Road Safety Evaluation by Surrogate Safety Parameters for Interurban Corridors

by

Dr. Satbir Singh Puwar

Director Technical

Gawar Construction Ltd

Gurgaon

s.puwar@gawar.in

09560280060

IRF-IC's Lecture Series: 2.0

INTERNATIONAL ROAD FEDERATION INDIA CHAPTER

27th SEPTEMBER, 2024

Contents

Preamble

Road safety is a major concern because of the growing trend of road crashes.

Reasons

- Insufficient existing road network.
- Weak Public Transport System.
- The common man is forced to use his vehicle to meet daily requirements.
- The expansion of road networks, has a negative externality of increasing road crashes and crash fatalities.
- Enforcement Issues.

Need of the Study

Limitations of Reactive Approach (crash data)

- Rare Events
- A small sample size may lead to inconclusive results
- Under Reporting
- Not all crashes are reported and all reported cash are not recorded correctly
- Vulnerable to random variation
- Lack of behavioral and situational aspects of events
- A large sample size.

Motivation of the Study

- Safety analysis with the Surrogate Safety Analysis Method is more efficient and quick.
- Better knowledge of the relationship between the user's behavior and crash risks.
- To characterize the event of crash risk clearly in both average and peak hour flow conditions.
- Surrogate measures of safety play an essential role in determining traffic conflicts and evaluating traffic safety.
- They are helpful in the development of real-time collision avoidance systems and automated driving.

Surrogate Safety Measures?

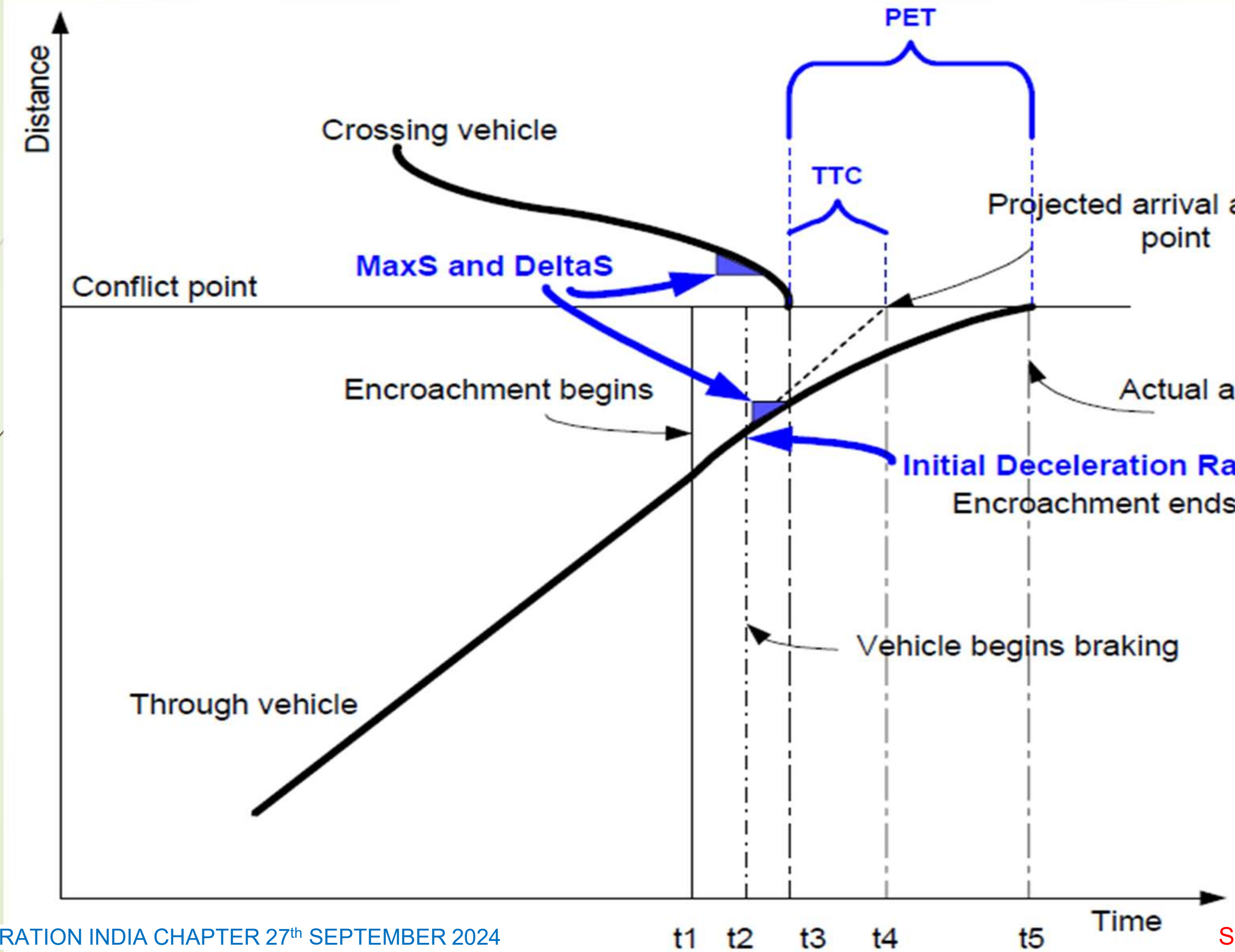
- Surrogate' means 'substitute' or 'replacement'. termed Indirect safety measures

  Using surrogate measures to determine traffic safety means substituting the need for crash data with another factor representing traffic safety.
- The surrogate measures developed are

  based on the identification, classification, and evaluation of traffic conflicts.
- Traffic Conflict

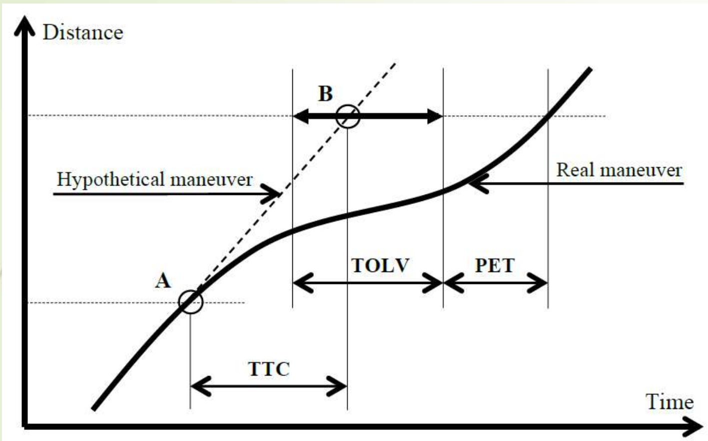
  Traffic conflict is the surrogate measure that can be substituted `with historical crash data

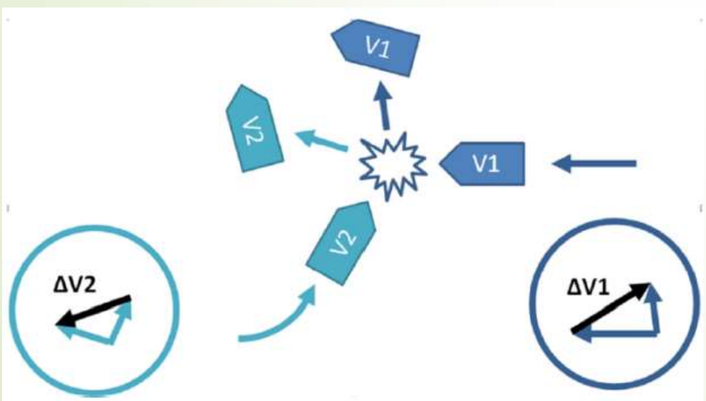
Surrogate Measures on Conflict Point Diagram



Source: FHWA Report

Definition of Surrogate Measures of Safety



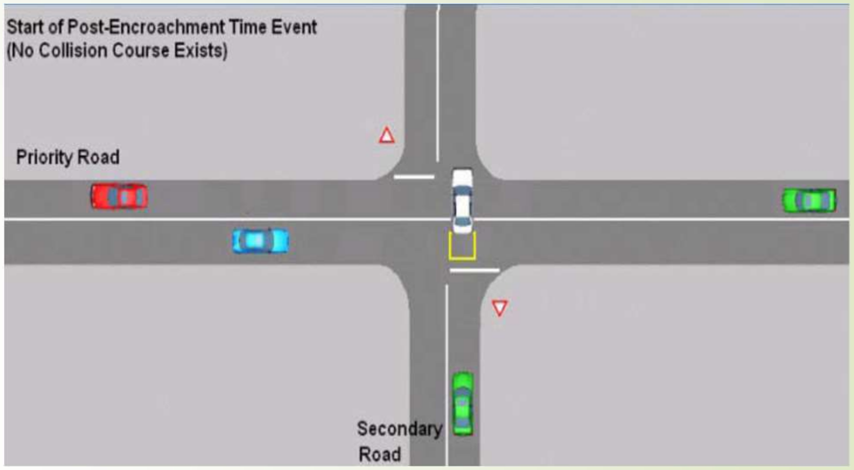


- **Time to Collision:** Time to Collision is defined as the expected time for two vehicles to collide if they remain at their present speed and on the same trajectory (Hayward 1971)

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

Definition of Surrogate Measures of Safety

- **Post-Encroachment Time:** PET is defined as the time between the departure of the encroaching vehicle from the conflict point and the arrival of the vehicle with the right-of-way at the conflict point. (FHWA Report) or Post Encroachment time is usually defined as the time between when the first vehicle last occupied a position and the time the second vehicle subsequently arrived at the same position (Hellen et al. 1978).



