APPLICATION OF SIMULATION-BASED TRAFFIC CONFLICT ANALYSIS FOR HIGHWAY SAFETY EVALUATION

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ABSTRACT

Highway safety evaluation is one of the critical processes for identifying transportation system performance. The capabilities of common used safety assessing methodologies such as naïve before-after comparisons, safety audit, and statistical modelling, etc, are limited due to historical data availability, observation periods, or observer' experience, and so on. Other than these traditional methods, it has been recognized that the development of traffic conflict techniques in conjugate with micro-simulation model could also offer a potentially innovative way for conducting safety assessment of traffic systems even before safety countermeasures are actually implemented. So in this paper, the application of this new method on highway safety analysis is further investigated. In the meanwhile, most of recent developed safety indicators are reviewed. Inspired by these potential safety indicators in support of traffic conflict analysis, a new time-based indicator is proposed. And the procedure describing the imputation procedure is presented. As an extension of previous study, the new indicator is tested under two different highway models to further highlight its performance. Other than the capability of capturing real crashes' temporal distribution feature showed in previous study, the comparative results also successfully identified the spatial distribution feature of real crash; especially highlight the most dangerous locations. Thus it is suggested that the new indicator has the capability to be applied for simulation-based safety analysis.

Keywords: traffic conflict, safety evaluation, simulation model, TCT

INTRODUCTION & MOTIVATION

Highway safety performance is one of the most important concerns for traffic system all over the world. All kinds of countermeasures including transportation policy, management as well as information assistant, etc, were introduced and implemented to decrease accident risks. Limited budget and resources require maximizing the countermeasures' performance economically without decrease their benefits. However, other than having various advantages, these countermeasures might have certain negative impact as well. It is necessary to identify the dual-effect of them before implementation, so that feasible strategies could be suggested.

One of the most common methodologies to conduct safety analysis or evaluation is the statistical approach on the basis of historical data. For instance, regression models or cluster analysis, etc, could be representatives of such approach to investigate potential impact of different elements, as well as forecast future accident trend. Simply, naïve before-after comparison can also be a useful way to compare the safety performance of certain countermeasure options. Besides, road safety audits (RSA) which is one of the popular safety review process by independent, qualified audit team since 1980s could also serves as a way to report safety issues. Though these methods were often used, several limitations of them should be noticed. For example, regression modelling tries to use other explanatory variables such as AADT, speed, number of lanes, and alcohol, etc, to explain the behaviour of the response variables including number of accidents, severity, and pedestrians involved, etc. It is able to find important predictors and tell a story, but it is difficult to observe all relevant explanatory variables and to perform predictions because of dynamic changes of conditions. For before-after comparisons, a relatively long observation period is needed to gather sufficient information for conducting the comparisons regarding the rare and random nature of traffic accidents. Using RSA in assisting making decisions could be a beneficial approach, but the level of its success will relay heavily upon the auditors' experience and individual preferences. Some other factors such as unreported accidents, length of the analysis period, and observation errors, may also deserve further consideration for safety studies.

Rather than relying on traditional methods, traffic conflict techniques (TCT) have being applied for traffic safety analysis. However, due to the difficulties of observation and data extraction, its application was limited during last few decades. And also most of the applications were concerned on intersection conflicts, which could be counted by well trained observers. Recently, with the advancement of computer technique, more detailed conflict information can be generated based on new computing tools, and therefore, researches are paying increasing attention to such technique again. As one of the popular topics, researches are examining the capabilities of micro-simulation models and alternative safety indicators in support of traffic conflicts collecting. So far, much work has been done, but which still seems to be focused on intersections. Researches on highway traffic conflicts are remain few in number. Thus, the main objective of this study is to extend the use of TCT based on micro-simulation models for highway accident analysis.

In the following sections of this paper, current practices of simulation-based safety analysis studies on highway are reviewed next. A modified crash indicator that can be implemented using micro-simulation models is proposed in the third section. Then, the proposed indicator is tested through two real-world highway models as well as the associated actual accidents, to explain some characteristics and the use of the proposed indicator. Other than identifying the performance of new indicator to capture the temporal features of real crashes as we studied before, this study also tries to demonstrate the indicator's capability of mapping spatial features of the historical accidents occurrence. Finally, the paper draws conclusion and discusses some potential research directions related to this type of study.

