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Surrogate safety evaluation and validation with crash history for interurban midblock sections under heterogeneous traffic conditions in India

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Traditionally, road safety analysis has been conducted by analysing collision records, which has a reactive approach as the analyst waits for collisions to occur. The alternate proactive approach in the form of surrogate safety measures is to study traffic conflicts which are bound to occur more frequently and thus has related them to the possible incidences of collisions. In the present study, traffic conflict indicators have been used to assess the level of safety by considering the typical midblock sections of an interurban corridor using vehicle trajectory data extracted through microscopic simulation. The surrogate safety parameters such as Time to Collision *(TTC)*, Deceleration Rate *(DR),* change in velocity (Delta V) as well as conflicting vehicle Speed (Max S) have been extracted from trajectory data through the application of numerical elaboration to evaluate safety. Further, an attempt has been made to quantify the traffic conflicts occurring at the midblock of referred study. The proposed threshold values of surrogate safety parameters have been validated using the reported three years' crash data. The approach presented in the paper has helped in the identification of midblock locations prone to road crashes and hence has served as a proactive alternative as opposed to historical crash based analysis.

Keywords: Intensity of traffic conflicts, Inter urban midblock sections, Microscopic simulation, Proactive approach, Surrogate Safety, Time to collision

1 Introduction

Traffic conflict has been defined as "an observable situation in which two or more road users approach each other in space and time for such an extent that there is a risk of collision if their movements remain unchanged". It has been noted that there is a close relationship between conflicts and road crashes. The interaction between road users has been described as a continuum of safety related events. These events can be looked upon at different levels in a pyramid which is conceived by Hyden and hence called as Hyden safety pyramid. Figure 1 shows the safety pyramid which has explained the various conflicts and crash severity (*Laureshyn, 2018*)[1]. The base of the pyramid has indicated undisturbed passages where road users are not influenced by any other user. Later on, the undisturbed passage may convert into potential conflicts where road users get influenced by another user but have time to take evasive action. From potential conflicts it may convert into slight conflicts where the road users would have very short time to take evasive actions. Slight conflicts can become serious conflicts when road users have to take sudden or harsh actions to avoid the incidence of road crashes. These serious conflicts may become road crashes in the foreseeable future.

The conflicts are bound to occur between two vehicles and some conflicts may convert as crash. Each road crash has been explained by a number of factors such as road, vehicle's condition, driver's emotional and physical state, the traffic situation etc. that has led to the crash. The word 'surrogate' means 'substitute' or 'replacement'. By using surrogate

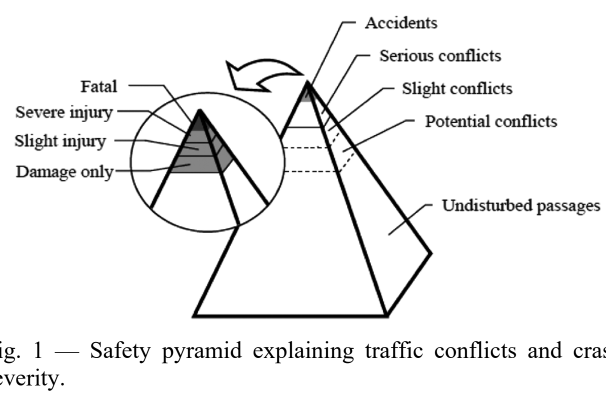

Fig. 1 — Safety pyramid explaining traffic conflicts and crash severity.

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measures to determine traffic safety, it has been intended to substitute the need for crash data with another factor which would represent traffic safety. In this regard, the surrogate measures have developed on the basis of the identification, classification and evaluation of traffic conflicts. This study has aimed to clarify the concept of surrogate measures of safety and has been used in assessing the safety of road facilities. Conventional traffic safety analysis has been evaluated by use of historical crash data, using different types of statistical approaches, mainly by use of before and after comparison of observed data and anticipatory estimation by traditional predictive models. This has primarily been carried out because of the direct correlation between the degree of safety on a road and the number of road crashes that occur there. Even though the road crash data is a true representation of safety, its use in safety studies has many disadvantages. The major disadvantage is that for analyzing the traffic safety aspect of a new facility, one has to wait till considerable number of accidents occurs, this is unethical also. There are many other techniques which can be used for traffic safety evaluation in advance before the accidents occur, these techniques are called surrogate models. In a nutshell, surrogate safety measures which have been discussed in this study, aimed to quantify the danger associated with traffic events in a meaningful way.

The literature reviewed in respect of conflict analysis and application of micro simulation for safety analysis has been presented in the succeeding sections separately followed by a discussion on the study motivation and the novelty behind this study.

The measures that have represented near crashes such as traffic conflicts have been commonly referred as proximal indicators of safety, or simply surrogate safety indicators. Research has shown that the numbers and severity of such near crash events have established close statistical relationship with crashes and in some cases have proved to be better predictor of the expected number of crashes than historical crash data[2].

There have been two categories of indicators namely, temporal and non-temporal proximal indicators. One of the temporal based indicators namely, Time to Collision *(TTC)* as well as some of the non-temporal indicators like Deceleration Rate *(DR)*, Conflicting vehicle Speed *(MaxS)* and relative speed *(Max DeltaS)* have been considered in this study. In this regard, surrogate measures have been extracted from the conflicts between two vehicles in which one vehicle should react to avoid crash. A brief of the above parameters and its applicability in this analysis has been highlighted in the subsequent sections.

