

A SIMULATION-BASED TRAFFIC SAFETY EVALUATION OF SIGNALIZED AND UN-SIGNALIZED INTERSECTIONS

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ABSTRACT

In many cases, crashes at intersections account for over 50% of all urban road accidents. 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 method for estimating crash potential at signalized and unsignalized intersections for different traffic characteristics. As long as Speeding is recognized as a major contributing factor in traffic crashes, in this study it is emphasized on the contribution of speed in traffic safety situation of intersections. In this study, proximal safety indicators which represent the temporal and spatial proximity characteristics of unsafe interactions and near-accidents are explored and then one of them is implemented in the safety evaluation process for unsignalized intersections and time headway for signalized intersections as a flow characteristic. Results show that an increase of speed limit on roads will end to a more dangerous situation. On the other hand the ability of microsimulator to evaluate safety effects of such policy measure like speed limit is proven.

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 proximity to intersections [1].

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 [2, 3]. 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. The 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

[4, 5] or on traffic safety [6, 7], while others evaluated both speed and safety [8-13]. 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 [12]. Another research presents the results of a comprehensive analysis of the impact of the 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 [13].

On the other hand the relationship between traffic flow and traffic safety should be considered. Benedetto et al. [14] verified the variability of probability and severity of 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 contribute to better road safety. In fact, microscopic traffic simulation helps to evaluate and optimize different routing strategies, without having to realize tests in the field. These tools are mainly used to estimate the performance level of road networks in terms of flow, speed or travel time. The possibilities offered by these software tools, in order to estimate the safety level, remain however limited. In a related research a new safety indicator is proposed which is called "unsafety density" (UD). The concept of the unsafety parameter is based on the direct interaction between 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 planned for highways network assessments. This indicator allows highlighting the difference in safety level between a fluid and a congested traffic flow situation, which cannot be shown by using traditional macroscopic outputs like speed, flow or occupancy [15,16] 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. Thus, it is possible to evaluate road safety. 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 [16].

The potential benefits of adopting a micro-level simulation approach were initially recognized by Darzentas et al. [17]. Although 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 [18]. 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-accidents. The main advantage of such measures is related to their resource-effectiveness given that they occur more frequently than accidents 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. [19, 20, 15, and 21]. Gettman and Head 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 [20]. 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 are able to react before most of the accident occurrences [21].

Recently, a procedure is presented for calibrating and validating a microscopic model of safety performance at signalized intersections, using the above mentioned indicators [22]. In this research a systematic procedure is 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

In this research, two different safety indicators are used to evaluate safety situation at signalized and unsignalized intersections. For signalized intersections, time headway as a safety indicator which can be obtained easily is chosen. Time headway is one of the indicators that are used to estimate the criticality of a certain traffic situation. It has been defined as the elapsed time between the front of the lead vehicle passing a point on the roadway and the front of the following vehicle passing the same point. Time headway is measured by taking the time that passes between two vehicles' reaching the same location. Different countries have slightly different rules with regard to the legal or recommended safety distance. In the US, e.g. several drivers training programs state that it is impossible to follow a vehicle safely with headway of less than 2 sec [23]. In Sweden the National Road Administration recommends time headway of 3 sec in rural areas, and the police use time headway of 1 sec as orientation for imposing fines. In Germany, the recommended minimum distance is "half the speedometer", which means a car traveling at 80 km/hr should keep a distance of at least 40 m. This rule translates to a recommended time headway of 1.8 sec. Fines are imposed when the time headway is smaller than 0.9 sec [24]. There are several other safety indicators, have been used for safety evaluation studies which were discussed about above. For instance, TTC is a very promising indicator for such purposes but the difficulty in its computation process brought us to this conclusion that time headway is a useful, easy to obtain and meaningful indicator. In a comparative research, Vogel [24] recommended that authorities use headway as criterion for tailgating, because it is easy to measure, it is easily understandable and interpretable, and most important of all, it is directed against potential danger, which effectively prevents dangerous TTC values from occurring at all. On the other hand, by defining a safety threshold for headway, it is possible to purify and filter the data in order to avoid too much work on the procedure of TTC calculation. In a car-following situation (e.g. vehicles are approaching a signalized intersection and rear-end accident may have occurred) TTC can never be smaller than the time gap between the lead and the following vehicle. Thus, if the two values are to be compared, it seems reasonable to keep out the cases that are not safety critical with respect to any of the two measures. In other words, for large values of headway, having small TTCs is impossible and having a TTC value bigger than the headway is not unsafe. As a result, sifting the data according to the headway critical threshold will help in reducing computational works. Therefore a short headway can be interpreted as potential danger,

