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Analysis of Surrogate Safety Performance Parameters for an Interurban Corridor

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Traditionally, road safety performance evaluation is an analysis of crash data from the past. However, methods of analysis from crash data have some well-known limitations from an analytical point of view. These limitations include small data samples causing statistical issues in analysis, under reporting of crashes and very little information about behavioral and environmental aspects at crash time. The micro simulation combined with traffic conflict technique enables the transportation engineers to investigate the safety performance of a corridor without using the crash data. Surrogate Safety Assessment Model (SSAM), utilizes simulated vehicle trajectories from the micro simulation software to investigate conflict severity and locations. In this study, safety performance evaluation is carried out of an interurban corridor of 24.3 km stretch from Gurugram to Faridabad in state of Haryana (India) using simulation software VISSIM (Verkehr In Städten – SIMulationsmodell) and SSAM. Simulated vehicular trajectories were generated and analyzed using SSAM to identify potential conflicts. The surrogate safety measures Time to Collision (TTC), Post Encroachment Time (PET) and Max ΔV are obtained by an analysis from SSAM model for all the three homogeneous sections such as midblock, curve section and intersections separately. The approach presented in the paper helps in the identification of inter-urban corridor locations prone to road crashes and hence serves as a proactive alternative as opposed to historical crashes based analyses.

Keywords: Risk of Collision, Severity, Time to collision, Trajectory Data, VISSIM

Introduction

Safety performance of an interurban corridor is an outcome of complex interactions among several contributing factors including geometric design, drivers' behavior, signal operations and vehicular performance. Traffic safety assessment of an intersection carried-out by two major approaches, crash-based approach (direct methods) and non–crashes based approach (indirect methods). The crash based approach uses the historical crash data for analysis, but this approach has several shortcomings such as collisions are rare events, extended observation periods are required to determine stable trends, under reported crashes. Unreliable crash records and the time required waiting for adequate sample sizes.

The crash based approaches impractical for evaluating safety of new transportation facilities or unconventional traffic control strategies. An alternative approach to crash-based analyses relies on surrogate safety data. Traffic conflict technique (TCT) is one of the non-crash based analyses represents the indirect method to assess safety condition of intersection sites to objectively measure the crash potential of location without having to wait for a suitable crash history to evolve. Traffic conflict is a traffic event involving the interaction of two vehicles where one or both drivers may have to take evasive action to avoid a collision

The Surrogate Safety Assessment Model (SSAM) generates outputs such as traffic conflicts and it related parameters by analyzing the vehicle trajectories generated from micro simulation software in the present study we used VISSIM.[1] To assess the surrogate safety measures for the roadway segments and intersections, SSAM can be used as a tool.[2] The surrogate parameters SSAM are Time-to-Collision (TTC), conflict speed, and post-encroachment time (PET) these identified conflicts can be classified into different severity levels based on the relationship between the conflict speed and TTC.[3] Souleyrette & Hochstein[4], 2012 studied the relationship between TTC and "maxDelta V" and find that it is the most accurate estimator of the severity of the conflict

Literature Review

Extensive studies have been conducted to explore indicators that strongly correlate with the frequency of

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crash occurrences and the severity of the resulting crashes. Baker studied the relationship between crash and traffic conflict and find that these two are statistically related.[5] Migletz[6] studied 46 controlled and uncontrolled intersection of varying traffic intensity in the greater Kansas City area and found that there is no added advantage of using crash data compared to conflict data. A study conducted by Sayed & Zein used the intersection conflict index (ICI) with the help of traffic conflict data for evaluation of intersection safety.[7] Souleyrette & Hochstein conducted a study based on estimation conflicts (conflict frequency and severity) from simulation models and using them in assessment safety for different design alternatives.[4] Archer & Young stated that the number and type of conflicts can be regarded as an indicator of the traffic safety.[8]

Chin *et al*.[9] devised an objective way of defining conflicts along with two conflict measures, one related to TTC and the other to deceleration. Al-Fawzan[10] studied various methods aimed at the estimation of Weibull parameters, namely, shape parameter (β) and scale parameter (η) considering the fact that Weibull distribution is an important distribution especially for carrying out reliability and maintainability analysis during microscopic simulation. Laureshyn *et al.*[11] presented the theoretical framework by using Delta-V as a measure for traffic conflict severity analysis based on site-based observations. The potentiality of microscopic simulation and modeling of traffic conflicts in the context of traffic safety and traffic conflict analysis has been recognized by many researchers during the last five decades (Autey *et al*.[12], Bagdadi[13] and Cafiso *et al.*[14]). In this regard, Deepak and Vedagiri[15] has inferred that prediction of road crashes based on the historical crash data has its own inherent drawbacks related to the quality and coverage of data especially in developing economies like India. Hence, it has been concluded that assessment of the level of traffic safety has been conducted by devising a unique strategy of measuring proximal safety indicator. Some of the Surrogate safety parameters and their definitions are discussed in subsequent sections.

