliable and effective safety assessment.

A number of related criteria that can be used to identify the usefulness of proximal safety indicators have been identified, suggesting that they must [2]:
1. Complement crash data and be more frequent than crashes
2. Have a statistical and causal relationship to crashes
3. Have the characteristics of 'near-crashes' in a hierarchical continuum that describes all severity levels of road-user interactions with crashes at the highest level and very safe passages with a minimum of interaction at the lowest level
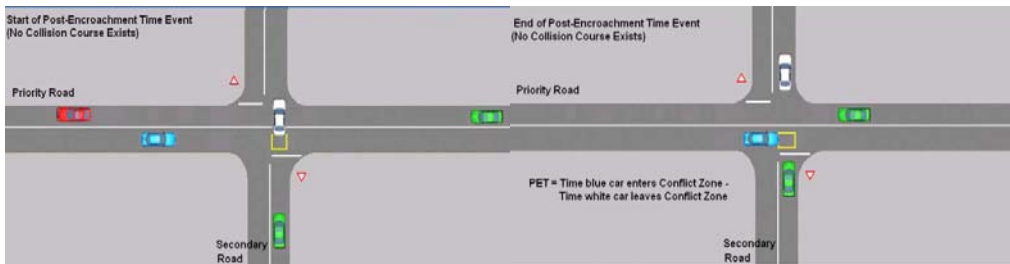
Fig. 1 (a) and (b) - Example of the calculation of a Post-Encroachment Time event [2]

There is a long list of candidate proximal safety indicators like TTC, Time Integrated TTC (TIT), TET, PET, Time-to-Zebra (TTZ), Deceleration Rate (DR), Deceleration-to-Safety Time (DST), Proportion of Stopping Distance (PSD), Shock-Wave Frequency, Time-to-Line Crossing (TLC) and Standard Deviation of Lateral Position (SDLP) which have been applied recently in different studies.

For the current research PET, as one of the most common used proximal safety indicators in the literature, is chosen to evaluate the safety situation of un-signalized intersections. This measure is used to evaluate situations in which two road-users that are on a collision course, pass over a common spatial point or area with a temporal difference that is below a predetermined threshold.

The measure represents the difference in time between the passages of the "*offended*" and "*conflicted*" road-users over a common conflict zone (i.e. area of potential collision). This makes PET not only a useful '*objective*' measure, but also one that is less resource-demanding than TTC with regard to the data-extraction process, i.e. not requiring constant recalculations at each time-step during a safety critical event [2]. An example representing the calculation of Post-Encroachment Time is illustrated above in Figures 1(a) and 1(b). The example shows the position of the two vehicles involved in the safety critical event at the start and end of the PET measurement.

In this research, a microsimulator (S-Paramics) is applied to investigate whether changing speed limits under different traffic volume conditions will affect traffic safety or not. Different simulations were carried out at different traffic volume and speed limit categories in order to make the survey as comprehensive as possible.

However, since proximal safety indictors are currently not implemented in Paramics, a procedure was developed to derive the desired safety measures out of the simulation output. To do this, four loop detectors were defined on outgoing links of the four approaches of the intersection. The detectors are located behind the conflict zones, so PET values are easily obtained. The detectors collect the needed data such as speed and position of each vehicle at each time step. In the context of traffic safety evaluation, data should be as precise as possible given that all conflict events will usually take place in less than 2 or 3 seconds. Therefore, the simulation rate was defined at 10 steps per second. It means that all the required data is gathered and available for each tenth of a second.

To simplify the process of PET computation, four different conflict zones are assumed and defined for each intersection on which all of the possible conflicts will occur. These four different conflict zones at a 4-leg intersection are depicted in Figure 2. Also it is assumed that each roadway on each direction contains 2 lanes.
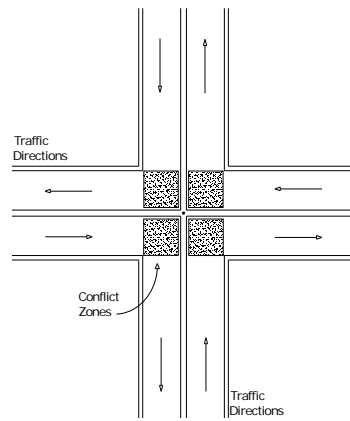
Fig. 2 - Conflict zones at intersection and traffic directions

3. Simulation results

The main objective of this paper is to evaluate the level of safety of an un-signalized 4-leg intersection under different traffic conditions. One of the major concerns for evaluating traffic safety at un-signalized intersections is the posted speed limit on different roadways.

Different scenarios based on different speed limits and traffic flow demands are implemented for a comprehensive study.

Traffic volume measures are chosen in a way not to have any kind of traffic congestion. Obviously in a congested situation, drivers' behavior is not the same as in free flow conditions. Furthermore, in a congested situation, vehicles will not drive at their desired speed; thus, evaluating the safety performance at different speed limits will be infeasible.

The intersection which is put into practice is presumed to be a two way stop control intersection. Therefore, vehicles on the major road have the priority and vehicles on the minor road have to give way and stop at the stop line. As it was discussed above, traffic demand should be in a way to avoid traffic congestion.

Different simulation runs were performed to evaluate the upper limit of traffic demand with respect to speed limit on both major and minor road. Based on the results of these simulation runs, traffic volume on the major road is assumed to vary from 500 vehicles per hour (vph) to 650 vph, whilst on minor roads it is supposed to vary from 150 vph to 250 vph. With respect to the variable speed, speed limits are assumed to vary from 45 kilometers per hour (km/hr) to 75 km/hr on the major road and from 35 km/hr to 50 km/hr on the minor road.