Time to Collision (TTC) is defined as the time taken by the following vehicle to collide with front vehicle if the speed of the vehicle remains constant. This measure is generally taken for the two vehicles travelling in the same direction. Considering the above, TTC is the most important attribute which would distinguish between a safe and an unsafe vehicle encounter. To avoid the incidence of road crashes, drivers frequently modify their manoeuvres in the space and time domain. As depicted in Fig. 2, two vehicles are approaching the same conflict point (B) with intersecting trajectories. The leading vehicle occupies the conflict point for a time (TOLV) which depends on its length and speed. The crash might be avoided only if the second vehicle has adopted an evasive manoeuvre. As a consequence, the second vehicle has to start decelerating at a point A, to arrive at the point B (presented in Fig. 2) after the so-called "post-encroachment" time (PET) of the leading vehicle *(Saulino et. al., 2014)*[3].

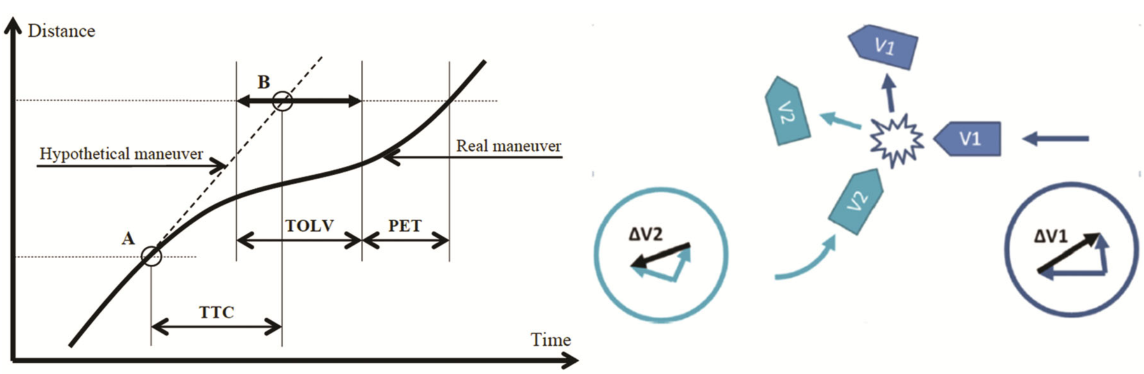

Fig. 2 — Definition of Time-To-Collision (TTC) and Illustration of Delta-V.

MaxDeltaV is the maximum DeltaV value of either vehicle in the conflict. This is a surrogate for the severity of the conflict, calculated by assuming a hypothetical collision of the two vehicles in the conflict. Figure 2 also presents the illustration of Delta V.

MaxS is referred as the maximum speed of the vehicles involved in conflict at TTC value which is less than the specified threshold.

Deceleration rate has been defined as the rate at which a crossing vehicle decelerate to avoid collision which can be the difference between speeds of leading vehicle and following vehicle divided by their closing time. In the case of conflict of two vehicle phenomena, if the vehicle applies break then negative acceleration will be observed for that vehicle if the vehicle does not apply break then lowest acceleration will be observed for that vehicle. Based on the various reviewed literature *[Anna Charly and Tom (2016)*[4]*, Shekhar Babu and Vedagiri. P., (2016)*[5]] the threshold value of deceleration rate for Indian vehicles has been observed to be 3.35 m/s^2. This has indicated that if the speed of the vehicle exceeds the above threshold value it might be involved in conflict whereas the American Association of State Highway and Transportation *(2018)*[6] has suggested a threshold value of 3.40m/s^2.

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 *(Lai Zheng et al., (2021)*[7]*; Autey et al., (2012)*[8]*, Bagdadi O, (2013)*[9] *and Cafiso et al., (2018)*[10]. In this regard, Cunto *(2008)* [11] has stated that the usefulness of microscopic simulation for assessing safety depends on the ability of these models to capture complex behavioral relationships that could lead to crashes and to establish a link between simulated safety measures and crash risk. *Deepak and Vedagiri (2014)*[11] 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. Accordingly, the assessment of the level of traffic safety has been conducted by devising a unique strategy of measuring proximal safety indicator. Time to Collision (TTC) of a midblock section using micro simulation modeling yields more statistically reliable proximal measure of traffic safety. Similarly, *Minderhoud et al., (2019)*[12] has inferred that identification of critical conflicts using a threshold value of TTC has been largely used around the globe especially in midblock 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 even to occur. It has been deduced from this study on Indian roads that conflicts with TTC less than the threshold value may not be critical if the speed of conflicting vehicle is less.

It is evident from the above reviewed literature that none of the studies has focused on the entire road stretch while devising the Surrogate Safety Measures addressing the traffic heterogeneity prevalent in the Indian traffic context. Considering the above research gap, it has been felt prudent to quantify the traffic conflicts occurring at the midblock of the above referred study section by considering only the candidate midblock sections falling on the entire study corridor. In this regard, the proposed surrogate safety parameters has been validated using the reported crash data, reported between 01.01.2015 to 31.12.2017 on the candidate midblock locations. Further, an approach has been deduced for the conduct of microscopic evaluation of traffic safety using surrogate safety parameters.

2 Material and Methods

2.1 Description of study corridor

Gurgaon - Faridabad Road is a major interurban road located on the urban periphery of National Capital Territory *(NCT)* of Delhi linking the above two cities by the shortest route bypassing Delhi. The study corridor spanning a length of 24.31 km long is a four lane divided interurban corridor having 7.0 m wide carriageway, 1.5 m paved shoulder, 2 m wide median, 0.25 m kerb shyness having an earthen shoulder width of 1.5 m on either side. It is to be borne in mind here that safety performance of any road corridor is strongly dependent on geometric features of the road and traffic conditions. The study corridor contains seven major intersections and out of which 5 are signalized and 2 are unsignalized coupled with the corridor traversing through 15 horizontal curves.