Definition of Surrogate Measures of Safety

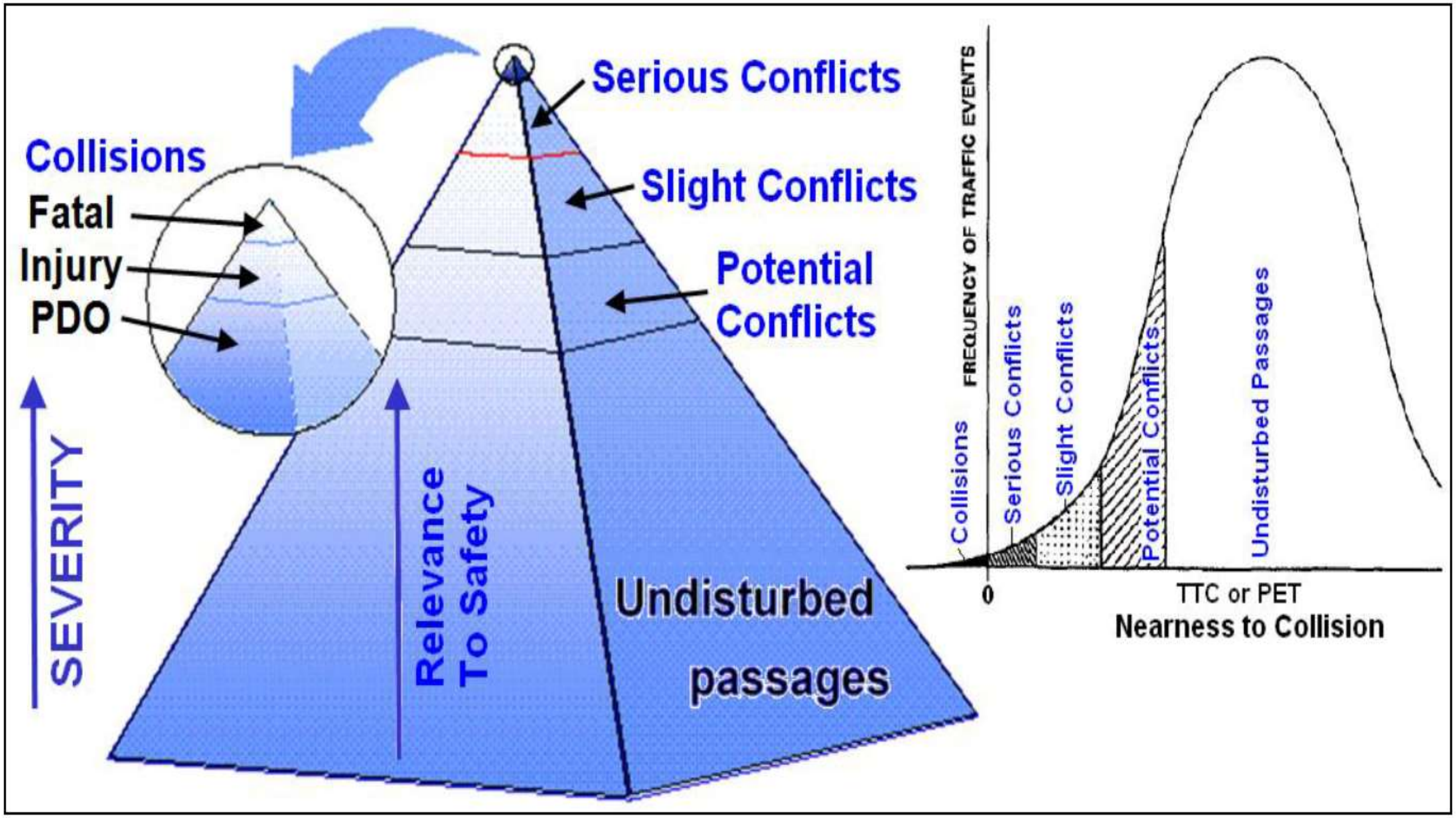
- **Max S:** Max S is defined for each vehicle as the maximum speed of the vehicle between the times t1 and t5. Then the maximum of those two maximum values for each vehicle is recorded as the Max S value for the conflict point event.
- **Delta V (ΔV):** Delta V is first defined for each time slice (from the beginning to the end of the conflict event) as the difference between the velocities of the two conflicting vehicles. Then the maximum of those Delta V values for each time slice would be recorded as the Delta V value.

Definition of Surrogate Measures of Safety

Initial Deceleration Rate:

Deceleration is the evasive action taken by the subject vehicle to avoid the collision. The initial DR would be a useful measure to indicate the potential severity of the conflict event.

Pyramid of Traffic Events



Source: Hyden C, (1987)

Objectives of the Study

- Identify the surrogate safety measures, and evaluate how they affect the crash and the intensity of the crash.
- Develop a methodology for measuring surrogate safety measures.
- Determination of probable locations of crash occurrence on the study corridor using surrogate safety measures.
- Microsimulation is applied to extract surrogate safety measures and develop surrogate safety assessment models (SSAM).

Scope

- The scope is limited to the study of
  - Road-related surrogate safety parameters,
  - The identified surrogate safety measures and driver behavior parameters are extracted Through microsimulation by calibration and validation of the microsimulation models using actual field data.
- The study focuses on an interurban four-lane divided carriageway corridor which covers the analysis of mid-blocks & Curves.

Selection of Study Area

The road section selected is a typical interurban highway located in the National Capital Region *(NCR)* catering to traffic from Faridabad to Gurgaon and vice versa. It is a toll road, DPR for widening to four lanes was prepared, and the concessionaire is also collecting traffic data regularly. The peak and off-peak hours are identified from secondary data such as DPR, and traffic data at Toll Plaza for midblocks, Curves, and Intersections.

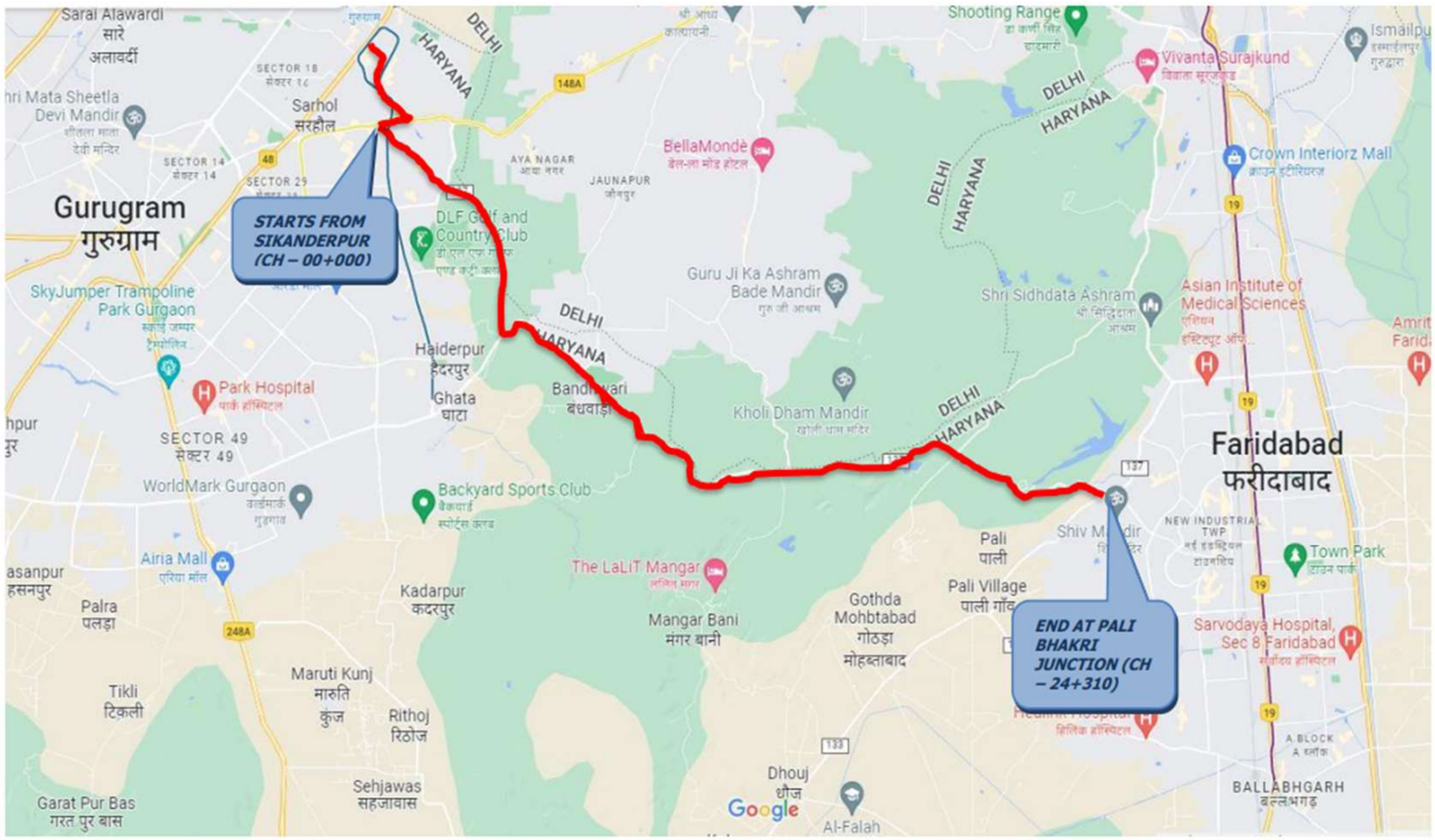
For the Present study traffic volume and speed data were collected at the Midblock, Curve, and Intersection during the peak hours and the same was used for analysis.

Study Corridor: Gurgaon - Faridabad Road:

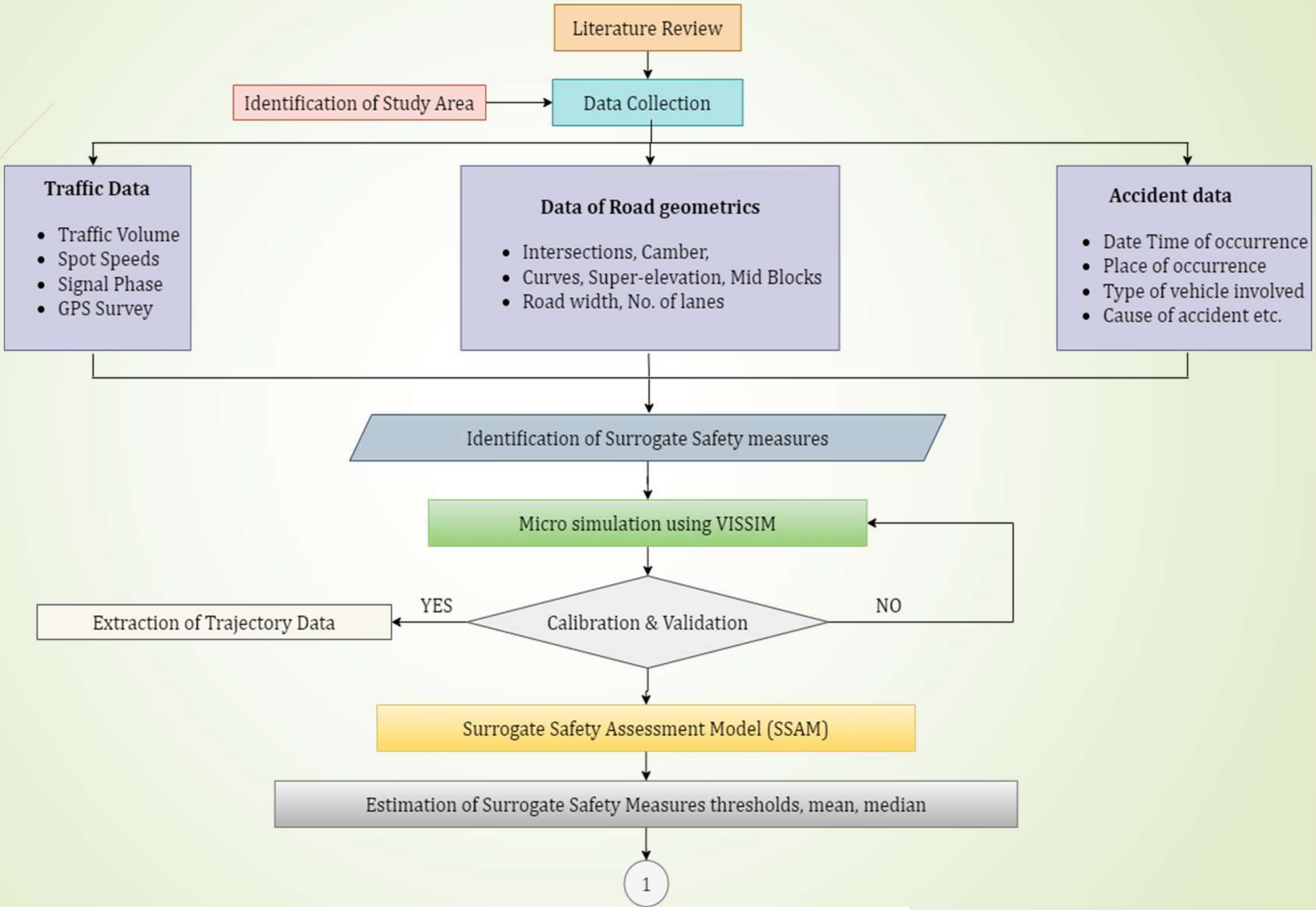
KEY MAP OF GURGAON-FARIDABAD ROAD

TOTAL LENGTH OF GF – 24.310 kms.

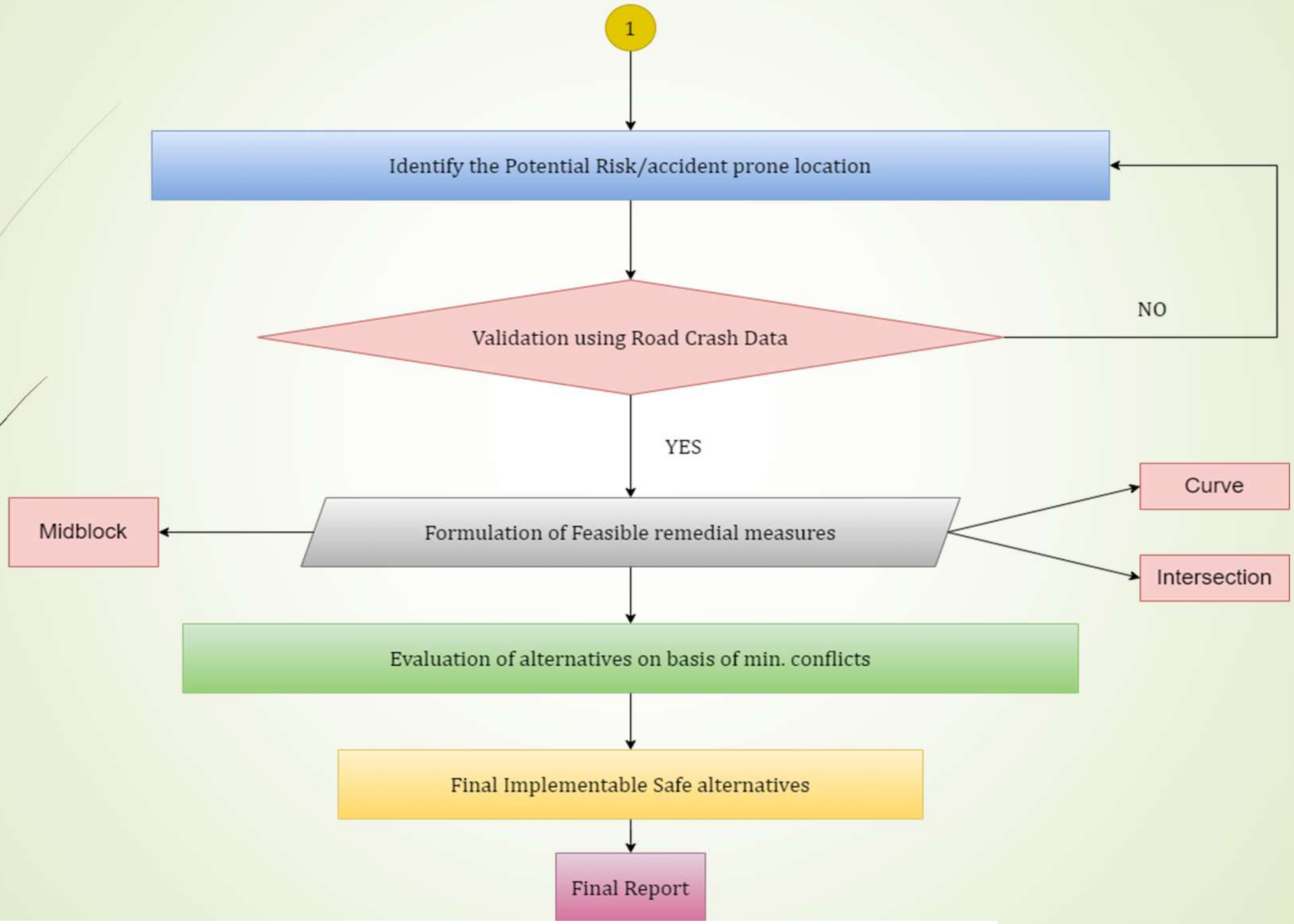
STARTS FROM SIKANDERPUR (CH – 00+000) AND END AT PALI BHAKRI JUNCTION (CH – 24+310)



Methodology



Methodology



Data Collection and Analysis

- **Secondary Data**

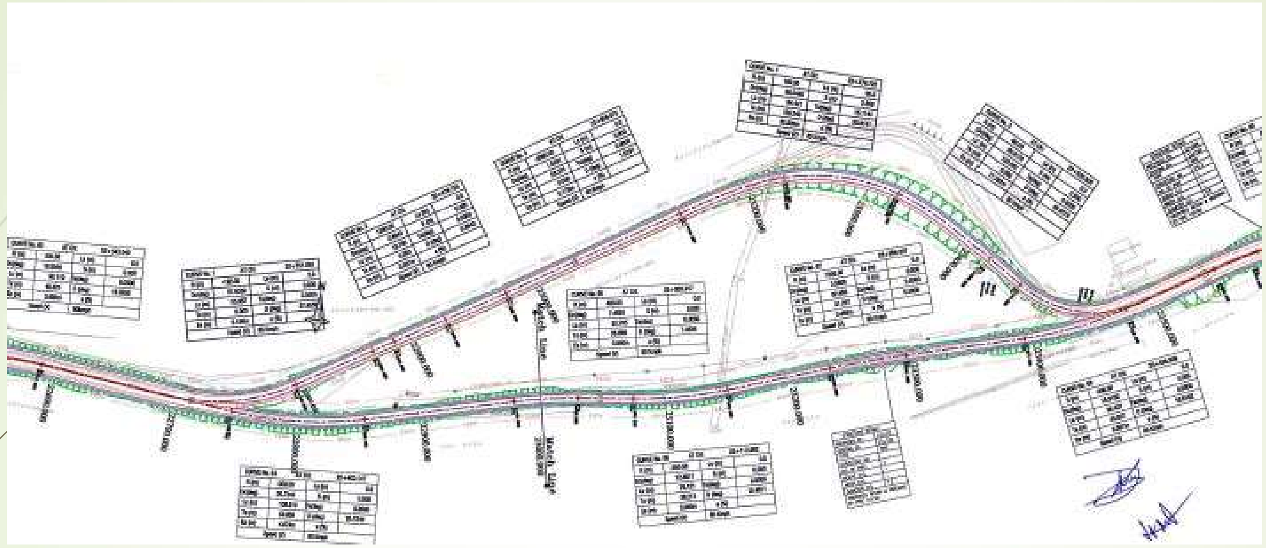
  - **DPR of the Study road Containing Typical Cross Sections, Plan Profile, and Traffic Data.**
  - **As-Built drawings**
  - **Crash Data Extraction from Accident reports**

    a) FIRs From Police Stations: 2008 to 2014.

    b) Based on Concessionaire Reports of Crashes from 2014 to 2023

- **Primary Data**
  - **Classified Traffic Volume Survey by Video recording**
  - **Spot Speeds by Radar Speed gun**
  - **Signal Phase and Timings Manually**

Typical Defective Geometric Alignment



LHS Carriageway of road passes through a very steep curve between km 23.200 to Km 23.450, where the radius of the curve is only 90 m and the length of the circular curve 104 m, with no transition length, combined with a steep vertical profile of 3.3 % falling gradient moving speeding vehicles very dangerously. In addition to the above, the sight distance is also restricted by a temple on LHS.

As per the requirement of IRC 73 for a design speed of 50 KMPH for a 90 m minimum radius of the curve, a 75 m transition length on both ends of the circular curve is required and an intermediate sight distance of 120 m is required which is not available making this location as crash-prone.

Microsimulation

- Microsimulation is a category of computerized analytical tools that perform highly detailed analyses of activities such as highway traffic flowing through an intersection/road facility.
- The software used to model the network in this study is VISSIM 7.0. VISSIM is a microscopic multi-modal traffic flow simulation software
- The VISSIM simulation model has been validated against data from various real-world situations. Vissim performs the following functions.

i) Development of multimodal networks.

ii) Realistic modeling of lane geometry and network element positions at any level of detail.

iii) Traffic Analysis.

