ESTIMATION OF MODIFIED TIME TO COLLISION AS SURROGATE FOR MID-BLOCK CRASHES UNDER MIXED TRAFFIC CONDITIONS

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Word Count: 5775 words + 6 figures + 1 table = 7525 words

Submission Date: November 14, 2016
ABSTRACT

Quantification of safety is necessary to assess the crash risk of a road facility and evaluate the effect of implemented accident countermeasures. Traditional safety quantification procedure uses accident data which in spite of being a direct measure of safety, has limitations such as recording errors, missing data, small sample size and reactive approach. In this context, surrogate safety measures offer flexibility to assess safety and evaluate the effectiveness of countermeasures. With advancement in micro simulation models these measures can be tested on road in their planning stage and can be implemented in Collision Avoidance Warning Systems in new generation vehicles for driver support. This demands a surrogate measure that has been validated and evaluated on different roads under different conditions to estimate conflicts with minimum error. The present study proposes a methodology to identify possible conflicts using width characteristics of vehicles and estimate an existing surrogate measure-Modified Time to Collision (MTTC)-under mixed traffic conditions with due consideration of all vehicle types and their characteristics. The proposed methodology has been implemented in a real case study using a micro simulation model and has been evaluated against real world accident data. Sensitivity of MTTC threshold is studied to arrive at an appropriate critical threshold. Results indicate a strong temporal and spatial correlation between the estimated conflicts and real accidents for a considerable time of the day. The study considers diverse vehicle characteristics and maneuvers. The limitations of MTTC as a surrogate for mid-block crashes has been studied and discussed.

Keywords: Surrogate Safety Measure, Modified Time to Collision, Mid-block Crashes, Mixed Traffic Conditions, Traffic Safety, Safety Evaluation
INTRODUCTION

Numerous approaches, involving education, enforcement, and engineering are being taken around the globe to minimize road accidents. In order to improve safety by any of these approaches, it becomes imperative to evaluate the associated crash risk, which is possible only through quantifying safety. Quantification of safety has traditionally been performed by using accident data, which is a reactive approach and has several limitations such as limited sample size, improper records, missing information about causal factors and rarity, randomness and stochasticity associated with accidents. Surrogate safety measures (SSM) on the other hand is a proactive approach that replaces the need for crash data with an observable non-crash event that is related to crashes and can further be converted into a corresponding crash frequency or severity. SSM identifies the less severe events that occur more frequently in a transport system as compared to severe accidents and the frequency of severe accidents is reduced by reducing these less-severe accidents (1). It is assumed for obvious reasons that if an accident counter measure affects the traffic safety, it should affect its surrogate as well (2).

Several surrogate measures have been developed by researchers in the past, each being one step ahead of the previous one in estimating crashes with accuracy. Most of these studies deal with scenarios involving cars alone and ignores the effect of mixed vehicle types, variations in driver behavior, and geometric characteristics which are key factors affecting the safety of any system. Mixed traffic conditions is characterized by different vehicle types leading to different types of movements and interactions along with weak lane discipline. This phenomenon is expected to have an effect on the surrogate as well, but hasn’t been studied until now. Variation in driver behavior especially during night time driving when the factors that influence crashes are mostly as a result of driver distraction due to sleep or drowsiness, poor visibility and geometric characteristics of the road section has not been studied much with relation to SSM. The present study attempts to take into account the mixed traffic condition in evaluating the measure and highlight the need for consideration of parameters related to night time, driver behavior, and geometry. From the several existing SSM, Modified Time to Collision (MTTC) has been applied in the present study as it considers few of the most relevant crash influencing parameters such as distance gap, relative speed and relative acceleration of interacting vehicles (3). Since the measure has previously been validated against real world accident data in homogeneous traffic conditions (3), it is assumed that the measure could be applied to mixed traffic conditions as well with modifications in the MTTC computational procedure.