Time to Collision (TTC)

Time to Collision is time based safety measure, it is the time taken by the following vehicle to collide with front vehicle if the speed of the vehicle is remained constant. This measure is generally taken for the two vehicles travelling in the same direction. Present study the threshold value of the TTC estimated for the study area and using the same safe and unsafe interactions are estimated. To avoid crashes, drivers frequently modify their manoeuvres in the space and time domain. The leading vehicle occupies the conflict point for a time which depends on its length and speed. The crash is avoided only if the second vehicle adopts an evasive manoeuvre. As a consequence, the second vehicle needs to start decelerating at a point A, to arrive in B after the so-called "post-encroachment" time *(PET)* of the leading vehicle.[16]

MaxDeltaV

MaxDeltaV is the maximum DeltaV value of either vehicle in the conflict. First DeltaV and Second DeltaV is the change between conflict and the post collision velocity. This parameter represents the severity of the accidents, present study this value is estimated by considering the Indian condition of crash types such as fatal, serious, property damage and minor crashes.

Maximum Speed (MaxS)

The general notion that high speeds can lead to road crashes as the higher speed gives the driver less time to react to any incident that might occur and similarly it also does not give time to the other road user involved in conflict to react accordingly which can also lead to crashes. One way of understanding relationship between speed and crash is through the basic principle of Newtonian physics according to which kinetic energy is related to mass and square of velocity, thus inferring that greater speed increases the risk of road crash severity. Accordingly, MaxS is the maximum speed of the vehicles involved in conflict at TTC value is less that the specified threshold.

Deceleration Rate (DR)

Deceleration rate can be defined as the rate at which a crossing vehicle must decelerate to avoid collision which can be the difference between speeds of leading vehicle and following vehicle divided by their closing time. In conflict of two vehicle phenomena if any vehicle applies break then negative acceleration will be observed for that vehicle, if the vehicle do not apply break then lowest acceleration will be observed for that vehicle. Based on the various literature threshold value of deceleration rate for Indian vehicles is observed to be 3.35 m/s^2. This indicates that if the speed of the vehicle exceeds the threshold value it can be involved in conflict whereas the American Association of State Highway and Transportation Officials (2004)[(17)] suggested a threshold value of 3.40 m/s^2.

Post Encroachment Time (PET)

Post Encroachment time defined as the difference between the time at which the leading vehicle enters a collision point and the time at which the following vehicle enters the same point.[18] Post encroachment time decreases the chances of collision increases. This surrogate safety parameter is highly relevant to the intersections present study the threshold value is estimated. It is easier to extract PET as compared to TTC as PET involves just the time difference and no derivations related to speed or distance. The two situations that can exist then would be either preceding vehicle moving at a lower speed than the following vehicle, or preceding vehicle moving at a higher speed than the following vehicle. A collision course always exists in the former case where as a collision course is not likely to exist in the latter case. Time to Collision might prove to be a better measure to determine traffic safety in such cases. Lower PET indicates higher probability of collision.

Methodology

Description of Study Area

Gurgaon - Faridabad Road is one of the important major interurban road located on the urban periphery of National Capital Territory *(NCT)* of Delhi linking the above two cities spanning length of 24.3 Km. It is a four lane divided interurban corridor having 7.0 m wide carriageway, 2 m wide median with 0.25 m kerb shyness, 1.5 m paved shoulder having an earthen shoulder width of 1.5 m on either side of the divided carriageway. The study corridor contains seven major intersections which includes 5 signalized and 2 un-signalized signalized coupled with the corridor traversing through 15 horizontal curves. It is to be borne in mind that safety performance of any road corridor is strongly dependent on geometric features of the road and traffic conditions. Therefore, surrogate safety measures proposed for any candidate road corridor will vary at different sections of the road namely at midblock, intersections and curves. In order to study the behavior of vehicles on different sections of the road, each surrogate safety measures are to be analyzed separately for midblock, intersections and curves. As mentioned earlier, this paper deals only with the estimation of potential crash prone sections using surrogate safety parameters by considering midblock sections only.

Data Collection

Traffic data was collected by conducting classified volume count (CVC) survey at 7 intersections, midblock and curve sections for the duration of 16 hours. Video graphic survey was conducted to record the volume. Spot speed survey was conducted at midblock, curve sections and 200 meters away from each intersection using radar speed gun. Journey speed data was collected using Performance Box helped in understanding speed variation coupled with acceleration / deceleration profiles at every 1 m as well as central line deviation, gradient and geometric details for the entire corridor. The geometric details of the whole road including width of the road, shoulder width, radius of the curves, gradient etc. are obtained from the AutoCAD drawings of Detailed Project Reports (DPR). For signalized intersection the signal phase or cycle time data (green, red and amber times) also collected.

