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Modeling Time-to-Collision for Road Work Zones under Varying Geometric and Traffic Conditions

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ABSTRACT

Highway transportation is an essential mode of transportation from both accessibility and mobility perspectives. There is more traffic demand for road transportation than for other modes. In addition, there is haphazard development of road construction in all states of India. Road construction and maintenance activities are more common due to catering to more supplies of traffic demands. In particular, the work zone (WZ) is an area designed for road construction activities in which a specific road section is blocked. Therefore, traffic safety issues are much more for various road conditions. Therefore, studying traffic safety at the microscopic level for varying roadway, geometric, and traffic conditions is necessary. For this, the present study adopts a surrogate safety measure, namely time-to-collision (TTC), to study traffic safety at a microscopic level. The analysis involves the average value of TTC, deceleration rate to avoid a collision, and trajectories for geometric parameters of WZ. Modeling of TTC is performed for various geometric parameters of the WZ. The study outcome will benefit the construction authority in planning safety measures to minimize the probability of conflicts and correspondingly achieve safety reasonably.

INTRODUCTION

Road Transportation is a crucial mode of transportation, having more demands from overall states of Indian country. Road construction and maintenance activities are common in India. Road construction and maintenance activities create various types of construction work zone (WZ). Traffic safety is the more concerning issue in the construction WZ area. Therefore, it is imperative to study traffic safety at a microscopic level. The researcher derives various surrogate safety measures, but their actual behavior concerning change in the geometric parameters of WZ is not considered. Hence, the present study modeled time-to-collision (TTC) for varying road geometric and traffic conditions under WZ conditions. Gettman et al. 2003 *(1)* studied various surrogate safety measures (SSM) from traffic simulation models such as TTC, post-encroachment time, deceleration rate, maximum speed, and speed differential. Measures of conflict intensity include the TTC, post-encroachment time, and deceleration rate. To gauge the severity of prospective crashes, use maximum speed and the speed differential. A post-processing tool is used to compute the statistics for the various measurements and compare design alternatives after the simulation model has been run through several iterations.

Wang et al. 2019 *(2)* reviewed SSM and their applications in connected and automated vehicle (CAV) safety modeling. Their main objectives included providing a thorough and organized assessment of critical SSM studies, highlighting challenges and openings for future SSM and CAV research, and helping researchers and practitioners select the best SSM for safety investigations. Several significant challenges are also identified, including SSM for CAV trajectory optimization, SSM for individual vehicles and vehicle platoons, and CAV as a new data source for creating SSM. Ozbay et al. 2008 *(3)* developed and verified a novel SSM based on simulation. They suggested a modified simulation-based SSM, which better captures the chance of crashes and the severity of these potential crashes than the previous one. These surrogate safety indices should be limited to the analysis of linear conflicts, as they are first advised for link-based research.

Morando et al. 2018 *(4)* examined autonomous vehicle's (AV) safety impact using simulation-based substitute safety measures. The safety study was performed for two case studies-a signalized intersection and a roundabout with various AV penetration rates. The findings show that AV significantly improves safety with high penetration rates, especially at short headways, to boost road capacity and reduce delay. With AV penetration rates between 50% and 100% for the signalized intersection, conflicts are reduced by 20% to 65%, statistically significant at a 95% confidence range. With 100% AV penetration, the roundabout's conflict rate drops by 29% to 64% (statistically significant at a 95% confidence interval). SSM for a simulation-based traffic study was researched by Wang et al. in 2013 *(5)*. To determine the crash risk of simulated conflicts, the distributions of response time and maximum braking rates are added to a probabilistic crash propensity model. This model can deliver the ACPM for the three crash types crossing, rear end, and lane change. As part of an experimental validation effort, 12 crossings were simulated using the simulation program VISSIM. To estimate the ACPM, valuable conflict data are retrieved utilizing the surrogate safety assessment approach. The ACPM can assess the relative safety of various traffic facilities and treatments using Spearman rank tests. Table 1 summarizes the available simulation-based literature and their implication on safety.

TABLE 1 Summary of simulation-based literature

Category	Reference	Research Features	Research Outcomes	Safety Measures
A	Zhu et al. *(6)*	Study on the effect of work-zone lane closures on traffic safety	Integration software and safety implications are calculated regarding deceleration and speed variance.	Deceleration
	Meng et al. *(7)*	Development of a cellular automata (CA) model to study the WZ traffic	CA model is the best-fitted model. A model shows the close agreement of travel time and traffic delay for CA model data and field data.	Travel time
	Hou et al. *(8)*	Development of an improved cellular automaton model for work zone traffic simulation	Results showed that the improved model could accelerate, decelerate, keep their velocity, and change lanes more realistically while passing the work zone.	Deceleration
	Lin et al. *(9)*	Investigating the effectiveness of variable speed limit controls on highway WZ operations	VSL algorithms can yield a substantial increase in both WZ throughputs and a reduction in vehicle delays.	Delays, TTC
	Hardy et al. *(10)*	Development of a document that guides the analyst, researcher or manager in performing a specific work zone analysis project	Traffic volume involves various case study examples, discussions, and analyses designed to provide helpful information to the WZ analysis.	TTC
B	Schrock et al. *(11)*	Study of rural interstate work zone traffic management plans in iowa using simulation	Simulation for WZ Traffic Management Plan gives a better alternative: implementing a nonstop work schedule until project completion.	Acceleration
	Bella et al. *(12)*	Validation of driving simulator for WZ design.	It is found that there is a statistical difference between field and simulated data.	DRAC
	Park et al. *(13)*	Calibration and validation of freeway work zone using VISSIM microsimulation	VISSIM Microsimulation results showed that the procedure effectively calibrated and validated a freeway work zone network.	Acceleration
	Edara et al. *(14)*	Multivariate regression for estimating driving behaviour parameters in work zone simulation	The estimated statistical models can generate a range of parameter values that produce a wide range of capacities used by state DOTs in the US.	Acceleration
	Moriarty et al. *(15)*	Assessment of the impacts of highway WZ strategies using simulation models	The results of this evaluation will be of interest to State and local transportation engineers responsible for planning and designing work zone strategies.	Acceleration
	Maze et al. *(16)*	Study on the various simulation models	All models are calibrated and validated with field data and simulation data.	Acceleration
	Nelson et al. *(17)*	Testing of WZ traffic control devices using driving simulations	There are significant changes in state and national standards.	Acceleration
C	Meng et al. *(18)*	Developing an improved cellular automata model for simulating heterogeneous traffic in work zone	The ICA model is used to estimate capacity in the WZ.	Deceleration
	Heaslip et al. *(19)*	Estimation of arterial WZ capacity using simulation	Simulation of arterial WZ showed that the distance of WZ to the downstream intersection affects the capacity of WZ.	Capacity
	Chatterjee et al. *(20)*	Replication of WZ capacity values in the simulation model	The study provides an appropriate method of choosing the lane-changing and car-following parameters.	Capacity
	Heaslip et al. *(21)*	Estimation of freeway WZ capacity by using simulation and field data	Capacity calculated from analytical models of CORSIM (version 5.1) is within 1% of the capacity of HCM 2000 and field data.	Acceleration