The present study proposes a method to identify possible conflict scenarios and estimate MTTC accurately under mixed traffic conditions. The study attempts to assess the strengths and weaknesses of MTTC in evaluating the safety of mid-block in mixed traffic conditions through application of the same on a real case study. In this context, mid-block section refers to the road segment between intersections where the interacting vehicles are exposed mainly to rear end, side swipe, or run off crashes. Sensitivity analysis has been carried out to arrive at a critical MTTC threshold. The effectiveness of MTTC in estimating conflicts under varying driver distraction and visibility conditions is evaluated. This study attempts to consider all mid-block crash types and proposes modification of MTTC computation procedure to account for all crash types which would result in an improved Modified Time to Collision model for a better estimation of safety at mid-blocks.
LITERATURE REVIEW
Several researchers in the past have tried to come up with surrogate measures based on different parameters that could replace the use of accident data in determining the safety of a facility. The measures can broadly be classified into time based, speed based, deceleration rate based, and event based measures. In the recent past, several comprehensive models have been developed combining 2 or 3 measures. Also with the advancement in simulation techniques, surrogate measures based on simulation has also been developed. Among these measures, time-based measures, namely variations of ‘Time to Collision (TTC)’ have been used largely in surrogate analysis around the globe especially in mid-block sections because of increased accuracy associated with it, physical significance and the ability to capture speed and gap at the same time giving a clear idea about the time left for an event to occur. These time based measures have been reviewed in detail in this study.

Time to collision has been defined originally as the time left for collision provided the speed and course of the colliding objects continue to remain the same during a car following scenario (4). TTC concept was redefined and renamed as ‘time to accident’, the TTC value at the moment where one of the road users react and starts braking (5,6). TTC for rear-end collision of a following vehicle \( f \) with respect to a leading vehicle \( l \) at time \( t \) is generally calculated using equation (1).

\[
TTC_f(t) = \frac{x_l(t) - x_f(t) - L}{\dot{x}_f(t) - \dot{x}_l(t)} \quad \forall \dot{x}_f(t) > \dot{x}_l(t)
\]  

where, \( \dot{x} \) denotes the speed, \( x \) the position and \( L \) the vehicle length. For the case of head-on collision between two vehicles ‘1’ and ‘2’, the previous equation can be easily modified to equation (2).

\[
TTC = \frac{x_1 - x_2}{\dot{x}_1 + \dot{x}_2}
\]

As per the basic TTC concept, TTC is measured for each instant or for many instances at a particular section of road. Also, to identify whether the event considered would result in a crash or not, a threshold TTC is to be defined indicating the minimum TTC for safe traffic operations. Two modified TTC indicators, namely Time Exposed Time to Collision (TET) and Time Integrated Time to Collision (TIT) which considers a longer time and section of road has been devised to overcome the error associated with instantaneous measurements. Time exposed time to collision is defined as the total duration of exposure to TTC value less than threshold value (7). This measure however does not consider the variations in safety levels below the threshold value. This draw back has been accounted for in the time integrated time to collision indicator which uses the integral of the TTC profile to indicate safety. Rate of change of TTC with respect to time, represented as TTC’ was considered to be a better measure to predict safety as compared to TTC values (8). The rate of change of TTC value is a reflective of the changes in driver behavior during the car following process and hence, is considered to be a critical factor in the assessment of road safety and collision prediction. As TTC’ falls below zero, the probability of collision increases. A comprehensive time-based surrogate measure (CTM) is hence devised to quantify the comparative levels of risk associated with each time period by integrating Rate of change of TTC, Time Exposed Time to Collision (TET), and Time Integrated Time to Collision (TIT). Another index, Rear End Collision Probability (RECP) has also been proposed combining the TTC variation and severity concurrently. This measure is developed aiming its application in collision avoidance system to reduce driver errors and rear end collisions (8).
The TTC measures and its variants discussed until now were purely based on relative distances and speeds. Several possible conflict cases that can arise because of changes in accelerations of the vehicles in consideration are ignored in these studies. The equation (1) becomes invalid when the following vehicle travels at a speed equal to or less than the leading vehicle. But even when following vehicle travels at a speed equal to or less than the leading vehicle, it still can lead to collision if the acceleration of following vehicle is increasing. Hence there is a need to incorporate acceleration into the model to compute time to collision accurately. Ozbay et al. (2008) made an effort to identify all possible conflict cases considering different combinations of relative speeds and accelerations of the two interacting vehicles (3). A relationship was formulated to predict the possibility of occurrence of conflict based on Newton’s equations of motion as shown in the equations (3) and (4).