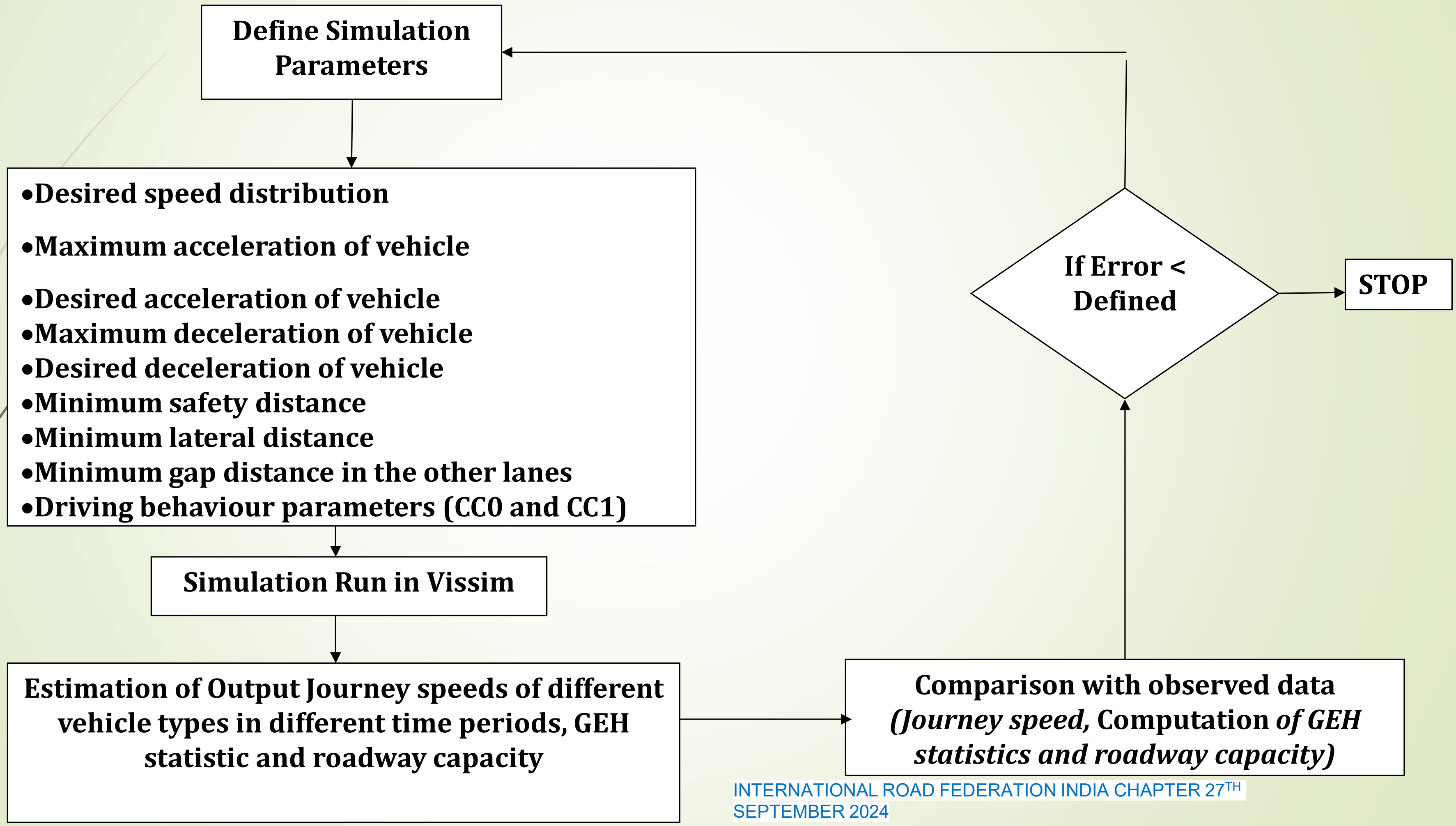
iv) Static signal optimization.

v) 2D/3D representation of the network.

Setting Network in VISSIM & Data Input

- The entire stretch from Gurgaon to Faridabad corridor is represented in VISSIM.
- Initially in VISSIM road configuration has been set up as a background image from the as-built drawings.
- Vehicle input is given as recorded from the site as the primary source data.
- Vehicle routes are given from Gurgaon to Faridabad and Vice Versa.
- Simulation is run by default inbuilt parameters.
- Calibration of the VISSIM carried out by changing input parameters

Calibration



Validation

- **GEH formula** Geoffrey E. Havers developed this formula in London, England in the 1970s. It is like a chi-squared test and an empirical formula that has proven useful for a variety of traffic analysis purposes.
- For hourly traffic flows, the GEH formula is:

$$GEH = \sqrt{\frac{2(m-c)^2}{m+c}}$$

Where:

'm' is the value from the traffic model (per hour)

'c' is the real-world traffic value (per hour)

- After calibration and validation, extract trajectory files.

Validation

Midblock Name	Simulated volume *(ALL)*	Simulated speed *(in KMPH)*	Actual Volume	Actual Speed *(in KMPH)*	GEH statistics	% age Error in speed
M1 @ KM3.00 - 3.30	1979	46.86	1999	43.99	0.45	6.5
M2@ KM3.40 - 3.90	2048	47.36	1999	43.99	1.09	7.7
M3@ KM 4.50 - 4.90	2008	46.97	1999	43.99	0.20	6.8
M4@ KM 5.10 - 5.60	3462	43.43	3565	47.54	1.74	8.6
M5 @ KM 11.0 -11.40	1398	59.89	1477	57.33	2.08	4.5
M6 @ KM 14.30 -14.70	1485	59.55	1477	57.33	0.21	3.9
M7 @ KM 16.450 -16.95	1717	45.83	1719	42.68	0.05	7.4
M8@ KM 18.250 - 18.830	1693	45.14	1719	42.68	0.63	5.7
M9@ KM 18.85 -19.44	1690	44.50	1719	42.68	0.70	4.2
M10 @ KM 23.80 - 24.20	1086	41.39	1064	45.07	0.67	8.2

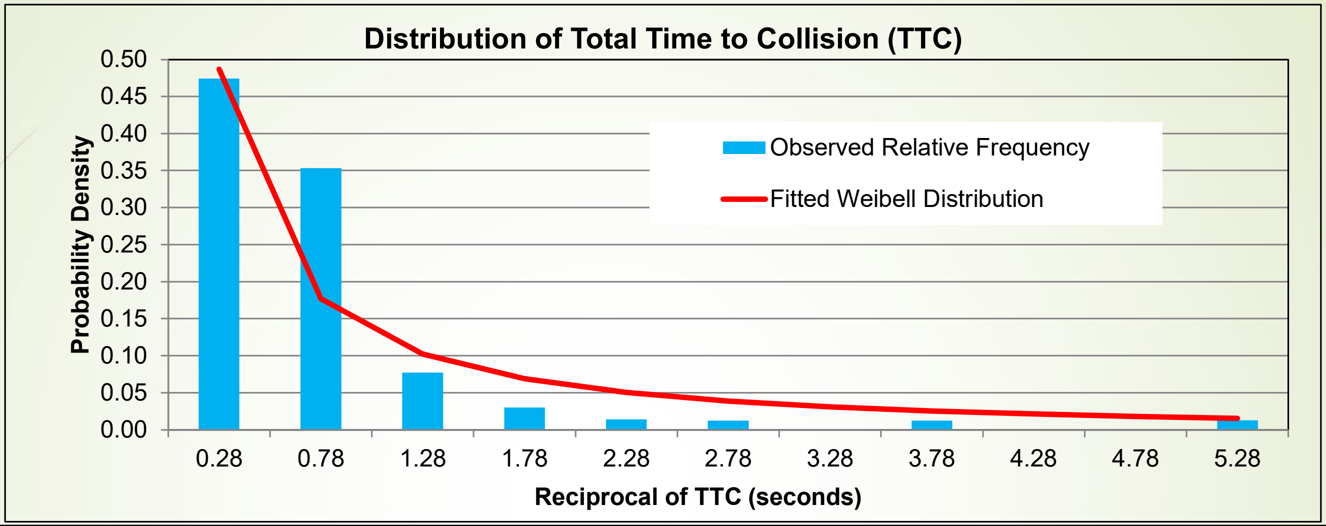
Surrogate Safety Assessment Model

- It is a software application that reads trajectory files generated by microscopic simulation programs and calculates surrogate measures of safety.
- This approach eliminates the subjectivity associated with the conventional conflict analysis technique and allows assessment of the safety of a road facility under a controlled environment before a road crash occurs.
- The surrogate safety parameters such as TTC, PET, DR, Max S, and Delta V are computed for each of the locations.

Analysis of Road Safety on Midblocks

- Vehicle trajectory data is built for each of the midblock sections based on the microscopic simulation through VISSIM.
- For an operating speed of 80 kmph on the corridor, the safe Stopping Sight Distance *(SSD)* is 120 m, which implies that the time headway of 5.4 seconds says 5 seconds. Therefore, a maximum TTC threshold of 5 seconds is adopted for TTC
- The range of the maximum PET threshold is limited by SSAM with a maximum allowed value of 9.95 seconds.
- Calibrated & validated vehicle trajectory files are imported to SSAM to drive the surrogate safety measures The surrogate safety parameters such as TTC, PET, DR, Max S, and Delta V are computed for each of the locations separately

