INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

Evaluation of Safety Performance of Road Infrastructure by Surrogate Measures

International Road Federation
अंतरराष्ट्रीय सड़क संघ
INDIA CHAPTER

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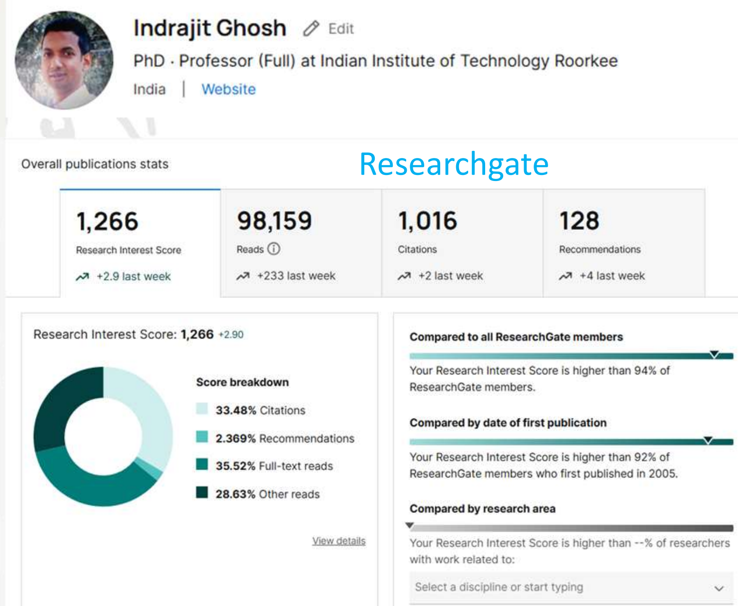
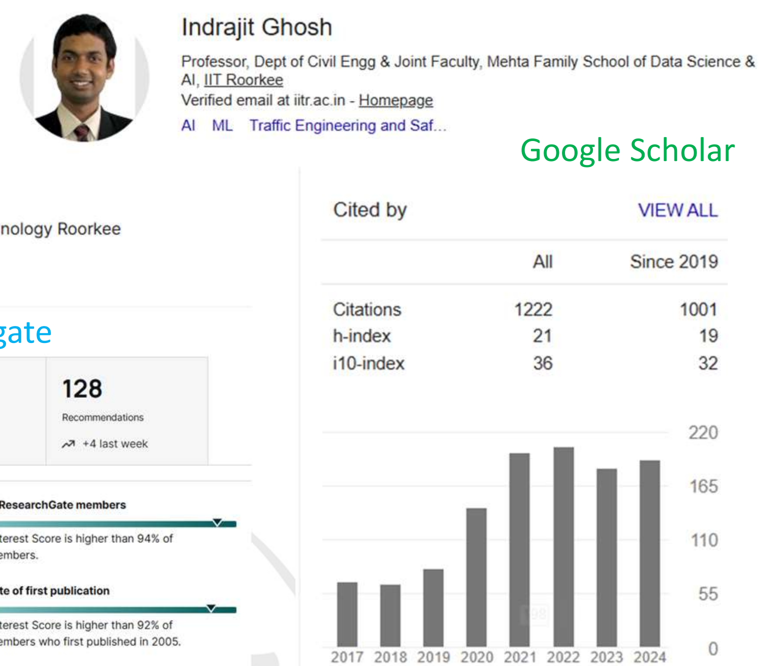
Public Profiles





Academic Qualifications

- **B.E. in Civil Engineering - 2003**
  - ✓ Indian Institute of Engineering Science and Technology (IIEST), Shibpur, West Bengal
  - ✓ Cleared GATE 2003 (All India Rank 566)
- **M.E. in Civil Engineering (Spl: Highway and Traffic Engineering) - 2005**
  - ✓ Indian Institute of Engineering Science and Technology (IIEST), Shibpur, West Bengal
- **M.Sc. in Civil Engineering (Spl.: Transportation Engineering) - 2008**
  - ✓ Wayne State University, Detroit, Michigan, USA
- **Ph.D. in Civil Engineering (Spl.: Transportation Engineering) - 2010**
  - ✓ Wayne State University, Detroit, Michigan, USA
- **Post-Doc @IIT Madras - 2011**

JOINED IIT Roorkee in July 2012

Recognition from Professional Bodies/Awards

- **DUO-India Fellowship (Professor)** 2020 to serve as **Academic Visitor** at **Newcastle University, United Kingdom** in 2022) – MHRD & ASEM DUO
- **International Standing Committee Member**, Traffic Control Devices Committee (ACP55), Transportation Research Board (TRB), **National Academies**, Washington D.C., USA; 2019 - To date
- **Member**, H-7 Committee: Road Safety and Design, **Indian Roads Congress** (IRC); 2021 - To date
- **Chairperson,** TCT-101 Committee: Other transportation modes (including NMT) and pedestrian, **Transportation Research Group (TRG) of India;** 2022 – To date
- **Outstanding Teacher Award @IIT Roorkee 2021**
- **Editorial Board Member**, **Journal of Advanced Transportation**, Wiley, United Kingdom; 2020 - To date
- **Education-Scholarship Award** from **Institute of Transportation Engineer (ITE),** USA; 2008
- **Solo recipient** of **Thomas C Rumble Fellowship** ($52,000/annum) during PhD; 2007

Background

- Road safety evaluation methodology can be broadly classified into two sub-groups:

- Traditional Crash Data Analysis → Historical Crash Data →
  - Long observation period
  - Non-reliability
  - Small sample size of data
  - Under reporting
  - Fails to assess driving behaviour and state at a particular instant

- Surrogate Safety Measures → Proxies assessing risk of unsafe conditions →
  - **DOES NOT** rely solely on actual crash data
  - **Proactive** approach towards safety assessment
  - Availability of a **larger dataset** for evaluation
  - Successfully depicts **temporal and spatial proximity** characteristics of near-crash situations

Surrogate Safety Measures

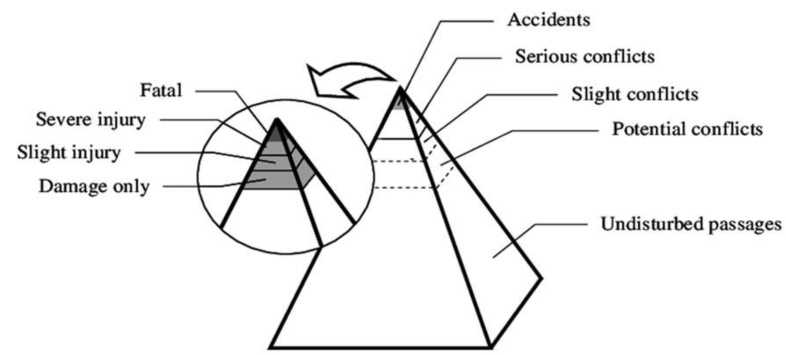
Surrogate Safety Measures

FHWA (1989)

an event that is proximate to and usually preceding an accident

- Volume
- Speed
- Accepted gap
- Headways
- Deceleration
- .
- .
- .
- **Conflicts (General Motors, 1967)**

A **traffic conflict** is a situation in road traffic where two or more road users (such as vehicles, pedestrians, or cyclists) approach each other in such a way that there is a **risk of a collision** if their movements continue **unchanged**.



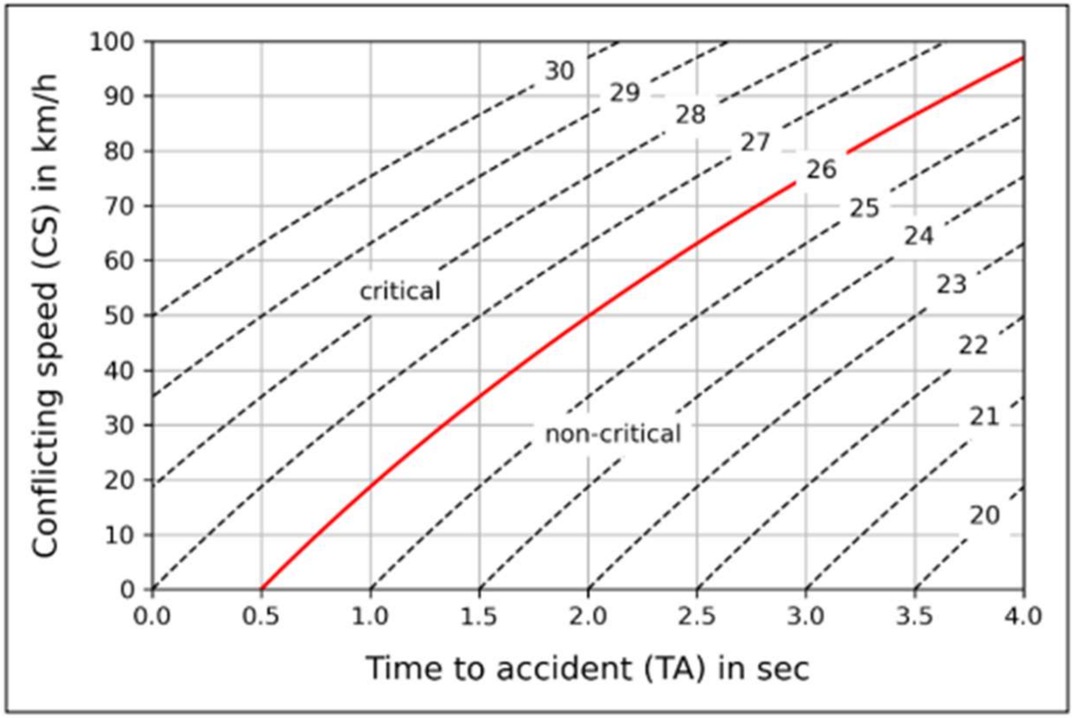
Pyramid of Traffic Events (Hyden, 1987)

Conflict Indicators

- Time-to-Collision (TTC)
- Time Exposed Time-to-Collision (TET)
- Time Integrated Time-to-Collision (TIT)
- Time-to-Accident (TTA)
- Time-to-Zebra (TTZ)
- Post Encroachment Time (PET)
- Gap Time (GT)
- Encroachment Time (ET)
- Initially Attempted Post Encroachment Time (IAPET)
- Deceleration Rate (DR)
- Deceleration-to-Safety Time (DST)

Traffic Conflict Techniques

- ❑ Swedish (STCT)
- ❑ Dutch (DOKTOR)
- ❑ British (UKTCT)
- ❑ Most successful applications of TCT
  - STCT
  - Use TA and CS
  - Determine severity of the encounter
    - ✓ Using Diagram
  - 30 severity levels are defined
    - ✓ Level => 26 ~ Critical



The conflict severity is based on two indicators:

- **Time-to-Accident (TA)** - time remaining to a collision when the evasive action is taken by the relevant road user;
- **Conflicting Speed (CS) -** speed of the relevant road user when he/she takes the evasive action.

Pedestrian-vehicle conflict studies @IIT Roorkee

Analysis of Pedestrian Conflict with Right-Turning Vehicles at Signalized Intersections

Pedestrian Deaths: **32,825 in 2022** vs. **15,746 in 2016** **(108% increase)**

Mechanism Of Right-turning Vehicle and Pedestrian Conflict

Permissive right turn phasing scheme.

Green interval is utilized by pedestrians of that approach for crossing the road.

Drivers pay very less attention to the pedestrians.

- Post Encroachment Time (PET)
- Time to Vehicle (TTV)
- Time to Accident (TTA)
- Deceleration to Safety Time of pedestrians (DST_{ped})
- Deceleration to Safety Time of vehicles (DST_{veh})

Formation of conflict zone at the crosswalk

Evasive actions by pedestrians and vehicles

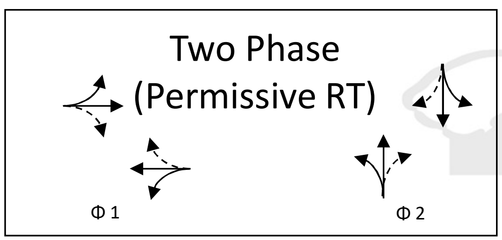
Chances of serious conflicts

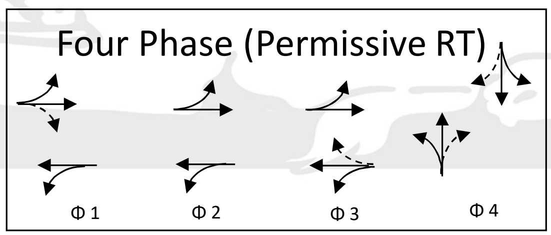
Kumar, A., Paul, M., & **Ghosh, I.** (2019). Analysis of Pedestrian Conflict with Right-Turning Vehicles at Signalized Intersections in India. *Journal of Transportation Engineering, Part A: Systems, ASCE*, 145(6), 04019018. https://doi.org/10.1061/JTEPBS.0000239

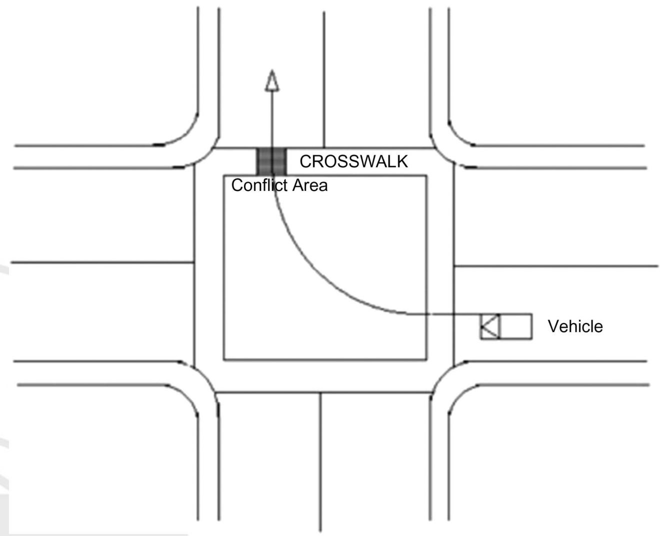
Photos from two sites

(a) (b)

Fig. 2. (a) Deshpriya intersection, Kolkata; and (b) Subhash Nagar intersection, New Delhi. (Images by Abhinav Kumar.)