At these traffic volume levels and speed limits, no traffic congestion was observed and the simulated vehicles were able to drive at their desired speed. This aspect is important to make sure that the output data is reliable and not affected by any other parameters.

Now, in order to assess the impact of different speed limits, each scenario is compared with the others at the same level of traffic volume. Because the simulator assigns traffic demand stochastically, to avoid any probable misinterpretation, the simulation was carried out 10 times for each scenario and the mean values of PET were calculated.

Analysis of the results (Table 1) indicates that there is a significant change in the traffic safety situation as shown by the mean PET values. It turns out that when the speed limit on both roadways increases, mean values of PET will decrease.

Tab. 1 - Mean PET values for different speed and traffic volume situations

| Volume/Speed	Maj=45 km/hr Min=35 km/h	Maj=55 km/hr Min=45 km/h	Maj=65 km/hr Min=50 km/h	Maj=75 km/hr Min=50 km/h
Maj=650 vph, Min=250 vph	23.6629	21.1768	20.7834	19.7155
Maj=650 vph, Min=200 vph	24.3998	21.8657	21.5988	20.1679
Maj=600 vph, Min=200 vph	24.387	22.7361	21.4859	20.1545
Maj=600 vph, Min=150 vph	28.23	26.4424	24.7612	24.226
Maj=550 vph, Min=200 vph	24.2051	22.8496	22.6376	21.5428
Maj=550 vph, Min=150 vph	29.0857	26.4458	25.846	24.9584
Maj=500 vph, Min=200 vph	22.1836	21.8768	21.0508	20.1744
Maj=500 vph, Min=150 vph	25.8352	24.8912	23.9772	23.3489
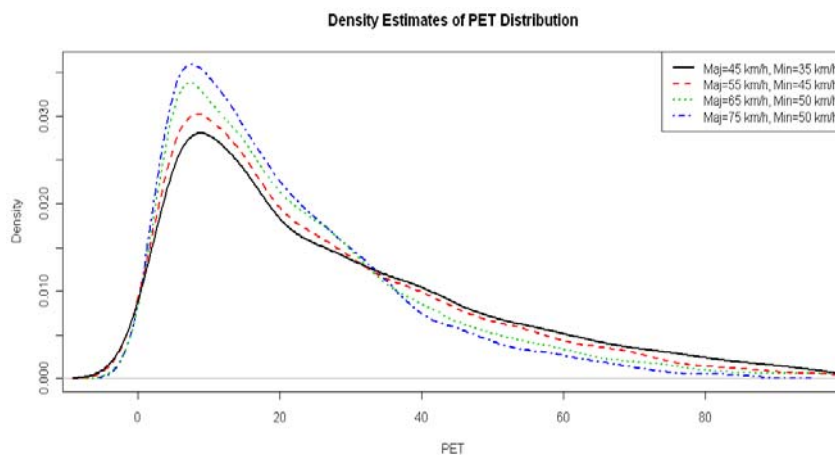
Fig. 3 - Density estimates of PET distribution for "Maj=500 vph, Min=150 vph"

In other words, when the speed on the major roadway increases, drivers on the minor roadway will accept a smaller gap to cross over the intersection and PET, as a proximal traffic safety indicator, decreases. Furthermore, 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. In other words, as long as there is no traffic congestion, the level of safety will become worse by increasing traffic volume. Arguably, at a higher level of traffic demand, vehicles on the major road will face more conflicting vehicles from the minor road on conflict zones. On the other hand vehicles on the minor road have to cross over the intersection, accepting shorter gap times as a result of higher traffic volumes on the major road. By increasing traffic volume, the probability of finding large gap times becomes smaller and consequently PET values will become smaller as well.

Also for a better comprehension, a "Density Estimate Distribution" of PET values for one scenario (Maj=500 vph, Min=150 vph) is depicted in Figure 3. The graph shows that the distribution for the highest speed limit is the densest for small values of PET and vice versa. It means that at higher speed conditions, simulated values of PET are smaller than at lower speed conditions.

4. Conclusions and future research

This paper presented a safety evaluation of unsignalized intersections using microsimulation and proximal safety indicators. Implementing PET as a safety indicator can provide useful comparisons for evaluating the safety level of unsignalized intersections under different traffic volume and speed limit conditions.

The practical merits of microsimulation were demonstrated with varying traffic volumes and speed limits on major and minor roads. The application shows how changes in speed limits and also traffic volume will affect the safety situation, as measured by PET.

Results indicate that increasing the speed limit on both roadways will deteriorate the safety situation. This will be more obvious for higher ranges of traffic volumes. On the other hand, increasing traffic volume, up to the range that does not cause congested traffic, will also worsen the safety situation. In other words, mean values of PET were found to decrease when increasing the speed limit and/or the traffic volume.

This study also shows that drivers' behaviors which have been defined in the microsimulator "S-Paramics" is sensitive to changes in speed limits as a policy measure.

The promising results found in this study pointed out the opportunity of expanding the research to a more complex, comprehensive and extensive traffic safety evaluation including other traffic policy measures.

However, it is necessary to point out that in this study we limited ourselves to the use of PET as a proximal safety indicator, which is only useful to investigate transverse collisions. The use of other safety indicators, like TTC and its derived sub-indicators such as Time Integrated Time-to-collision and Time Exposed Time-to-collision would enable to investigate also other types of collisions, like rear-end and converging collisions. Nevertheless, since most of the collisions at unsignalized intersections are transverse collisions, we believe that the use of PET for this type of intersection is appropriate.

On the other hand, for future studies it would be worth evaluating the safety condition using other types of proximal indicators and also to expand the current research for signalized intersections and roundabouts. A comparison study including implementation of many kinds of safety proximal indicators will also lead researchers to a better understanding of this proactive traffic safety evaluation approach.

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