because only vehicles that travel with short headways have the possibility to produce small TTC values and then causing accidents.

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

Paramics is a tool for answering traffic-related questions. The program was developed by traffic and transportation experts of SIAS. This Scottish company developed the model from sketch to higher computer language. From the start, Paramics was implemented using modern computer architecture. The name Paramics stands for **Parallel Microscopic Computer Simulation**, although the use of parallel computers is no longer necessary due to technological developments. Paramics contains a good model for car-following and the possibility to communicate with sources of real-time traffic data.

Headway is one of the outputs of the simulator. To achieve headways of all vehicles on different approaches, several different loop detectors are defined on the network to collect the needed data.

While the use of statistical models based on historical accident 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 accidents must occur before the problem is identified and suitable corrective measures are implemented. Understanding these problems, researchers have recently proposed a framework for “proactive” safety planning, i.e. planning that is not entirely based on historical accident data, but uses other measures such as the use of safety indicators and predictive models [25].

An alternative and/or complementary approach to safety prediction is to measure the more frequent occurrence of near-accidents using proximal safety indicators where these are believed to have an established relationship to accident occurrence. Proximal safety indicators have been suggested as an alternative to the use of accident data. These are defined as measures of accident proximity, based on the temporal and/or spatial measures that reflect the “closeness” of road-users (or their vehicles), in relation to projected point of collision. The actual measure of accident 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 accidents. 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 [25]:

1. Complement accident data and be more frequent than accidents
2. Have a statistical and causal relationship to accidents
3. Have the characteristics of ‘near-accidents’ in a hierarchical continuum that describes all severity levels of road-user interactions with accidents at the highest level and very safe passages with a minimum of interaction at the lowest level

There is several number of proximal safety indicators like TTC, Time Integrated TTC (TIT), TET, PET, Time-to-Zebra (TTZ), 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 unsignalized 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 data-extraction process, not requiring constant recalculations at each time-step during a safety critical event [25]. An example representing the calculation of Post-Encroachment Time is illustrated below in Figures 1(a) and 1(b). The example shown below indicates the position of the two vehicles involved in the safety critical event at the start and end of the PET measurement.