Evaluation of Conflict Indicators

Post Encroachment Time

Time between the moment that the first road user leaves the potentially occupied conflict zone and the moment the second road user reaches it.

Time to vehicle

Time that remains until a collision to happen if the pedestrian maintains the same speed and path after realizing the abnormal traffic conditions.

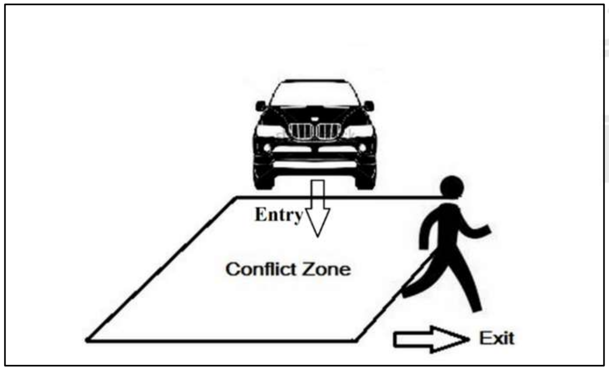
Deceleration to safety time

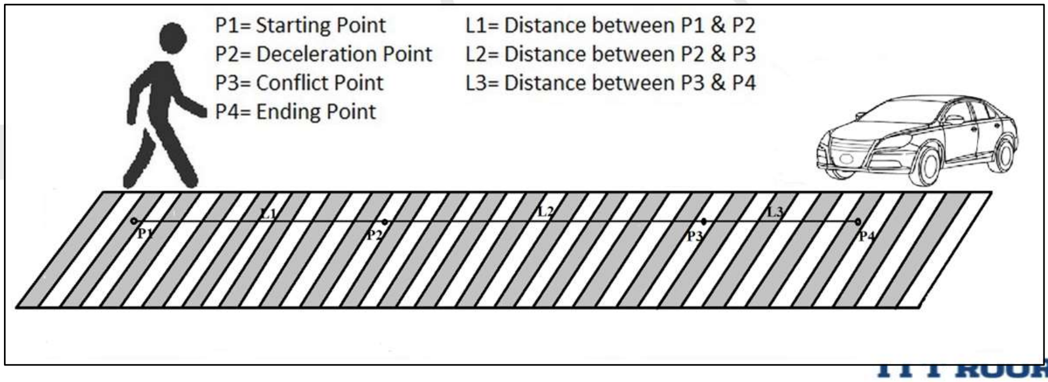
Necessary deceleration to reach a nonnegative PET value if the movements of the road users remain unchanged.

$PET = T_2 - T_1$

$TTV = L/V$

$DST = 2L_1/(T_2 - T_1)^2$





Descriptive Statistics

Table 1: Minimum, maximum and average values of PET, TTV and DST

		Site 1	Site 2	Site 3	Site 4
PET values (sec)	Minimum	0.48	0.96	0.84	0.50
	Maximum	5.40	4.78	3.21	3.10
	Average	2.65	2.41	**2.21**	2.52
TTV values (sec)	Minimum	0.64	0.68	0.61	0.52
	Maximum	4.51	3.28	2.84	3.00
	Average	5.16	5.02	**3.44**	4.91
DST_{ped} values (m/sec^2)	Minimum	0.60	0.54	0.62	0.49
	Maximum	2.74	1.85	1.64	1.52
	Average	**1.69**	1.24	1.15	1.02
TTA values (sec)	Minimum	0.68	0.62	0.54	1.32
	Maximum	3.24	2.35	1.64	1.52
	Average	1.32	1.04	**0.98**	1.14
DST_{veh} values (m/sec^2)	Minimum	0.71	0.50	0.58	0.49
	Maximum	1.30	1.85	1.24	1.68
	Average	1.04	0.98	0.72	**1.20**

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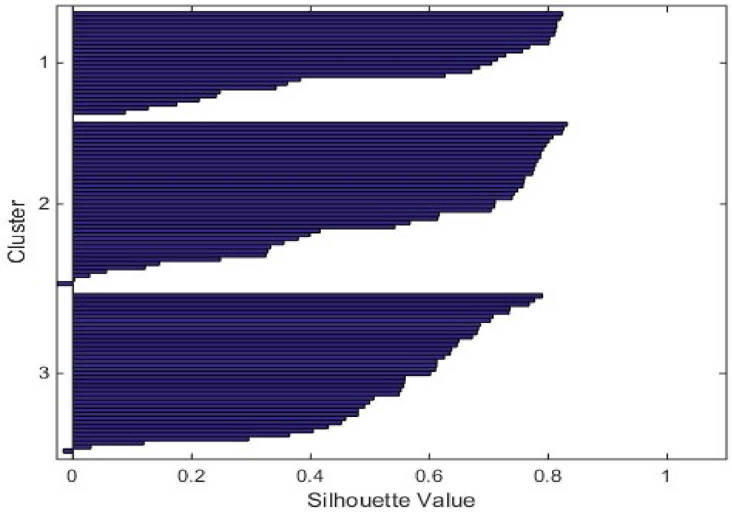
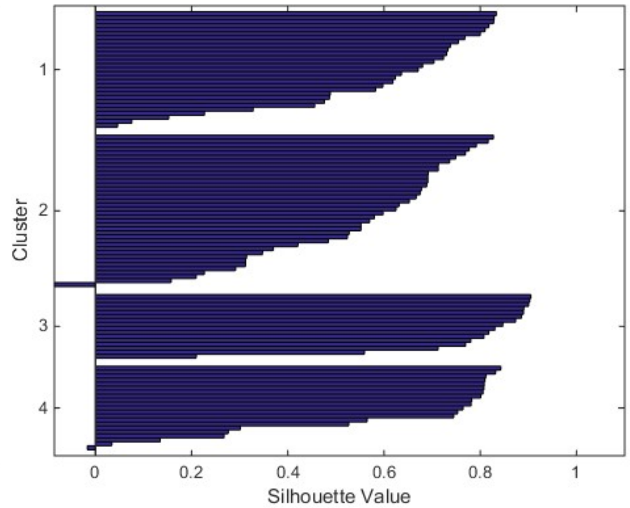
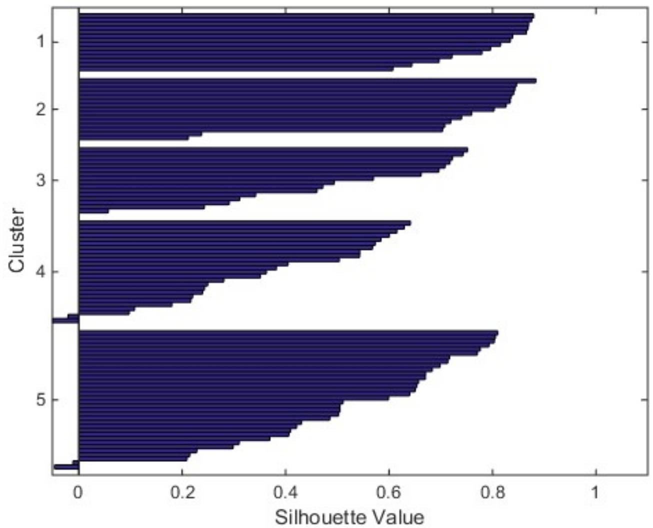
Classification of Conflict Indicators by K-mean clustering



Silhouette plot for K = 3
Global Silhouette Value = 0.60



Silhouette plot for K = 4
Global Silhouette Value = 0.71



Silhouette plot for K = 5
Global Silhouette Value = 0.55

Table 2: Interpretation of Silhouette values (Spector, 2011)

Range of Average Silhouette Value	Interpretation
0.71-1.0	A strong structure
0.51-0.70	A reasonable structure
0.26-0.50	A weak structure
<0.25	No substantial structure

Kumar, A., Paul, M., & **Ghosh, I.** (2019). Analysis of Pedestrian Conflict with Right-Turning Vehicles at Signalized Intersections in India. *Journal of Transportation Engineering, Part A: Systems, ASCE*, 145(6), 04019018. https://doi.org/10.1061/JTEPBS.0000239

Classification of Conflict Indicators by K-mean Clustering

Table 3: Final cluster ranges for indicators

Indicators	Severity level			
	1	2	3	4
PET	0.48-2.32	2.40-2.88	3.12-3.56	4.48-5.40
TTV	0.52-1.12	1.28-1.90	2.42-2.88	3.16-4.51
DST_{ped}	1.50-2.74	1.28-1.44	0.94-1.24	0.48-0.90
TTA	0.54-0.88	0.94-1.62	1.70-2.26	2.40-3.24
DST_{veh}	1.24-1.68	1.00-1.18	0.58-0.94	0.36-0.52

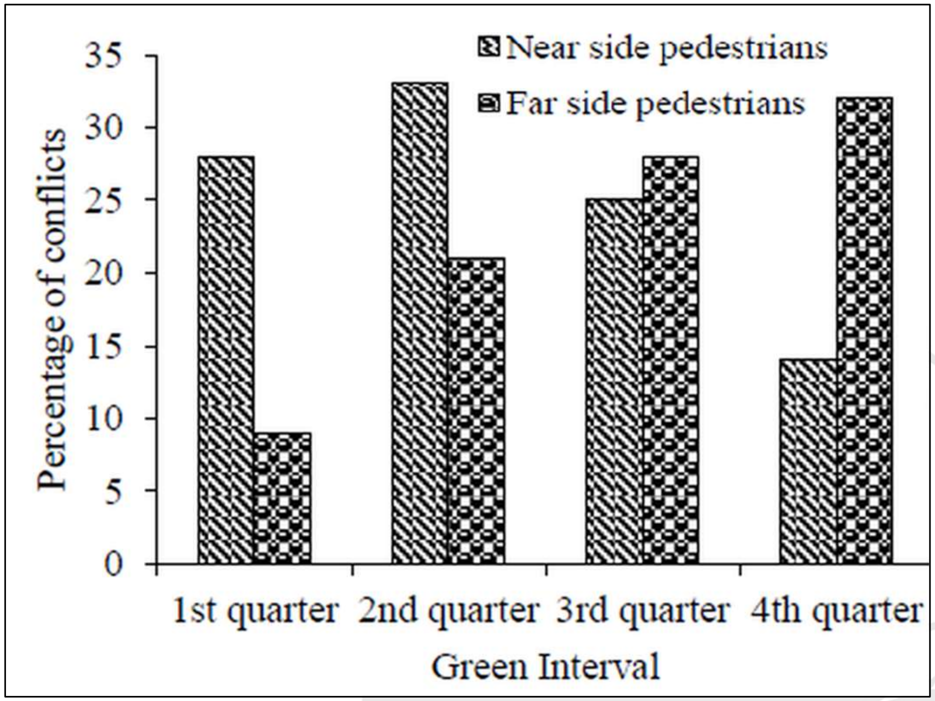
1 = Most severe
4 = Least severe

Table 4: ANOVA results for indicators

Indicators	Cluster		Error		F	Sig.
	Mean Square	df	Mean Square	df		
PET	8.852	3	0.244	130	135.022	0
TTV	144.226	3	1.980	130	136.525	0.003
DST_{ped}	1.329	3	0.078	130	9.228	0.001
TTA	12.236	3	1.828	130	88.242	0.000
DST_{veh}	98.122	3	4.560	130	32.446	0.002

Kumar, A., Paul, M., & **Ghosh, I.** (2019). Analysis of Pedestrian Conflict with Right-Turning Vehicles at Signalized Intersections in India. *Journal of Transportation Engineering, Part A: Systems, ASCE*, 145(6), 04019018. https://doi.org/10.1061/JTEPBS.0000239

Distribution of Conflicts in Green Interval of Right Turning Traffic



Distribution of conflicts in the green interval of right turning traffic

Table 5: Distribution of conflicts with severity level-1

Green Interval	Percentage of conflict with near side pedestrians	Percentage of conflict with far side pedestrians
First quarter	10%	18%
Second quarter	14%	16%
Third quarter	**30%**	**25%**
Fourth quarter	**46%**	**51%**