Microscopic Simulation and Surrogate Safety Assessment Model

In this study, VISSIM multimodal traffic simulation model was used to model the study corridor. Microscopic simulation is a category of computerized analytical tools that perform highly detailed analysis of activities such as highway traffic flowing on road corridors and an intersection. In the present study, the entire corridor which includes midblock, curve sections and intersections have been simulated using VISSIM by resorting to thorough calibration and validation of results. Vehicle trajectories are extracted through VISSIM for the above mentioned sections. The network for midblock, curve sections and intersection along with the traffic signal phase are presented in Fig. 1. Observed traffic flow in each link with left turning and right turning volume along with vehicle composition such as two wheeler, three wheelers, car, LCV, bus, truck and HGV at the different midblock, curves and intersections were given as input. The desired speed distribution and vehicle characteristics such as length, width, maximum speed, desired and maximum acceleration and deceleration are also given for each type of vehicle as input. Signal phasing data collected from each 5 signalized intersections were given as signal program in VISSIM.

Model Validation

Model was calibrated adopting trial and error method by modifying the drivers' car following and lane change parameters in accordance to Weidman

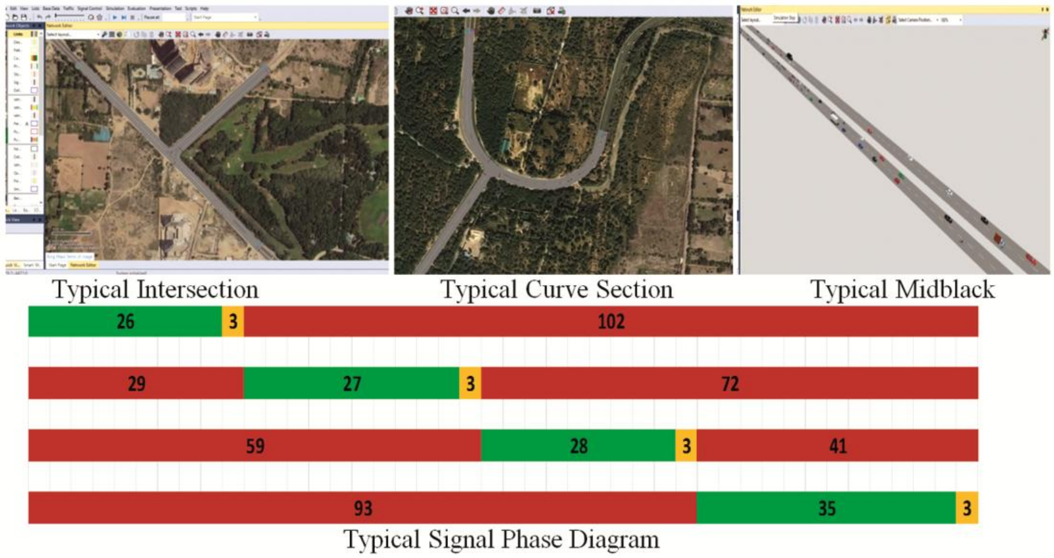


Fig. 1 — Road network and signal phase diagrams prepared in micro-simulation

model till the error between observed and estimated data is acceptable. For calibration the Geoffrey E. Havers (GEH) statistic and absolute percentage error were determined and the lower values obtained represent a better calibrated model. Geoffrey E. Havers developed a continuous volume tolerance formula while working as a transport planner in London, England in the 1970s. Although its mathematical form is similar to a chi-squared test, is not a true statistical test. Rather, it is an empirical formula that has proven useful for a variety of traffic analysis purposes.

For hourly traffic flows, the GEH formula is:

$$G_H = \sqrt{\frac{2(m-c)^2}{m+c}} \quad \dots (1)$$

where, m is the values from the traffic model (per hour); c is the real-world traffic value (per hour)

For traffic modeling work in the "baseline" scenario, a GEH of less than 5.0 is considered a good match between the modeled and observed hourly volumes (flows of longer or shorter durations should be converted to hourly equivalents to use these thresholds). Micro simulation model should have a GEH less than 5.0. GEHs in the range of 5.0 to 10.0 may warrant investigation. If the GEH is greater than 10.0, there is a high probability that there is a problem with either the travel demand model or the data. Simulation results should within an acceptable range of values using the GEH statistic. The GEH statistic is a modified Chi-squared statistic that incorporates both relative and absolute differences. For validating the VISSIM model the two hours peak volume data are given as input and the output volume and speed that are collected from VISSIM were compared with the input values. GEH statistic calculated for typical midblock sections for total traffic volume and the Maximum Absolute Percentage Error (MAPE) calculated for journey speed are given in Table 1.

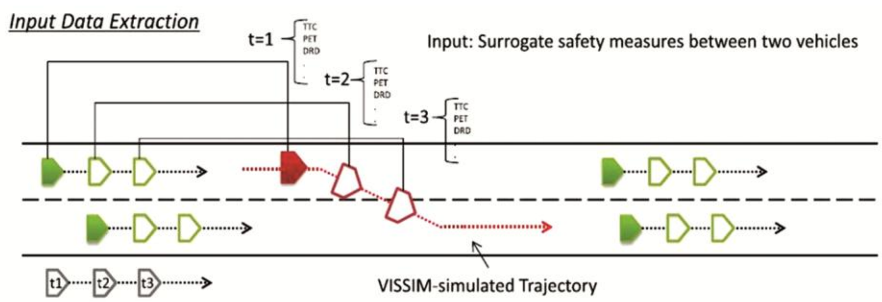
From the Table 1 it can be noted that the GEH statistic calculated for typical midblock volume is within the acceptable limit of 5.0.