Obviously, the surrogate safety measures that is evolved for any road corridor will vary for various sections of any road namely midblock, curves and intersections. In order to study the behavior of vehicles on different sections of the road, each surrogate safety measures is to be analyzed separately by considering midblock, curves and intersections. As mentioned earlier, this paper deals only with the estimation of potential crash prone sections using surrogate safety indicators by considering midblock sections only. The minimum and maximum length of midblock section varied between 310 m to 1400 m respectively. The midblock sections considered encompasses straight sections as well as road sections having curve radius more than 1200 m and a typical illustration of the study corridor is presented in Fig. 3.

2.2 Data collection

The traffic data has been collected by conducting classified volume count *(CVC)* survey and recording spot speeds at the identified midblock sections. Further, the journey speed data has been 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. This data has been used for validating the simulation of study corridor. The entire corridor is simulated using VISSIM software, and their trajectory data file is extracted to find the intensity of traffic conflicts from calibrated simulation models using the data mentioned above. The procedure of simulation and validation statistics is not included in the present paper due to constraint of length of the paper. The road crash data, collected for the period from 01.01.2015 to 31.12.2017 was collected from the records maintained by the concessionaire of the study corridor. The above data provided the chainage details, cause and type of each road crashes on the entire study corridor. This eventually helped in the segregation of number of road crashes occurring at various midblock, curves and intersections as per their occurrence on the study corridor. Table 1 presents the number of road crashes taken place during the last 3 years and their share in total road crashes on the entire

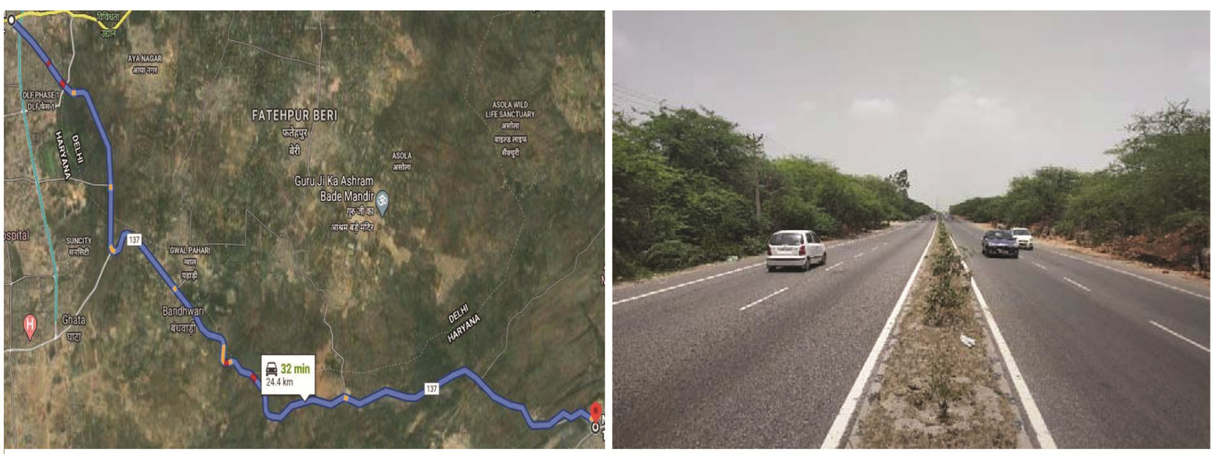

Fig. 3 — Gurugram to Faridabad Study Corridor.

Table 1 — Number of Road Crashes during 2015 to 2017 on the Study Corridor

Reference of Midblock location (M) and parameters considered	2015	2016	2017	Grand Total
M1 @ Km 3.000 -3.300 = 300 m	6	4	1	11
M2 @ km 3.500- 4.200 = 700 m	5	2	7	14
M3 @ km 4.400- 4.900 = 500 m	2	1	1	4
M4 @ km 5.100 -5.970 = 870 m	13	8	5	26
M5 @ km 11.000 -11.300 = 300 m	10	13	15	38
M6 @ km 14.330 -14.800 = 470 m	3	5	4	12
M7 @ km 16.500 - 16.920 = 420 m	14	6	3	23
M8 @ km 18.290 -19.690 = 1400 m	12	4	5	21
M9 @ km 20.940 -21.340 = 400 m	1	1	1	3
M10 @ km 23.890- 24.200 = 310 m	1	2	1	4
Total number of road crashes at the midblock locations	67	46	43	156
Total Number of Road Crashes on the entire corridor	325	221	186	732
Share of road crashes on the Midblock locations (%)	20.62	20.81	23.12	21.31

M-1, M-2, M-3, M-4, M-5, M-6, M-7, M-8, M-9 and M-10 indicate the midblocks on the study corridor

corridor. It was evident from Table 1 that the percentage share of road crashes at midblock sections of the study corridor was ranging between 20.62 to 23.12 per cent during the period of analysis considered in this study.