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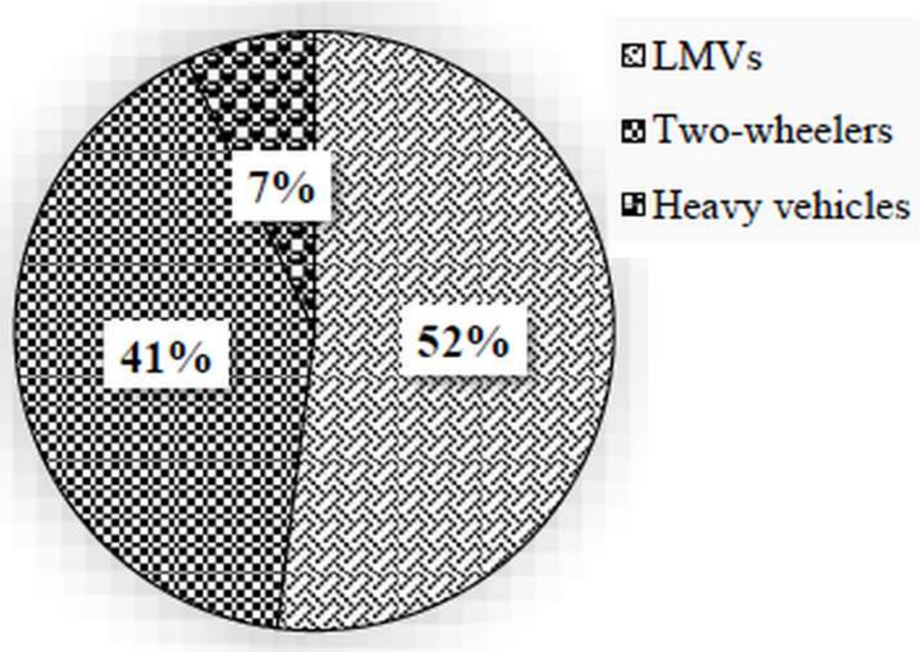
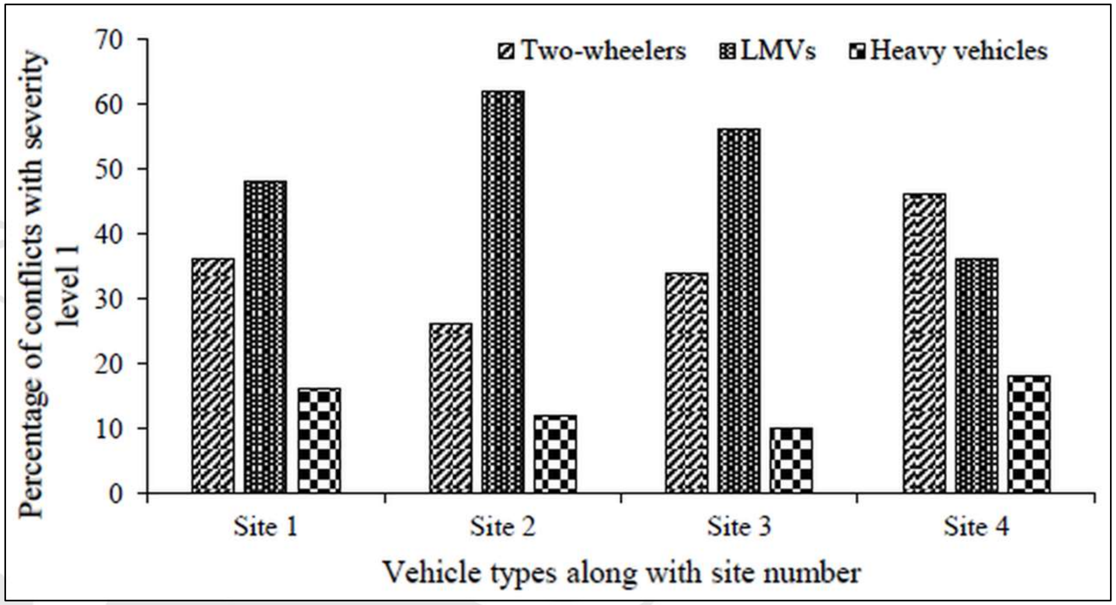
Relation of Conflicts with Vehicle Type



Frequency of conflicts with different vehicle types



Distribution of conflicts with severity level-1 with associated vehicle types at each site

Kumar, A., Paul, M., & **Ghosh, I.** (2019). Analysis of Pedestrian Conflict with Right-Turning Vehicles at Signalized Intersections in India. *Journal of Transportation Engineering, Part A: Systems, ASCE*, 145(6), 04019018. https://doi.org/10.1061/JTEPBS.0000239

Statistical Modelling Results

Table 6: Results of Logistic Regression Model - Risk taking behavior ["1" (risk taken) and "0" (risk not taken)]

S. No.	Variables	Coefficient	Significance level	Standard Error
1.	Pedestrian with more than one company	-2.189	0.036	0.110
2.	(a) 1.07 m/sec< Crossing speed ≤1.49 m/sec	1.333	0.008	0.215
	(b) Crossing speed >1.49 m/sec	2.352	0.012	0.350
3.	(a) 64 sec <Waiting time ≤90 sec	1.500	0.045	0.289
	(b) Waiting time >90 sec	3.522	0.049	0.680
4.	Young pedestrians	2.456	0.001	0.442
5.	(a) Male pedestrians	4.318	0.026	1.986
	(b) Female pedestrians	-1.233	0.029	0.200
6.	Rolling while crossing	0.564	0.046	0.018
7.	Third quarter of green interval	4.676	0.002	2.348
	Fourth quarter of green interval	1.912	0.008	0.389
8.	Right turning vehicle volume	0.889	0.010	0.036
9.	Constant	7.864	0.048	4.654

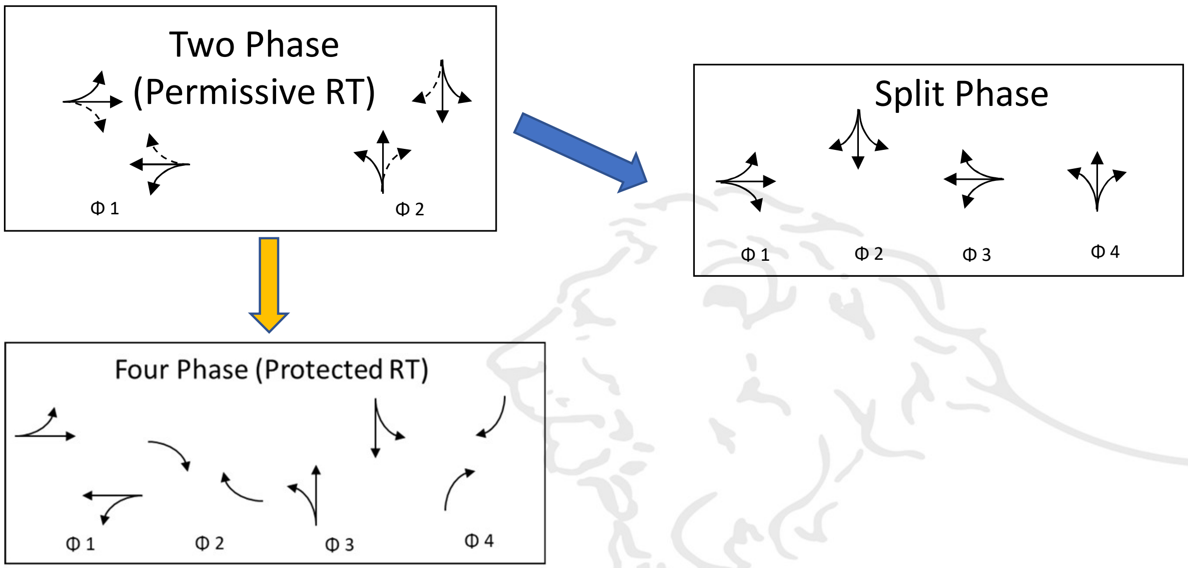
- A test of the full model against a constant only model was significant, therefore indicating that the predictors as a set reliably distinguished between 'risk taken' and 'risk not taken' (*chi-square = 42.148, p<0.001 and df =4*).
- *Nagelkerke's* R^2 value of 0.712 indicated a strong relationship between prediction and grouping. Prediction success overall was 81%.

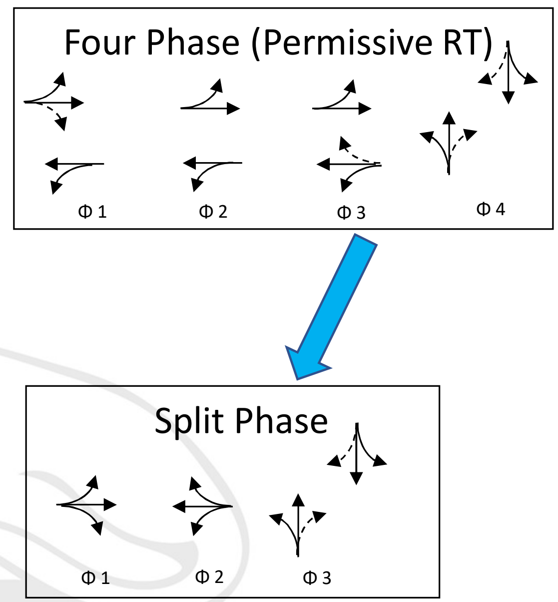
Kumar, A., Paul, M., & **Ghosh, I.** (2019). Analysis of Pedestrian Conflict with Right-Turning Vehicles at Signalized Intersections in India. *Journal of Transportation Engineering, Part A: Systems, ASCE*, 145(6), 04019018. https://doi.org/10.1061/JTEPBS.0000239

Summary of Findings

- Traffic Conflict Technique: PET, TTV, DST_{ped}, TTA and $DST_{veh.}$
- Four classes of severity levels- 1, 2, 3 & 4
- Maximum conflicts @first and second quarters of green interval.
- Severe most conflicts occurred in the third and fourth quarters of green interval.
- Maximum and severe most conflicts occurred with LMVs such as cars and SUVs.
- Pedestrians' age, gender, waiting time, speed, type of crossing, group, and vehicle volume have a significant effect on the risk-taking behavior of pedestrians.

Changes in Traffic Signal Operational Modes





Slower turning speed, no interaction with opposing through: Better yielding

Analysis of Spontaneous Order of Pedestrian-Vehicle Conflicts at Signalized Intersections

Spontaneous Order

Traditional Safety Design

- Segregation of transportation modes from each other.
- Focus is to minimize conflicts.
- Use of signs, markings, signals, traffic calming measures, etc.

Concept of Shared Space

- Removing physical barriers and abolishing rules.
- Behavior of road users to rely on social cues (i.e., spontaneous order).
- No use of signs, signals, and markings, etc.

The disorderly type of setting, built from the silent cues of other road users instead of pre-defined rules, is termed as spontaneous order.

Kumar, A., & **Ghosh, I.** (2020). Analysis of Spontaneous Order of Pedestrian–Vehicle Conflicts at Signalized Intersections. *Transportation Research Record*, 2674(11), 440-454. https://doi.org/10.1177/0361198120945994

Spontaneous Order

Ice Skating rink

Rinkonomics: A Window on Spontaneous Order

Daniel B. Klein*

"An important quality of collision is ***mutuality***. If I collide with you, then you collide with me. And if I don't collide with you, you don't collide with me. In promoting my interest in avoiding collision with you, I also promote your interest in avoiding collision with me."

Daniel B. Klein

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Spontaneous Order

Before

After

Skvallertorget, Norrköping, Sweden before and after remodelling of the intersection (Ref: Hamilton-Baillie B, 2008)

Study Sites (Zebra Crossing ~ Partial Shared Space)

- A total of twelve signalized intersections were selected from the following three cities of India:-
  (1) New Delhi, (2) Jaipur, and (3) Dehradun

Table 7: Features of the selected intersections

Site No.	Name of Sites	Subject Crosswalk	Size of Intersections	Signal Cycle Length (sec)	Conflicting Traffic Flow (veh/hr)	Pedestrian Flow (ped/hr)
Site 1	Mulchand Intersection, New Delhi	Northbound	50m x40m	180	1120	380
Site 2	Peeragarhi Intersection, New Delhi	Westbound	45m x30m	180	1055	462
Site 3	Subhash Nagar Intersection, New Delhi	Eastbound	30m x30m	185	1385	375
Site 4	Madhuban Intersection, New Delhi	Northbound	40m x30m	180	1246	323
Site 5	Darshanlal Intersection, Dehradun	Southbound	20m x18m	140	1150	310
Site 6	Ballupur Intersection, Dehradun	Eastbound	25m x20m	145	1421	282

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Study Sites

Table 7 continued….