Note: A = Simulation using various modeling techniques, B = Simulation using various simulation software, and C = Capacity estimation using simulation technique.

The previous literature shows that traffic safety affects macroscopic and microscopic traffic flow parameters. Microscopic parameters, namely various derived SSM, are used to capture the behavior of crashes and conflicts on various roads. Hence, it is necessary to study the descriptive statistics of SSM along with various road parameters which affect the modeling. One of the research gaps is no literature available in the study where the modeling of the SSM has taken place. SSM modeling is important because it gives insights into various parameters that affect SSM. Hence, this motivation study uses different study parameters to model the SSM.

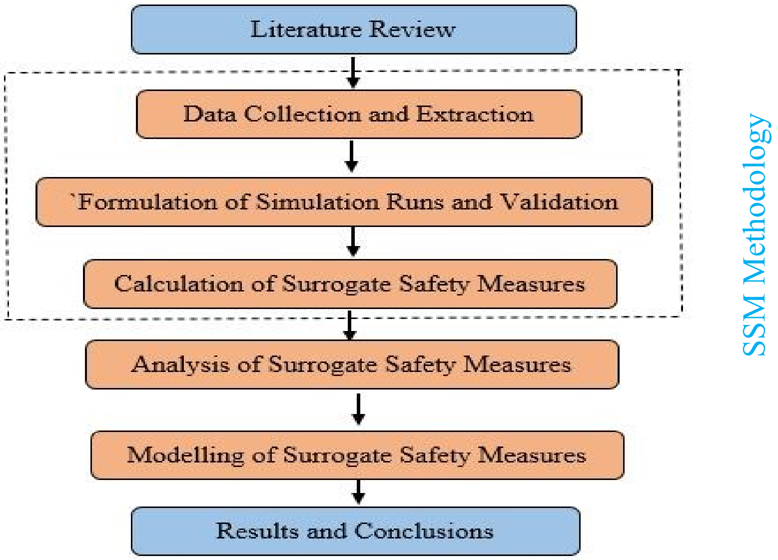


FIGURE 1 Stepwise methodology of the study

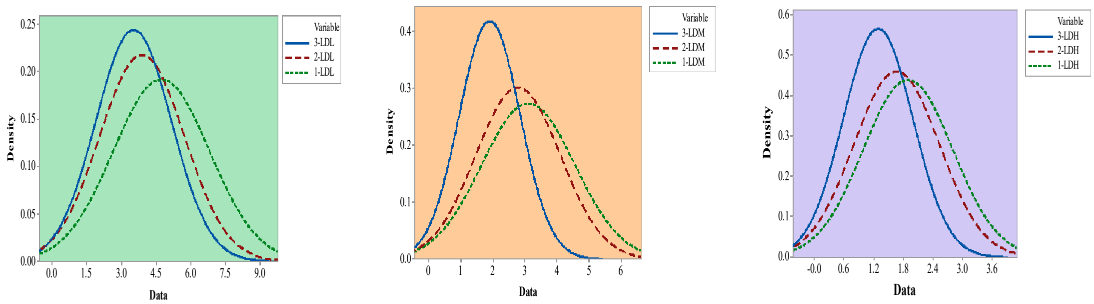
Figure 1 shows various tasks of the present study in the form of research methodology and involved the following seven steps. .

1. A detailed literature review was performed related to the SSM and modeling.
2. The required data were collected in Western Expressway of India for WZ and Without (WWZ) sections using traffic data extractor software. MATLAB coding was used to calculate leader-follower pairs, which were calculated by considering three conditions: (1) the leader should be ahead of their follower, (2) the lateral distance should be less than the lateral threshold, and (3) the distance between the leader and follower should be minimum.
3. Once the leader-follower pairs were drawn, TTC was calculated for each pair. Various simulation runs are developed in VISSIM software with varying lane drops, tapers and lengths of WZ. Calibration and validation were done using the Widemann 74 Models. Macroscopic and microscopic validations were then performed. Macroscopic validation involved speed versus flow plots for field data and normal data. Plots were made, and it was found that simulated data was matched with field data. MAPE values are also less than 15%. Microscopic validation also involved relative velocity and spacing histograms. The results showed that simulated data significantly matched field data with 95% confidence interval. Various lane drops, tapers and WZ lengths were varied, considering the guidelines of IRC SP:55 2014.
4. Data were imported into SSAM software for each simulation policy. Once data was extracted, MATLAB coding was applied to calculate leader-follower pairs. After the calculation of leader-follower pairs, the TTC value is calculated for each pair.
5. Analysis of Surrogate Safety Measures involves the Histogram of SSMs, Heat map of SSMs and Descriptive Statistics of SSMs.
6. The generalized Linear Model is used to model TTC for various roadways and traffic conditions. The model is developed for multiple lane drops, tapers and lengths of Work-Zones.
7. Finally, various results and conclusions are made.