TCT BASED HIGHWAY SAFETY EVALUATION

Traffic conflict technique initially emanated from research of identifying safety problems related to vehicle construction at the Detroit General Motors laboratory in the late 1960's (Perkins and Harris, 1968). It was then extended as a popular surrogate safety evaluation method for traffic accident analysis. Though many of its applications were focused on traffic intersections, such as predicting high fatal crash intersections (Tiwari et al., 1998), pedestrian conflicts with left-turning traffic (Lord, 1996), etc, some researchers have being investigating its potential utilization in highway safety evaluation. For example, Fazio and Rouphail (1990) investigated the use of vehicle conflicts, including lane change (LC) and rear-end (RE) conflicts, instead of traffic speed as the indicator for traffic performance evaluation of weaving sections. Using the recorded number of conflicts by Integrated Transportation Simulation (INTRAS) model, it was found that conflict rates were founded to be potentially more effective than speeds as a measure of effectiveness (MOEs) for the analysis of weaving sections. Moreover, their further research (Fazio et al., 1993) studied the relationship between the simulated conflicts of 10 waving sites on Interstate 294 with the real crash rates. A correlation coefficient of 0.74 between LC conflicts rates and the police reported angle/sideswipe accident rates was found, and the higher coefficient of 0.95 was obtained between RE conflict rates and actual RE crash rates, for eight ramps that had moderate lengths ranging from 260m to 305m. It suggested that the simulated conflict rates variations could mimic the directional changes and magnitude of freeway weaving section crash rate variations.

To illustrate the capabilities of TCT in capturing the accident risk, Chin et al. (1991) analyzed conflicts characteristics during the expressway on-ramp merging process. In the study, the conflicts data, time-to-conflict (TMTC, or TTC), was extracted from the video record of a weaving area in Singapore. The inverse of TMTC, which was well-fitted by the mixed Weibull distribution, was used as a measure of the conflict severity. The tail end of the distribution was then used as an fundamental to estimate the average probability of near accident per merge, which was suggested to be used as an indicator of the accident potential of a merging event at the merging area. Since there was no comparison between the real crash rate and estimated accident, the effectiveness of the indicator still needs to be examined. Similarly, Uno et al. (2002) also studied the lane-changing conflict at the weaving section by extracting vehicle movement trajectories from the digital video images in Kyoto. Besides TTC, the study also presented a new indicator, named potential index for collision with urgent deceleration (PICUD), which was defined as the distance between two consecutive vehicles considered when they completely stop. These two measures were compared based on their characteristics of fluctuation against time, and suggested that PICUD was more sensitive than TTC for evaluating the danger of collision of the consecutive vehicle with similar speeds. Detail comparison information was also included in their further study (Bin et al., 2003).

As an attempt to implement TCT through simulation model, European researches (Barcelo et al., 2003 and Torday et al., 2003) proposed another simulation-based safety indicator named unsafety density (UD) and applied it to a case study of ramp metering comparison. AIMSUN was used to gather the particular parameters necessary for the calculation of UD. It suggested that UD can successfully distinguish the effectiveness of applying ramp metering from no implementation. For a further step, Huguenin et al. (2005) examined the relationship between the proposed UD and the real accident at the same site. It was found that the evolution of UD and the number of accidents correspond quite well if a space aggregation was made to the modelled network.

Moreover, Garber and Liu (2007) evaluated the impact of different truck-lane restriction strategies on highway safety through simulation-based analysis. They applied traffic conflict method in micro-simulation model which was developed in Paramics to analyze the performance of each strategy. Three types of conflicts, including lane-changing conflicts, merging conflicts, and rear-end conflicts data was collected from testing scenarios. These simulated conflicts helped to identify the different impact of restriction strategies, geometric factors as well as traffic factors on highway safety performance.

Recently, Pham et al. (2007) applied two alternative safety indicators including TTC and J-value to assess driving risks in Swiss motorways. It was an attempt to extend the motorway automatic traffic counts (ATCs) utilization in combination with surrogate measures for safety analysis. Sensitivity of each indicator corresponding to traffic flow and weather conditions was discussed, and it was found that both indicators were highly depend on traffic flow, while only J-value can also reflect the weather conditions impact on risk. Their case study for the real accident scenario showed that these two indicators were valuable for crash-predicting model. Latest FHWA sponsored research made another step forward to show the potentials of surrogate safety measures (Gettman et al., 2008).

Although great progress has been made on applying TCT for highway safety evaluation, most of aforementioned studies were still focused on specific site or special case studies, such as ramp metering, weaving or merging section. To identify the relationship between real crashes on highway and traffic conflicts, more calibration and validation work is still needed. Though aforementioned studies has already shown that micro-simulation models have the potential in support of TCT application using different alternative indictors, few of them compared the real accident with the simulated results. The positive correlation of these simulated results and real accident risks yet need further examination.