Site No.	Name of Sites	Subject Crosswalk	Size of Intersections	Signal Cycle Length (sec)	Conflicting Traffic Flow (veh/hr)	Pedestrian Flow (ped/hr)
Site 7	Crossroad Mall Intersection, Dehradun	Eastbound	20m x18m	135	1210	356
Site 8	Tehsil Intersection, Dehradun	Southbound	20m x18m	140	1100	392
Site 9	JDA Circle, Jaipur	Westbound	25m x22m	145	1350	410
Site 10	Sanganeri Gate Intersection, Jaipur	Westbound	25m x20m	140	1400	322
Site 11	Gopalpura Intersection, Jaipur	Northbound	20m x18m	140	1236	374
Site 12	Shaheed Smarak Intersection, Jaipur	Northbound	40m x20m	145	1108	385

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Yielding Behavior of Pedestrians and Vehicles

Vehicle Dominance

Normal Dominance: The vehicle continues moving and pedestrian yields to the vehicle by slowing down and allows the vehicle to pass.

Coercive Dominance: Vehicle speeds up or accelerates (sometimes blinks the headlight and blows the horn) as an indication to pedestrian to slow down or stop and passes prior to the pedestrian.

Pedestrian Dominance

Normal Dominance: Pedestrian continues walking, and the vehicle yields to pedestrians by slowing down and allows the pedestrian to pass.

Coercive Dominance: Pedestrian uses hand gestures by raising the hand and showing palm towards the oncoming vehicles as an indication to slow down or stop, thereby passes prior to the vehicle.

$$\textit{Modal Dominance Index (MDI)} = \frac{\textit{Number of times pedestrians yielded} - \textit{Number of times vehicles yielded}}{\textit{Total number of conflicts}}$$

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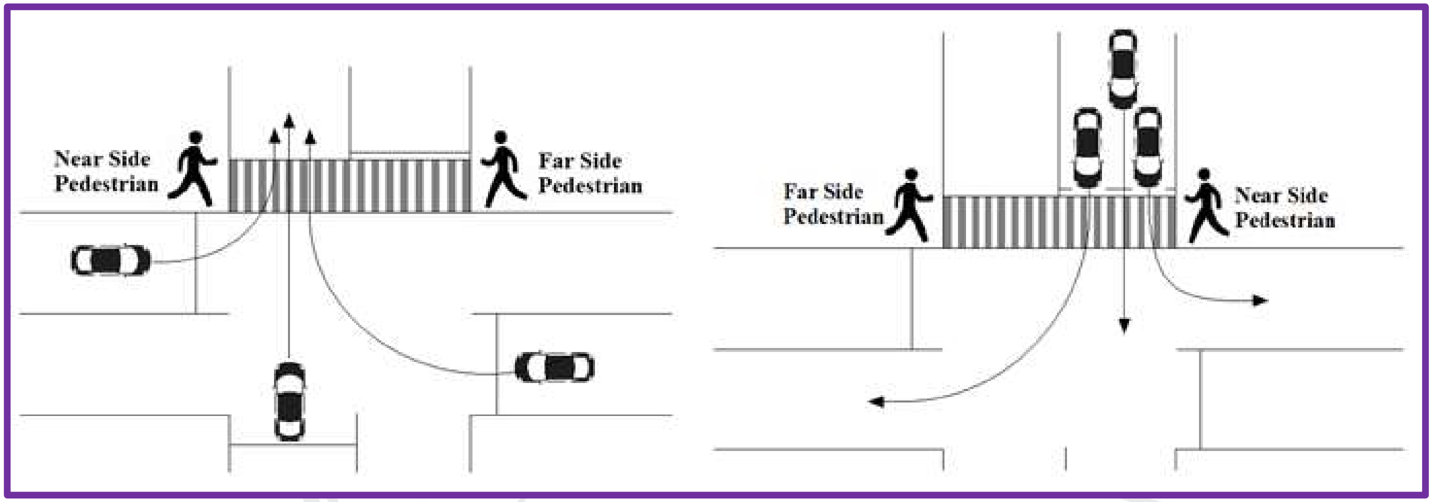
Pedestrian-Vehicle Interactions and Conflicts



1. Left turning vehicles (entering)
2. Straight moving vehicles (entering)
3. Right turning vehicles (entering)
4. Left turning vehicles (departing)
5. Straight moving vehicles (departing)
6. Right turning vehicles (departing)

Kumar, A., & **Ghosh, I.** (2020). Analysis of Spontaneous Order of Pedestrian–Vehicle Conflicts at Signalized Intersections. *Transportation Research Record*, 2674(11), 440-454. https://doi.org/10.1177/0361198120945994

Analysis and results

Table 8: Frequency of Conflicts

Site No.	Number of conflicts						Total
	Entering vehicles			Departing vehicles			
	Left turn (Type 1)	Straight (Type 2)	Right turn (Type 3)	Left turn (Type 4)	Straight (Type 5)	Right turn (Type 6)	
1	21	37	18	20	40	15	151
2	30	42	21	24	48	23	**188**
3	17	34	20	18	42	17	148
4	15	30	24	16	39	18	142
5	22	15	23	31	22	15	128
6	22	15	16	28	25	14	**120**
7	18	41	20	21	30	21	150
8	22	35	18	25	37	17	154
9	38	25	20	36	26	21	166
10	19	24	23	31	15	24	136
11	25	38	17	22	35	18	155
12	33	18	20	22	38	16	147
	Total number of conflicts						**1785**

Kumar, A., & **Ghosh, I.** (2020). Analysis of Spontaneous Order of Pedestrian–Vehicle Conflicts at Signalized Intersections. *Transportation Research Record*, 2674(11), 440-454. https://doi.org/10.1177/0361198120945994

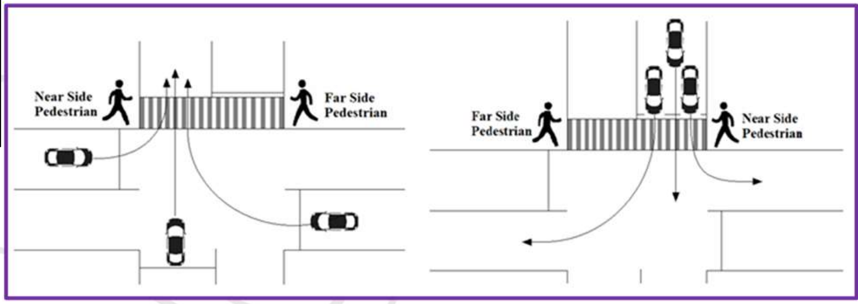
Pedestrian Dominance at Intersection

Table 9: Proportion of Pedestrians Exhibiting Normal and Coercive Dominance

	Conflict with Entering Vehicles		Conflict with Departing Vehicles	
	Near Side Pedestrians	Far Side Pedestrians	Near Side Pedestrians	Far Side Pedestrians
Normal Dominance	89 (35%)	**202 (92%)**	124 (46%)	**195 (84%)**
Coercive Dominance	**164 (65%)**	16 (8%)	**146 (54 %)**	37 (16%)
Total	253	218	270	232

Entering approach

Exiting approach



There was a statistically significant difference (χ^2=163.87, p<0.001) in the number of pedestrians of the near side and far side for showing normal and coercive dominance at the intersection for entering vehicles (χ^2=163.87, p<0.001) and departing vehicles (χ^2=78.29, p<0.001).

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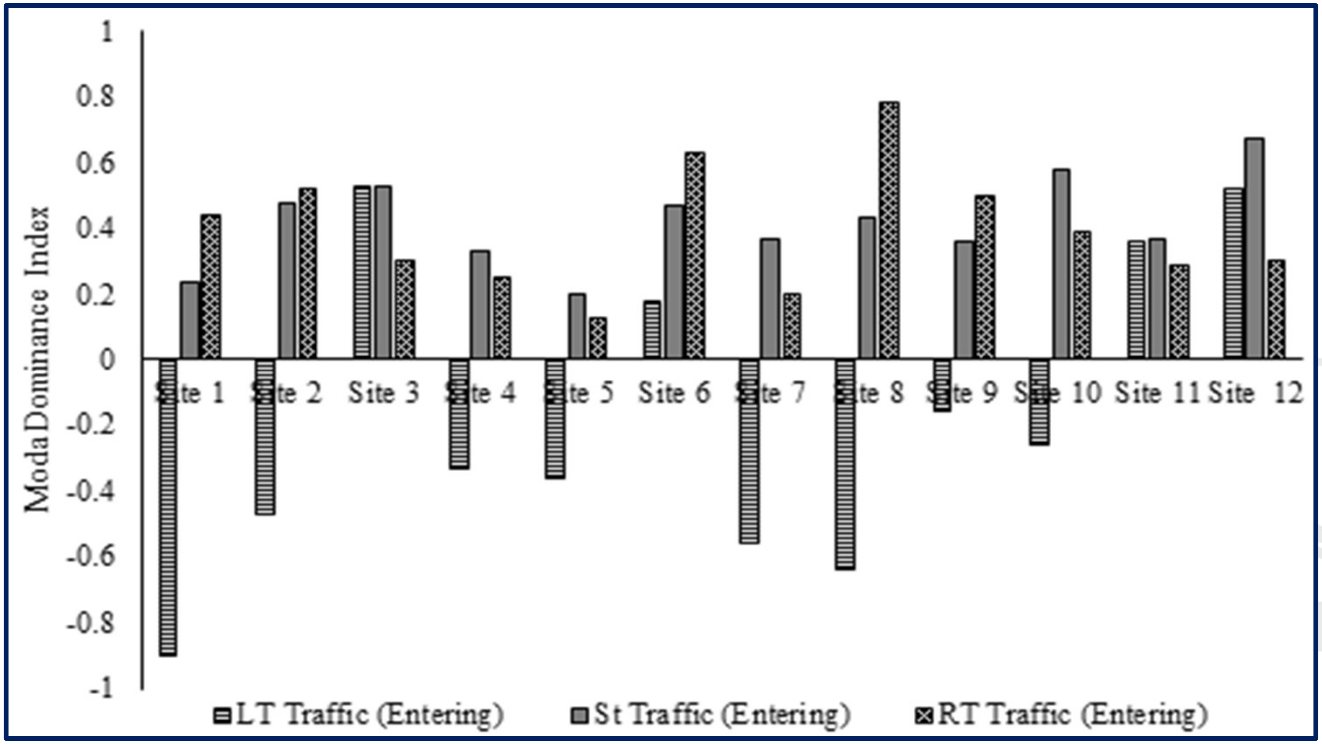
Analysis of Modal Dominance Index

- **MDI values for entering vehicles at each intersection**

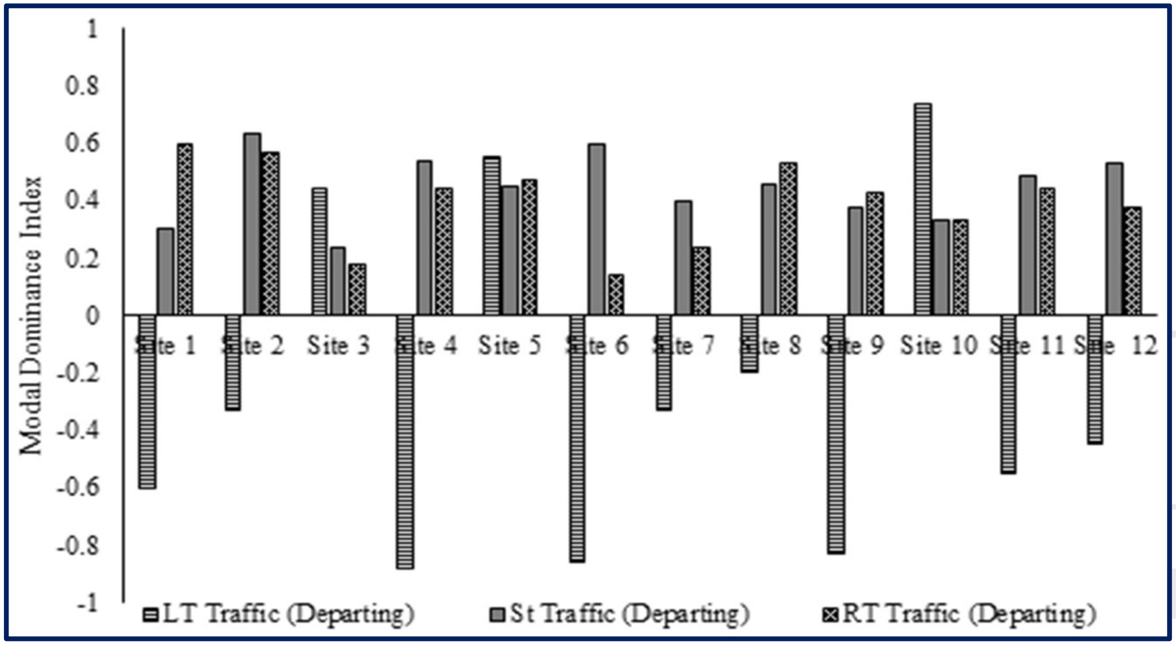


- The difference in the number of yields by pedestrians and vehicles for three types of maneuvering was significant for six sites (Site 1, Site2, Site 7, Site 8, Site 9, and Site 10).
- At rest six sites, the difference was not found to be statistically significant.