1 ANALYSIS OF SURROGATE SAFETY MEASURES

1.1 SSM Histogram

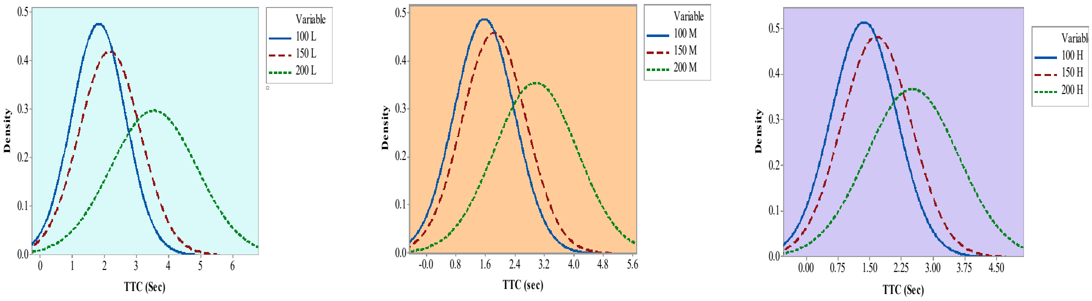
Histograms of SSM are plotted for lane drops, WZ length, and taper rate for various traffic volumes like low, medium and high traffic volume, respectively, as shown in Figure 2. It is shown that the variation of TTC decreases as an increase in lane drops. Similarly, there is more variation of TTC with an increase in the WZ length and taper rate, respectively. Further, this variation also varies for the varying conditions for the same traffic volume. This shows that the WZ conditions significantly influence traffic safety and operations. Additionally, for all three conditions, the TTC is normally distributed.