POTENTIAL INDICATORS FOR HIGHWAY SAFETY ANALYSIS

One of the major concerns on TCT is how to identify the potential conflicts. Other than depending on subjective observation and judgement, alternatively, objective measures have being developed by many researchers. Generally, such kind of alternative measures can be classified into four groups, including time-based, distance-based, deceleration-based, as well as other composite measures. One of the most frequently used time-based measures is, as mentioned in previous section, the TTC. Besides, TET (Time Exposed Time-to-collision) and TIT (Time Integrated Time-to-collision) extended from TTC were also introduced by Minderhoud and Bovy (2001). Deceleration rate to avoid the crash, namely, DRAC could be a typical deceleration-based indicator. Crash potential (CP), proposed by Saccomanno and Cunto (2006), could also be an indirect use of such kind of measure. One important example of distance-based indicator could be the Possibility Index for Collision with Urgent Deceleration (PICUD) mentioned in previous section. Besides these time-based, distance-based, and deceleration-based measures, several other studies also proposed specific indicators such as UD, J-value, and CI, etc, in support of safety evaluation.

Table 1 summarizes the potential traffic conflict indicators that can be applied to highway safety analysis. Figure 1 demonstrates the evolution process of these indicators which have been proposed or applied for highway safety evaluation. During 1991~2001, there were few deployment of the indicators. While in recent years, such kind indicators were more frequently used. This is possibly due to the development of the technology such as video image analysis, sensor, etc, to collect more detail information of vehicle trajectories for indicators derivation. In practice, some of the indicators can be used together to get more features of the conflict. But there is still no clear quantitative relationship among them. Each indicator tries to describe traffic conflict in certain aspect. In the meanwhile, since few performance comparisons were made, it's hard to distinguish the dominated one from the others. So, in the following section, we only selected the frequently used TTC as a fundamental to illustrate performance of a new proposed time-based indicator for highway safety analysis.

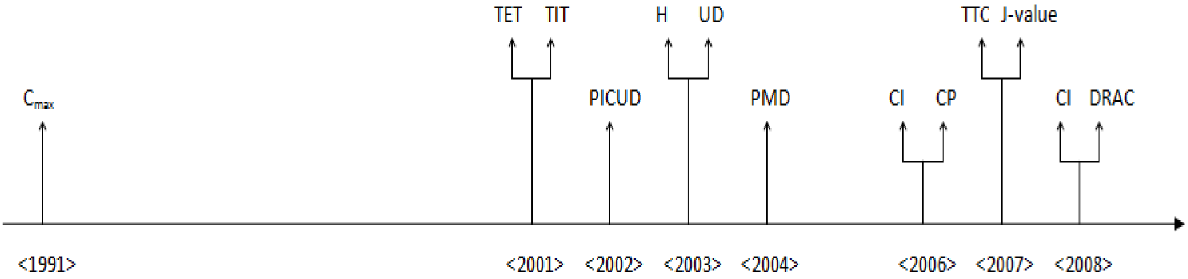


Figure 1 Evolution of traffic conflict indicators for highway safety evaluation

Table 1 Potential traffic conflict indicators for highway safety analysis

Indicator	Unit	Description	Computation	Year
C_{max}	1/s	Inverse of time-to-collision*(6)*	$C_{max} = \frac{\Delta V}{D}$	1991
TTC	s	Time-to-Collision*(12)*	$TTC = \frac{D}{\Delta V}$	2007
UD	N/A	Unsafe Density*(9) (10) (11)*	$UD = \frac{\sum_{s=1}^{S_t} \sum_{v=1}^{V_t} (\Delta S \cdot S \cdot R_d) \cdot d}{T \cdot L}$	2003
PICUD	m	Potential Index for Collision with Urgent Deceleration*(7)(8)*	$PICUD = \frac{V_1^2 - V_2^2}{2\alpha} + s_0 - V_2 \Delta t$	2002
J-value	N/A	An accumulative safety indicator*(13)*	$G(i) = Max[0, log_2(\frac{1}{2}\frac{v_i}{\gamma_{max}}\frac{1}{Gap_i})]$ $J(i) = \begin{cases} 0 & if G(i) = 0 \\ J(i-1) + G(i-1) & if\ G(i) > 0 \end{cases}$	2007
CI	m^2/s^2	Criticality Index*(15)*	$CI = \frac{V^2}{TTC}$	2006
TET	s	Time Exposed time-to-collision*(16)*	$TET_i^* = \sum_{t=0}^{T} \delta_i(t) \cdot \tau_{SC}$ $\delta_i(t) = \begin{cases} 1 & if\ 0 \leq TTC_i(t) \leq TTC^* \\ 0 & otherwise \end{cases}$	2001
TIT	s^2	Time Integrated time-to-collision*(16)*	$TIT^* = \sum_{i=0}^{N} \int_0^T [TTC^* - TTC_i(t)] dt$ $\forall\ 0 \leq TTC_i(t) \leq TTC^*$	2001
CP	s	Crash potential*(17)*	$CP_i = \sum^{T_i} b \cdot \delta t$ $b = \begin{cases} 1 & if\ DRAC > MADR\ for\ each\ time\ interval \\ 0 & otherwise \end{cases}$	2006
H	s	Headway of vehicle i and ahead vehicle i-1*(19)*	$H = t_i - t_{i-1}$	2003
DRAC	m/s^2	Deceleration rate to avoid the crash*(20)*	$DRAC_{i,t+1} = \frac{(V_{i,t} - V_{i-1,t})^2}{(V_{i-1,t} - V_{i,,t}) - L_{i-1,t}}$	2008
PMD	m	Predicted minimum distance*(21)*	$pd(k+i) = d[x_{SVf}(k+i), x_{Of}(k+i)]$ $PMD = \min_{i=1 \ldots MaxPoint\ s} pd(k+i)$	2004
CI	N/A	Crash Index*(18)*	$CI = \frac{(V_F + a_F.MTTC)^2 - (V_L + a_L.MTTC)^2}{2} \times \frac{1}{MTTC}$	2008
Note: Please see the reference for detail explanation of each parameter used in above formula.				