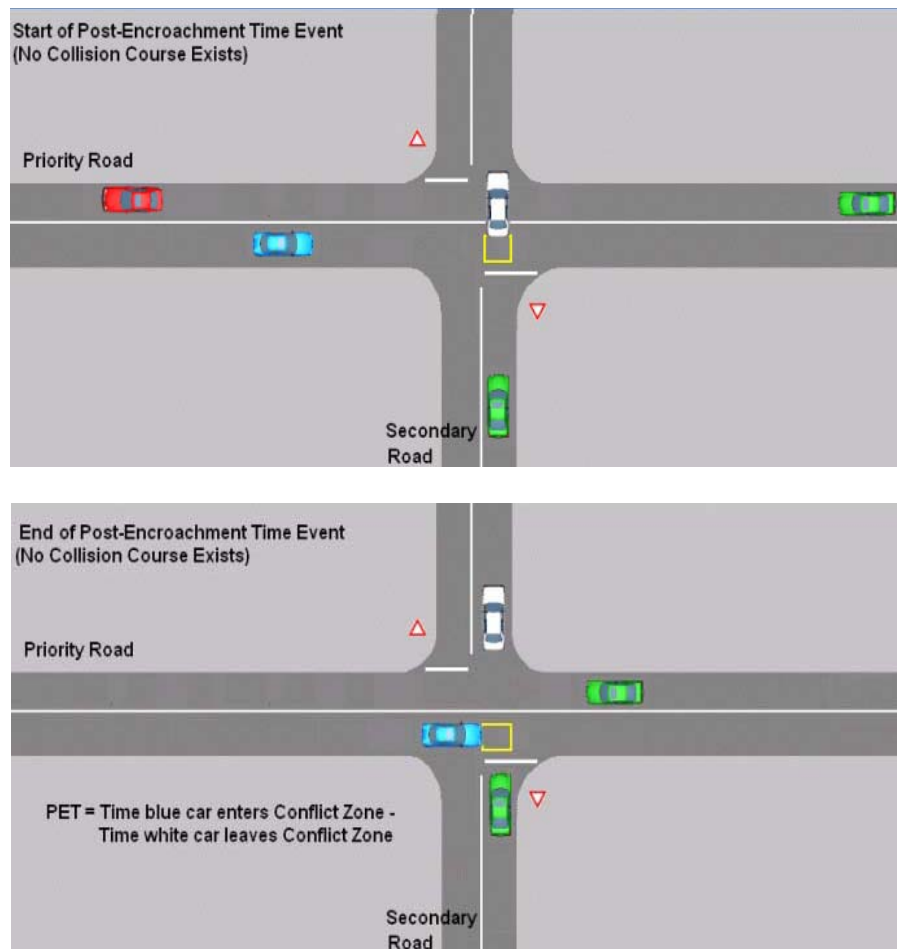


Figure 1: (a) and (b): Example of the calculation of a Post-Encroachment Time event [25]

Outputs of the microsimulator don't provide any direct data about safety situation so a procedure should be adopted to derive desired safety measures out of the output files. To do this, four loop detectors are defined on outgoing links of the four approaches of the intersection. The

detectors are located after the conflict zones; so PET values are easy to be obtained. These detectors will collect needed data such as speed and position of each vehicle. In the context of traffic safety evaluation, data should be as precisely as possible. This issue will become clearer if take it into account that all conflict events will usually take place in less 2 or 3 seconds. To do so, simulation rate is 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.

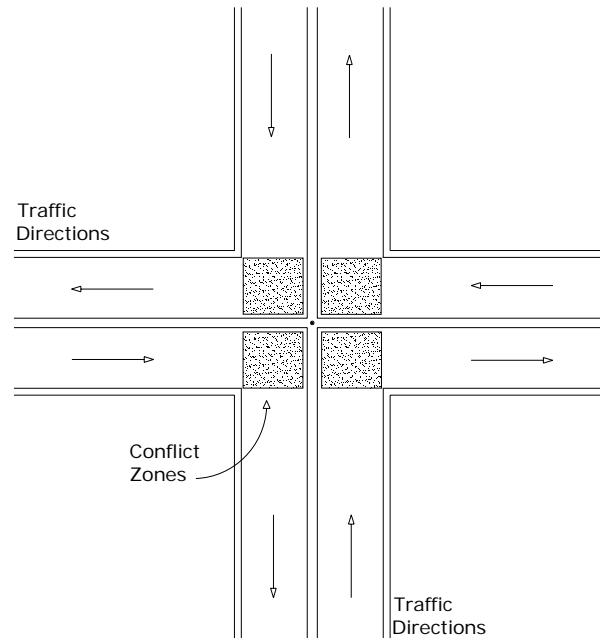


Figure 2: conflict zones at intersection and traffic directions.