Kumar, A., & **Ghosh, I.** (2020). Analysis of Spontaneous Order of Pedestrian–Vehicle Conflicts at Signalized Intersections. *Transportation Research Record*, 2674(11), 440-454. https://doi.org/10.1177/0361198120945994

Analysis of Modal Dominance Index

- **MDI values for departing vehicles at each intersection**

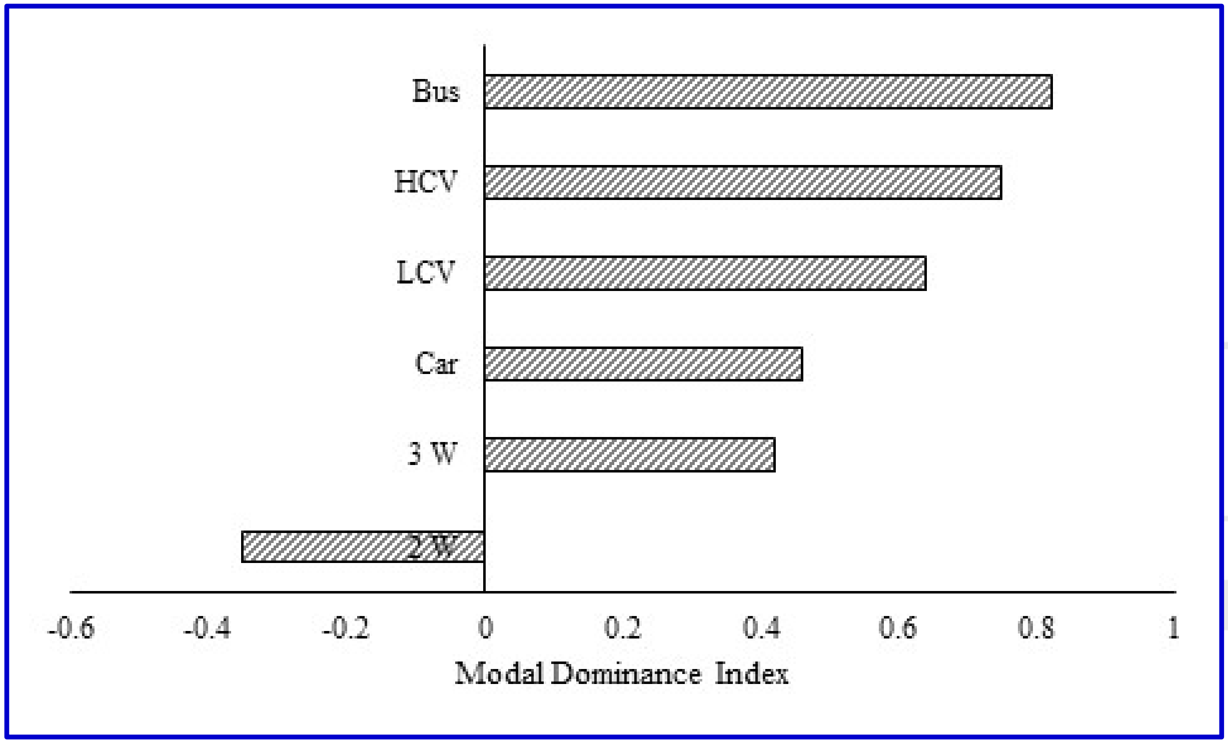


The chi-square test results suggested that the difference in the number of yields by pedestrians and vehicles were significant for all the nine intersections on which pedestrian dominance prevailed.

Kumar, A., & **Ghosh, I.** (2020). Analysis of Spontaneous Order of Pedestrian–Vehicle Conflicts at Signalized Intersections. *Transportation Research Record*, 2674(11), 440-454. https://doi.org/10.1177/0361198120945994

Analysis of Modal Dominance Index

- **MDI values for different categories of vehicles**



Difference in the yielding preference by pedestrians and vehicles for various vehicle types was found to be statistically significant (χ^2= 349.54, p<0.0001).

Kumar, A., & **Ghosh, I.** (2020). Analysis of Spontaneous Order of Pedestrian–Vehicle Conflicts at Signalized Intersections. *Transportation Research Record*, 2674(11), 440-454. https://doi.org/10.1177/0361198120945994

Pedestrian Violation Analysis

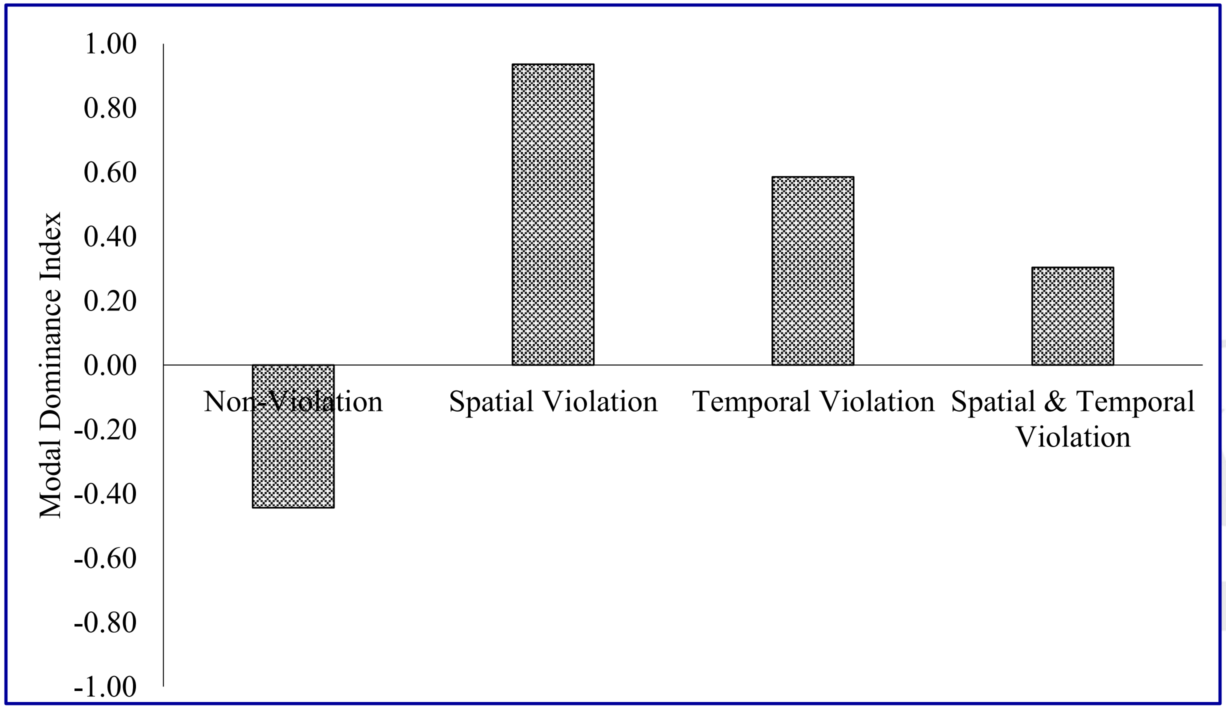
Table 10: Number of yields by pedestrians and vehicles for the types of violations

Violation Type	Number of Conflicts (Percentage)	Number of Times Pedestrians Yielded	Number of Times Vehicles Yielded
Non-Violation	719 (40.28%)	200	519
Spatial Violation	188 (10.53%)	182	6
Temporal Violation	763 (42.74%)	605	158
Spatial & Temporal Violation	115 (6.45%)	75	40

Kumar, A., & **Ghosh, I.** (2020). Analysis of Spontaneous Order of Pedestrian–Vehicle Conflicts at Signalized Intersections. *Transportation Research Record*, 2674(11), 440-454. https://doi.org/10.1177/0361198120945994

Pedestrian Violation Analysis

- **MDI values for type of violation**



- The number of yields by pedestrians exceeds the number of vehicle yields during the spatial violation, temporal violation, and spatial & temporal violation.
- Only for non-violation conflicts, the number of vehicular yields is higher.
- These results were found to be statistically significant with χ^2= 349.54, $p < 0.0001$.

Kumar, A., & **Ghosh, I.** (2020). Analysis of Spontaneous Order of Pedestrian–Vehicle Conflicts at Signalized Intersections. *Transportation Research Record*, 2674(11), 440-454. https://doi.org/10.1177/0361198120945994

Estimated Results of Development of Dominance Model

Table 11: Estimated results of the binary logit model – 'Vehicle dominance' (1) vs. 'Pedestrian dominance' (0)

Variables	Coefficient	Significance	Standard Error
Vehicles/cycle	4.318	0.002	0.110
Type of vehicle			
2W	-1.254	0.005	1.325
Car	2.535	0.000	0.215
Pedestrian violation			
Temporal violation	4.292	0.011	0.552
Group size of crossing pedestrians			
Single pedestrian	3.262	0.003	0.350
More than two pedestrians	-1.010	0.049	0.289
Type of pedestrian-vehicle interaction			
With left turn entering vehicle	-1.824	0.045	0.680
With straight entering vehicle	2.815	0.026	1.986
Size of intersection			
Small	-5.322	0.001	0.565
Constant	3.875	0.002	1.442

- *Nagelkerke's* R^2 value was found to be 0.814, which indicates a strong relationship between grouping and prediction.
- The overall predictive accuracy was 87.7%.

Kumar, A., & **Ghosh, I.** (2020). Analysis of Spontaneous Order of Pedestrian–Vehicle Conflicts at Signalized Intersections. *Transportation Research Record*, 2674(11), 440-454. https://doi.org/10.1177/0361198120945994

SUMMARY

- Modal Dominance Index: *Pedestrian Dominance & Vehicle Dominance*
- MDI values for the interaction of pedestrians with straight and turning vehicles needs to be checked.
- Motorized two-wheelers are more likely to yield to pedestrians during the crossing.
- High pedestrian flow leads to a greater number of conflicts at the intersections.
- The size of the intersection is found to be related to conflict proximity (PET).
- Vehicle volume (per cycle), type of vehicles, pedestrian violation, the group size of crossing pedestrian, type of pedestrian-vehicle interaction, and size of intersection have been found to be in relationship with the dominance of road users at the intersections.

Pedestrian Behavior and the Associated Conflicts at Signalized Intersections

Types of Signal Violations

Dangerous violations

Pedestrians commit a dangerous violation when crossing during the red phase.

Non-dangerous violations

Pedestrians start to cross too late but still manage to finish before conflicting traffic gets the green light.

Dangerous crossings

Pedestrians start to cross at the green light, and the end of crossing during the red light.

$$\textit{Violation Prevalence} = \frac{\textit{Number of pedestrians crossing on red}}{\textit{Total number of pedestrians that arrived during red phase}}$$

Kumar, A., & **Ghosh, I.** (2022). Non-compliance behaviour of pedestrians and the associated conflicts at signalized intersections in India. *Safety Science, Elsevier*, 147, 105604. https://doi.org/10.1016/j.ssci.2021.105604

Pedestrian-Vehicle Conflicts

A conflict is said to have occurred if either of the following interaction types is observed:

1. A pedestrian yields by slowing down and allows the vehicle to pass.
2. A pedestrian speeds up and passes the conflict zone before the arrival of the vehicle.
3. A vehicle yields by braking and slowing down and allows the pedestrian to pass.
4. A vehicle accelerates and passes the conflict zone before the pedestrian arrives.
5. Neither of the road users takes evasive action, but there is a small-time lapse between the moments they pass the conflict zone.

Kumar, A., & **Ghosh, I.** (2022). Non-compliance behaviour of pedestrians and the associated conflicts at signalized intersections in India. *Safety Science, Elsevier*, 147, 105604. https://doi.org/10.1016/j.ssci.2021.105604

Study Sites ~ Issue with Pedestrian clearance time

- A total of twelve signalized intersections were selected from the following three cities of India:- **(1) New Delhi, (2) Jaipur, and (3) Dehradun**

Table 12: Features of the selected intersections

Site No.	Name of Sites	Subject Crosswalk	Size of Intersections (mxm)	Signal Cycle Length (sec)	Conflicting Traffic Flow (veh/hr)	Pedestrian Flow (ped/hr)
Site 1	Mulchand Intersection, New Delhi	Northbound	50 x40	180	1120	380
Site 2	Peeragarhi Intersection, New Delhi	Westbound	45 x30	180	1055	462
Site 3	Subhash Nagar Intersection, New Delhi	Eastbound	30 x30	185	1385	375
Site 4	Madhuban Intersection, New Delhi	Northbound	40 x30	180	1246	323
Site 5	Darshanlal Intersection, Dehradun	Southbound	20 x18	140	1150	310
Site 6	Ballupur Intersection, Dehradun	Eastbound	25 x20	145	1421	282

Kumar, A., & **Ghosh, I.** (2022). Non-compliance behaviour of pedestrians and the associated conflicts at signalized intersections in India. *Safety Science, Elsevier*, 147, 105604. https://doi.org/10.1016/j.ssci.2021.105604

Study Sites ~ Issue with Pedestrian clearance time

Table 12 continued….