2.3 Microscopic simulation and surrogate safety assessment model

Micro 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 all the midblock sections as mentioned in the previous section were simulated and validated separately after satisfactory completions of validation using VISSIM software. Surrogate Safety Assessment Model *(SSAM)* is a software freely available to identify, classify and evaluate traffic conflicts based on the vehicle trajectory data output from microscopic traffic simulation models. The software computes a number of surrogate measures of safety for each conflict that is identified in the trajectory data and then computes and summarizes mean, max, and other associated statistics for each of the surrogate measure. The surrogate safety parameters such as TTC, Max S, and Delta V were computed for each of the midblocks separately. Surrogate safety analysis for identification of threshold value was carried out using aggregate data *i.e. adding all the individual midblock sections*. The severity analysis to identify the intensity of road crashes in terms of their severity namely Fatal, Serious Injury, Minor Injury and Property damage using the conflict data. In this regard, the developed severity zones and the threshold values have been utilized for any midblock section of interurban corridor. The validation of the threshold values and severity zones were carried out by using the individual midblock surrogate parameter and the actual crash history data collected for three years. The detailed methodology of surrogate safety analysis for interurban midblock section is discussed in detail in the subsequent sections.

2.4 Surrogate safety parameters

In this study, vehicle trajectory data was built for each of the midblock sections based on the microscopic simulation through VISSIM and thereafter vehicle trajectory files were imported to SSAM to arrive at the surrogate safety parameters. In this regard, the vehicle-to-vehicle conflict data was obtained from SSAM.

2.5 Geometric design standards of study corridor

The design speed of the study corridor is 80 Kmph and the operating speed/speed limit on the corridor is 70 Kmph *[IRC: 73-2018*[13] *and IRC: SP-84 (2018)*[14]*].* Considering the operating speed of 80 Kmph the safe Stopping Sight Distance (SSD) is 120 m, which implies that the time headway of 5.4seconds say 5 seconds should be considered for the study section. Based on the above the TTC threshold used is 5 seconds whereas the PET threshold is set as 9.5 seconds for the identification of serious conflicts on the study corridor.

3 Results and Discussions

3.1 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 might be carried out by finding the frequency distribution of the conflicts and thereby assess the median values that could be declared as threshold. Major disadvantage of this process was that the conflicts were not events they were the process hence the present study tried 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 were used to find the distribution instead of the direct values of TTC. For the values of 1/TTC measure, various mathematical functions were tested to fit Probability Density Function (PDF). The probability density function which was better fitting the study data find was that Weibull distribution[15], the pdf function for this distribution is given in Eq.1.

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

A brief description on the applicability of Weibull distribution and statistical tests are given in the succeeding sections.

3.1.1 *TTC Distribution observed at the Midblocks*

As explained earlier, vehicle trajectories were extracted through VISSIM and thereafter conflicts and surrogate safety parameters such as TTC Values for each conflict were 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. 4 indicates that the data fitted with the Weibull distribution for the entire set of midblock sections considered on the study corridor.

K-S test was used to determine the goodness of fit of the distribution. At 95 percent confidence 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. Further, the goodness of fit statistic as K-S test *(D-statistic)* for all the midblock sections is presented in Table 2.

The mean TTC value obtained for the midblocks from the distribution was 1.44 sec which was taken as the critical threshold value of TTC. This implied that if the value of TTC was less than 1.4 sec for a conflict, then the conflict could be considered as a serious one leading to the incidence of fatal crashes.

3.2 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 toreciprocal of TTC, the variation of Deceleration Rate *(DR)* reflected the crash severity at higher values of deceleration rate. The data values of distribution of deceleration rate were also used to fit a number of mathematical distributions. In this regard, the Weibull distribution was 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 and all the midblock sections together. The probability density

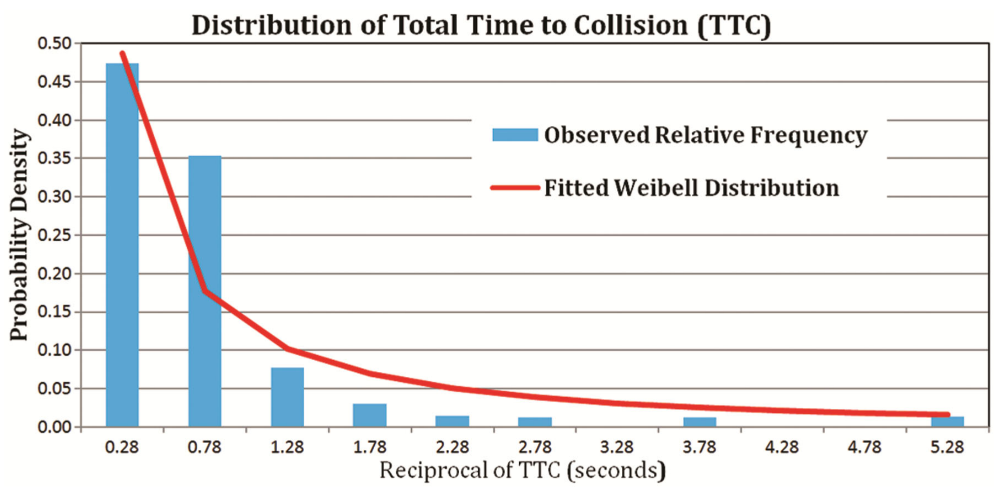

Fig. 4 — Distribution of Total Time to Collision (TTC) for Midblock Sections.

Table 2 — Probability distribution table of 1/TTC for total midblock sections

Limit	Frequency	Observed Relative Frequency	Fitted Weibull Distribution	Cumulative dist. Function CDF(1)	Cumulative dist. function CDF(2)	D-statistic
0.28	14043	0.4740	0.4869	0.4740	0.5474	0.0733
0.78	10461	0.3531	0.1769	0.8272	0.6896	0.1375
1.28	2283	0.0771	0.1021	0.9042	0.7564	0.1478
1.78	889	0.0300	0.0689	0.9342	0.7983	0.1360
2.28	419	0.0141	0.0505	0.9484	0.8277	0.1206
2.78	365	0.0123	0.0389	0.9607	0.8499	0.1108
3.28	0	0.0000	0.0311	0.9607	0.8673	0.0934
3.78	361	0.0122	0.0254	0.9729	0.8813	0.0916
4.28	0	0.0000	0.0212	0.9729	0.8929	0.0800
4.78	0	0.0000	0.0180	0.9729	0.9027	0.0702
5.28	380	0.0128	0.0155	0.9857	0.9111	0.0747

function and the fitted Weibull distribution function of deceleration rate for the considered midblock sections are presented in Fig. 5. 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.