3 SIMULATION RESULTS

The main objective of this paper is to evaluate the safety condition of signalized and unsignalized 4-leg intersection under different traffic characteristics. One of the major concerns for evaluating traffic safety at intersections is 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 suggested in a way not to have any kind of traffic congestion. Obviously a situation like traffic jam, drivers' behavior is not the same as normal situation. On the other hand in traffic congestion situation, vehicles will not drive at their desired speed; thus, evaluating the safety performance at different speed limits will be infeasible.

For the signalized intersection which is implemented in this simulation, has traffic volume on major roads is assumed to vary from 750 vehicles per hour (vph) to 2000 vph and on minor roads is supposed to be from 350 vph to 1000 vph. Also speed limits are assumed to vary from 45 kilometers per hour (km/hr) to 85 km/hr on major roads and on minor roads from 35 km/hr to 60 km/hr.

Analyzing the results, shows a significant different in headway distribution at different levels of speed limits. When drivers drive faster, distribution at low values of headway is denser. This fact indicates that a higher speed limit which actually ends to a higher level of operating speed will produce smaller values of headway which is more dangerous in terms of traffic safety. However, the mean value of headway for all speed limits will be approximately constant, if there is no change in traffic demand, because the mean time headway is just depended on traffic flow. Figure 3 depicted a “Density Estimate Distribution” of one scenario with the flow rate of 1000 vph for major road. In order to have a better view, the distribution graph is limited to 3 seconds. As it is shown, the distribution for highest speed limit is the densest for small values of headway and vice versa. It means that at high speeds, simulated values of headway are smaller than lower speed limit situations.

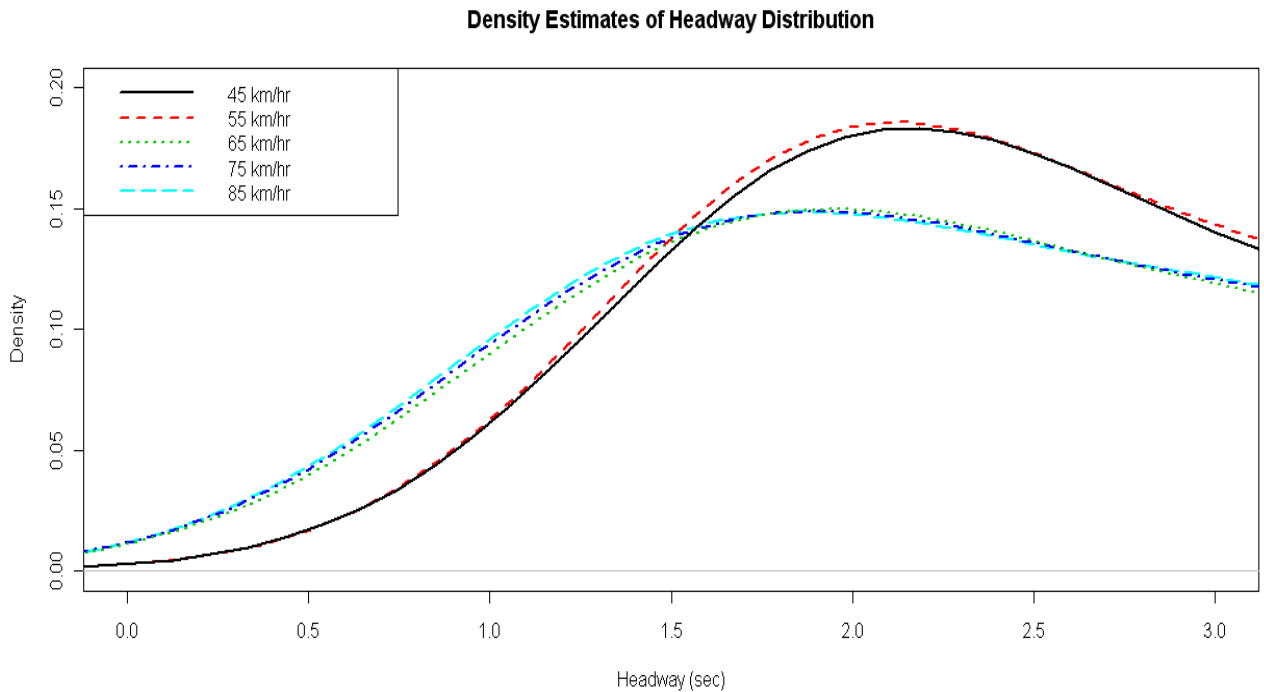


Figure 3: Density estimates of headway distribution for 1000 vph on major road.