A NEW TIME-BASED INDICATOR

Traditional TTC was defined as the time it would take a following vehicle to collide with the leading vehicle if both vehicles' movements remain unchanged. If proper precautions were taken within this time interval, then collision can be avoided. Figure 2 illustrates the evolution process of rear-end conflict if the following vehicle took no or improper countermeasures to respond to the leading vehicle's deceleration.

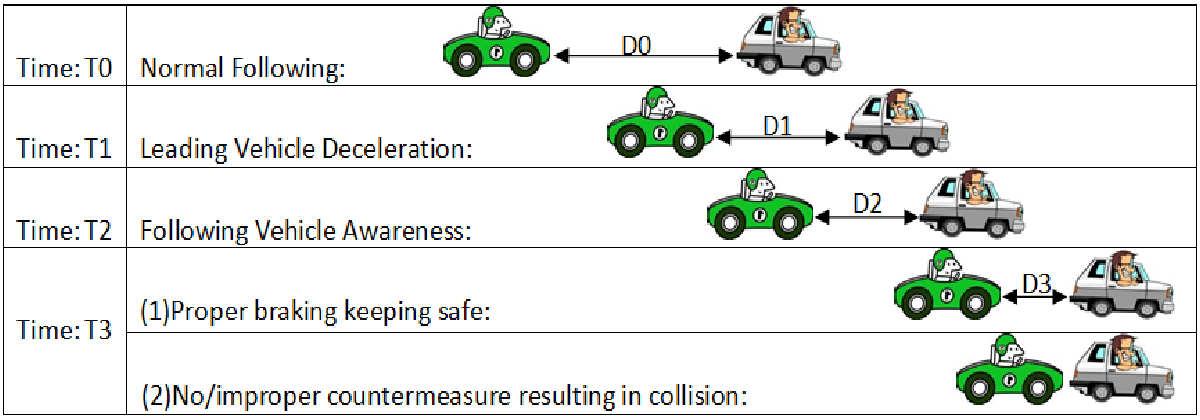


Figure 2Typical car-following and rear-end collision scenario *(18)*

TTC can be derived from the relationship of relative space gap D (m) and relative speed ΔV (m/s) between a pair of consecutive vehicles. This is formulated as follows:

$$TTC = \frac{D}{\Delta V} \tag{1}$$

The above equation is based on the assumption that the consecutive vehicles will keep constant speeds until the collision occurs. Moreover, this definition of TTC signifies that only if the speed of the following vehicle is greater than that of the leading vehicle, it will result in a collision. Ozbay et al. (2008) suggested that such assumptions ignored many potential conflicts due to acceleration or deceleration discrepancies. Modified models were presented which considered all of the potential longitudinal conflict scenarios as summarized in Table 2. In the table, V_F, V_L, a_F, and a_L are the speed and acceleration of the following and leading vehicles, respectively.

Table 2 Description of possible scenarios between two vehicles one following the other

V	$V_F > V_L$			$V_F \leq V_L$		
a	a_L >0	a_L <0	a_L =0	a_L >0	a_L <0	a_L =0
a_F >0	P	C	C	P	C	P
a_F <0	P	P	P	I	P	I
a_F =0	P	C	C	I	C	I
Note: C-Conflict occurs; P-Possible Conflict; I-Impossible conflict with each other.						