\[
v_f t + \frac{1}{2} a_f t^2 \geq d + v_l t + \frac{1}{2} a_l t^2 \quad (3)
\]

\[
\frac{1}{2} \Delta a \ t^2 + \Delta v \ t - d \geq 0 \quad (4)
\]

where \(v_f\) and \(v_l\) denotes the speed of the following and leading vehicles, \(a_f\) and \(a_l\) denotes the acceleration of the following and leading vehicles, and \(\Delta v\) and \(\Delta a\) denotes the relative speed and relative acceleration of the interacting vehicles, \(d\) is the initial relative distance, and \(t\) is the time gap.

Based on these equations, a surrogate measure, Modified Time to Collision (MTTC) has been proposed (3). This measure considers the speeds and accelerations of both the vehicles and is calculated according to the equation (5).

\[
MTTC = \frac{-\Delta v \pm \sqrt{\Delta v^2 + 2\Delta a \ d}}{\Delta a} \quad (5)
\]

MTTC is evaluated using an algorithm to check for non-negativity of time, relative speeds and relative accelerations, and assigns the most accurate value as time to collision. It is validated using Paramics micro simulation model on a 6.67 mile mid-block section of the 3 lane New Jersey Turnpike against real accident data.

A low value of TTC indicates high probability of collision and a high value of TTC indicates low probability of collision. To distinguish between safe and unsafe vehicle encounters based on these TTC values, an accurate TTC threshold needs to be defined (6). Different thresholds have been adopted in the past studies. A threshold of 1 second has been proposed based on a quantitative analysis of 43 critical situations (4). A threshold value of 1.5 seconds has been proposed for urban areas (6). A threshold value of 4 seconds has been used in another study to distinguish between safe and unsafe situations (9,3). The Surrogate Safety Assessment Model considers an event with TTC less than 1.5 seconds as a conflict (10). A sensitivity analysis is conducted in a study varying the threshold from 2 to 8 seconds at an interval of 1 second (11).

Majority of the studies in surrogate analysis has been conducted in homogeneous traffic conditions and in most cases specifically for passenger car pairs. In mixed traffic conditions, with change in vehicle type, the ease of maneuverability of vehicles through traffic platoon varies, which in turn is expected to have an effect on TTC. Since car following behavior is not completely adhered to in such conditions, considering a continuous TTC for a single leader and follower becomes meaningless. The critical threshold which identifies conflicts would also depend on traffic
and driver behavior parameters and hence is expected to be different for mixed traffic conditions. Standards or guidelines on how to arrive at a threshold has not been discussed much in previous studies. Sensitivity analysis of threshold TTC has been considered only in a single study. The present study attempts to apply the concept of TTC, specifically, MTTC, because it considers relative acceleration and has been validated against accident data. The present study aims to modify the procedure for MTTC calculation for mixed traffic conditions, identify a suitable critical threshold, and assess the effectiveness of MTTC in evaluating the safety of mid-block section in mixed traffic conditions. A general drawback of all TTC measures is that it doesn’t account for some of the major factors causing accidents such as driver distraction, visibility and geometric parameters. In this study an attempt is made to study the effectiveness of MTTC with respect to driver distraction and visibility characterized by night time conditions. Also, out of the few surrogate measures which have been validated against real accident data, most of them have used rear end and swipe crashes alone to validate the model which is not a complete characteristic of mid-block section. In this study, an attempt was made to consider all mid-block crash types and propose appropriate modification of MTTC computation procedure and critical threshold identification to account for all crash types which would result in an improved MTTC model for safety evaluation of mid-blocks.

**METHODOLOGY**

Considering Modified Time to Collision (MTTC) as the surrogate measure, the study aims to modify the procedure for computation of MTTC under mixed traffic conditions. An algorithm is framed to study the inter-vehicular characteristics at every second. Based on these, longitudinal gaps and lateral overlaps are computed. Possible conflict cases are identified based on longitudinal gap between vehicles and lateral overlap of vehicles considering the width characteristics of the subject vehicle, thus accounting for vehicle type to some extent. For the identified possible conflicts, MTTC is computed based on relative speeds, accelerations, and gap. A critical threshold is defined based on sensitive analysis to arrive at conflicts which can then compared with the actual crash data to evaluate the efficiency of MTTC in estimating crashes in mixed traffic conditions.