Absolute error calculated for journey speed at each midblock is within the acceptable limit of 10 %. It can be observed that at some mid block sections (M7, M8, M4, M10) the percentage error of vehicular speed is high, these higher percentage errors are investigated further then the reasons found were as follows; the sections (M4 and M10) are having dense settlements, the field speed variations are more due to the influence of local traffic. The other mid blocks (M7, M8 etc.) are having the down gradients and actual field speeds are have wide variation same was reflected in simulation results, but the percent error is below the 10% acceptable limit. Similar results were obtained for curve and intersection also.

Surrogate Safety Assessment Model (SSAM) is software freely available to identify, classify and evaluate traffic conflicts based on the vehicle trajectory data output from microscopic traffic simulation models. Using SSAM, a host of surrogate measures of safety for each conflict have been

Table 1 — GEH statistic and absolute error calculated for midblock sections

Midblock Name	Simulated Volume	Simulated speed (kmph)	Actual Volume	Actual Speed (kmph)	GEH statistic	Percentage Error , Speed
M1 KM3.0–3.29, UP Direction	1979	46.86	1999	43.99	0.45	6.5
M 1 KM3.0–3.29, Down Direction	1788	55.2	1765	55.33	0.55	0.2
M2 KM3.5–3.87, UP Direction	2048	47.36	1999	43.99	1.09	7.7
M 2 KM3.5–3.87, Down Direction	1752	54.94	1765	55.33	0.31	0.7
M3 KM4.6–4.9, UP Direction	2008	46.97	1999	43.99	0.2	6.8
M 3 KM4.6–4.9, Down Direction	1827	54.44	1765	55.33	1.46	1.6
M4 KM 5.1–5.6, UP Direction	3462	43.43	3565	47.54	1.74	8.6
M4 KM 5.1–5.6, Down Direction	1625	50.19	1686	52.69	1.5	4.7
M5 KM11.00–11.4, UP Direction	1398	59.89	1477	57.33	2.08	4.5
M5 KM11.0–11.4, Down Direction	4224	52.92	4208	50.79	0.25	4.2
M6 KM14.3–14.77, UP Direction	1485	59.55	1477	57.33	0.21	3.9
M6 KM14.3–14.7, Down Direction	4124	51.94	4208	50.79	1.3	2.3
M7 KM 16.45–16.9, UP Direction	1717	45.83	1719	42.68	0.05	7.4
M7 KM 16.4–16.9, Down Direction	4485	48.09	4483	53.31	0.03	9.8
M8 KM 18.1–18.8, UP Direction	1693	45.14	1719	42.68	0.63	5.7
M8 KM 18.1–18.8, Down Direction	4536	48.01	4483	53.31	0.79	9.9
M9 KM 18.8–19.4, UP Direction	1690	44.5	1719	42.68	0.7	4.2
M9 KM 18.8–19.4, Down Direction	4374	50.32	4483	53.31	1.64	5.6
M10 KM 23.8–24.2,UP Direction	1086	41.39	1064	45.07	0.67	8.2
M10 KM 23.8–4.2, Down Direction	1622	39.25	1635	41.38	0.32	5.2



Typical SSAM Outputs with Sample Parameters

TTC	PET	MaxS	DeltaS	DR	MaxD	Max DeltaV	Conflict Angle	Conflict Type	Post Crash V	Post Crash Heading
0.3	0	14.51	1.65	−6.73	−6.87	0.91	−6.03	lane change	13.09	210.45
4.4	1	16.93	2.64	−0.2	−0.27	1.47	−5.13	lane change	15.68	28.24
1.3	0.3	11.66	3.35	−3.24	−3.44	2.48	8.62	lane change	9.42	199.54
5	0.5	11.42	0.98	−0.1	−0.13	0.49	−0.34	rear end	10.93	299.93

Fig. 2 — Typical simulated vehicle trajectory and sample Output Parameters of SSAM

identified for the trajectory data obtained through microscopic simulation and thereafter mean, max, and other associated statistics have been computed for each of the surrogate measure. The vehicle trajectory and typical SSAM outputs are shown in Fig. 2.

Results and Discussion

Analysis of TTC

As mentioned earlier, TTC is an important spatial parameter to measure surrogate safety. In the present study, an objective way of defining conflicts is proposed. Conflict analysis can be carried out by finding the frequency distribution of the conflicts and thereby assess the median values that can be declared as threshold. Major disadvantage of this process is that the conflicts are not events they are the process hence the present study tries to establish the distribution of the TTC using the values extracted from the SSAM output. The severity and the TTC values are inversely proportional i.e. severity increases as TTC decreases. Reciprocal of the TTC values is used to find the distribution instead of the direct values of TTC. For the values of 1/TTC measure, various mathematical functions have been tested to fit Probability Density Function (PDF). The probability density function which is better fitting the study data find is that Weibull distribution, the pdf function for this distribution is given in Eq. 2.