Site No.	Name of Sites	Subject Crosswalk	Size of Intersections (mxm)	Signal Cycle Length (sec)	Conflicting Traffic Flow (veh/hr)	Pedestrian Flow (ped/hr)
Site 7	Crossroad Mall Intersection, Dehradun	Eastbound	20 x18	135	1210	356
Site 8	Tehsil Intersection, Dehradun	Southbound	20 x18	140	1100	392
Site 9	JDA Circle, Jaipur	Westbound	25 x22	145	1350	410
Site 10	Sanganeri Gate Intersection, Jaipur	Westbound	25 x20	140	1400	322
Site 11	Gopalpura Intersection, Jaipur	Northbound	20 x18	140	1236	374
Site 12	Shaheed Smarak Intersection, Jaipur	Northbound	40 x20	145	1108	385

Kumar, A., & **Ghosh, I.** (2022). Non-compliance behaviour of pedestrians and the associated conflicts at signalized intersections in India. *Safety Science, Elsevier*, 147, 105604. https://doi.org/10.1016/j.ssci.2021.105604

Data Description

Table 13: Observed frequencies of violation and non-violation by pedestrians

	Violation	Non-violation	Total
Gender			
Male	1550 (66%)	3554 (62%)	5104
Female	792 (34%)	2193 (38%)	2985
Total	2342	5747	8089
Age			
Young	1439 (61.5%)	1906 (33.2%)	3345
Middle-aged	856 (36.5%)	3108 (54%)	3964
Old	47 (2%)	733 (12.8%)	780
Total	2342	5747	8089

Kumar, A., & **Ghosh, I.** (2022). Non-compliance behaviour of pedestrians and the associated conflicts at signalized intersections in India. *Safety Science, Elsevier*, 147, 105604. https://doi.org/10.1016/j.ssci.2021.105604

Data Description

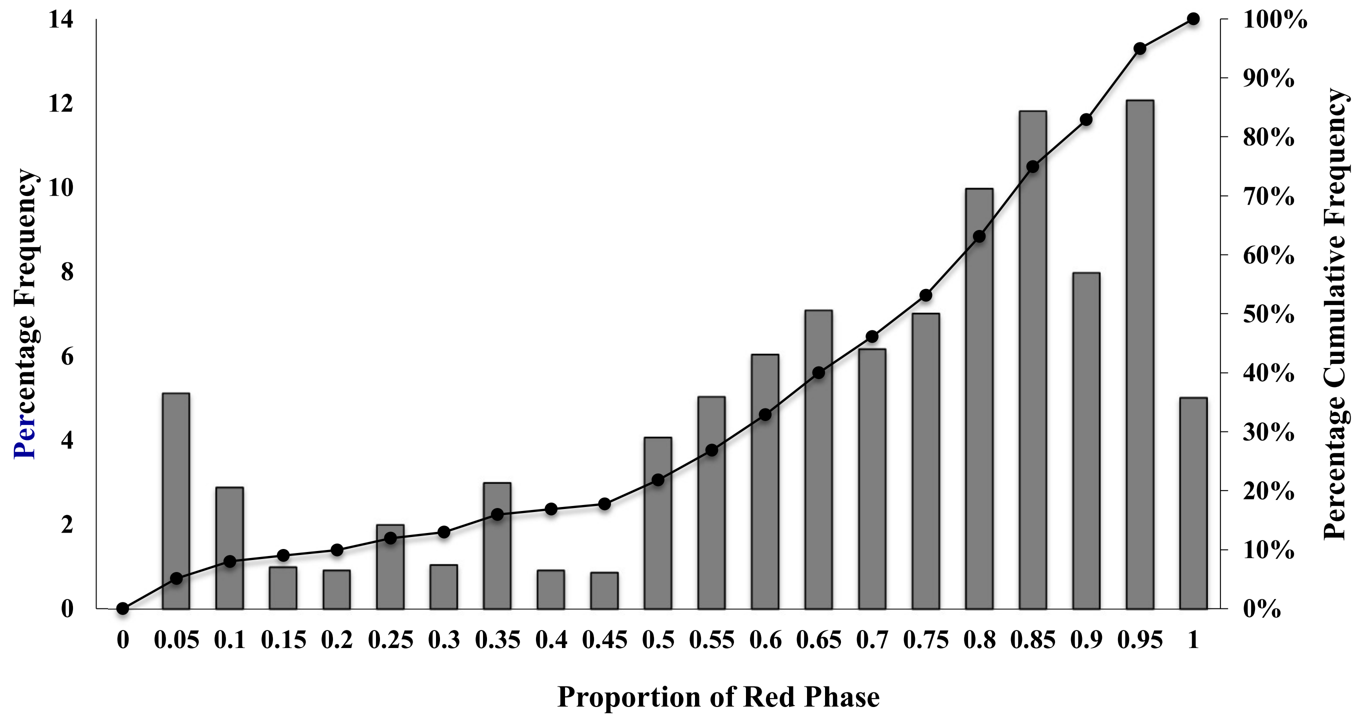
Table 14: Observed frequencies of pedestrian arrival in red and green

	Number of pedestrians arrived in red			Number of pedestrians arrived in green		
Site No.	Crossed in red	Waited for green	Total	Completed crossing in green	Crossed at the end of green	Total
Site 1	462 (46.9%)	523 (53.1%)	985	510 (95.3%)	25 (4.7%)	535
Site 2	368 (49.1%)	382 (50.9%)	750	1076 (98.0%)	22 (2.0%)	1098
Site 3	292 (45.6%)	348 (54.4%)	640	844 (98.1%)	16 (1.9%)	860
Site 4	244 (40.3%)	361 (59.7%)	605	677 (98.5%)	10 (1.5%)	687
Site 5	225 (38.8%)	355 (61.2%)	580	624 (94.5%)	36 (5.5%)	660
Site 6	185 (38.9%)	290 (61.1%)	475	636 (97.4%)	17 (2.6%)	653
Site 7	258 (41.5%)	363 (58.5%)	621	778 (96.9%)	25 (3.1%)	803
Site 8	329 (46.7%)	376 (53.3%)	705	836 (96.9%)	27 (3.1%)	863
Site 9	362 (47.9%)	394 (52.1%)	756	866 (98.0%)	18 (2.0%)	884
Site 10	240 (40.7%)	349 (59.3%)	589	685 (98.0%)	14 (2.0%)	699
Site 11	310 (45.1%)	378 (54.9%)	688	786 (97.3%)	22 (2.7%)	808
Site 12	333 (47.9%)	362 (52.1%)	695	810 (95.9%)	35 (4.1%)	845
Total	3608	4481	8089	9128	267	9395

Kumar, A., & **Ghosh, I.** (2022). Non-compliance behaviour of pedestrians and the associated conflicts at signalized intersections in India. *Safety Science, Elsevier*, 147, 105604. https://doi.org/10.1016/j.ssci.2021.105604

Analysis and Results

- **Frequency distribution of pedestrian violations**



Frequency distribution of pedestrian violations

Kumar, A., & **Ghosh, I.** (2022). Non-compliance behaviour of pedestrians and the associated conflicts at signalized intersections in India. *Safety Science, Elsevier*, 147, 105604. https://doi.org/10.1016/j.ssci.2021.105604

Analysis and Results

- **Violation Prevalence Model**

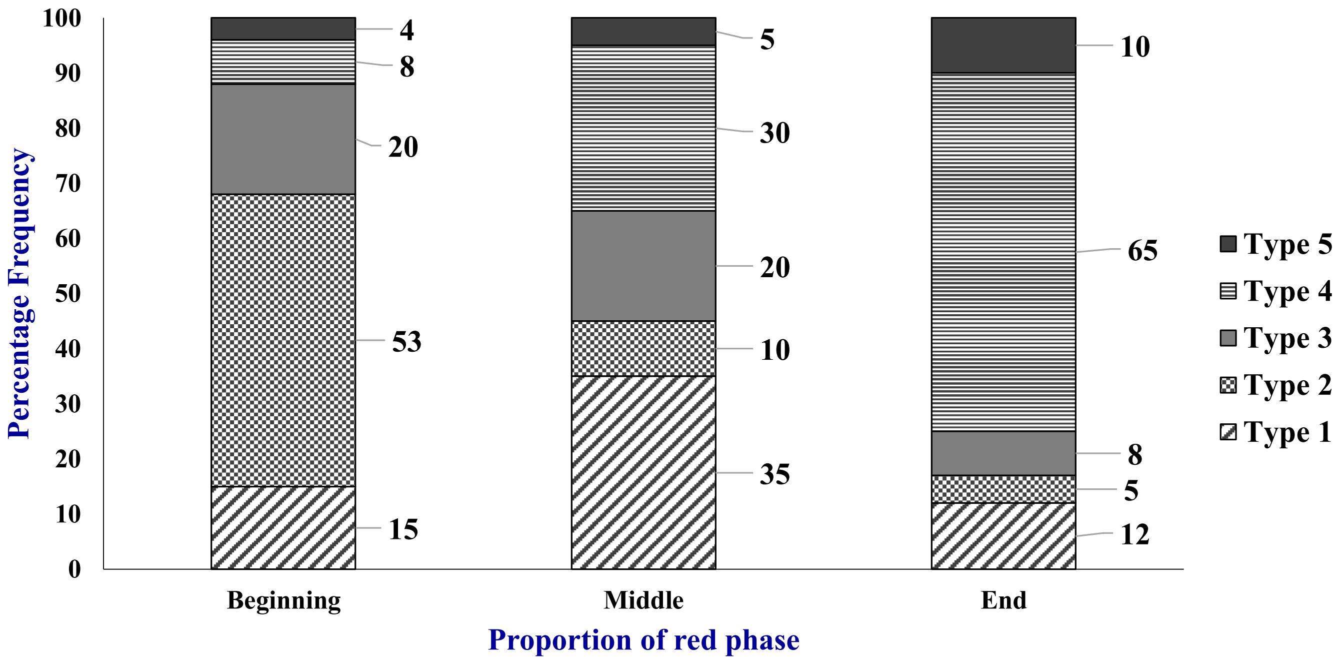
Table 15: Model Results for Violation Prevalence

Variable	Standard Error	Coefficient	p-value
Pedestrian volume during red phase	0.020	-5.529	**0.001**
Vehicle volume during red phase	0.521	-1.334	**0.020**
Speed of vehicles (km/h)	0.369	-0.512	0.082
Speed of pedestrians (m/sec)	0.045	1.201	0.099
Mean waiting time of pedestrians during red interval	0.712	2.821	**0.001**
Crosswalk length (m)	0.185	-2.538	**0.003**
R^2 = 0.954, Number of observations= 950			

Kumar, A., & **Ghosh, I.** (2022). Non-compliance behaviour of pedestrians and the associated conflicts at signalized intersections in India. *Safety Science, Elsevier*, 147, 105604. https://doi.org/10.1016/j.ssci.2021.105604

Analysis and Results

- **Distribution of Conflicts in Red Phase**



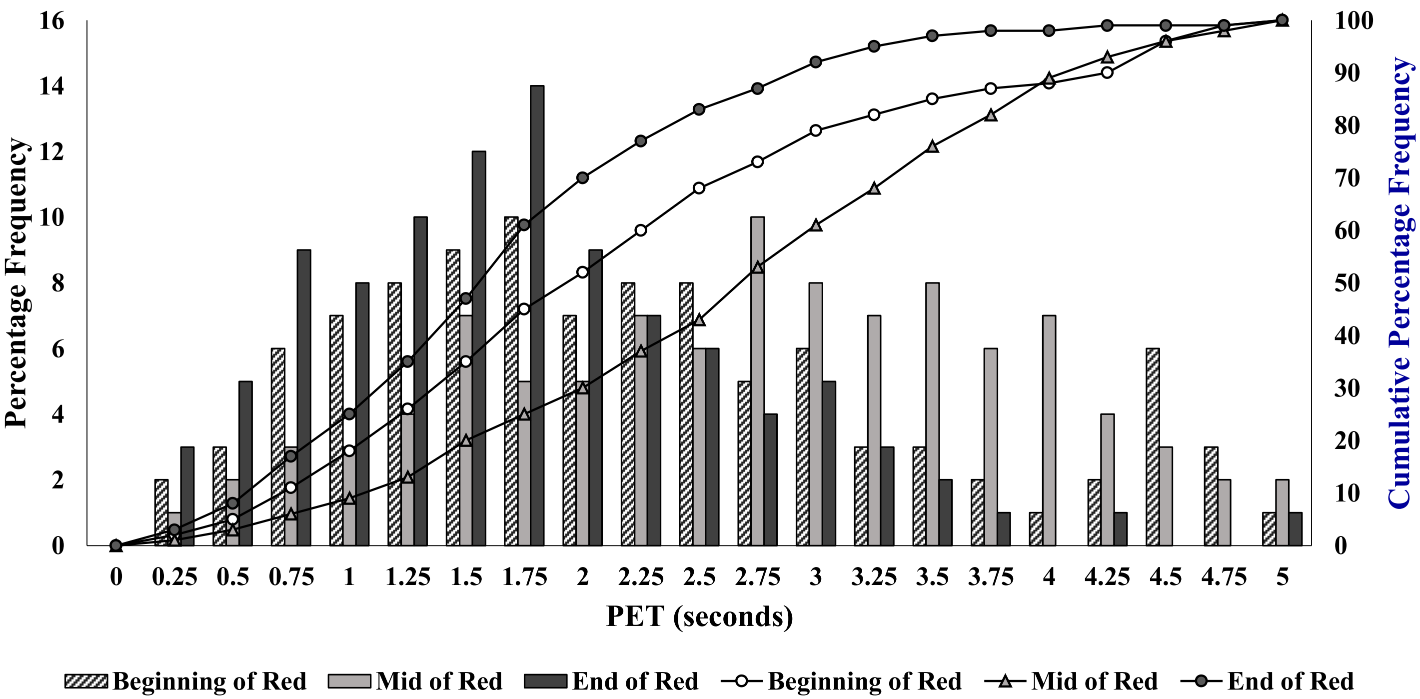
Frequency distribution of conflict types

1. A pedestrian yields by slowing down and allows the vehicle to pass.
2. A pedestrian speeds up and passes the conflict zone before the arrival of the vehicle.
3. A vehicle yields by braking and slowing down and allows the pedestrian to pass.
4. A vehicle accelerates and passes the conflict zone before the pedestrian arrives.
5. Neither of the road users takes evasive action, but there is a small-time lapse between the moments they pass the conflict zone.