**Identifying Possible Conflicts**

In a traffic stream, especially in mixed traffic conditions with no car following, weak lane following pattern and high volume of traffic, it is meaningless to calculate surrogate measures for all vehicle pairs because of many crash scenarios that are impossible. Hence, for efficient computation, the possible crash scenarios need to be identified and then analyzed for surrogate measurement. To identify such scenarios, the inter-vehicle characteristics such as longitudinal gap and lateral overlap are used. Any subject vehicle can have a single leader or multiple leaders or no leader at all. In weak lane based traffic with weak car following pattern, there arises a need to identify the leader. To achieve this, an imaginary strip with width equal to the width of the subject vehicle is considered for a particular vehicle at a particular time instant as shown in Figure 1. It is assumed that any vehicle which overlaps the width strip of the subject vehicle and is longitudinally ahead of the subject vehicle at that time instant has a chance of being collided by the subject vehicle. With multiple overlapping vehicles, the one nearest to the subject vehicle is considered for obvious reasons. The length of strip to be considered may be a point of discussion that needs further on-field research as it depends on the maximum speeds and accelerations of vehicles and the critical threshold value to be considered in identifying a conflict. For the present study the maximum
longitudinal gap for vehicle to be considered as a leader is chosen as 250 meters to be on the safer side. The definitions of these parameters have been illustrated in the Figure 1. Longitudinal gap between vehicles is the clear gap in the longitudinal direction between the front point of following vehicle and rear point of leading vehicle. Lateral overlap is the extent to which the width of leading vehicle overlaps the width of the following vehicle. It is calculated as the smaller distance between the opposite edges of the two vehicles. According to this definition, the lateral overlap may be greater than 100% if the following vehicle is narrower than the leading vehicle. Assuming that we know the front center coordinates of the following vehicle \((x_f, y_f)\) with width \(w\) and leading vehicle \((x_l, y_l)\) with width \(w_l\) and length \(L_l\), these parameters are calculated using the (6) and (7).

\[
\text{Longitudinal Gap} = x_l - x_f - L_l
\]

\[
\text{Lateral Overlap} = |y_l - y_f| - \frac{w_l}{2} - \frac{w}{2}
\]

A vehicle interaction is assumed to lead to a crash if Longitudinal Gap > 0 and Lateral Overlap < 0. This process of identifying possible conflicts is performed every second.

**Modified Time to Collision**

The possible interactions between two vehicles depend on their relative speed, gap maintained, and relative acceleration. The following vehicle \(f\) is considered as the subject vehicle in the present study. With respect to the subject vehicle, the characteristics of the lead vehicle \(l\) is analyzed. If the relative velocity \((\Delta v = v_f - v_l)\) is greater than zero, there exists a possibility of collision. In cases where relative velocity is less than or equal to zero, there are still chances of collision if the relative acceleration \((\Delta a = a_f - a_l)\) in such cases is greater than zero. Thus, depending on these dynamic characteristics of interacting vehicles, MTTC computation differs as shown in Table 1. For cases where relative acceleration is positive, MTTC is computed with due consideration of acceleration, ensuring non-negative MTTC according to the constraints mentioned in Table 1. Four cases shaded in gray represent vehicle interactions wherein both relative speed and acceleration are not positive leading to less crash probability. These cases have not been considered in the study. In cases where
there was no relative acceleration, the original TTC definition was adhered to. Thus MTTC can take three possible values \( t_1, t_2, \) or \( t_3. \) \( t_1 \) and \( t_2 \) represent the two cases of MTTC model in equation (5). \( t_3 \) represents the original TTC definition applicable when \( \Delta a \) is negative.

\[
\begin{align*}
    t_1 &= -\Delta v + \sqrt{\Delta v^2 + 2\Delta a d} / \Delta a \\
    t_2 &= -\Delta v - \sqrt{\Delta v^2 + 2\Delta a d} / \Delta a \\
    t_3 &= \frac{d}{\Delta v}
\end{align*}
\]

(8)

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### TABLE 1: MTTC Based on Possible Crash Scenarios