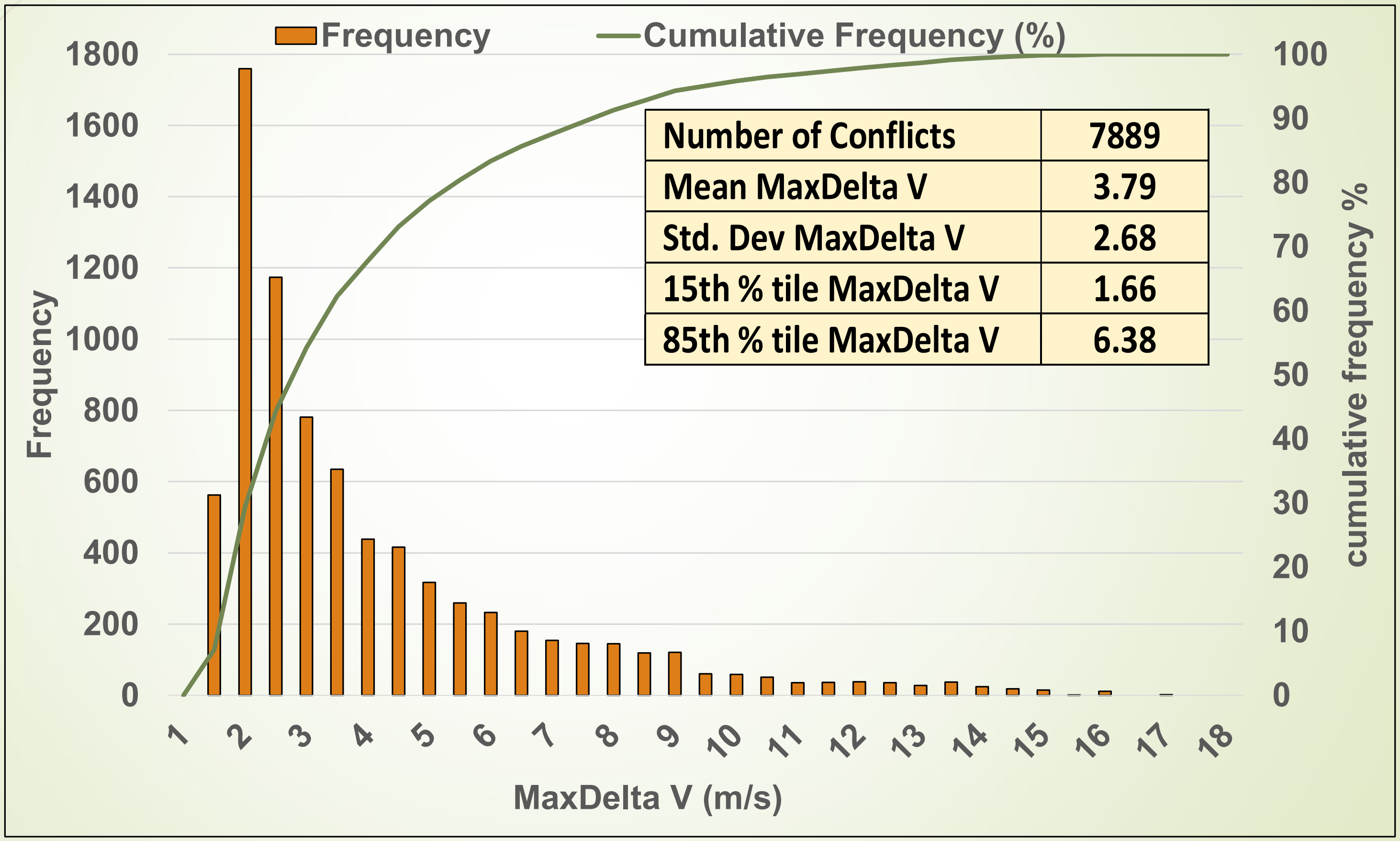
Analysis on Midblock Based on TTC



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

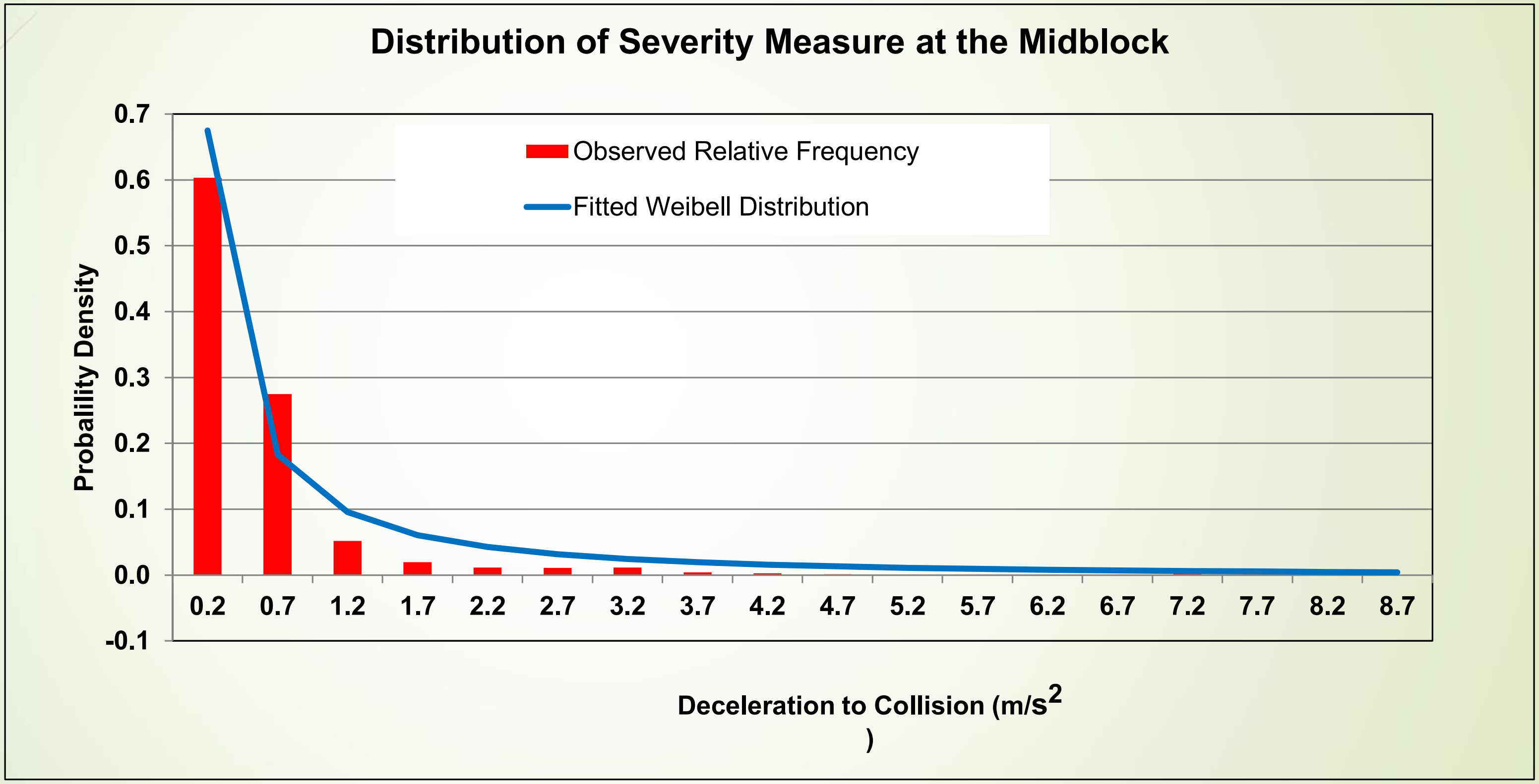
Analysis On Midblock Based Max ΔV

MaxDelta V frequency distribution on Midblock

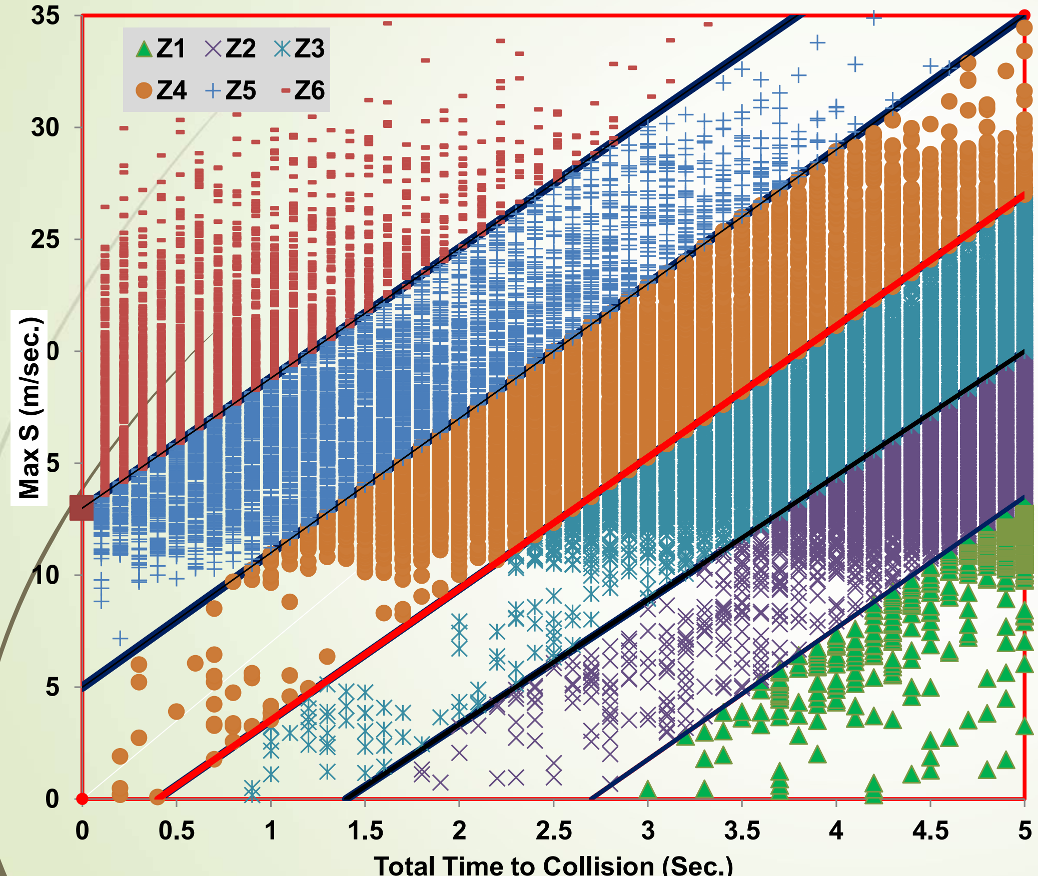


Number of Conflicts	7889
Mean MaxDelta V	3.79
Std. Dev MaxDelta V	2.68
15th % tile MaxDelta V	1.66
85th % tile MaxDelta V	6.38