Occurrence of conflict is associated with the trajectory of the two vehicles, including their relative distance, relative speed and relative acceleration. This relationship is shown by the equations (2) and (3) to determine whether a conflict would occur.

$$V_F t + \frac{1}{2} a_F t^2 \geq D + V_L t + \frac{1}{2} a_L t^2 \tag{2}$$

$$\frac{1}{2} \Delta a t^2 + \Delta V t - D \geq 0 \tag{3}$$

Where, V_F is the following vehicle's speed (m/s); V_L is the leading vehicle's speed (m/s); a_F is following vehicle's acceleration (m/s^2); a_L is leading vehicle's acceleration (m/s^2); ΔV is relative speed (m/s), $\Delta V = V_F - V_L$; Δa is relative Acceleration (m/s^2), $\Delta a = a_F - a_L$; D is initial relative space gap between the two vehicles (m); and t is time (s).

By solving the equation (2) or (3) the minimum MTTC for all the possible conflicts will be calculated. If there is no relative acceleration difference between following and leading vehicle, MTTC still follow the above formula (1). However, if there is acceleration difference, MTTC is derived by the minimum non-negative solution of formula (4):

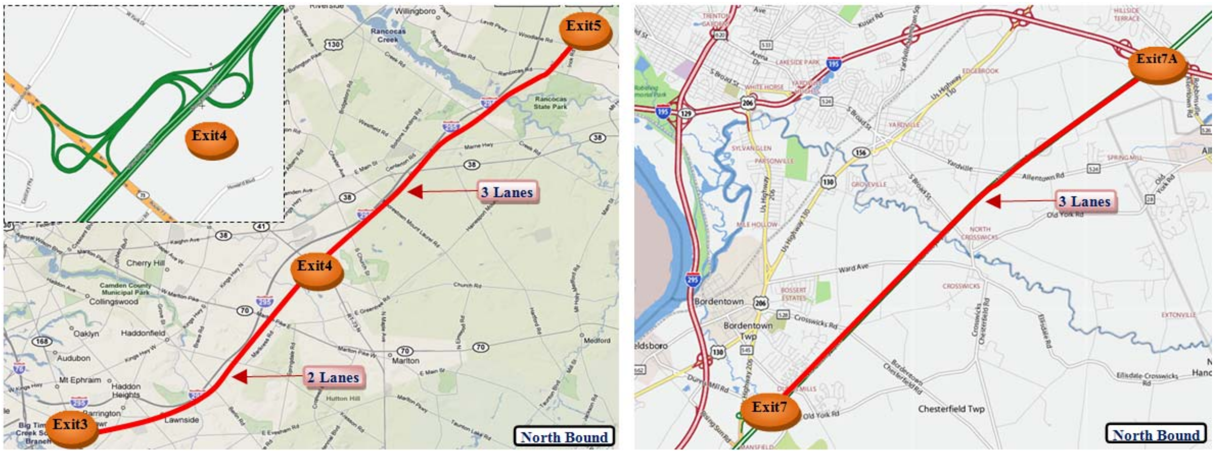
$$MTTC = \frac{-\Delta V \pm \sqrt{\Delta V^2 + 2\Delta a D}}{\Delta a} \tag{4}$$

Comparing the calculated MTTC with a threshold value, the risky conflicts will be highlighted. However, the magnitude of a threshold below which would indicate a serious traffic conflict deserves further consideration. As there are different kind of aggressive, awareness drivers, each one may have different judgment when facing the same potential collision situation. So this may results in no unique threshold value for application. Indeed, there is still no agreement with specification of the threshold TTC. For example, Van der Horst (1991), and Farber (1991) suggested a TTC value of 4 seconds to distinguish between safe and uncomfortable situations on road. Hogema and Janssen (1996) suggested a minimum TTC value of 3.5 seconds for drivers without an automatic cruise control system and 2.6 seconds for drivers with equipped vehicles. As MTTC in this study will be implemented in simulation model, it should have special consideration for applying in a simulation environment. Actually, most commercially available simulation models are still accident free systems, in which the simulated drivers do not really suffer from distraction, misjudgement, and errors which would result in many accidents under real world conditions. A relatively longer MTTC, therefore, is deemed to be a reasonable choice. Thus, four-second is then considered as the threshold value applied in this study.

To test the performance of the new indicator MTTC, a detailed comparison between simulation results and real accident records was conducted. The proposed MTTC was tested based upon two simulation models of the New Jersey Turnpike. Firstly, without considering the geometric discrepancies, the section of 6.67 miles between Exit 7 and 7A (northbound) was modelled. This section has three lanes with no on-ramps or off-ramps within the section. Secondly, in order to investigate the new indicator's capability of indentifying geometric difference, another section of 17.70 miles between Exit 3 to Exit 5 (northbound) was modelled, in which the interchange of Exit 4 was included. The segment between Exit 3 and 4 has two lanes, while from Exit 4 to 5 it has 3 lanes. Both models have a posted speed of 65 mph. 24-hour actual traffic volumes with variation were coded as the basic input so that the random fluctuation features of traffic flow can be captured. Figure 3 gives the basic schematic diagrams of these two tested sections.