Kumar, A., & **Ghosh, I.** (2022). Non-compliance behaviour of pedestrians and the associated conflicts at signalized intersections in India. *Safety Science, Elsevier*, 147, 105604. https://doi.org/10.1016/j.ssci.2021.105604

Analysis and Results

- **Temporal proximity of conflicts**



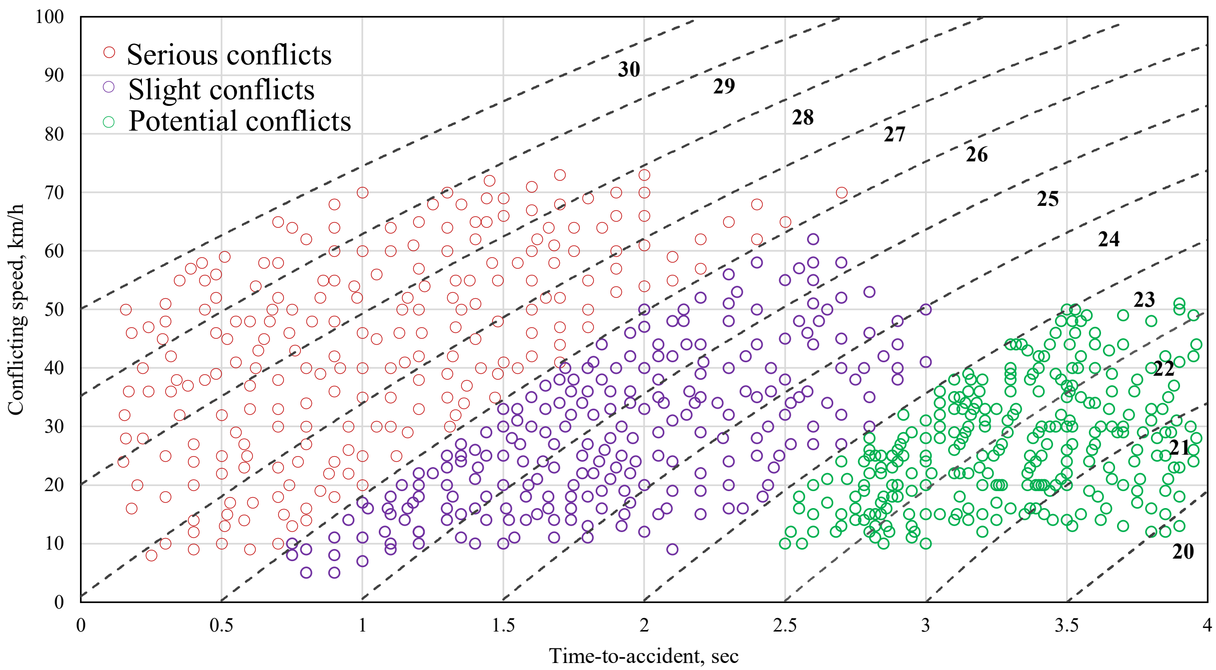
- At the beginning of the red phase, approximately half of the conflicts (about 52%) have PET values of less than 2 seconds.
- At the end of the red interval, about 70% of the conflicts have PET values less than 2 seconds

Comparison of PET distributions in the beginning, middle, and end of the red interval

Kumar, A., & **Ghosh, I.** (2022). Non-compliance behaviour of pedestrians and the associated conflicts at signalized intersections in India. *Safety Science, Elsevier*, 147, 105604. https://doi.org/10.1016/j.ssci.2021.105604

Analysis and Results

- **Severity of pedestrian-vehicle conflicts using STCT**



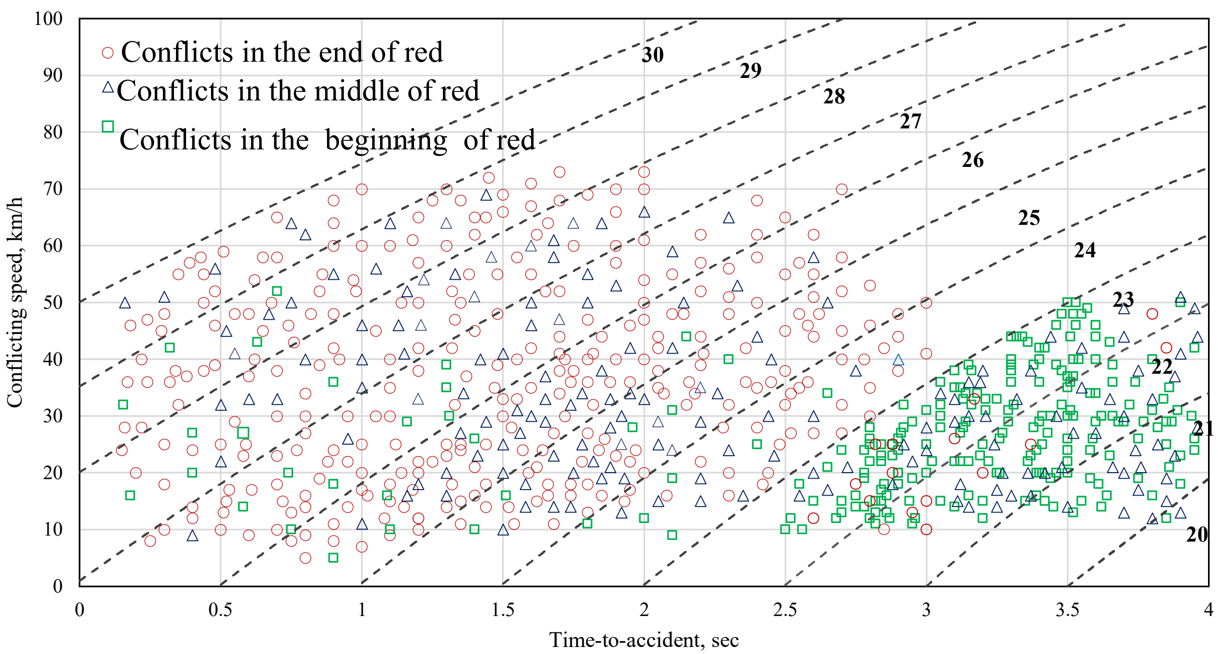
Classification of vehicle-pedestrian conflicts based on severity levels

Out of 877 conflicts identified for severity analysis, 385 (44%) were potential conflicts, 255 (29%) were slight conflicts, and 237 (27%) were serious conflicts

Kumar, A., & **Ghosh, I.** (2022). Non-compliance behaviour of pedestrians and the associated conflicts at signalized intersections in India. *Safety Science, Elsevier*, 147, 105604. https://doi.org/10.1016/j.ssci.2021.105604

Analysis and Results

- **Severity of pedestrian-vehicle conflicts using STCT**



Classification of vehicle-pedestrian conflicts based on severity levels

- About 60% of the serious conflicts occurred at end of red.
- The potential conflicts were predominant (65%) in the beginning of the red interval.
- About 58% of the slight conflicts occurred at the end of the red interval.

Kumar, A., & **Ghosh, I.** (2022). Non-compliance behaviour of pedestrians and the associated conflicts at signalized intersections in India. *Safety Science, Elsevier*, 147, 105604. https://doi.org/10.1016/j.ssci.2021.105604

Ordered response model for conflict severity

Table 16: Estimated results of the ordered logit model

Variable	Standard Error	Coefficient (B)	Exp (B)	p-value
Vehicle speed	0.218	0.981	2.667	0.001
Type of vehicle				
2W	0.214	0.348	1.416	0.010
Gender of pedestrian				
Male	0.308	0.512	1.668	0.004
Group size of crossing pedestrians				
Single pedestrian	0.089	0.243	1.275	0.003
Proportion of red phase				
Middle	0.075	0.588	1.800	0.001
End	0.152	0.481	1.617	0.000
Length of crosswalk				
Large	0.108	0.712	2.038	0.003
Threshold 1	0.402	1.413	3.980	0.855
Threshold 2	0.359	1.205	3.412	1.200
Threshold 3	0.510	−0.452	1.748	0.685

Dependent Variable:
1 = severity level-I (potential conflicts)
2 = severity level-II (slight conflicts)
3 = severity level-III (serious conflicts)

Log-likelihood = -3002.144
Number of observations = 1787
LR chi square (8) = 42.114
Prob > chi square = 0.000
Pseudo R^2 = 0.598

Kumar, A., & **Ghosh, I.** (2022). Non-compliance behaviour of pedestrians and the associated conflicts at signalized intersections in India. *Safety Science, Elsevier*, 147, 105604. https://doi.org/10.1016/j.ssci.2021.105604

Summary of Findings

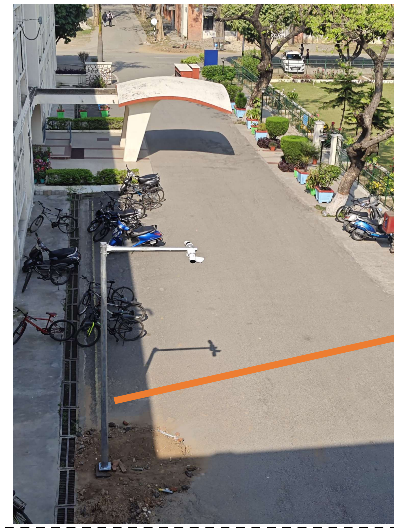
- 44.6% of pedestrians violate the traffic signals.
- Latter half of the red phase is the violation-dense period.
- Violation prevalence increased with the increase in waiting time of pedestrians.
- The violation prevalence decreased with the increase in pedestrian volume, vehicle volume, and crosswalk length.
- Critical conflicts occurred more frequently at the beginning and end of the red phase.
- Severity of conflicts- Time to accident and conflicting speed.
- Vehicle speed, vehicle type, pedestrians' gender, the group size of crossing pedestrians, proportion of red phase, and crosswalk length were found to be significantly affecting the severity of conflicts.