Analysis on Midblock Based on DR



Severity Analysis on Midblocks Based on TTC V/S Max S



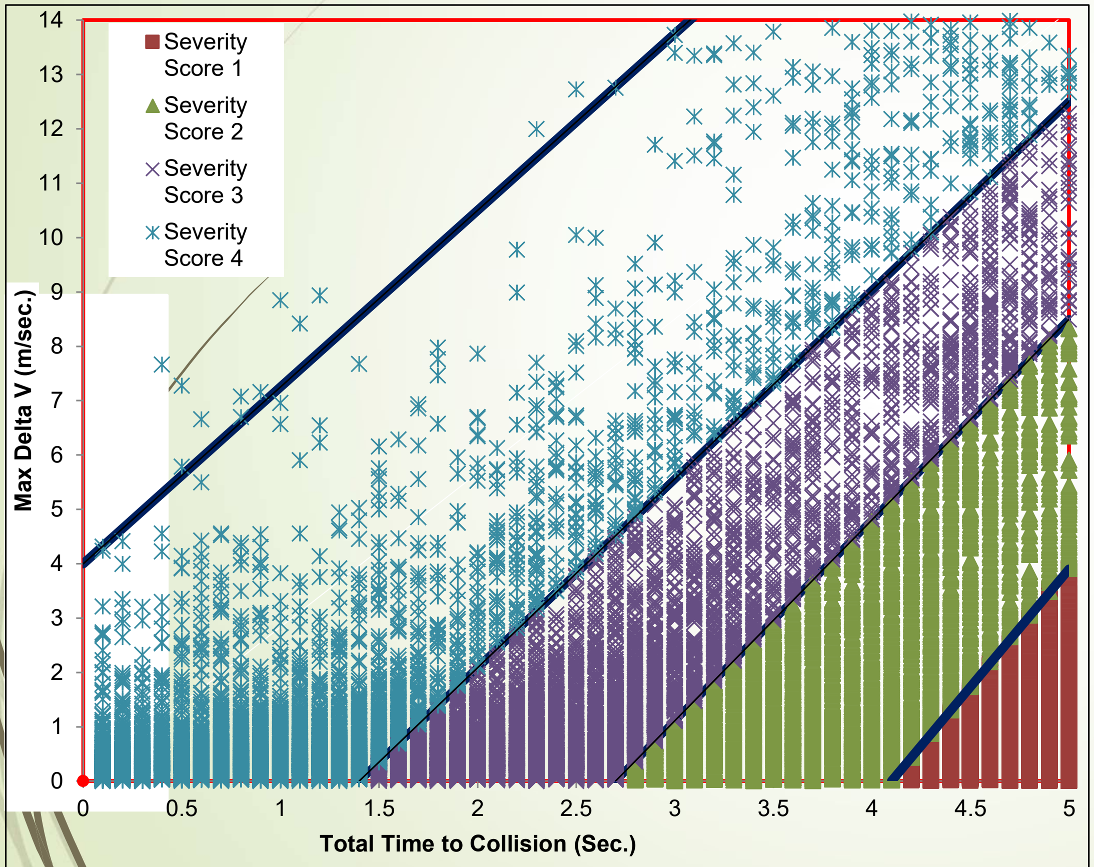
MaxS versus TTC conflict severity zone

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

Severity Score by Max ΔV V/S TTC

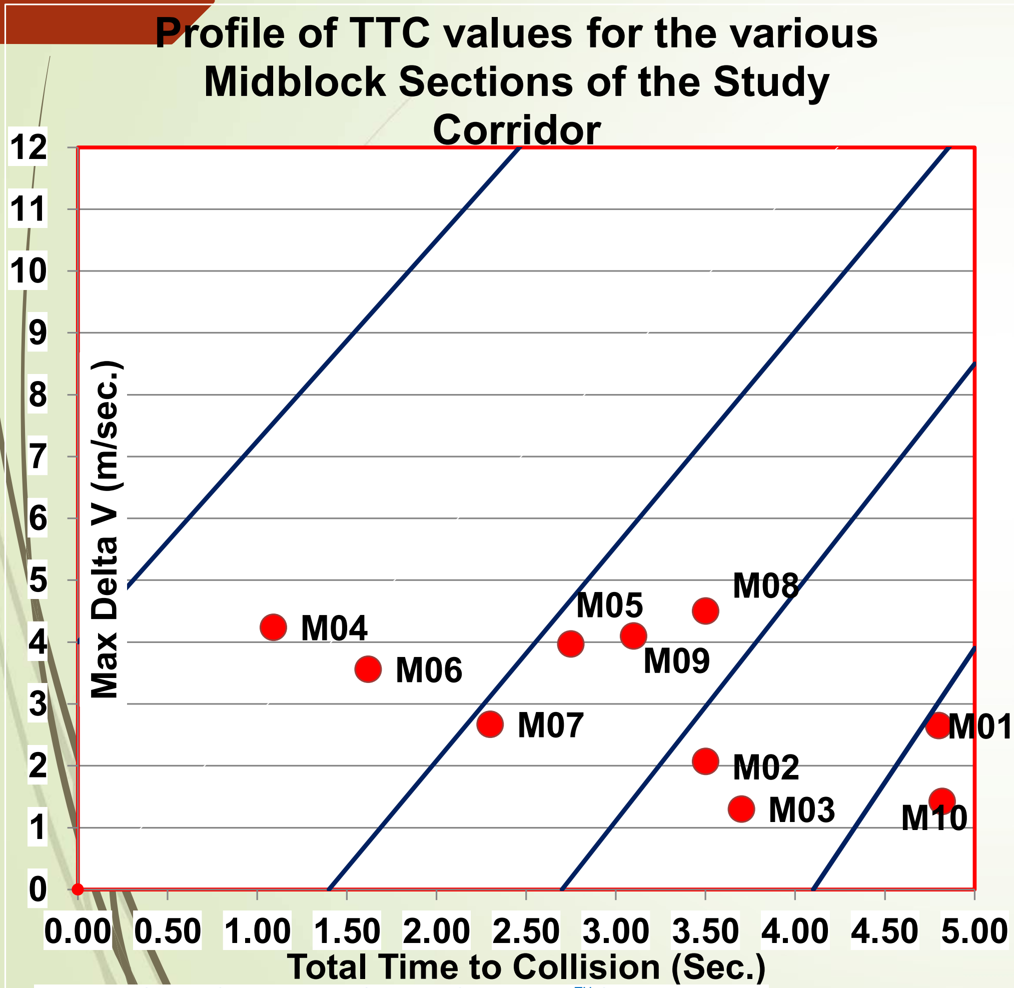
Delta V versus TTC conflict zones



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

Crash Potential V/S Crash History on Midblocks



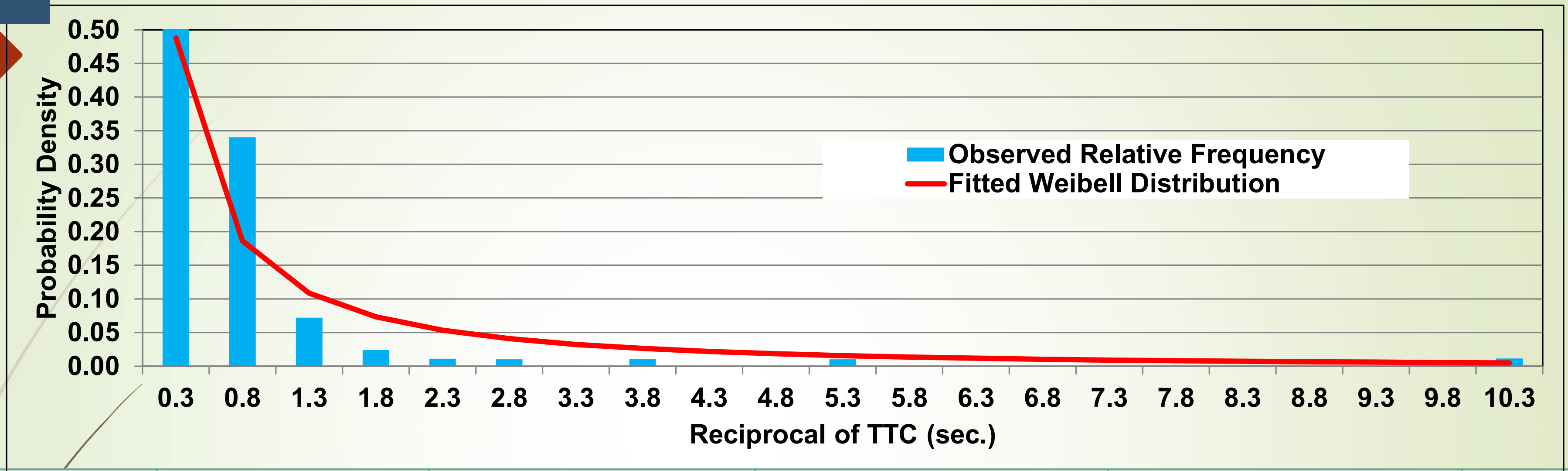
Number and Severity Type of Road Crashes from 2015 to 2021 on the Midblocks

S.No.	Section No.	Number of Fatal Crashes	Number of Grievous Crashes	Number of Minor Crashes	Number of Non-injury Crashes
1	M-1	1	3	2	4
2	M-2	2	2	9	3
3	M-3	1	1	2	2
4	M-4	5	8	5	14
5	M-5	1	18	26	19
6	M-6	7	8	9	5
7	M-7	4	13	13	14
8	M-8	2	23	23	10
9	M-9	0	4	0	1
10	M-10	0	2	3	3

Conclusion for Midblocks

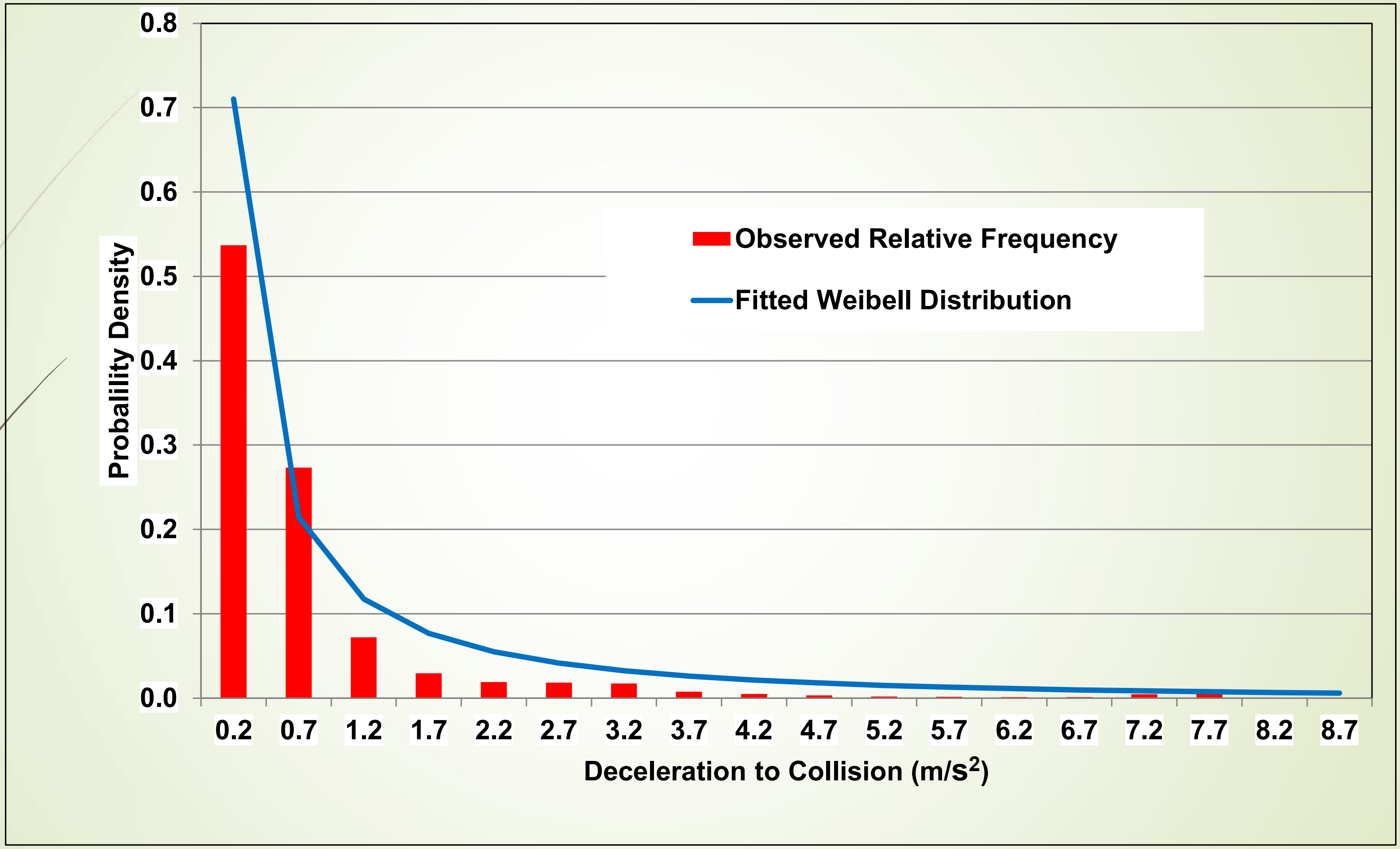
- The study on midblocks revealed that TTC and DR follow the Weibull distribution.
- The critical TTC on interurban midblock sections catering to heterogeneous traffic movement is 1.4 seconds, means that any conflict occurring less than this time would invariably lead to a fatal crash.
- The critical deceleration rate is observed as 0.406 m/s^2, implying that any conflict with more than this value will lead to a fatal crash under traffic heterogeneity.
- Further, the Delta V values deduced for the study corridor on interurban midblock sections catering to heterogeneous traffic movement is 3.79 m/s, & conflict more than this value can turn into a potential crash.
- The above-referred safety parameter values are validated with the crash data collected on the study corridor over seven years from 2015 to 2021.