(a) 1-Lane-drop

(b) 2-Lane-drop

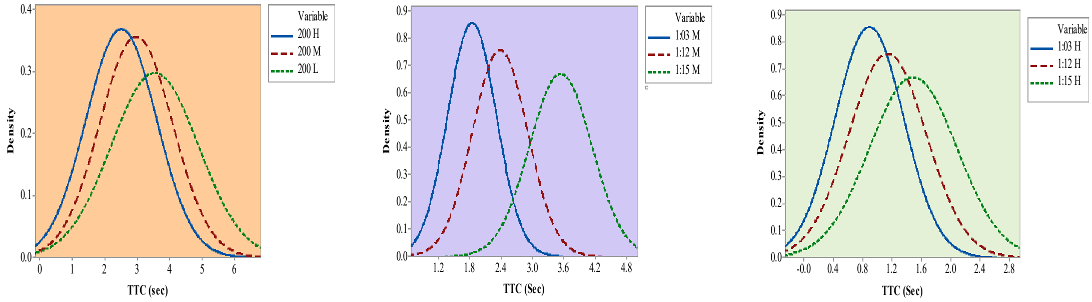
(c) 3-Lane-drop



(d) WZ length = 100 m

(e) WZ length = 150 m

(f) WZ length = 200 m



(g) Taper rate = 1:03

(h) taper rate = 1:12

(i) taper rate = 1:15

Low volume

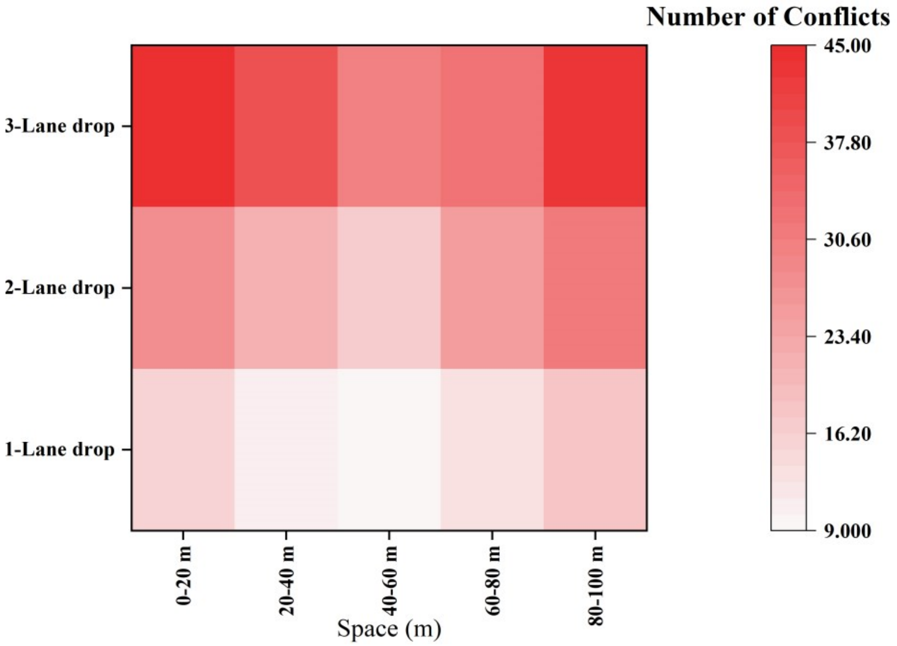
Medium volume

High volume

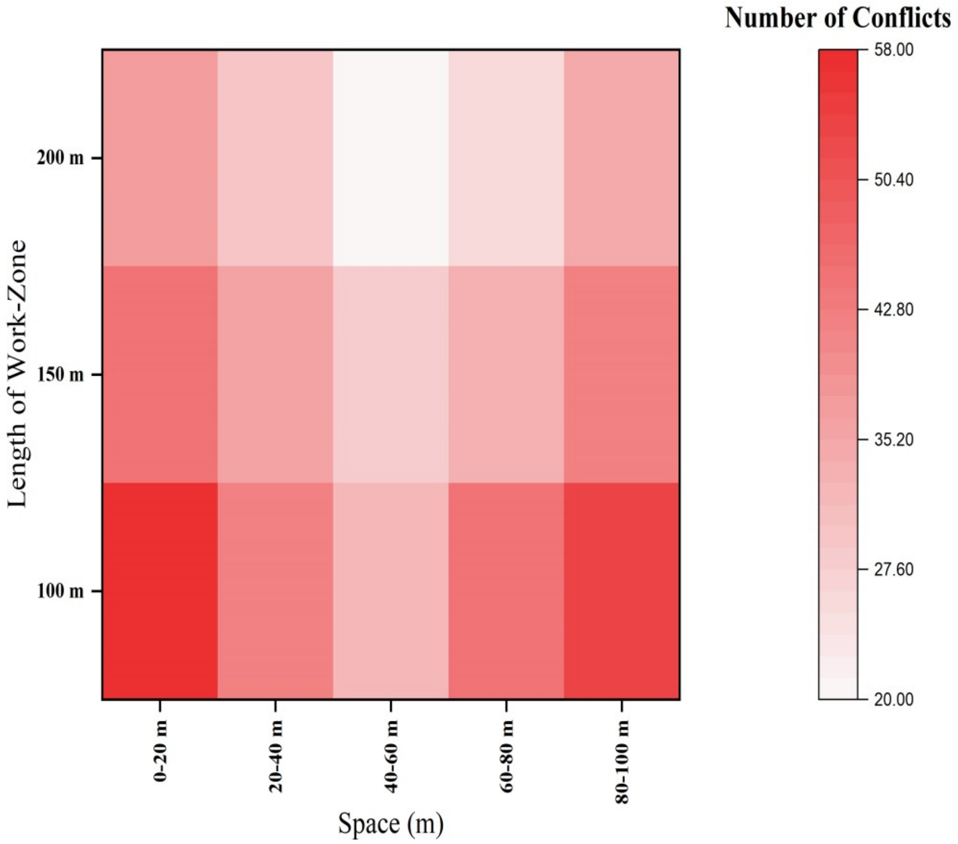
FIGURE 2 TTC distribution for various WZ conditions

1.2 Heat Map of TTC-Based Conflicts

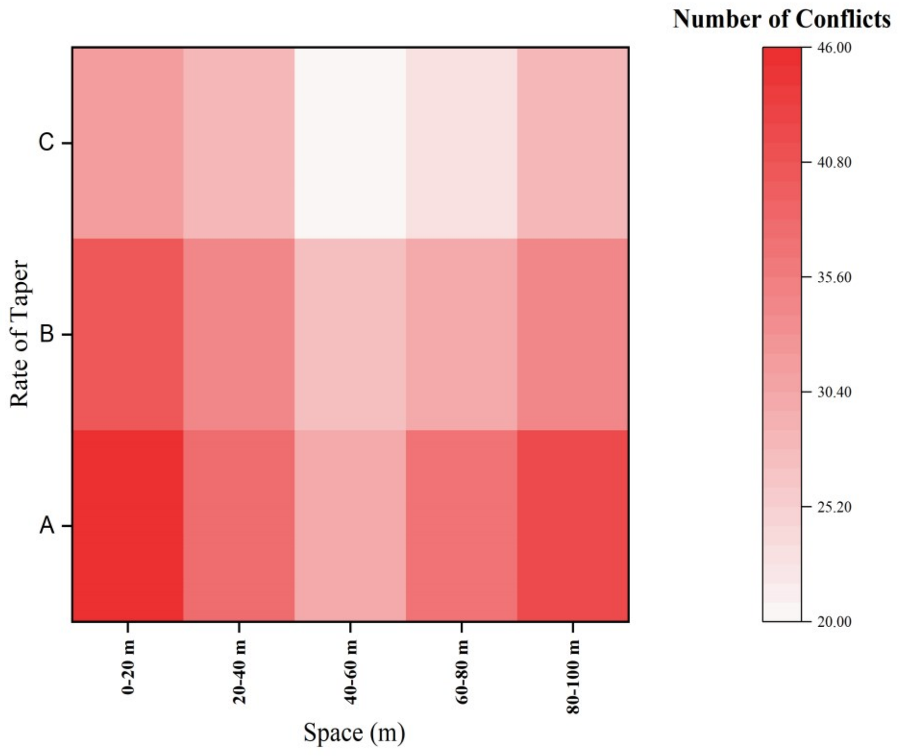
The number of conflicts is calculated based upon the TTC as criteria for identification of conflicts. Heat maps are plotted for various lane drops, tapers and WZ lengths, as shown in Figure 3.



(a) Lane drop



(b) WZ Length

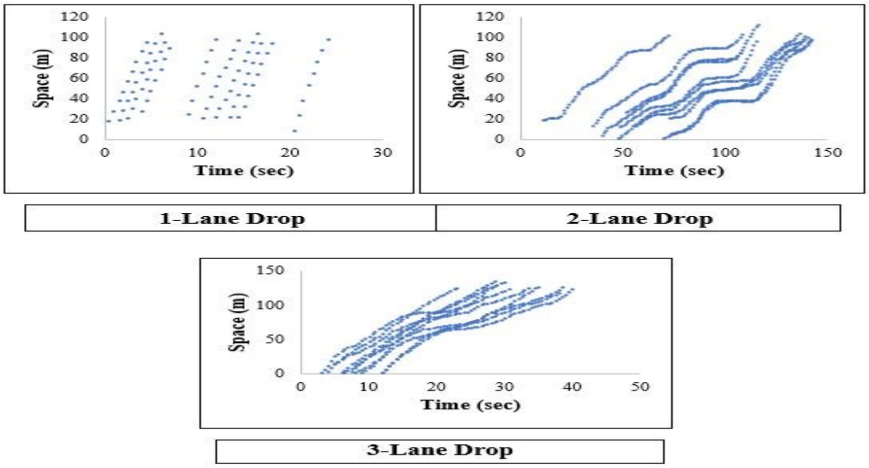


(c) Rate of Taper

FIGURE 3 Spatial distribution of TTC-based conflicts in the WZ area

It is found that the number of conflicts increases with an increase in lane drops and decreases with an increase in the WZ length. It is also found that the number of conflicts decreases with an increase in the taper rate of WZ.