3.3 Analysis of Max Delta V

Max Delta V was the maximum change in the velocity of the vehicles involved in the conflict. First DeltaV and Second DeltaV were the change between conflict velocity and the post collision velocity as explained in previous sections. This was 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 was carried out separately. The frequency distribution of Max ΔV for the entire midblock section along with mean value, 15th and 85th percentile values are shown in Figure 6. It is evident from Fig. 6 as the value of Max ΔV increased, the seriousness of conflict also increased.

The mean value of Max ΔV obtained for midblock sections was 3.79 m/s i.e.13.64 Kmph, which was 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 was more than threshold value of Max ΔV for a conflict, then it was considered as a serious conflict.

3.4 Analysis of conflict severity

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

3.4.1 Severity analysis at Midblock

In this study, the road crashes were classified as fatal, seriously injured, minor injury and property damage conforming to MoRT&H, 2018[16]. This classification was finalised based on the quantum of

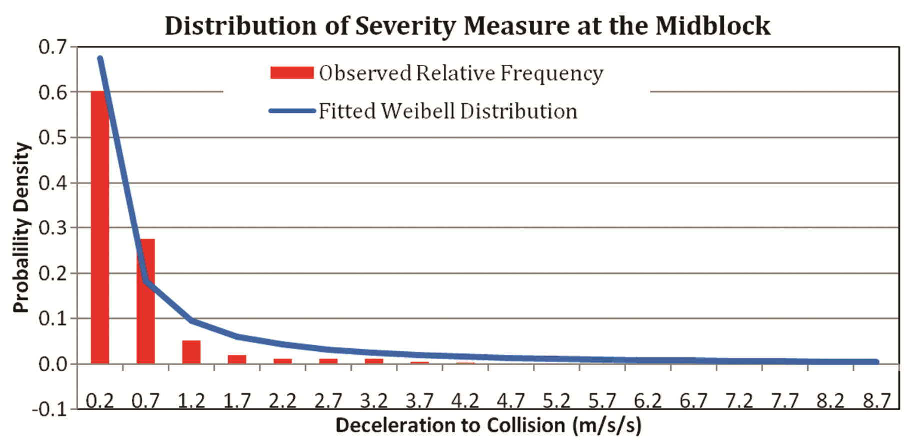

Fig. 5 — Probability Distribution of DR for all the Midblock Sections.

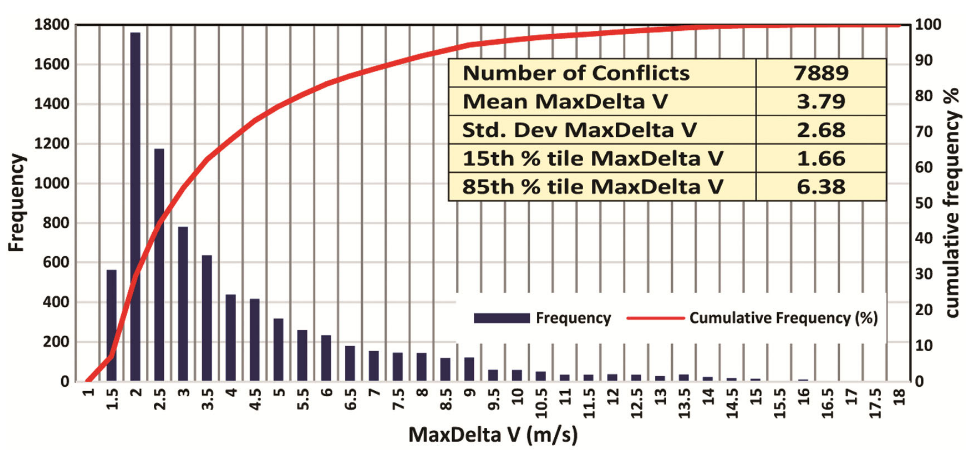

Fig. 6 — MaxDelta V frequency distribution plots for Midblocks.

damage caused to the person and vehicle. The classification of severity of crash with respect to traffic conflict had different procedure based on the parameter selected. The severe conflicts indicated 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.

3.4.2 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 was considered as appropriate indicator for defining the severity of crash because it represented "Speed Kills" *(Vittorio Astarita et. al., 2018)*[17]. Max S versus TTC plot was drawn for all the midblock sections based on the scattering of the data in the plot which was characterized under six severity zones (Fig. 7). Severity line was 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. 7. 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. 7. The various midblock related conflicts were divided into uniform severity zones and the same were plotted by giving different colors / texture as per their severity as illustrated in Fig. 7. Table 3 presented the severity zone, the criteria of TTC Max S and number of samples falling in each severity zone and percentage of total samples.