$$g(s) = \left[\frac{k}{w}\right]\left(\frac{s}{w}\right)^{k-1} exp\left[-\left(\frac{s}{w}\right)^{k}\right] \quad \dots (2)$$

TTC Distribution observed at the Midblocks

As explained earlier, vehicle trajectories have been extracted through VISSIM and thereafter conflicts and surrogate safety parameters such as TTC Values for each conflict are thoroughly analyzed. The analysis of TTC was done for the entire set of midblock sections combined as well as for each midblock section separately. The probability density function fitted with Weibull distribution function of reciprocal TTC for entire midblock sections and the goodness-of-fit statistics as judged by the Kolmogorov - Smirnov *(K-S)* test. The results presented in Fig. 3 indicate that the data fitted with the Weibull distribution for the entire set of midblock sections considered on the study corridor.

K-S test is used to determine the goodness of fit of the distribution. At 95 percent significance level, the value of α=0.5, the critical value p for number of observations greater than 50 is obtained as 0.296. In the null hypothesis it is assumed that the data follows a specified distribution. If the calculated D-statistic value is less than the critical value of p, then the null hypothesis is accepted. Since, the D-statistic estimated from the distribution is less than the critical value of 0.296, the probability density function fitted with Weibull distribution function of reciprocal TTC. The mean TTC value obtained for the midblock sections from the distribution is 1.44 sec which is taken as the critical threshold value of TTC. This implies that if the value of TTC is less than 1.4 sec for a conflict, similarly the TTC value for intersection is 1.5 sec and TTC values for curve sections is 1.6 sec then the conflict less than the above mentioned values

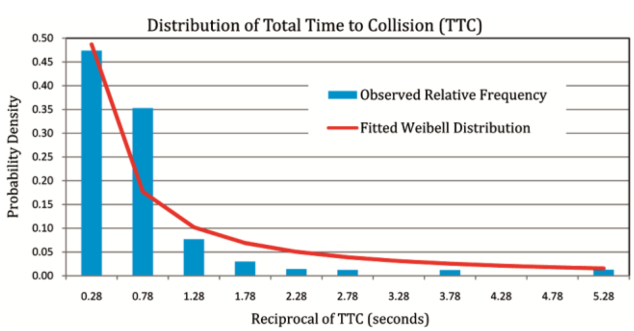


Fig. 3 — Distribution of Total Time to Collision (TTC) for midblock sections

on the specific section can be considered as a serious one leading to the incidence of fatal crashes.

Analysis of Deceleration Rate (DR)

The variation of deceleration rate is quite similar to that of reciprocal TTC. In the cases of more serious conflict scenario, the variation in deceleration rate would be high. Compared to reciprocal of TTC, the variation of Deceleration Rate *(DR)* reflects the crash severity at higher values of deceleration rate. The data values of distribution of deceleration rate have also been used to fit a number of mathematical distributions. In this regard, the Weibull distribution is found to yield the best fit.

The probability density function and cumulative distribution function were calculated for deceleration rate for each of the midblock sections, curve sections, intersections. Further, goodness-of-fit statistics was carried out using K-S test which is found to be satisfactory. The mean deceleration rate for midblock sections is found to be 0.406 m/s. Similarly the mean deceleration rate for intersections is found to be 0.486 m/s^2 and for curve sections is found to be 0.569 m/s^2.

Analysis of Max Delta V

Max Delta V is maximum change in the velocity of the vehicles involving in the conflict. First DeltaV and Second DeltaV is the change between conflict velocity and the post collision velocity as explained in previous sections. This is a surrogate for the severity of the conflict, calculated assuming a hypothetical collision of the two vehicles in the conflict. The frequency distribution of Max ΔV for the entire midblock sections is carried out separately. As the value of Max ΔV increases, the seriousness of conflict also increases. The mean value of Max ΔV obtained for midblock sections is 3.79 m/s i.e.13.64 Kmph, curve sections is 4.1 m/s (14.76 Kmph), intersections is 4.58 m/s (16.49 Kmph) which are basically the threshold value for finding the critical section under heterogeneous traffic conditions prevailing on the Indian interurban roads. If the value of Max ΔV is more than threshold value of Max ΔV for a conflict, then it is considered as a serious conflict.

Analysis of PET

For ascertaining suitable PET threshold values, statistical distributions of vehicle-vehicle interactions are established so that the proportion of critical situations (i.e., conflicts) is not merely counted, but derived mathematically. Therefore, statistical frequency distributions were developed for PET for all the intersections. PET measure is not a useful indicator for road users traveling in the same direction, Hence PET values for midblock and Curve sections are not considered for the analysis. PET concept is only useful for measuring safety critical events where there are transversal (i.e. crossing) vehicle movements of road-users involved. The threshold value of PET for an urban intersection is found 1.71 sec. any vehicle crossing conflict less than this value is serious and leads to crash.