2.3 Trajectory Analysis

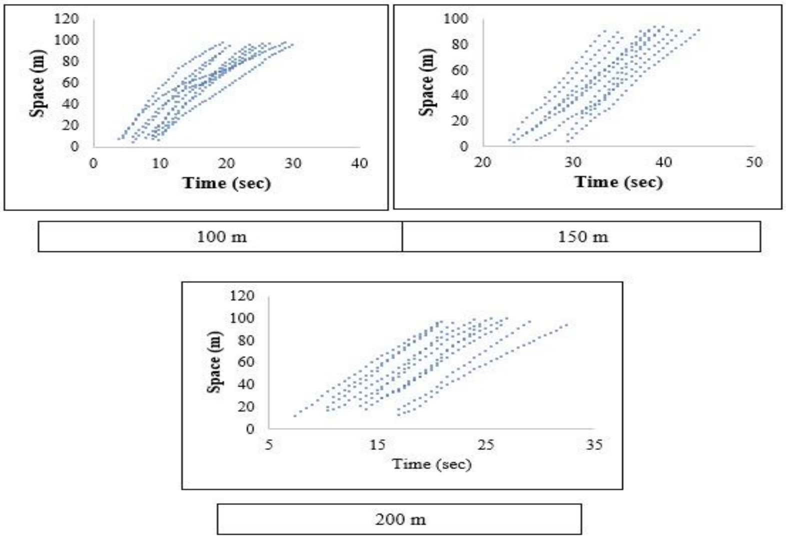


1-Lane Drop

2-Lane Drop

3-Lane Drop

(a) Lane-dropwise Trajectories

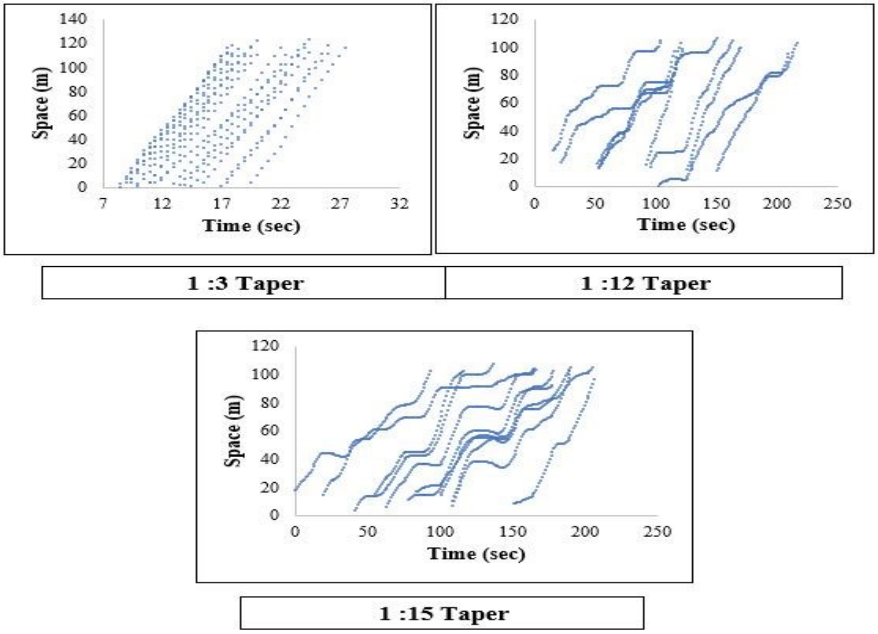


100 m

150 m

200 m

(b) WZ Length wise trajectories



1 :3 Taper

1 :12 Taper

1 :15 Taper

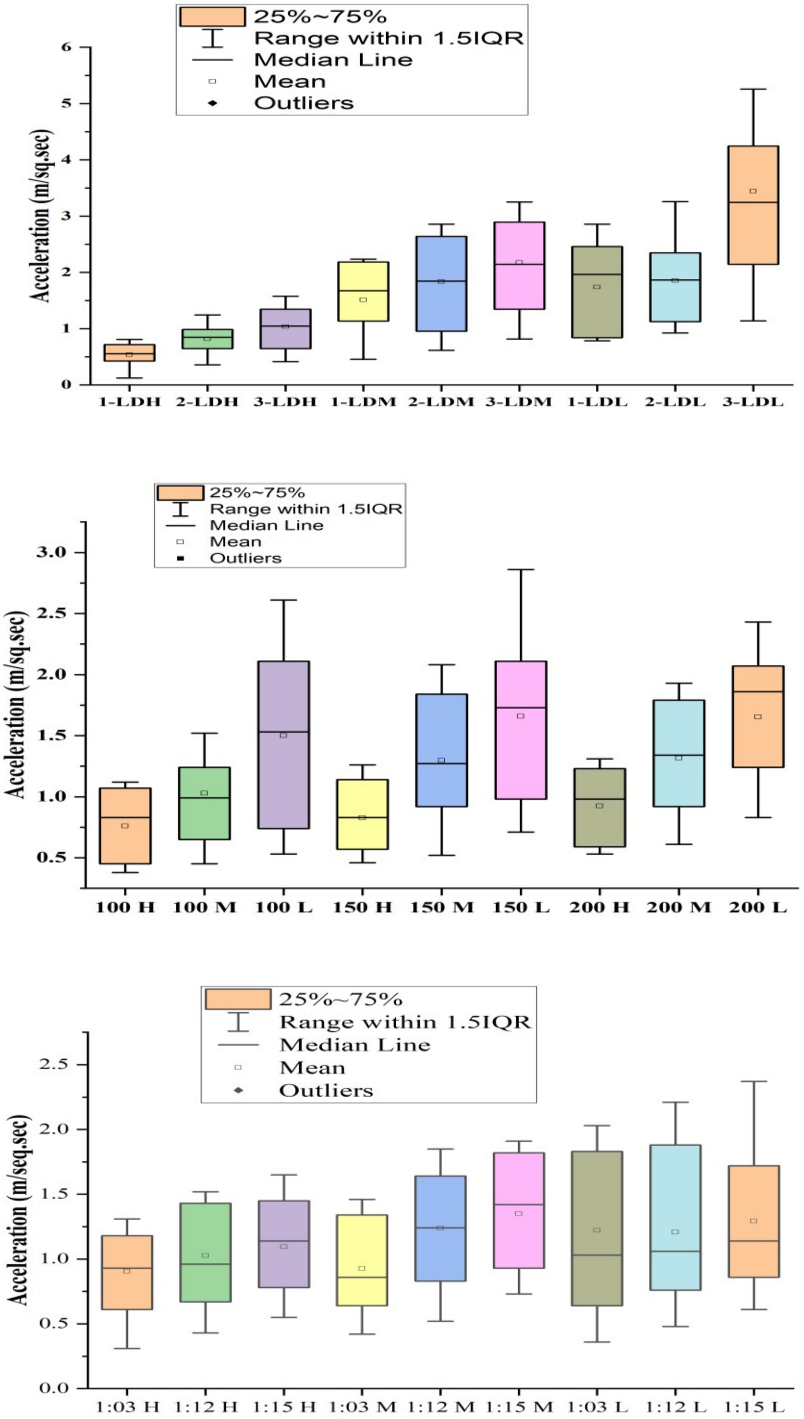
(c) Taper-wise trajectories

FIGURE 4 Vehicular trajectories for various WZ conditions

The analysis section also involves trajectory data at certain road sections for various lane drops, WZ lengths and taper rates. At a microscopic level, traffic behavior is studied. Lane drop, WZ length, and taper rate-wise vehicular trajectories are plotted at a microscopic level, as shown in Figure 4. Similarly, for modeling TTC concerning geometric parameters such as lane drops, WZ length, and taper rate, various types of variables were considered, such as the transverse angle between vehicles, vehicle type, volume type, longitudinal velocity, lateral velocity and length of WZ, tapering length, etc. Table 5 shows the description and type of variables used for modeling.

2.4 Box and Whisker Plots of Acceleration

Box and whisker plots of acceleration are plotted concerning lane drops, tapers and length of work zones. Figure 5 shows the Box and whisker plots for acceleration for various lane drops, tapers and lengths of work-zone.



(H=High Volume, M=Medium Volume, L=Low Volume)

FIGURE 5 Box and Whisker plots of Acceleration

It is found from the figure that the acceleration increases with the increase in the length and the rate of tapers of the work zone.

2 TTC MODELLING UNDER VARYING GEOMETRIC CONDITIONS