3.4.3 Crash severity based on TTC values

Time to Collision *(TTC)* and Deceleration Rate *(DR)* are direct indicators of the severity of the conflict. The lower TTC value indicated higher

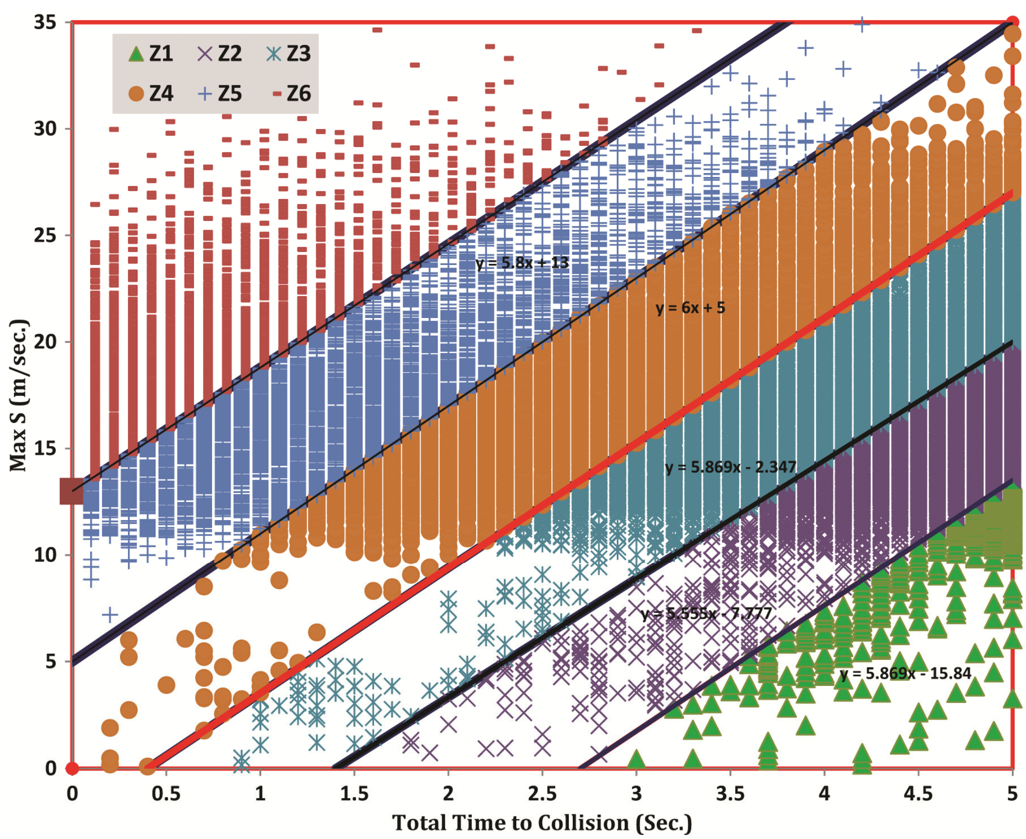

Fig. 7 — MaxS versus TTC conflict severity zone for various midblock sections of the Study Corridor.

Table 3 — 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

probability of crash 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 was 1.4 seconds and the conflicts with this TTC values were falling in the severity zones 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. 7).

On applying the above analogy, it was found that approximately 22 percent of the data fell below the critical range of 1.4 seconds of TTC. Considering the above phenomenon, the other TTC ranges were 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 was the more extreme condition. On the contrary, the conflicts which yielded TTC greater than 4.4 seconds were assigned a score of 1 because these conflicts were at a low propensity level. Table 4 presents the ROC score based on TTC and the sample size and the TTC range values.

3.4.4 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 were used for defining the severity of conflict which were 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 Figure 8. TTC value of 1.4 was the critical value obtained from the probability distribution and the mean value of Delta V was 3.79 which illustrated that all these conflicts mostly fell in the severity zone of 3 and 4.

ROC score based on Max Delta V were assigned to each conflict. The frequency distribution of Max ΔV values for midblock sections were calculated and found the mean value of 3.79, 85th percentile Max ΔV value was 6.38 and the 95th percentile Max ΔV value

Table 4 — Assigned ROC Scores based on TTC scores for the various midblocks 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

Table 5 — 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	5.1	Fatal

observed was 9.44. Based on the frequency distributions of the Max, ΔV the ranges were fixed and the ROC scores were assigned to each conflict. Table 5 presents the ROC scores and range of Delta V and collision propensity level for the study corridor which exhibited the typical traffic heterogeneity prevalenton Indian roads.

As discussed in the previous sections, the range of the TTC and Delta V severity score plot was deduced for the potential conflicts on the various midblock sections of the study corridor. Figure 9 shows the different severity scores evolved based on the TTC and Delta V. For easy identification purpose, different color and legends are given for different zone values.

Figure 8 shows the severity zones which are presented in the form of grid type whereas the severity contour scores for the conflicting zones are depicted in Fig. 9. The values of TTC and Delta V values were modified slightly by taking into consideration of Hyden uniform conflict zones theory discussed in Section 1. Further, Fig. 9 also presents the potential conflicts on the various midblocks 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 6. Table 6 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.

3.4.5 Crash potential versus Crash history

As mentioned earlier, the 10 midblock sections on the study corridor of 24.3 km were simulated using