Police reported crashes records between 1996 and 2005 for each section were used. The records consist of detailed information on each accident, including type, time, location, as well as some other information. The major types of crashes, including rear-end and sideswipe accidents on highway, were extracted from the dataset. By comparing the simulated traffic conflicts with the corresponding real accident characteristics, if the new indicator is versatile, it should keep a strong relationship with the real accidents either in time or space, or even both. This assumption will serve as the rule for testing the performance of the indicator.

Paramics was selected as the test platform because of the its customizable potential. Detail simulation data were collected according to the replication procedure presented in our previous study (Ozbay et al., 2008).Then the outputs were obtained for further analysis.

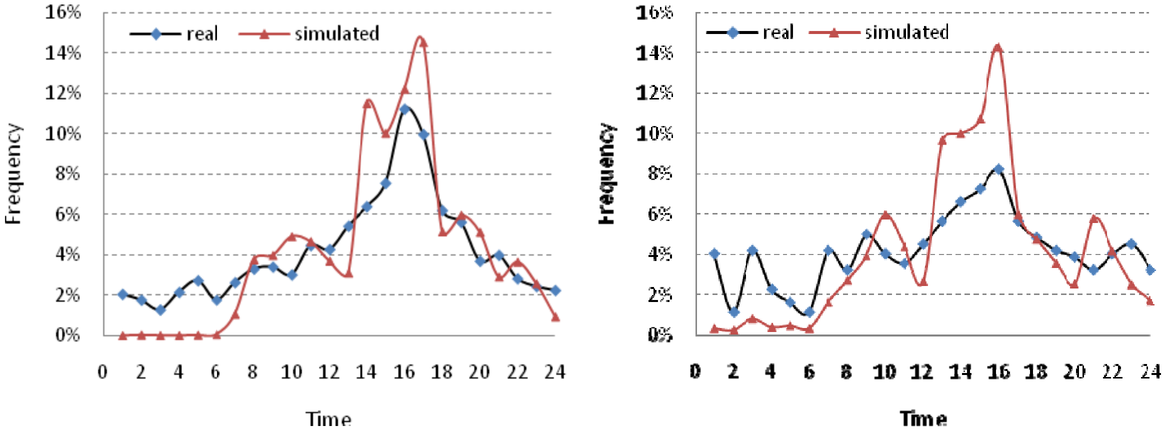


(a) Exit 3 to Exit 4 (b) Exit 7 to Exit 7A
Figure 3 Schematic diagrams of the studied sections

ANALYSIS OF RESULTS

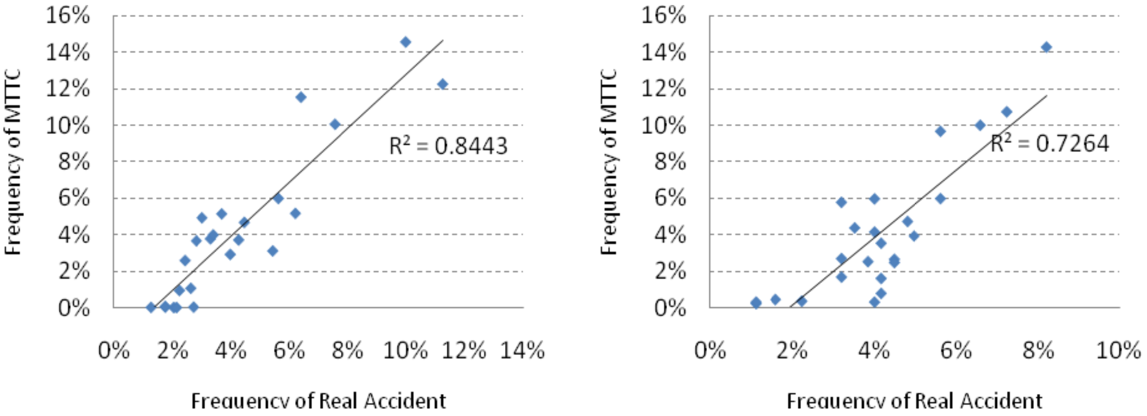
For a daily commute corridor, due to the traffic flow pattern, road geometric condition, etc, the accidents along it should also have certain pattern over time and space. There might be high accident risks at some special times or locations. For instance, more accident may occur during the rush hours. Before exploring the accident database of New Jersey Turnpike, it was intuitively assumed that there might be more accidents during the morning peak hours. However, in-depth analysis of historical accidents records for several locations indicates that more accidents actually occurred in the afternoon rather than the morning peak hours. As an example, Figure 4 shows that the most dangerous times are around 16:00 pm in both of the two objective sections studied here. Lots of factors might be able to explain such phenomenon, but it was assumed that drivers are more alert and awareness during the morning, while in the afternoon there might be more users who are less familiar with the roadway and its driving conditions (since more familiar drivers i.e. more commuters, might be on the southbound direction in the afternoon), and thus relatively less careful while driving. In order to get more reasonable simulation results, our model reflected these driver characteristics. As Paramics simulator provides us two parameters, including aggression and awareness, to control driver behavior between different periods during the simulation, the two parameters were then adjusted to mimic different driver groups during different time periods.