The analysis section involves the average value of TTC, Deceleration-Rate to Avoid Collision (DRAC), and Following Time (FT). The corresponding mean value for various traffic flow conditions for the TTC, DRAC and FT with their standard deviation in the parenthesis is shown in Table 2. The results show that all three SSM values vary significantly for all three traffic states with varying WZ conditions.

TABLE 2 The average value of TTC, DRAC, and FT concerning geometric parameters

SSM	Traffic State	Section Type								
		1-Lane drop	2-Lane drop	3-Lane drop	100 m	150 m	200 m	01:03	01:12	01:15
TTC	High (sec)	3.12 (1.12)	2.12 (0.96)	1.06 (1.24)	1.21 (1.03)	2.03 (2.01)	3.04 (1.85)	1.15 (1.04)	2.16 (0.96)	3.01 (2.01)
	Medium (sec)	4.26 (1.08)	3.24 (2.04)	2.03 (1.64)	1.45 (1.21)	2.15 (1.54)	3.24 (2.01)	1.34 (0.96)	2.64 (1.21)	3.64 (1.13)
	Low (sec)	5.42 (2.04)	3.89 (1.64)	2.85 (1.96)	1.64 (1.45)	2.48 (2.04)	3.75 (1.64)	1.74 (1.04)	3.02 (1.23)	4.04 (1.07)
DRAC	High (sec)	3.22 (1.11)	4.23 (2.04)	5.23 (0.96)	3.44 (0.86)	4.64 (1.07)	6.24 (0.89)	2.85 (1.28)	4.08 (1.39)	5.22 (1.24)
	Medium (sec)	2.64 (1.08)	3.46 (1.64)	4.16 (1.25)	2.85 (1.16)	4.01 (1.16)	5.87 (1.37)	2.61 (2.14)	4.21 (1.06)	4.28 (1.56)
	Low (sec)	2.01 (1.34)	2.65 (1.32)	3.27 (1.34)	2.07 (1.28)	2.84 (1.63)	5.21 (0.93)	2.22 (1.67)	4.84 (0.93)	5.08 (0.97)
FT	High (sec)	4.6 (1.02)	3.9 (1.05)	3.4 (0.92)	2.2 (0.79)	3.2 (1.01)	4.6 (0.81)	1.8 (1.01)	2.2 (1.08)	3.1 (0.86)
	Medium (sec)	5.4 (0.86)	4.6 (0.76)	4.1 (1.03)	2.9 (0.87)	3.8 (0.95)	5.1 (0.79)	2.1 (0.89)	2.7 (0.76)	3.8 (1.04)
	Low (sec)	6.2 (0.91)	5.2 (0.89)	4.7 (0.87)	3.5 (1.06)	4.5 (0.61)	5.8 (1.05)	2.4 (0.95)	3.2 (0.92)	4.2 (0.84)