Analysis of Road Safety on Curves by TTC



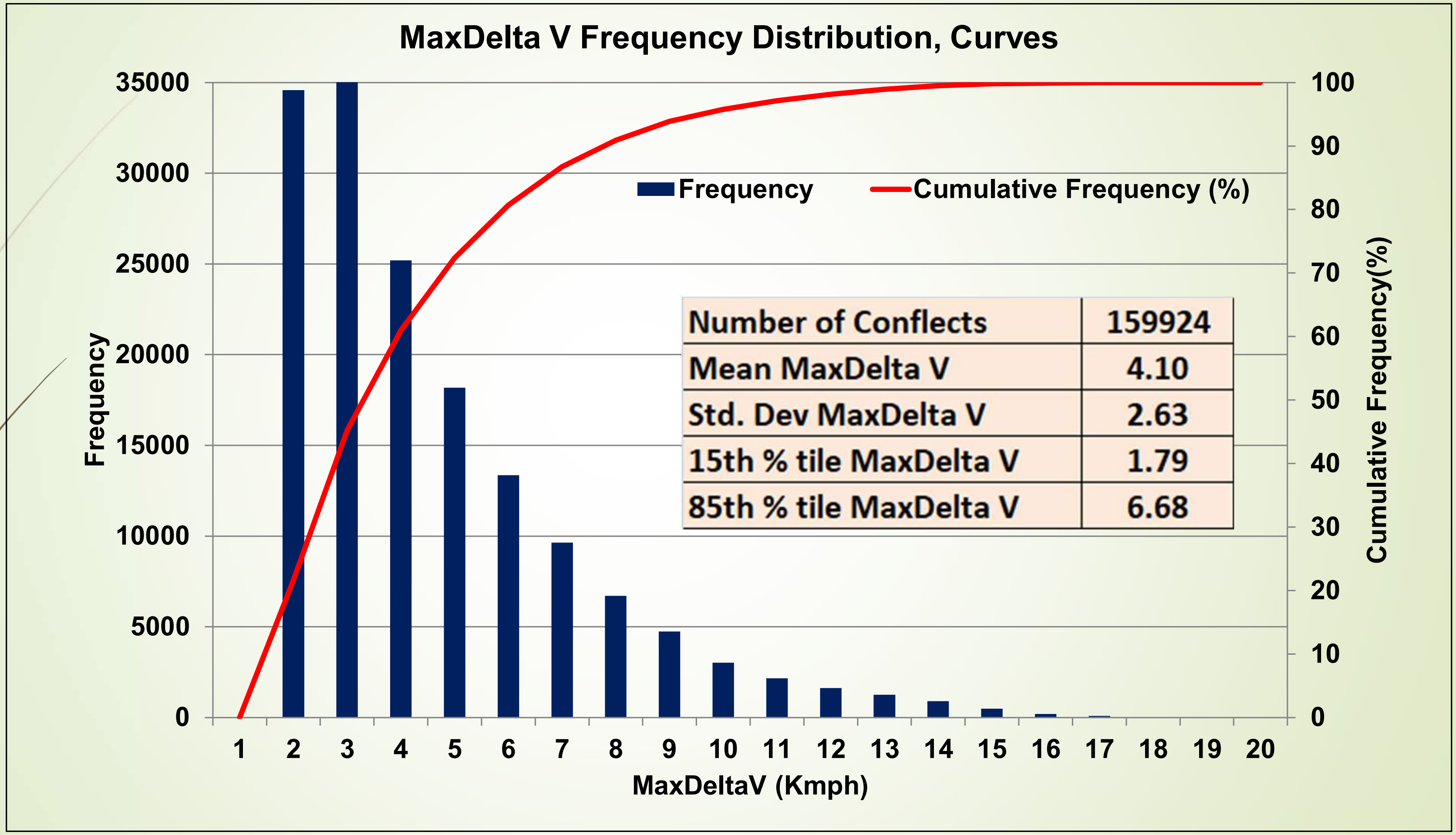
Limit	Frequency	Observed Relative Frequency	Fitted Weibull Distribution	Cumulative dist. Function CDF(1)	Cumulative dist. function CDF(2)	D-statistic
0.3	162960	0.51	0.49	0.51	0.54	0.03
0.8	108699	0.34	0.19	0.85	0.69	0.16
1.3	23067	0.07	0.11	0.92	0.76	0.17
1.8	7689	0.02	0.07	0.95	0.80	0.15
2.3	3520	0.01	0.05	0.96	0.83	0.12
2.8	3272	0.01	0.04	0.97	0.86	0.11
3.3	0	0.00	0.03	0.97	0.87	0.09
3.8	3364	0.01	0.03	0.98	0.89	0.09
4.3	0	0.00	0.02	0.98	0.90	0.08
4.8	0	0.00	0.02	0.98	0.91	0.07
5.3	3307	0.01	0.02	0.99	0.92	0.07
5.8	0	0.00	0.01	0.99	0.93	0.06

Analysis of Road Safety on Curves by DR



Probability Distribution of DR for Curve Sections

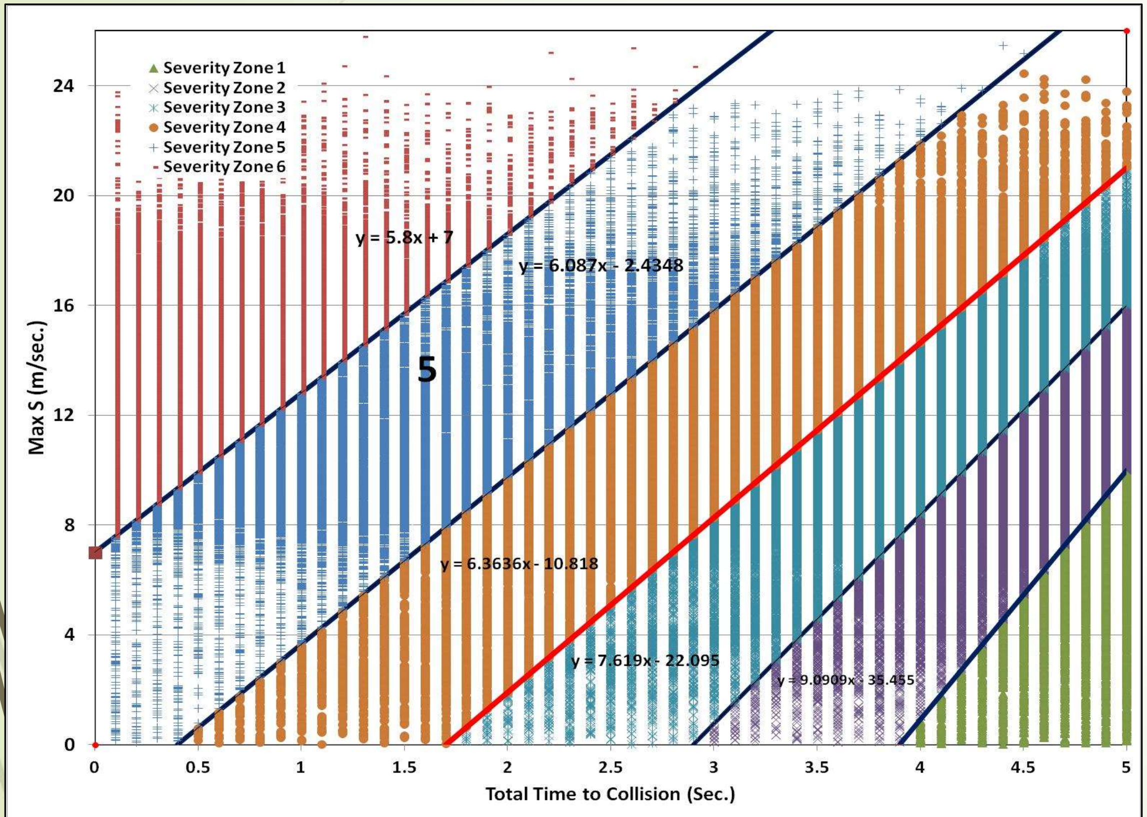
Analysis of Road Safety on Curves by ΔV



Number of Conflects	159924
Mean MaxDelta V	4.10
Std. Dev MaxDelta V	2.63
15th % tile MaxDelta V	1.79
85th % tile MaxDelta V	6.68

Max Delta V frequency distribution plots for Curves

Analysis of Severity Score by Max S V/S TTC & Severity Zones Based on TTC on Curves



MaxS Versus TTC Conflict Severity Zones Plot

Severity Zone	Criteria (TTC)	Criteria Max S	Number of Curve Sections (in %)
1	3.9	10	4.88
2	2.9	16	22.55
3	1.6	23	21.84
4	0.2	30	21.66
5	0	36	20.96
6	0	>36	8.11

Number of Severity Zones based on TTC

Assigned Severity Score Based on TTC for Curves

TTC Values ROC Score	TTC Range (Seconds)	Number of Curve Sections (in %)	Collision Propensity Level
1	TTC > 4.3	27.93	Low
2	3.10 < TTC ≤ 4.3	27.32	Moderate
3	1.60 < TTC ≤ 3.10	24.32	High
4	TTC ≤ 1.60	20.43	Extreme