Figure 4 shows the time distribution of actual accident records, and frequency of MTTC which below the threshold for each hour. The number of actual accidents for each hour used in the figure was the subtracted records of ten years (1996~2005) for each corresponding hour. Figure 4 illustrated that MTTC can capture the temporal features of accident occurrence, especially highlight the periods with high crash risks. This is signified by their positive correlation, 0.852 and 0.918 respectively (in Figure 5 (a, b)). The higher frequency of the MTTC is the more real-world accidents tend to be observed. This result therefore illustrates the performance of MTTC that can be correlated to the actual accidents trend in time. One thing it should mention, that during the lower volume periods, it seems few MTTCs below the threshold were detected. This can be attributed to two aspects: The simulation itself is an accident free system, and its internal models such as car-following, lane-changing, under such kind operation condition may limit the performance. Also, only a fixed threshold value was used. During the lower volume condition, it may need adjustment. In other words, a dynamic critical value or threshold to determine the conflict scenarios deserves consideration.



(a) Exit 7 to7A (b) Exit 3 to 5

Figure 4 Temporal distributions of real accidents and simulated MTTC.

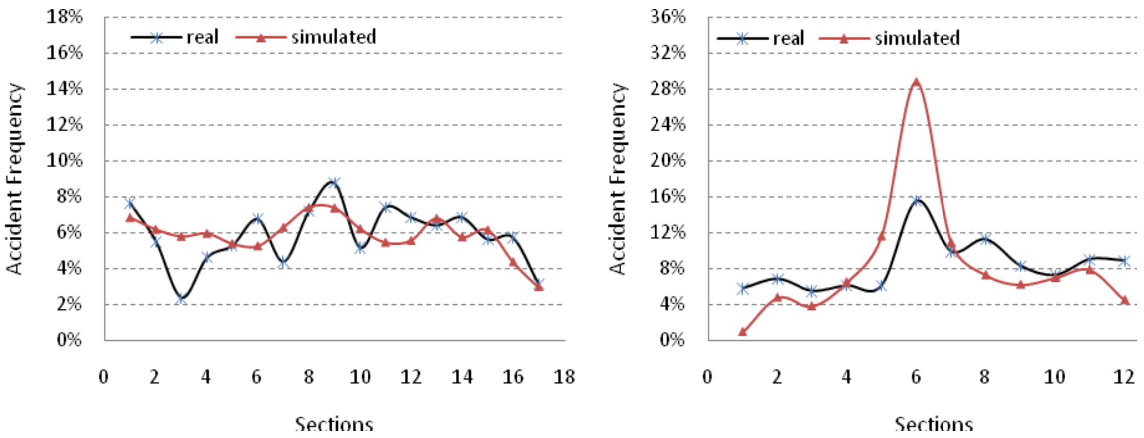


(a) Exit 7 to7A (b) Exit 3 to 5

Figure 5 Temporal correlations between real accident and simulated MTTC.