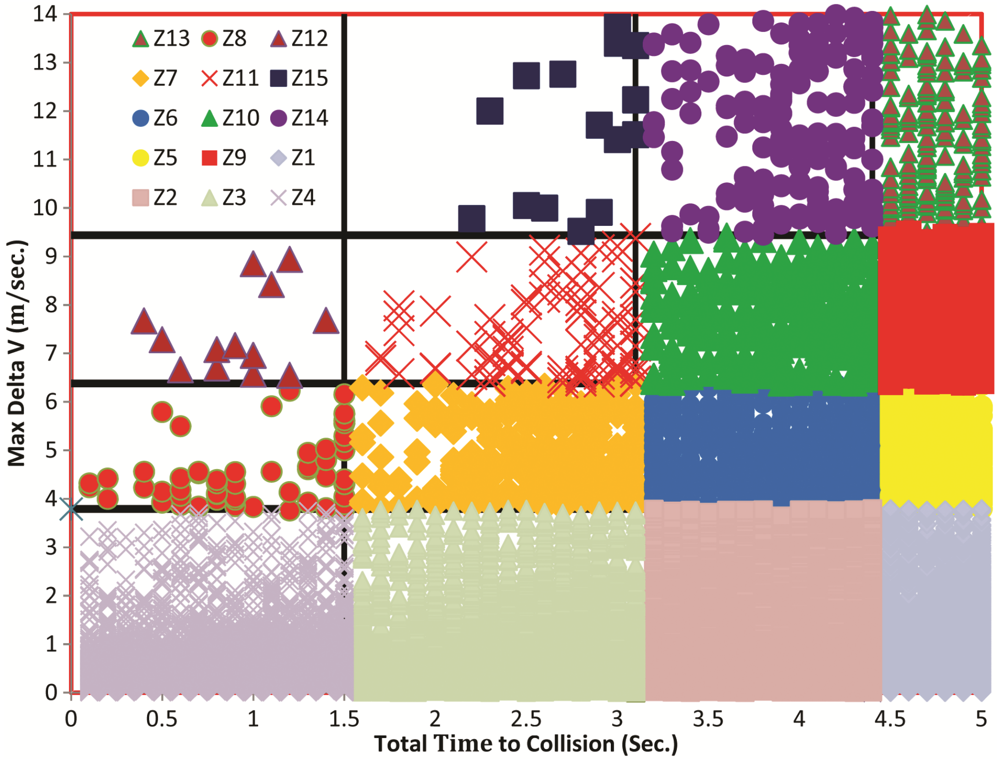

Fig. 8 — Max ΔV versus TTC plot by severity score for various midblock of the study section.

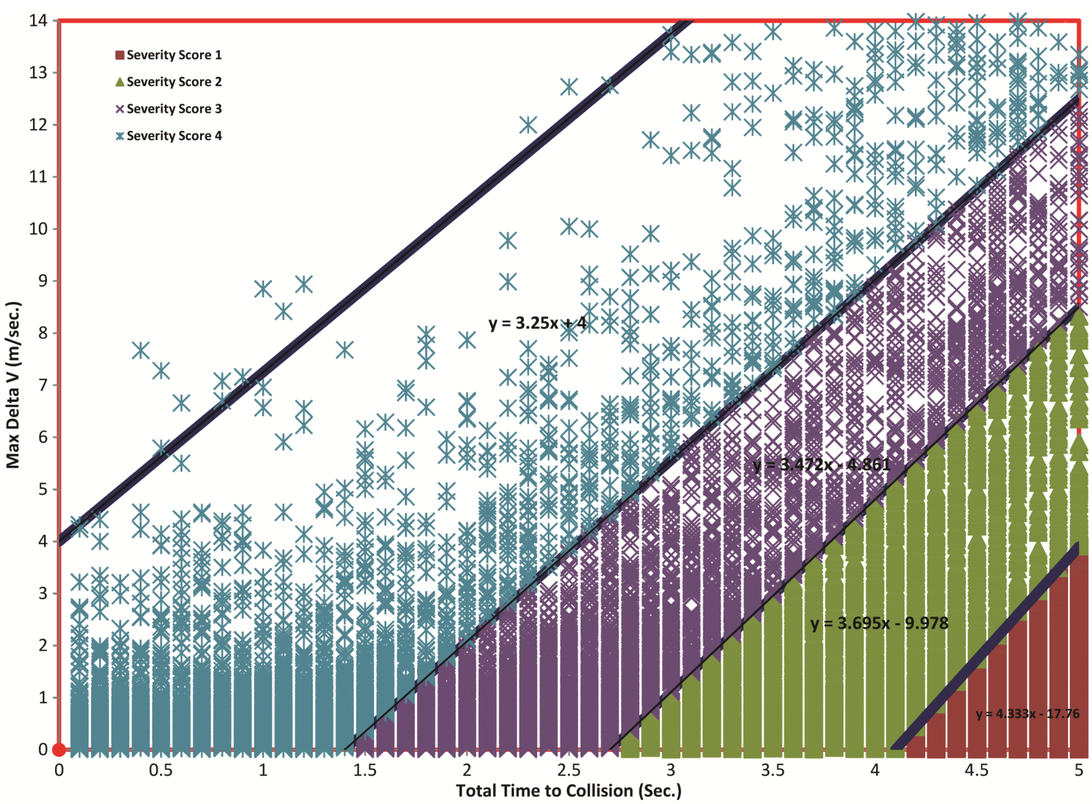

Fig. 9 — Delta V versus TTC conflict zones for various midblock sections of the study corridor.