Analysis of Conflict Severity

Severity of each conflict is estimated by finding out the severity score for each conflict based on its TTC value and MaxDeltaV, MaxS values for the candidate midblock sections and the same is discussed in the succeeding sections

Severity Analysis at Midblock

In this study, the road crashes are classified as fatal, seriously injured, minor injury and property damage conforming to Ministry of Road Transport and Highways.[19] This classification is finalised based on the quantum of damage caused to the person and vehicle. The classification of severity of crash with respect to traffic conflict has different procedure based on the parameter selected. The severe conflicts indicate the proximity or how close these conflicts to the crash. Generally, the classification of severity of crash is based on the following parameters of traffic conflicts in SSAM.

- Crash Severity based on Max S values.
- Crash Severity based on TTC values.
- Crash Severity based on Max S and TTC values.
- Crash Severity based on Delta V values.

Crash Severity based on Max S values

As explained in previous sections, Max S is the maximum speed observed among the vehicles involving in the conflict and this maximum speed is extracted from the trajectories of these vehicles. The indicator Max S is considered as appropriate indicator for defining the severity of crash.[20] Max S versus TTC plot has been drawn for all the midblock sections based on the scattering of the data in the plot which is characterized under 6 severity zones (Fig. 4). Severity line is drawn by taking mean TTC value obtained from the TTC distribution curve and the mean Max S value determined from the conflict data of midblock sections.

A total of 29,605 potential conflicts on the various midblock sections of the study corridor are plotted in Fig. 4. The severity line joining with the TTC value is less than 0.4 and the Max S value is more than 27 which implies that the midblock conflicts at the study corridor is approximately split in 50:50 ratios which is otherwise termed as Uniform Severity Line as depicted through the thick solid line in Fig. 4. The various midblock related conflicts is divided into uniform severity zones and the same are plotted by giving different colors / texture as per their severity as illustrated in Fig. 4. The severity zone, the criteria of TTC Max S and number of samples falling in each severity zone and percentage of total samples are presented in Table 2.

Crash Severity based on TTC values

Time to Collision *(TTC)* and Deceleration Rate *(DR)* are direct indicators of the severity of the conflict.[13] The lower TTC value indicates higher probability of crash[2] based on the TTC values computed for the severity of crash. In this regard, the mean/critical value of TTC for midblock sections of the study corridor is 1.4 seconds and the conflicts with this TTC values are falling in the severity zones

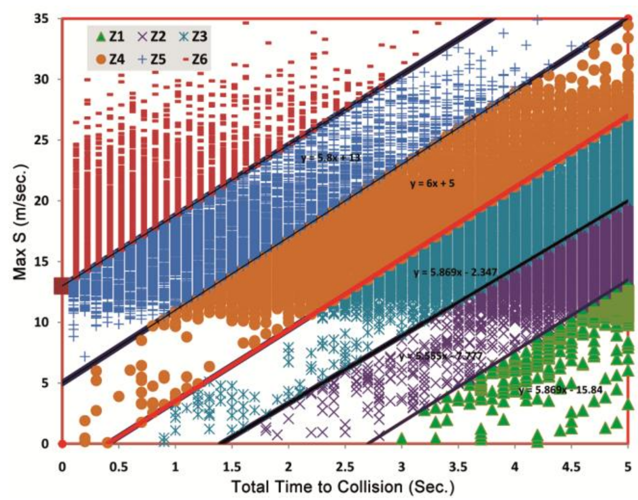


Fig. 4 — MaxS versus TTC conflict severity zone for various midblock sections of the study corridor

Table 2 — Number of Severity Zones and percentage of samples in each zone

Severity Zone	Criteria *(TTC)*	Max S	Percentage (%)
1	2.7	13.5	2.94
2	1.4	19.5	22.01
3	0.4	27	23.96
4	0	35	21.37
5	0	42	20.06
6	0	>42	9.66

3 and 4. On the other hand, conflicts with TTC ≥ 1.40 seconds lies in severity zones 1 and 2 as per the Hyden severity zone matrix (Fig. 4).

On applying the above analogy, it is found that approximately 22% of the data fell below the critical range of 1.4 seconds of TTC. Considering the above phenomenon, the other TTC ranges are selected by spreading the conflicts uniformly in different severity zones for the study corridor.

Hence, in the case of conflicts having TTC less than 1.4 seconds a Risk of Collision (ROC) score of 4 because it is the more extreme condition. On the contrary, the conflicts which yielded TTC greater than 4.4 seconds have been assigned a score of 1 because these conflicts are at a low propensity level. In Table 3, the ROC score based on TTC and the sample size and the TTC range values are presented.

Crash Severity based on Delta V Values

Delta-V (Δv) is the change in velocity before and after the virtual collision. Delta V values extracted from vehicle trajectories are used for defining the severity of conflict which are mostly used for crash reconstruction analysis. TTC values and Delta V values are further employed to identify the characteristics of each potential conflict through segregation based on type of severity zones as shown in Fig. 5. TTC value of 1.4 is the critical value obtained from the probability distribution and the mean value of Delta V is 3.79 which illustrate that all these conflicts mostly fall in the severity zone of 3 and 4.