5 **DETERMINATION OF MTTC**

In the present study, MTTC is used to compute its applicability and reliability in predicting crashes on Yashwantrao Chavan Mumbai Pune Expressway, India’s first six-lane, concrete, high speed, and access controlled tolled expressway. The 94.5 km long stretch connects the two major cities of India, Mumbai and Pune. Classified traffic volume count was collected for the stretch for 24 hours along with basic geometric details. The total daily traffic volume comprised of 83% passenger cars, 3% buses, and 14% goods vehicles. Though the expressway is closed to two wheelers and three wheelers, a considerable proportion of Indian vehicle traffic, the mixed vehicle characteristics and lane changes are prevalent. Accident data for the past 3 and a half years starting from October 2012 to March 2016 was collected. The data included details of all type of crashes that had occurred on the Mumbai Pune Expressway (12). Video data which was collected on the expressway for short intervals of time was used to study the speed characteristics of the vehicles plying on the road. It was decided to study all vehicular interactions occurring throughout the day for an entire time span of 24 hours to identify the possible conflicts. This demanded the usage of a microsimulation model that would simulate the stretch with minimum error, and maximum efficiency and VISSIM was chosen.

The geometric characteristics collected were used to create the Mumbai Pune Expressway in VISSIM. VISSIM was calibrated based on the guidelines provided in a previous study for mixed traffic conditions (13). First forty kilometers of the study stretch from Mumbai to Pune with more or less homogeneous geometry was simulated for the study. Actual hourly traffic volume was given as input to VISSIM model along with vehicle composition. An initial warm up time of 5 hours was provided taking into consideration the length of the road stretch and variety in different vehicle type characteristics. Each simulation was run for a total time period of 24 hours in addition to the initial warm up period of 5 hours. Trajectory data was collected for all vehicles from the 6th hour to 30th hour to account for 24 hours. Hourly traffic volume and speed data was also extracted from VISSIM. Though simulation was run at a resolution of 0.1 second, the best possible in VISSIM, trajectories were extracted and analyzed for every 1 second. The trajectory data obtained
from VISSIM was processed using the MTTC algorithm to identify the possible conflicts. The algorithm was coded in C++ language and was framed to compute the MTTC values for all vehicle interactions with possible chances of collision. Rules to check the possibility of collision was defined within the algorithm using the longitudinal gap and lateral overlap methodology. The algorithm processes the trajectory data on a second by second basis to identify any possible conflicts, thus ensuring consideration of merging and lane changing movements. If there is a possibility of collision, the algorithm then computes the corresponding modified time to collision using the gap, relative speed and relative acceleration characteristics. Only those vehicle interactions involving the presence of a leading vehicle overlapping the width strip of the subject vehicle as discussed in the earlier section is considered for computation of MTTC. From the computed MTTC values, conflicts were identified based on threshold values as discussed in the following section. Multiple runs of simulation were performed using varying random seeds. The data required for analysis was obtained by averaging the corresponding results from multiple simulation runs.

ANALYSIS & RESULTS

To assess the strengths and weaknesses of MTTC, especially with respect to different times of the day and night, hourly conflicts are to be estimated from the simulation. Estimation of conflicts required a critical threshold to be defined. Hence a sensitivity analysis is performed to identify the most appropriate threshold which is used to identify conflicts. The estimated conflicts and actual accidents are compared with respect to time of the day, traffic volume on the road, and their spatial location along the stretch.

Dependence of Hourly Conflicts on MTTC Threshold Value

An accurate threshold value is the key to accurate estimation of conflicts, but not much has been discussed about which threshold value to consider for a particular roadway facility or associated traffic volume. According to literature the critical threshold values vary from 1 second to 4 seconds. Since vehicle trajectories were extracted at a resolution of 1 second, it doesn’t seem logical to select a threshold value below 1 second. Hence to arrive at an appropriate critical threshold value, several sets of hourly simulated conflicts were estimated assuming different threshold values varying from 4 seconds to 1 second at an interval of 0.5 seconds. To assess the accuracy and reliability of the simulated results, hourly simulated conflict frequencies for different thresholds are then compared with the hourly actual accident frequencies. Coefficient of correlation is assumed to give a good prediction of the correlation between the simulated and actual data and hence, correlation coefficients were computed for different sets of simulated conflicts against actual conflicts, as shown in Figure 2. It can be seen that the coefficient of correlation varies from 0.41 to 0.56 depending on the threshold used. The low correlation in general for all data sets might be attributed to usage of real accident data representing field characteristics such as driver distraction, geometry, visibility etc. that are harder to replicate in a simulation environment. Considering these limitations, a correlation coefficient of 0.56 seems to be reasonable for selecting the corresponding threshold value, 1 second as the critical threshold value for the study. The hourly simulated conflict frequency used for further analysis is computed based on this critical threshold.