Table 6 — Changes from initial to modified overall severity score

Overall ROC Score	Criteria (TTC)	Criteria Delta V	Samples, Size, *(%)*	Line Number	Equation *(Max ΔV =)*	Collision Propensity Level
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

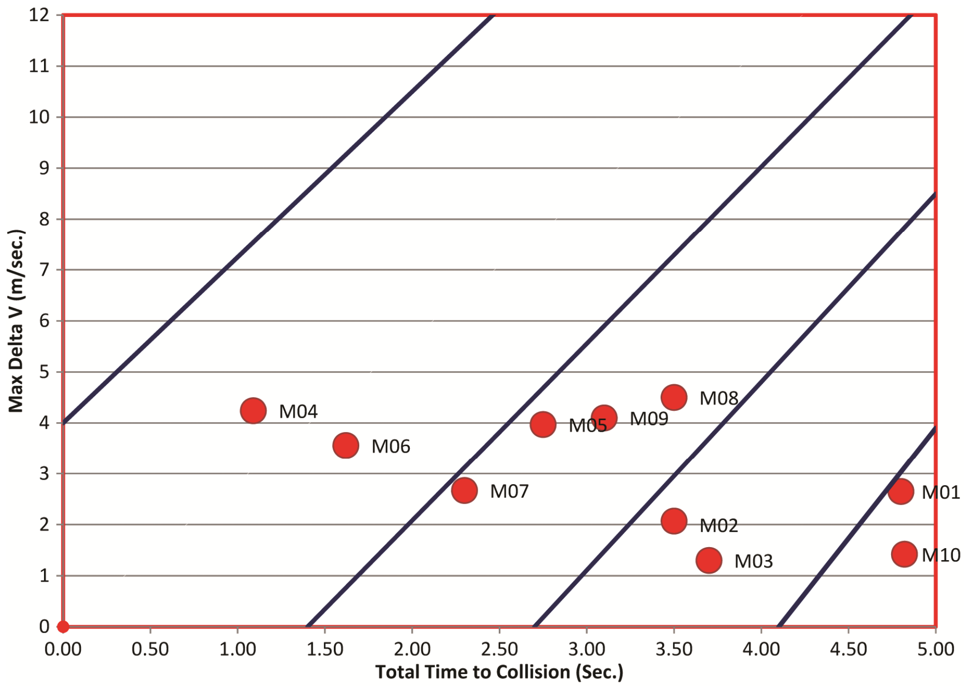

Fig. 10 — Profile of TTC values for the various Midblock Sections of the Study Corridor.

VISSIM. Thereafter, SSAM software was used to extract the surrogate safety parameters such as TTC, Max S and Delta V. Surrogate safety parameters were determined for each of the individual midblock sections by determining the severity zone plot and the type of severity zone exists in each one of them. Accordingly, Fig. 10 presents the individual midblock sections and the severity zones to which it belongs.

The crash data collected for the study corridor during 3-year period along with type of crashes is presented in Table 7 which in turn was used to validate the potentiality of each midblock section by comparing with SSAM modeled values. The following inferences were drawn based on the comparison of SSAM results *(refer Figure 10)* and crash data *(refer Table 7)* based on the reported crashes:

- In most of the midblocks, all types of road crashes were occurring except at the same time, midblocks namely, M-4 and M-6 accounted for 3 and 1 number of fatal crashes respectively; this denoted that the above midblock sections were true representations of the ground realties and hence falling under Zone 4.
- Further, midblock sections namely, M-5, M-7, M-8 and M-9 fell under Zone 3 as this zone represented serious injury and hence again truly representing the ground conditions. Further, M-5 and M-7 also accounted for sizable proportion of minor and non-injury crashes and this was aptly reflected *(vide Fig. 10)* as both these midblocks fell on the periphery under Zone 4.
- Matching with the pattern of reported road sections, M-2 and M-3 was falling under Zone 2

Table 7 — Number and Severity Type of Road Crashes on the Midblocks of the Study Corridor based on the Crash Records

S. No.	Section No.	Number of Fatal Crashes	Number of Grievous Crashes	Number of Minor Crashes	Number of Non-injury Crashes
1	M-1	0	3	4	4
2	M-2	0	1	5	3
3	M-3	0	1	2	1
4	M-4	3	4	5	12
5	M-5	0	10	9	15
6	M-6	1	2	4	3
7	M-7	0	6	5	10
8	M-8	0	5	6	7
9	M-9	0	3	0	0
10	M-10	0	0	1	3

M-1, M-2, M-3, M-4, M-5, M-6, M-7, M-8, M-9 and M-10 indicate the midblocks on the study corridor

and thus accounting for the dominant share of minor injury and property damage related crashes.

- Lastly, matching with the reported trend in the road crashes, M-1 and M-10 were falling under Zone 1 as both of mostly account for property damage type crashes only.

4 Conclusions

In this study, an interurban road corridor having a length of 24.31 Kms encompassing 10 typical straight midblock sections falling between two adjacent intersections or curves have been studied to understand the behavior of surrogate parameters. The above midblock sections have been simulated using VISSIM software by calibrating field data and its satisfactory validation. Thereafter, the vehicle trajectories for all midblock sections have been extracted coupled with trajectory analysis for surrogate safety parameters using SSAM software. In this regard, the various surrogate safety parameters have been thoroughly evaluated so as to determine threshold values of surrogate parameters and severity zones have been developed to assess the potential crash locations and to understand which type of crash will occur *i.e. severity of crash.*

Further, the study revealed that TTC and DR follow the Weibull distribution. Moreover, the critical TTC on interurban midblock sections catering to heterogeneous traffic movement is 1.4 seconds meaning thereby that any conflict which have taken place lesser than this time would invariably led to a fatal crash. Similarly, the critical deceleration rate has been observed as 0.406 m/s which again imply that any conflict with more than this value will led to a fatal crash under the scenario of traffic heterogeneity. Further, the Delta V values have been deduced for the study corridor on interurban midblock sections catering to heterogeneous traffic movement is 3.79 m/s which again indicated any conflict more than this value can turn to be a potential crash.

Importantly, the above referred surrogate safety parameters values have been validated with the actual road crash data collected on the study corridor over three-year period. The developed threshold values can be used to identify potential crash prone location for any interurban highway exhibiting similar traffic heterogeneity. Thus, it can be concluded that the severity zones developed in the study can be used to find the intensity of severity ata potential road crash prone location.

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