TABLE 3 Description and type of variables

Sr. No	Variables Description	Variable Type	Measurement (Min-Max)
1	Transverse angle	Continuous	5 degrees to 45 degree
2	Vehicle type (VehT)	Discrete	1-2W, 2-3W, 3-CAR, 4-LCV, 5-HCV,6-Bus
3	Volume type (VolT)	Discrete	1-Low Traffic Volume, 2-Medium Traffic Volume, 3-High Traffic Volume
4	Longitudinal velocity (LongV)	Continuous	0.8 m/sec -15 m/sec
5	Lateral velocity (LatV)	Continuous	0.2 m/sec – 1.4 m/sec
6	WZ length (Length)	Continuous	100 m-200 m
7	Tapering length (TL)	Continuous	30 m- 75 m
8	Lane drops (LD)	Continuous	1-Lane drop, 2-Lane drop, 3-Lane drop

2.1 Generalized Linear Model

A generalized linear model (GLM) is a versatile generalization of traditional statistical linear regression. By allowing the linear model to be connected to the response variable via a link function and by allowing the size of each measurement's variance to be a function of its predicted value, the GLM generalizes linear regression. John Nelder and Robert Wedderburn developed generalized linear models to combine many different statistical models, such as linear regression, logistic regression, and Poisson regression. They suggested an iteratively reweighted least squares method for maximum likelihood estimation (MLE) of the model parameters. MLE is still widely used and is often used as the default method in statistical computer programs. Other methods, such as least squares fitting to variance-stabilized answers and Bayesian regression, have been developed. The families of probability distributions parameterized by the bold symbols theta and tau, whose density functions f (or probability mass function, in the case of a discrete distribution), can be expressed in the form, are included in the over-dispersed exponential family of distributions. The families of probability distributions parameterized by the bold symbols theta and tau, whose density functions f (or probability mass function, in the case of a discrete distribution), can be expressed by equation 1, are included in the over-dispersed exponential family of distributions.

$$f_Y(\mathbf{y} \mid \boldsymbol{\theta}, \tau) = h(\mathbf{y}, \tau) \exp\left(\frac{\mathbf{b}(\boldsymbol{\theta})^{\mathrm{T}} \mathbf{T}(\mathbf{y}) - A(\boldsymbol{\theta})}{d(\tau)} \right).$$

……………….(1)

where θ and τ are the parameters for the exponential distribution model and y is an independent variable.

The quantity incorporating knowledge of the independent variables into the model is called the linear predictor. A linear predictor is represented by the symbol (Greek "eta"). The link function connects it to the expected value of the data. The expression for is given as linear combinations of unknown parameters (thus, "linear"). The matrix of independent variables X is used to represent the linear combination coefficients. Consequently, it can be written as

$$\eta = \mathbf{X}\boldsymbol{\beta}.$$

…………………(2)

where β is a constant and X is a matrix of the independent variables.

There are five essential assumptions for which the generalized linear model will work: linear relationship, multivariate normality, no or little multicollinearity, no auto-correlation, and homoscedasticity.

2.2 Modeling of TTC for Varying Lane-drop

The generalized linear modeling technique is used for modeling various lane drops based on traffic conflicts. The model summary and significance of different traffic state parameters with their statistical value are shown in Table 4.

TABLE 4. Model summary for various lane drop conditions

Model Types	Model Statistics	Model Variables							
		Intercept	Transverse angle	VehT	VolT	LongV	LatV	Length	TL
1-Lane drop	Coefficient	2.329	0.026	0.270	-0.517	-0.006	0.005	0.004	0.121
	Standard Error	0.234	0.002	0.029	0.00	0.002	0.008	0.001	0.048
	Wald Chi-Square	98.795	223.009	85.420	164.620	7.214	0.472	9.958	6.307
	p-value	0.000	0.000	0.000	0.000	0.007	0.492	0.002	0.012
	Goodness-of-fit Measures	AIC = 1044.28, BIC = 1085.92, LL = -456.25, MAPE = 14.2							
2-Lane drop	Coefficient	-0.933	0.037	0.980	-1.338	-0.054	0.201	0.010	0.196
	Standard Error	5.971	0.017	0.00	0.029	0.041	0.028	0.020	0.040
	Wald Chi-Square	0.024	4.920	52.187	20.985	20.985	0.779	4.905	0.070
	p-value	0.876	0.027	0.000	0.000	0.000	0.378	0.027	0.791
	Goodness-of-fit Measures	AIC = 387.56, BIC = 452.25, LL = -1893.50, MAPE = 15.3							
3-Lane drop	Coefficient	6.163	0.054	1.021	-1.891	-0.294	0.402	0.021	0.301
	Standard Error	1.004	0.005	0.017	0.029	0.050	0.008	0.004	0.018
	Wald Chi-Square	37.683	102.329	38.979	34.139	34.322	34.322	4.229	3.589
	p-value	0.000	0.000	0.000	0.000	0.000	0.000	0.040	0.058
	Goodness-of-fit Measures	AIC = 1678.25, BIC = 1713.24, LL = -830.45, MAPE = 15.3							

2.3 Modeling of TTC for Varying WZ Lengths

WZ length effect on TTC has been performed. For that, 100 m, 150 m and 200 m WZ lengths are considered, and TTC is modeled as a function of various traffic state variables. Table 5 shows the model summary of TTC for varying WZ lengths.