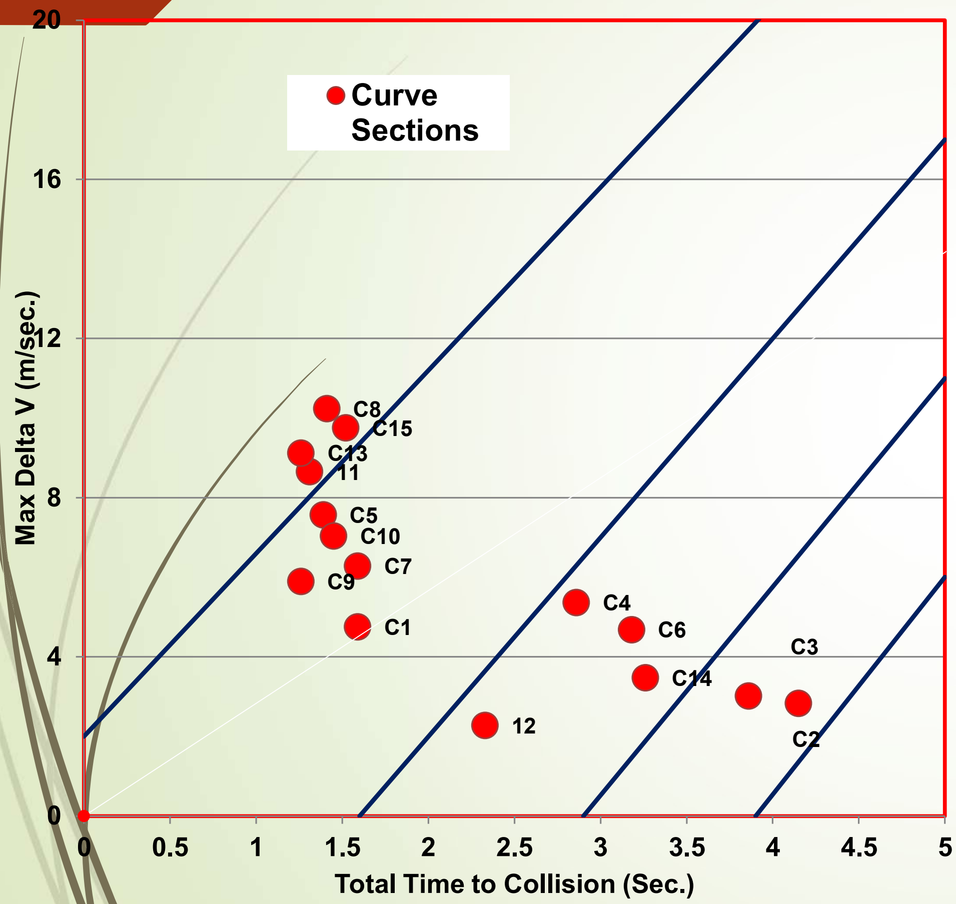
Assigned ROC Scores based on TTC scores

Assigned Severity Score Based on Max. Delta V

Max Delta V ROC Score	Max ΔV Range (m/sec)	Number of Curve Sections (in %)	Collision Propensity Level	Number of Conflicts	Percentage of Conflicts
1	Max ΔV < = 4.13	88465 (62.26)	Low	88465	62.26
2	4.13 < Max ΔV >= 6.72	32299 (22.73)	Moderate	32299	22.73
3	6.72 < Max ΔV >= 10	15277 (10.75)	High	15277	10.75
4	Max ΔV > 10	6057 (4.26)	Extreme	6057	4.26

Assigned ROC based on Max ΔV

Crash Potential V/S Crash History on Curves



Individual Curve Sections in Developed Crash Severity Zone

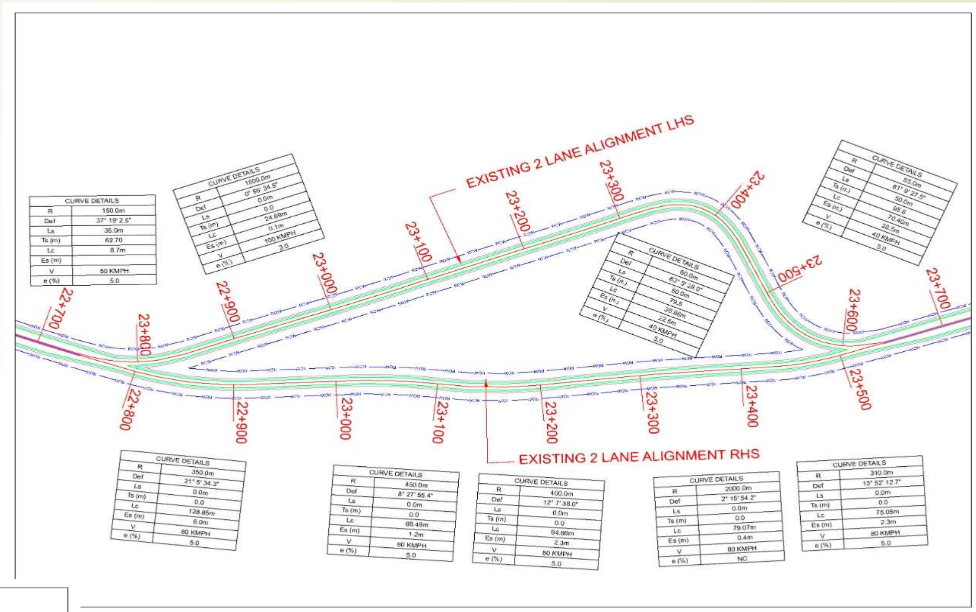
S.No.	Section No.	Number of Fatal Crashes	Number of Grievous Injury Crashes	Number of Minor Crashes	Number of Non-injury Crashes
1	C 1	2	3	14	10
2	C 2	2	1	1	4
3	C 3	0	3	8	2
4	C 4	1	19	7	11
5	C 5	5	34	52	59
6	C 6	0	6	2	13
7	C 7	3	36	64	21
8	C 8	7	71	102	57
9	C 9	2	33	58	31
10	C 10	2	33	47	17
11	C 11	3	30	31	10
12	C 12	5	27	21	7
13	C 13	6	49	39	26
14	C 14	0	7	6	1
15	C 15	10	38	26	38

Number and Severity of Road Crashes from 2015 to 2021 on the Curve Sections

Conclusion for Curve Sections

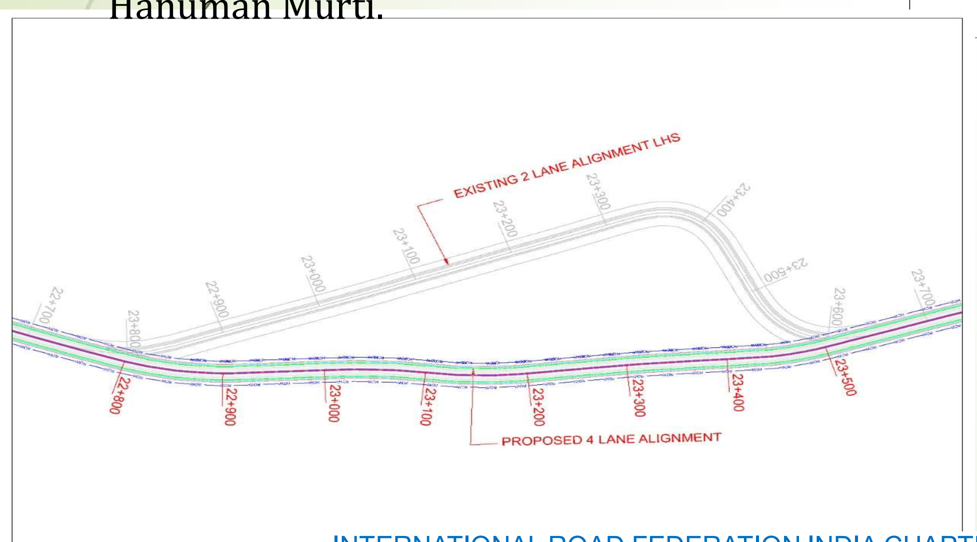
- The study found that TTC and DR follow the Weibull distribution.
- The critical TTC on interurban curve sections catering to heterogeneous traffic movement is 1.6 seconds, meaning any conflict occurring less than this time would invariably lead to a fatal crash.
- The critical deceleration rate on curve sections is observed as 0.569 m/s^{2}, implying that any conflict with more than this value will lead to a fatal crash under traffic heterogeneity.
- Further, the Delta V values deduced for the study corridor on interurban curve sections catering to heterogeneous traffic movement is 4.1 m/s. Again, any conflict more than this value can turn into a potential crash.
- The above-referred surrogate safety parameter values are validated with the crash data collected on the study corridor over seven years. The methodology deduced in this study can be employed to identify potential crash-prone locations, intensity, and severity on the curve locations.

Improvement of Alignment



Alignment Improvement by providing LHS carriageway alongside RHS Carriageway from km 22.800 to 23.500 Hanuman Murti.

The existing alignment from km 22.800 to Km 23+600 has deficient curves and a steep gradient at Hanuman Murti



Limitations and Future Course of Research

- Limitations

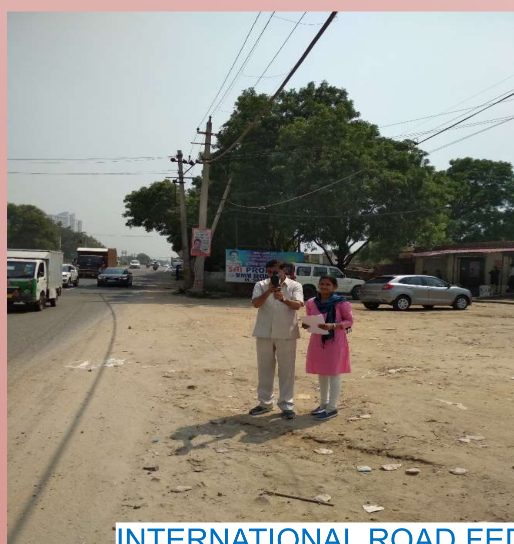
Though the present study has successfully developed the surrogate safety measures on the interurban corridor and has suggested the probable crash locations of midblock and curves on a typical interurban corridor, this study has not considered variables like axle configuration, or turning radius. Further, the road pavement's environment and quality have also not been considered in the analysis, which may influence the accuracy of the results. From the analysis of trajectory files in SSAM, the number of conflicts and their type are only determined, which is only a proxy of the crashes.

- Future Research

To address the above issues, future studies can be conducted by considering missed variables like axle configuration, turning radius, the environment, and road pavement quality. Further, the crashes derived from the analysis should be compared with the actual crashes to validate the study.

INDIA CHAPTER

T



IRF
INDIA CHAPTER

Thank You!