Relation between Estimated Conflicts and Actual Accidents

For MTTC to be used as a surrogate measure to evaluate safety, it needs to be validated with actual accident data. Even though validation has been done by the Ozbay et al. (2008) on New Jersey
FIGURE 2  Relation between estimated conflicts and actual accidents for varying MTTC thresholds
Turnpike, different traffic and driver behavior characteristics that exist in India demanded a comparison of the simulated conflicts with actual real-world accident data for the same stretch. To examine whether the estimated conflicts match with the actual accidents, simulated conflict frequencies and actual accident frequencies are plotted with respect to the time of the day. According to Ozbay et al. (2008), MTTC has been derived for link analysis of rear end crashes. Preliminary accident analysis of the study stretch reveals a variety of crash types that occur along the Mumbai Pune Expressway. Whether to consider rear end and side swipe crashes alone or all type of crashes for comparing with the simulated conflicts was a dilemma that the author faced. A surrogate for mid-block crashes should ideally take into consideration all factors leading to mid-block crashes. Hence, the normalized accident frequencies for different types of crashes were plotted with respect to time of the day as shown in Figure 3. It can be seen that all type of crashes followed a similar pattern with respect to the time of the day. Hence comparison was done with respect to total accidents and rear end and side swipe accidents. Actual total accidents and rear end and side swipe

![FIGURE 3 Proportion of different types of accidents on Mumbai Pune Expressway](image-url)

accidents were plotted with respect to time of the day along with simulated conflicts. As observed in Figure 4a and 4b, the simulated conflict frequency pattern matches the actual total and rear end and side swipe accident frequencies during the time window of 6 hrs to 22 hrs. This may be because, from 6 hrs to 22 hrs possible distractions in driver behavior owing to drowsiness or sleep and visibility are less, thus crash influential parameters would be traffic volume speeds or accelerations of vehicles which has been modeled by both MTTC and simulation. It is also observed from 4a that for time period from 22 to 6 hrs, the actual accident frequencies are still high with highest value at 4 hrs in early morning, whereas the simulation and MTTC could not identify any conflicts during that time period. One possible reason could be that the time from 22 hrs to 6 hrs mark the wee hours of the night and early morning when drivers tend to doze off, or get distracted due to poor visibility. Hence, the accidents that occur during this time period would be mostly due to driver characteristics which are not represented in MTTC. Another possible reason could be the higher speeds maintained at night due to low volume. The zero conflict values in simulation might be due to low volume leading to no chances of calculation of MTTC values as per the algorithm. This shows the effect of driver behavior, visibility, and geometric characteristics on MTTC and
the need for inclusion of these in the surrogate measure through simulation environment or model parameters. The relationship between volume and conflicts has been discussed in detail in the following section.

Relation between Hourly Conflicts and Hourly Traffic Volume
To evaluate the influence of traffic volume on accidents, hourly traffic volumes for 24 hours is collected from field which were given as input to VISSIM. Also, simulated hourly traffic volume was extracted from VISSIM. To check the dependence of both, the traffic volume and conflict frequencies from both field and simulation were plotted with respect to the time of the day. Considering simulated conflicts, it can be seen from Figure 5b that the simulated conflicts from MTTC depend on the traffic volume. This is obvious since MTTC considers only inter-vehicular
FIGURE 5 Comparison of hourly conflicts and hourly traffic volume