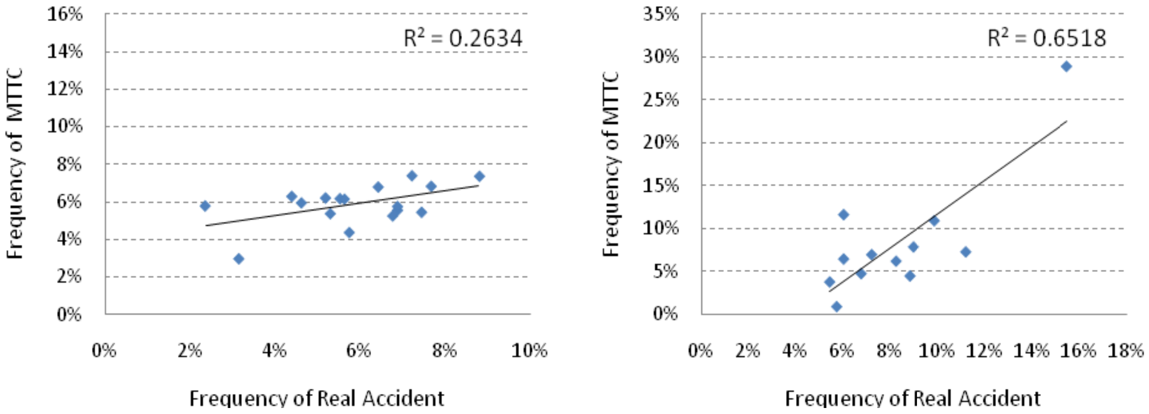
For spatial characteristics, since there were no obvious discrepancies in terms of the geometric features of the section between Exit 7 to 7A, it is safe to assume the accidents can randomly happen anywhere along the section and thus no significant difference could be observed. While for the section between Exit 3 to Exit 5, the transition of different geometric configurations and the interchange Exit 4 both will disturb the through traffic flow, thus the accident occurrences along this section is expected to have some special features. Since the section between Exit 7 to 7A looks like a straight link, it was split into a series of small segments with length of 600 meters (0.37 miles). To capture the interchange impact in a single segment, Exit 3 to 5 was, however, divided into 1-mile segments. Historical accident records of the ten years were then associated with these shorter segments in each objective respectively to test the assumptions of the spatial features in each case. If the MTTC is effective, its spatial features should also correspond to the real situation demonstrated by the accident records.

Following Figure 6 illustrates the frequency of accident happened at each segment and the simulated MTTC frequency at the same site. For Exit 7 to 7A, though Figure 7 indicates that there is no strong correlation (0.513) between the spatial distribution of real accidents and the frequency of MTTC, it still can be seen that the both crashes and conflicts trends of their majority are about 6%~8%. For the section of Exit 3 to 5, the segments between Exit 3 and 4 with two lanes tend to have lower risk, while the parts with three lanes have a slightly higher risk in reality. The most dangerous segment was found to be the one covering Exit 4. This is obvious due to the complex weaving and merging process around this segment. In this case, MTTC seems to perform much better. It follows the general trend of the real accident, especially highlight the most dangerous interchange segment. The correlation between simulated results and the actual crash record is 0.807, which is pretty good compared to the other section.



(a) Exit 7 to7A (b) Exit 3 to 5

Figure 6 Spatial distributions of real accidents and simulated MTTC.



(a) Exit 7 to7A (b) Exit 3 to 5

Figure 7 Spatial correlations between real accident and simulated MTTC.

CONCLUSIONS & FUTURE WORK

This study investigated current application of traffic conflict technique (TCT) for highway safety evaluations. Alternative safety indicators that can be used in assisting implementing TCT also were summarized and their evolution processes were illustrated. Based on the understanding of these surrogate measures, a new time-based indicator MTTC which can better capture the potential conflicts scenarios was proposed based upon the extension of the well-known TTC. Its application was demonstrated through the case studies of two real highway sections of New Jersey Turnpike. The detail imputation procedure of MTTC was described in the paper, and was finally integrated into the Paramics model to obtain the analysis results. In order to investigate the performance of the new indicator, 10-year real accidents records associated to the studied objectives were subtracted from New Jersey Turnpike accident database and their temporal and spatial characteristics were directly compared with simulation results using MTTC. Figure 4 and Figure 5 shows that the new indicator can be a reasonable measure to capture the temporal trends of real crashes in both of the two scenarios. The spatial prediction performance of MTTC to Exit 7~7A as shown in Figure 6 and Figure 7 was not as good as to that of Exit 3~5. It was not expected that the indicator can exactly match all the situations. This indicates there are some underlying influential factors which cannot be explained by the indicator. But as a reasonable measure in the later case, the indicator was shown to be capable of highlighting the real dangerous location. It is satisfied with the common agreement that accident rates increase significantly when vehicles egress and ingress into the stream or converge around highway weaving and merging area. Therefore, the new indicator can be implemented as potential surrogate safety measures for highway safety analysis.

Since the indicator was derived based on the trajectory information of two consecutive vehicles, it is mainly related to longitudinal conflicts. This may be one of the reasons why the detected conflicts were correlated with the crash features but cannot completely explain it at the studied sites.

For future studies, as the new indicator seems difficult to identify those potential conflicts when traffic volume is low, the critical threshold value still deserves more investigations. The procedure to establish a threshold value prior the conflicts analysis deserves more consideration. Similar test studies can be conducted to identify the performance of the indicator for more applications.

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