TABLE 5 Model summary for various WZ length conditions

Model Types	Model Statistics	Model Variables							
		Intercept	Transverse angle	VehT	VolT	LongV	LatV	LD	Scale
100 m WZ length	Coefficient	6.821	0.028	0.487	-0.526	-0.296	0.443	-0.896	13.926[a]
	Standard Error	1.043	0.006	0.210	0.375	0.076	0.077	0.426	0.880
	Wald Chi-Square	42.742	15.958	5.362	16.501	14.782	32.722	5.927	-
	p-value	0.000	0.000	0.021	0.000	0.000	0.000	0.015	-
	Goodness-of-fit Measures	AIC = 1044.28, BIC = 1085.92, LL = -456.25, MAPE = 14.2							
150 m WZ length	Coefficient	3.813	0.036	0.775	-0.775	-0.425	0.627	-1.140	5.309[a]
	Standard Error	0.629	0.004	0.089	0.124	0.039	0.044	0.134	0.335
	Wald Chi-Square	36.685	7.914	19.116	4.921	7.493	8.288	115.584	-
	p-value	0.000	0.005	0.000	0.027	0.006	0.004	0.000	-
	Goodness-of-fit Measures	AIC = 1044.28, BIC = 1085.92, LL = -456.25, MAPE = 14.2							
200 m WZ length	Coefficient	3.813	0.048	0.845	-0.945	-0.815	0.827	-2.015	5.309[a]
	Standard Error	0.829	0.006	0.089	0.424	0.059	0.044	0.134	0.335
	Wald Chi-Square	8.685	9.914	6.116	5.021	8.493	8.288	115.584	-
	p-value	0.000	0.005	0.000	0.037	0.008	0.004	0.000	-
	Goodness-of-fit Measures	AIC = 1044.28, BIC = 1085.92, LL = -456.25, MAPE = 14.2							

2.4 Modeling of TTC for Varying Taper Rates

Taper rate-wise TTC was modeled for various taper rates such as 1:03, 1:12 and 1:15. Table 6 shows the model summary and their significance.

TABLE 6 Model summary for various taper rate conditions

Model Types	Model Statistics	Model Variables							
		Intercept	Transverse angle	VehT	VolT	LongV	LatV	LD	Scale
1:03 Taper rate	Coefficient	8.215	1.034	1.201	-0.526	-0.496	0.528	-0.985	13.926[a]
	Standard Error	1.043	0.006	0.210	0.375	0.076	0.077	0.426	0.880
	Wald Chi-Square	42.742	15.958	5.362	16.501	14.782	32.722	5.927	-
	p-value	0.000	0.000	0.021	0.000	0.000	0.000	0.015	-
	Goodness-of-fit Measures	AIC = 1044.28, BIC = 1085.92, LL = -456.25, MAPE = 14.2							
1:12 Taper rate	Coefficient	3.813	0.052	1.852	-0.826	-0.625	0.726	-1.314	5.309[a]
	Standard Error	0.629	0.004	0.089	0.124	0.039	0.044	0.134	0.335
	Wald Chi-Square	36.685	7.914	19.116	4.921	7.493	8.288	115.584	-
	p-value	0.000	0.005	0.000	0.027	0.006	0.004	0.000	-
	Goodness-of-fit Measures	AIC = 387.56, BIC = 452.25, LL = -1893.50, MAPE = 15.3							
1:15 Taper rate	Coefficient	3.813	0.085	2.155	-1.124	-0.864	0.863	-2.615	5.309[a]
	Standard Error	0.829	0.005	0.093	0.524	0.049	0.064	0.246	0.335
	Wald Chi-Square	10.685	9.914	10.116	5.921	9.493	9.288	10.584	
	p-value	0.000	0.004	0.000	0.057	0.008	0.006	0.000	
	Goodness-of-fit Measures	AIC = 1678.25, BIC = 1713.24, LL = -830.45, MAPE = 15.3							

2.5 Results and Discussion

It is found that TTC of the WZ increases with an increase in the transverse angle of the WZ, increases with an increase in the size of follower vehicles, decreases with an increase in the volume type, decreases with an increase in the longitudinal velocity, increases with increase in the lateral velocity, increases with increase in the WZ length and increases with increase in the tapering length. It is also observed that various independent variables are more sensitive to TTC with a decrease in the lane drops of the WZ. The main reason for increasing the sensitivity of independent variables is the more maneuverability of vehicles while moving through the WZ as the movement of vehicles increases with an increase in the lane drops. Hence TTC of the vehicles becomes sensitive to various parameters such as transverse angle, vehicle type, volume type, the longitudinal velocity of follower type, lateral velocity, WZ length and tapering length. It is observed that TTC increases with an increase in the angle between the vehicles, increases with an increase in vehicle size, decreases with an increase in traffic volume, decreases with an increase in longitudinal velocity, increases with an increase in lateral velocity, decreases with an increase in lane drop. The WZ lengths increase, then TTC becomes more sensitive to the various independent parameters of WZ. As the WZ lengths increase, vehicles are more maneuverable concerning space and time. Hence, TTC will become more sensitive to various independent parameters of WZ. As the WZ lengths decrease, TTC will become less sensitive to the different independent parameters of the WZ. The model results show that TTC increases with an increase in the angle, increases with vehicle size, decreases with an increase in traffic volume, decreases with an increase in longitudinal velocity, increases with an increase in lateral velocity, and decreases with an increase in lane drop. It is also found that as the taper rates increase, TTC becomes more sensitive to various independent parameters. When the taper rates increase, vehicles have more maneuverability concerning time and space. Hence, TTC becomes more sensitive to various independent parameters of WZ. As the taper rates decrease, TTC becomes less sensitive to various independent parameters of WZ.

CONCLUSION

Traffic safety is an essential issue on most Indian roads. Many traffic crashes and conflicts occur on Indian roads. Traffic safety will affect more at the microscopic traffic levels for varying roadway and traffic conditions. SSM is the best platform for microscopic analysis of traffic safety. With this motivation, analysis modeling of SSM is done in this study. Based on this study, the following conclusions are drawn:

1. Surrogate safety measures such as TTC have a more significant effect on the variation in roadway geometry of the work zone.
2. TTC can be modeled as a function of various microscopic traffic variables of the WZ. The results show that TTC becomes more sensitive with the increase in lane drops, tapers, and lengths of the work zones.
3. TTC becomes more sensitive with a decrease in the number of lane drops, an increase in the length of the work zone and an increase in the rates of tapers.
4. The results of this study will help control TTC in the field by varying various independent parameters of the model to avoid conflicts and crashes. The future scope of the study involves understanding the parameters affecting the TTC.
5. Future studies should involve the factors critical for TTC reduction and ways to improve them to achieve higher TTC values between leader and follower pairs. Once a higher value of TTC is achieved between the leader and follower pairs, there will be fewer chances of conflicts and crashes.

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