ROC score based on Max Delta V are assigned to each conflict. The frequency distribution of Max ΔV values for midblock sections are calculated and found the mean value of 3.79, 85^{th} percentile Max ΔV value is 6.38 and the 95^{th} percentile Max ΔV value observed is 9.44. Based on the frequency distributions of the Max, ΔV the ranges are fixed and the ROC scores are assigned to each conflict. The ROC scores and ranges of Delta V and collision propensity level for the study corridor are presented in Table 4 which typically exhibit traffic heterogeneity prevailing on Indian highways.

Table 3 — Assigned ROC Scores based on TTC scores for the various midblock sections of the study corridor

Risk of Collision Score (ROC)	TTC Range (Sec.)	Sample Size (%)	Collision Propensity Level
1	TTC > 4.40	28.1	Low
2	3.10 < TTC ≤ 4.40	26.3	Moderate
3	1.50 < TTC ≤ 3.10	23.7	High
4	TTC ≤ 1.50	21.9	Extreme

As discussed in the previous sections, the range of the TTC and Delta V values severity score plot have been deduced for the potential conflicts on the various midblock sections of the study corridor. The different severity scores evolved based on the TTC and Delta V is shown in Fig. 5. For easy identification purpose, different color and legends are given for different zone values.

In Fig. 6 severity contour scores for the conflicting zones are depicted in form of grids. The values of TTC and Delta V values are modified slightly by taking into consideration of Hyden uniform conflict zones theory. Further, Fig. 6 also present the potential conflicts on the various midblock sections of the study corridor and each zone conflicts are given in different color and legend for easy identification.

The modified values of TTC and Delta V along with their sample sizes are presented in Table 5. It also shows the contour lines along with their equations whereas Line # 1 is the lower contour line and similarly other contour lines are based on their ROC scores.

Identification of crash prone location using surrogate safety measures

Surrogate Safety Assessment Model (SSAM) was used to extract the vehicle to vehicle conflicts by processing the vehicle trajectory data from the calibrated model. Surrogate safety parameters analyzed

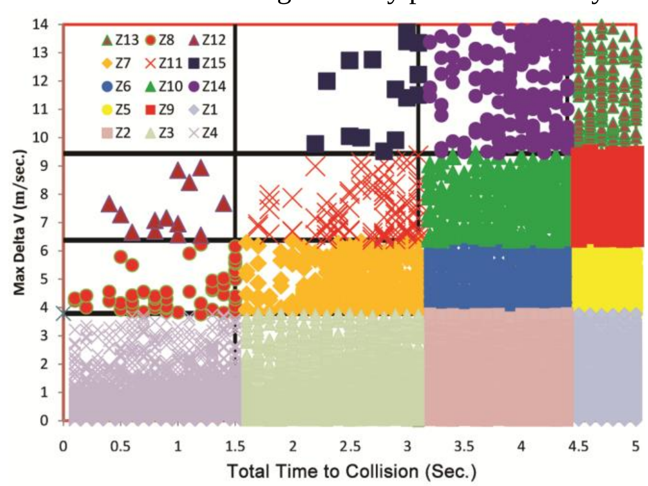


Fig. 5 — Max ΔV versus TTC plot by severity score for various midblock of the study section

Table 4 — Assigned ROC based on Max ΔV for midblock

ROC Score Based on Delta V	Max ΔV Range (m/sec.)	Sample size (%)	Collision Propensity Level
1	Delta V < = 3.79	65.5	Low
2	3.79 < Delta V ≤ 6.38	19.5	Property Damage
3	6.38 < Delta V ≤ 9.44	9.9	Serious
4	Delta V > 9.44	5.0	Fatal

Table 3 — Changes from initial to modified overall severity score

Overall ROC Score	Criteria		Samples, Size, *(%)*	Line Number	Equation *(Max ΔV =)*	Collision Propensity Level
	TTC	Delta V				
1	>4.1	3.9	7502 *(25.34)*	1	4.333 × x −17.76	Low
2	2.7	8.5	7224 *(24.40)*	2	3.695 × x −9.978	Property Damage
3	1.4	12.5	7466 *(25.22)*	3	3.472 × x −4.861	Serious
4	<1.4	>12.5	7413 *(25.04)*	4	3.25 × x+4	Fatal