The unsignalized intersection which is put into practice is presumed to be a two way stop control intersection. Therefore, vehicles on major roads have the priority and vehicles on minor road have to 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 done to evaluate the upper limit of traffic demand with respect to speed limit on both major and minor road. Based on the results of this simulation runs traffic volume on major roads is assumed to vary from 500 vehicles per hour (vph) to 650 vph and on minor roads is supposed to be from 150 vph to 250 vph.

On the other hand speed limits are assumed to vary from 45 kilometers per hour (km/hr) to 75 km/hr for major roads and on minor roads from 35 km/hr to 50 km/hr.

At these volume levels and speed limits no traffic congestion was seen and vehicles were driven at their desire speed; so the output data is reliable and not affected by other parameters.

In order to assess the impact of variable 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, simulation has been carried out 10 times for each scenario and the mean values of PET were calculated.

Analyzing the results indicates that there is a significant change in traffic safety condition in terms of PET values. It was turned out that by increasing speed limits on both roadways, mean values of PET will decrease. It means that in such situations which drivers are driving faster on the major roadway, drivers on the minor roadway will accept a smaller gap to cross over the intersection and PET, as a proximal traffic safety indicator, specifies a worse safety situation at higher levels of speed limit.

Furthermore, it was found that increasing the traffic volume on both major and minor roadways, will conduce to a decrease of mean PET values. It might be interpreted that the traffic safety situation will become worse by increasing traffic volume as long as no traffic congestion has happened. Arguably at the higher level of traffic demand, vehicles on major roads will face more conflicting vehicles from minor roads on conflict zones. On the other hand vehicles on minor roads have to cross over the intersection, accepting shorter gap times because of more traffic on major roads. By increasing traffic volume, probability of finding large gap times becomes less and consequently PET values will become shorter as well.

Mean values of PET are shown in Table 1 regarding the speed limits and traffic volume on major and minor roads. Also for a better comprehension, a “Density Estimate Distribution” of one scenario (Maj=500 vph, Min=150 vph) is depicted in Figure 4. As it is shown, the distribution for highest speed limit is the densest for small values of PET and vice versa. It means that at high speeds, simulated values of PET are smaller than lower speed limit situations.

Table 1: Mean PET values for different speed and traffic situations.

Volume/Speed	Maj=45 km/hr	Maj=55 km/hr	Maj=65 km/hr	Maj=75 km/hr
	Min=35 km/hr	Min=45 km/hr	Min=50 km/hr	Min=50 km/hr
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