It can be inferred that the accidents that occur during 6 to 22 hrs is greatly influenced by the traffic volume on road, as a similar trend is also observed from the actual accident frequency variation with time as seen in Figure 5a. It is interesting to note that characteristics and not the driver distraction or visibility issues and simulation model could not replicate exact field conditions.
for volumes higher than 1000 veh/hr, the corresponding hourly accident and conflict frequencies reduce with increase in volume and increase with reduction in volume. This trend may be explained using the two major factors that influence the occurrence of collision: traffic volume and average
speed. With lesser traffic volume on road, the chances of vehicle to vehicle collision is very less. As volume increases, the possibility of collision also increases up till a particular volume after which, the vehicles are forced to travel at lower speeds due to increased volume leading to lesser conflicts. Even though this trend is observed for the simulated data from which estimated conflicts were computed, the same trend could be observed in the actual hourly accident frequencies only for a selected time window of 6 to 22 hrs. From 22 to 6 hrs, it was observed that the actual hourly accident frequencies were high even at low volumes.

Spatial Distribution of Estimated Conflicts and Actual Accidents
To study the spatial distribution of accidents, the actual accident spots for which Global Positioning System (GPS) coordinates were recorded were plotted along the road stretch. Simulated conflict spots were also plotted along the road stretch. For better understanding the stretch was divided into 7 sections as shown in Figure 6. In section 1, it can be observed that the actual accident locations are few with greater gaps and only few simulated conflicts have been identified in this section. The same pattern can be observed in sections 3 also. In sections 2, 4, and 7, many accident locations and many simulated conflict locations can be observed. There are sections like 5 and 6 where the exact opposite is also observed. But taking into consideration that the geometric parameters weren’t considered explicitly, the results seem to be good. Much better correlation could possibly be arrived at with due consideration of geometry.

CONCLUSIONS
This paper evaluates the strengths and weaknesses of Modified Time to Collision (MTTC) in estimating mid-block crashes under mixed traffic conditions using a micro simulation model. The study proposes a methodology for identifying possible conflict scenarios and estimating MTTC based on width characteristics of interacting vehicles under mixed traffic conditions at every instant, thus giving due consideration to all vehicle types and all vehicular movements on the road. The proposed methodology has been implemented in a real world scenario and has been evaluated using actual accident data including all type of crashes that can occur at mid-block. Sensitivity analysis has been carried out to arrive at an appropriate critical threshold. Results indicate a strong correlation between estimated and actual conflicts during a certain time window. The study also assesses the efficiency of MTTC in estimating crashes associated with driver distraction and poor visibility which are a characteristic of night time.

Sensitivity analysis resulted in identifying a critical threshold value of 1 second which is very low compared to the existent threshold values used in homogeneous conditions indicating the distinctive driver behavior associated with mixed traffic characteristics. A better estimate of the critical threshold could be possible by extracting and analyzing vehicle trajectories at an interval of less than one second, which has not been carried out in the present study and hence is a limitation of the study. The temporal distribution of simulated conflicts and actual accidents show that MTTC is successful in estimating real world conflicts for a time period of 6 hrs to 22 hrs. The model could not represent night time crashes due to limitations in both the MTTC model and simulation model to account for driver distraction, geometric parameters and visibility factors. Since safety on roads is important irrespective of time of the day, these factors need to be incorporated in order to come up with an accurate surrogate model for mid-block. Comparison study with volume data shows that simulated conflicts were influenced primarily by the traffic volume on road which is in compliance with field data for the time window 6 to 22 hrs. Finally a spatial correlation of actual
and simulated conflicts show that the simulated conflicts could represent the actual accident spots at certain stretches of the road though geometric parameters like curvatures and gradients were not considered explicitly in simulation. The present study has not quantified the spatial correlation since spatial features of the road system weren’t considered in simulation. Consideration of the same could be a possible extension of the work. Since the estimated conflicts based on MTTC shows adequate temporal correlation with real world accident data for a considerable period of the day, the model may be used as a surrogate measure for safety evaluation of mid-block crashes under mixed traffic conditions with due consideration of driver behavior during night. Parameters representing loss of attention, poor visibility and geometry may be incorporated either through modification of the MTTC model or through simulation to get a better representation of field.

ACKNOWLEDGMENTS

The authors would like to thank JP Research India Pvt Ltd. for providing the necessary accident data for the study. The authors would also like to thank Mr. Vivek M. for his assistance in efficient algorithm implementation.
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