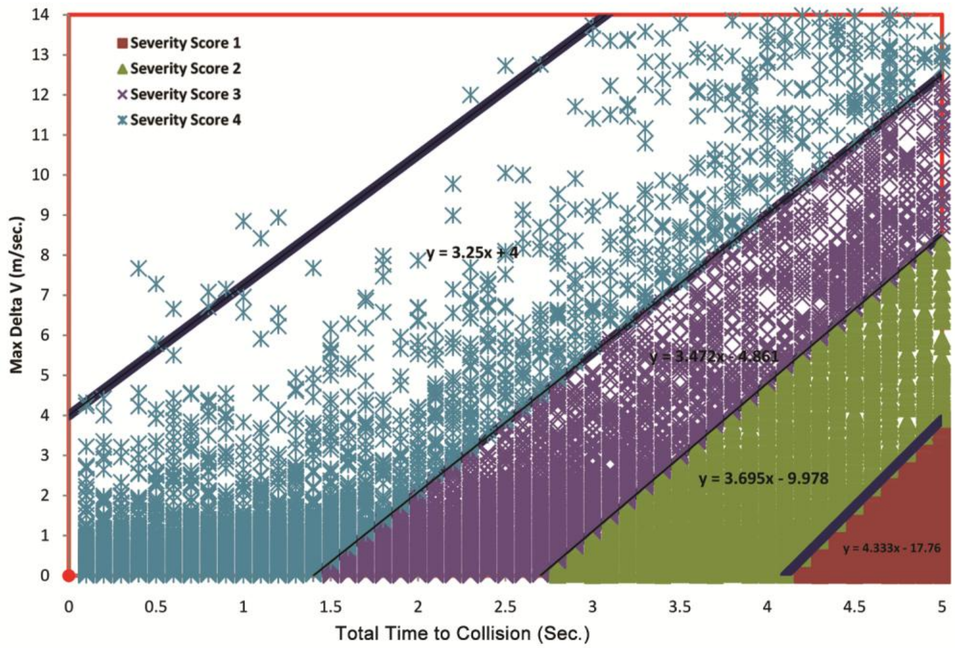


Fig. 6 — Delta V versus TTC conflict zones for various midblock sections of the study corridor

in the corridor are Time to Collision (TTC), Post encroachment time (PET), Max Delta V and deceleration rate (DR). From the conflict data TTC and other surrogate parameters mentioned earlier were taken as an indicator of collision propensity. By taking the threshold values of various parameters which were explained in earlier sections, the crash prone locations are identified for midblock, curves and intersections. The identified sections are listed below;

- Midblock section at chainage KM 5.1 to KM 5.6 (M4) is accounts for very less value of (1.09 sec) TTC as well as high value of (22.34 kmph, i.e.13.96 mph) Max ΔV, these values indicate this midblock section have highest chance of occurrence of fatal accidents.
- Curve section at chainage KM 5.60 - 6.35 observed TTC value of 1.01 sec and the curve section at chainage Km 15.95 to 16.45 is having values of TTC 1.56sec are less than the threshold value. Similarly, MaxDeltaV (3.98 kmph) are above the threshold value, hence these two curve sections has highest chance of occurrence of fatal accidents. .
- Intersection at KM 15.9 is very critical section which is basically an unsignalized intersection as its PET value of 0.44 sec is very less as well as the TTC value (1.38s) is less than the threshold value of 1.5 seconds.

Since the above identified road chainages are prone to serious conflicts and have highest chance of occurrence of fatal accidents and these sections require suitable mitigation measures need to be evolved for enhancing safety. The measures suggested at these locations are speed reduction techniques (installations of speed breakers/Transfers Bar Markings), installation of signals at intersection to be taken on priority basis to avoid fatal crashes at these locations.

Conclusions

The major conclusions of the present study are listed below

- Micro simulation and surrogate safety parameters can be used to find accident prone location and probable intensity at a particular location, this method can be used for proactively evaluate the inter-urban corridors safety without waiting for the accidents data.

- The study found that TTC and DR follow the Weibull distribution for all the sections such as midblock, curve section and intersection.
- The mean Total Time to Collision (TTC) value obtained for the midblock sections is 1.4 sec, intersection is 1.5 sec and for curve sections is 1.6 sec, TTC values less than these values at respective sections can be considered as a serious one leading to the incidence of fatal crashes.
- The mean Deceleration Rate (DR) for midblock sections is found to be 0.406 m/s^2, intersections is 0.486 m/s^2 and for curve section is 0.569 m/s^2. DR values less than these values at respective sections can be considered as a serious one leading to the incidence of fatal crashes.
- The mean value of Max ΔV obtained for midblock sections is 3.79 m/s (13.64 Kmph), curve sections is 4.1 m/s (14.76 Kmph), intersections is 4.58 m/s (16.49 Kmph) which are basically the threshold value for finding the critical section under heterogeneous traffic conditions prevailing on the Indian interurban roads. If the value of Max ΔV is more than threshold value of Max ΔV for a conflict, then it is considered as a serious conflict.
- PET concept is only useful for measuring safety critical events where there are transversal (i.e. crossing) vehicle movements of road-users involved. The threshold value of PET for an urban intersection is found 1.71 sec. any vehicle crossing conflict less than this value is serious and leads to crash.
- Using the threshold valves for various surrogate safety, the crash prone location on the study area are identified and suitable measure are suggested, the road owning agencies should act proactively to implement the suggest measures.

As part of this study the VISSIM and SSAM models developed can be utilized to provide reasonable results of surrogate safety measures. The developed threshold values can be used for any inter-urban corridor with similar heterogeneity to identify the accident prone location in proactive manner without using historical accident data. PET analysis values give good safety assessment for intersections only. The conflict severity score derived by considering TTC and Delta V can also be used to rate conflicts as low, property damage, serious and fatal potential, slight, or serious. This score can be used to rate the conflict severity in advance at a particular location.

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