Density Estimates of PET Distribution

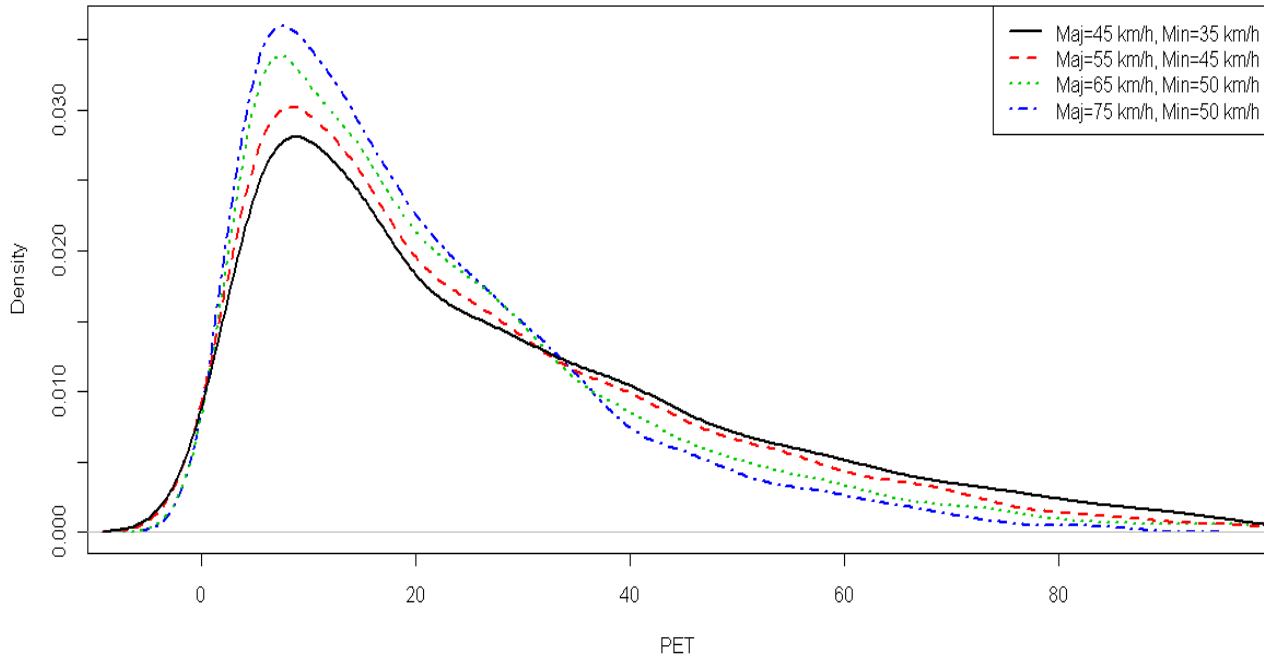


Figure 4: Density estimates of PET distribution for the traffic category “Maj=500 vph, Min=150 vph”.

4 CONCLUSIONS AND FUTURE RESEARCH

This paper presented a safety evaluation of signalized and unsignalized intersections using microsimulation, headway; a flow characteristic and proximal safety indicators. Applying time headway offers a safety evaluation of signalized intersection, while implementing PET as a safety indicator provides useful comparisons for evaluating safety conditions at unsignalized intersection with in different scenarios based on dissimilar traffic volume and speed limit categories.

In this research the practical merits of microsimulation is 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 safety situation.

Results indicated that increasing in speed limits on both roadways will deteriorate 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 doesn't cause any traffic congestion, will worsen safety situation. Mean values of PET will be decreased by increasing speed limits and also traffic volumes. Also at higher speeds on the roadways, approaching a signalized intersection, number of observed short headways is more than lower speed limit situations. It means that speeding will make the traffic safety situation worse.

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. Nonetheless it is still like a black box that how changing in speed limit or traffic demand will affect drivers' behavior and other inter-models like car following models used in the simulator.

This study's promising results pointed out the opportunity of expanding the research to a more complex, comprehensive and extensive traffic safety evaluation including other traffic policy measures.

Although it is necessary to point out that this study does not cover all of the most often used traffic safety proximal indicators like TTC and its derived sub-indicators such as Time Integrated Time-to-collision and Time Exposed Time-to-collision. TTC and its resultant indicators could be used to investigate many types of collisions like transverse, rear-end and converging collisions, while PET can just explore transverse collisions. Nevertheless, besides the simple procedure of calculating PET and its great indication of safety situation, authors believe that this safety indicators yields promising results for a safety evaluation, specifically for unsignalized intersections where most of the collisions are transverse collisions.

On the other hand for the future studies it would be ideal to evaluate safety condition using other types of proximal indicators and also expand the current research for signalized intersections and roundabouts, implementing a more complex safety indicator like TTC. 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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