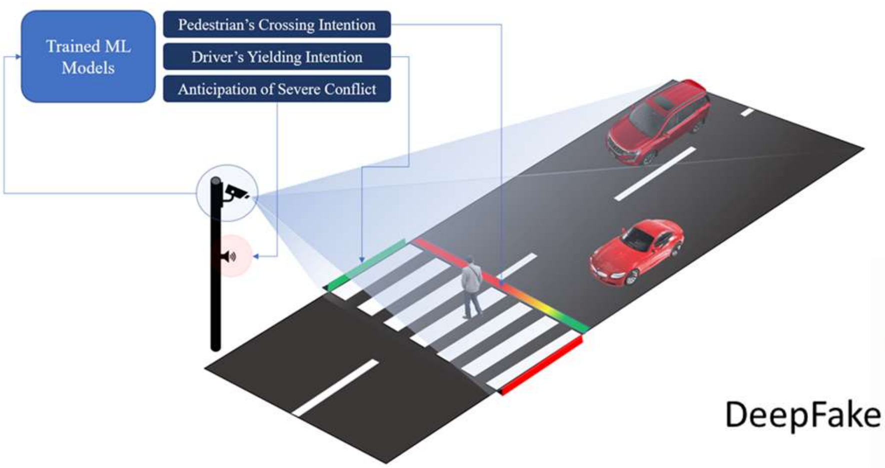
Recent works at IIT Roorkee

Machine learning framework for the development of an interactive pedestrian crossing to enhance pedestrian safety

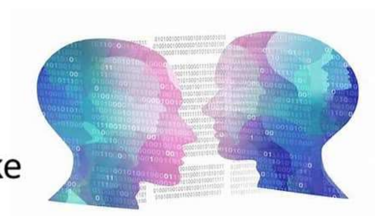
Safety issue: Miscommunication

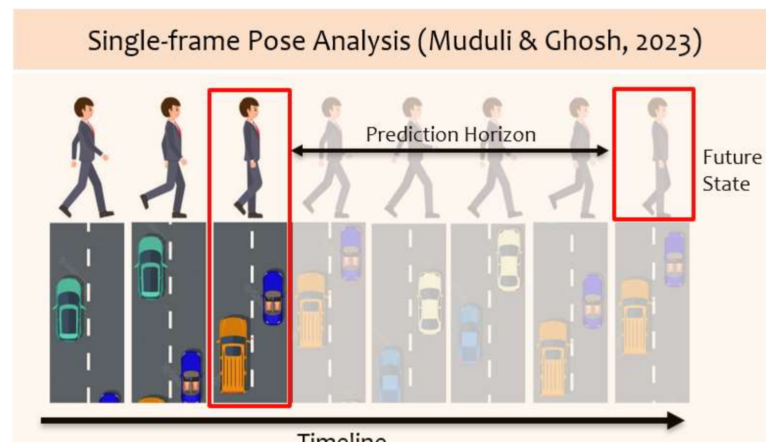
Source: www.twitter.com/hydcitypolice



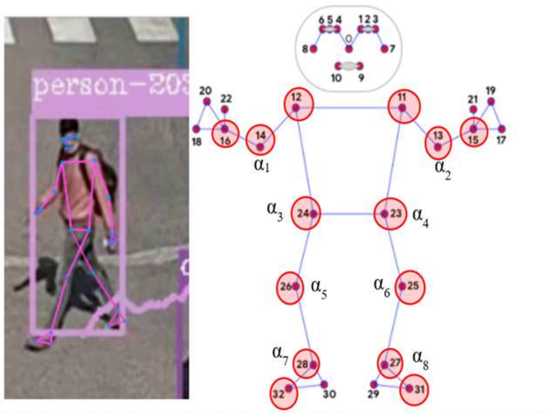


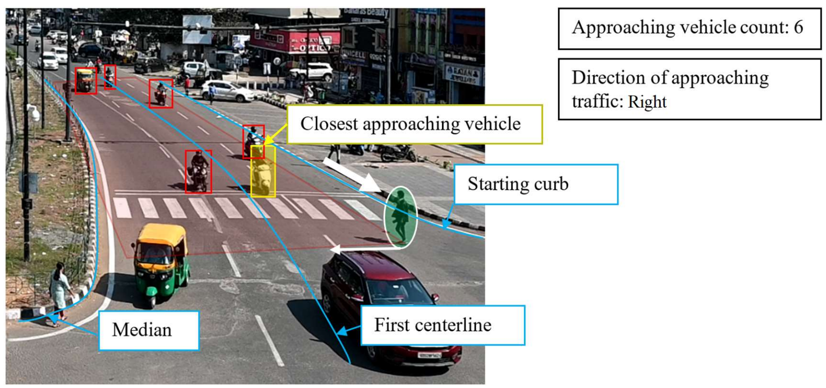
DeepFake

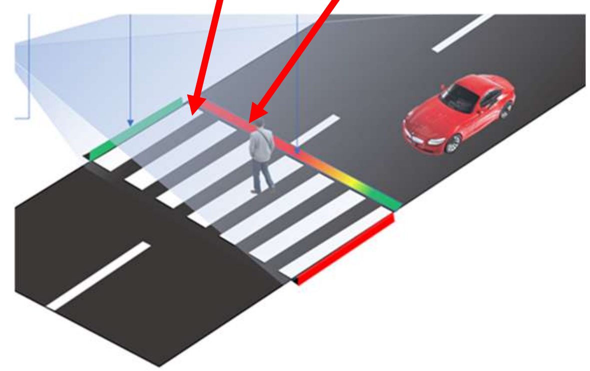


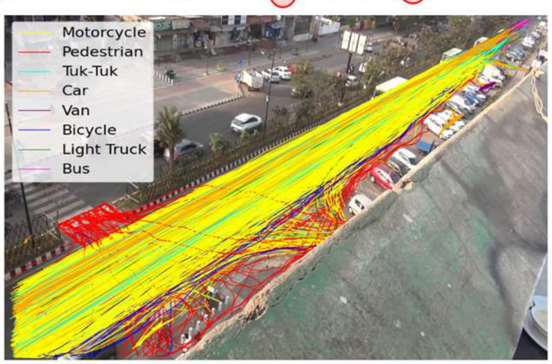


Studies	Models used	Prediction Horizon	Predictive Performance
Muduli & Ghosh (2023)	**Random forest (RF)**	**4s**	**0.883 (AUC)**
Rasouli et al. (2020)	stacked GRU	2s	0.829 (AUC)
Kotseruba et al. (2020)	RNN	2s	0.85 (AUC)
Muduli & Ghosh (2023)	Random forest (RF)	2s	0.911 (AUC)
Zhang et al. (2020)	LSTM	1.5s	0.938 (AUC)
Muduli & Ghosh (2023)	**Random forest (RF)**	**1.5s**	**0.940 (AUC)**





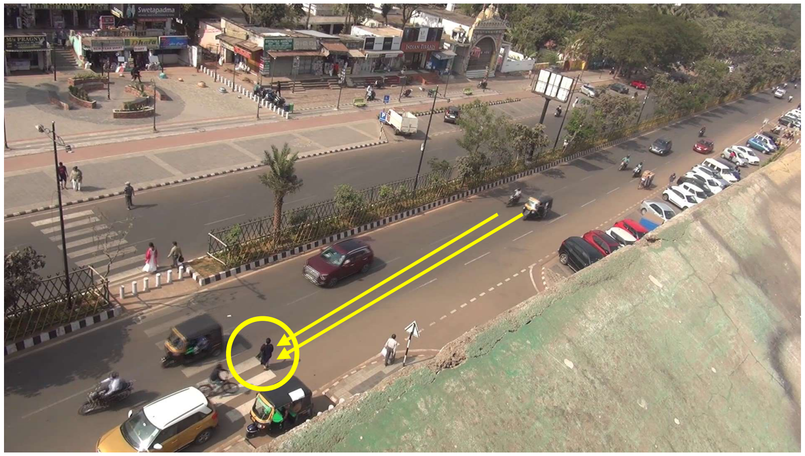




- YOLO
- COCO dataset
- DeepSORT
- MediaPipe

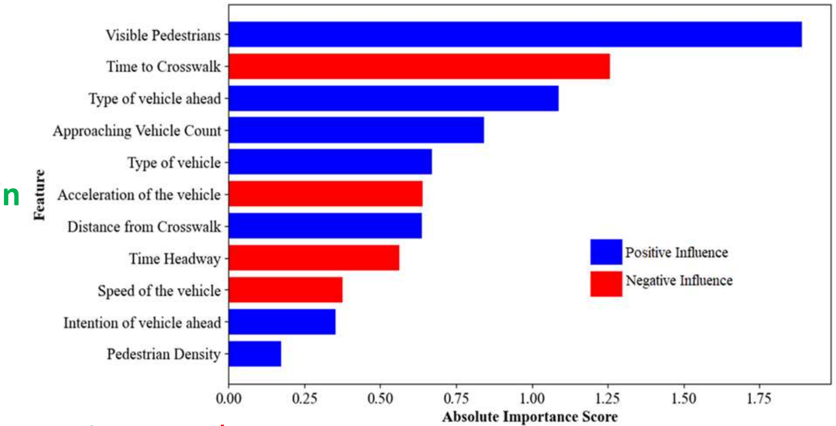
Prediction of Pedestrian Intention

Muduli, K. and **Ghosh, I.** (2023) Prediction of the Future State of Pedestrians While Jaywalking Under Non-lane-based Heterogeneous Traffic Conditions. DOI: 10.1177/03611981231161619, ***Transportation Research Record***, Sage Publications.



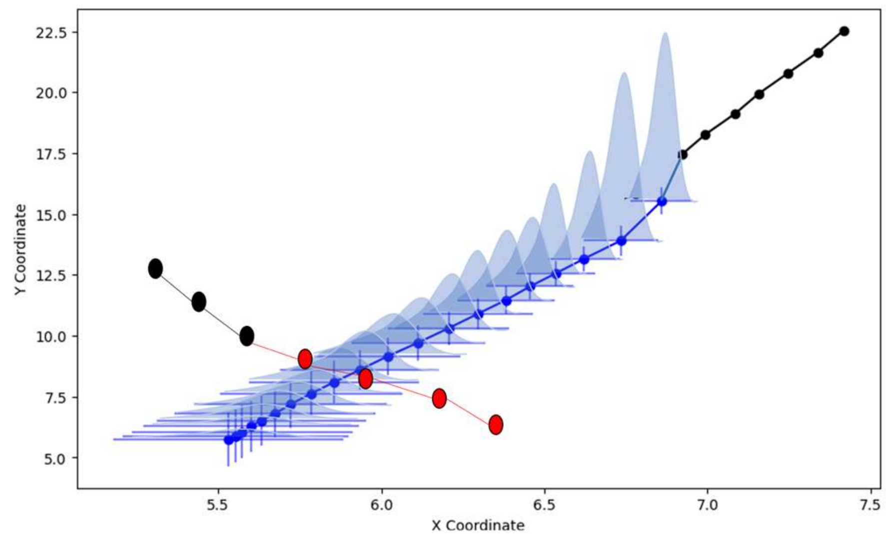
Transformer with Attention Mechanism (Google, 2017)

First application @road safety in Developing Country



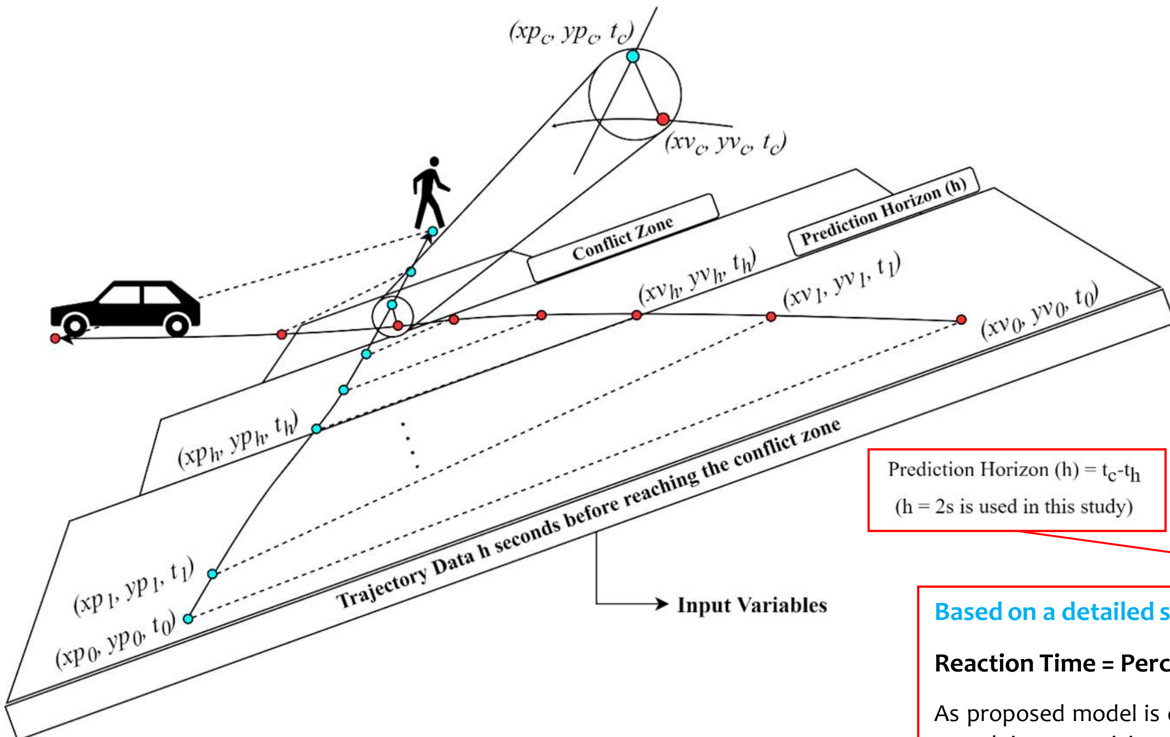
ADAS – higher Level of automation – I2V/I2P

Sequence based Prediction of **Vehicular Yielding Intention**



Muduli, K. and **Ghosh, I.** (2024) Prediction of Vehicular Yielding Intention While Approaching a Pedestrian Crosswalk. 10.1177/03611981241252835, ***Transportation Research Record***, Sage Publications.

Predicting Pedestrian-Vehicle Interaction Severity at Unsignalized Intersections



Prediction Horizon (h) = t_c-t_h
(h = 2s is used in this study)

A typical pedestrian-vehicle interaction

Based on a detailed study by Nie et al. (2021):

Reaction Time = Perception + Decision Time + Execution Time

As proposed model is designed to predict interaction severity, pedestrians no longer need to spend time perceiving and interpreting the situation. This reduces the cognitive load and allows them to focus solely on how to respond.

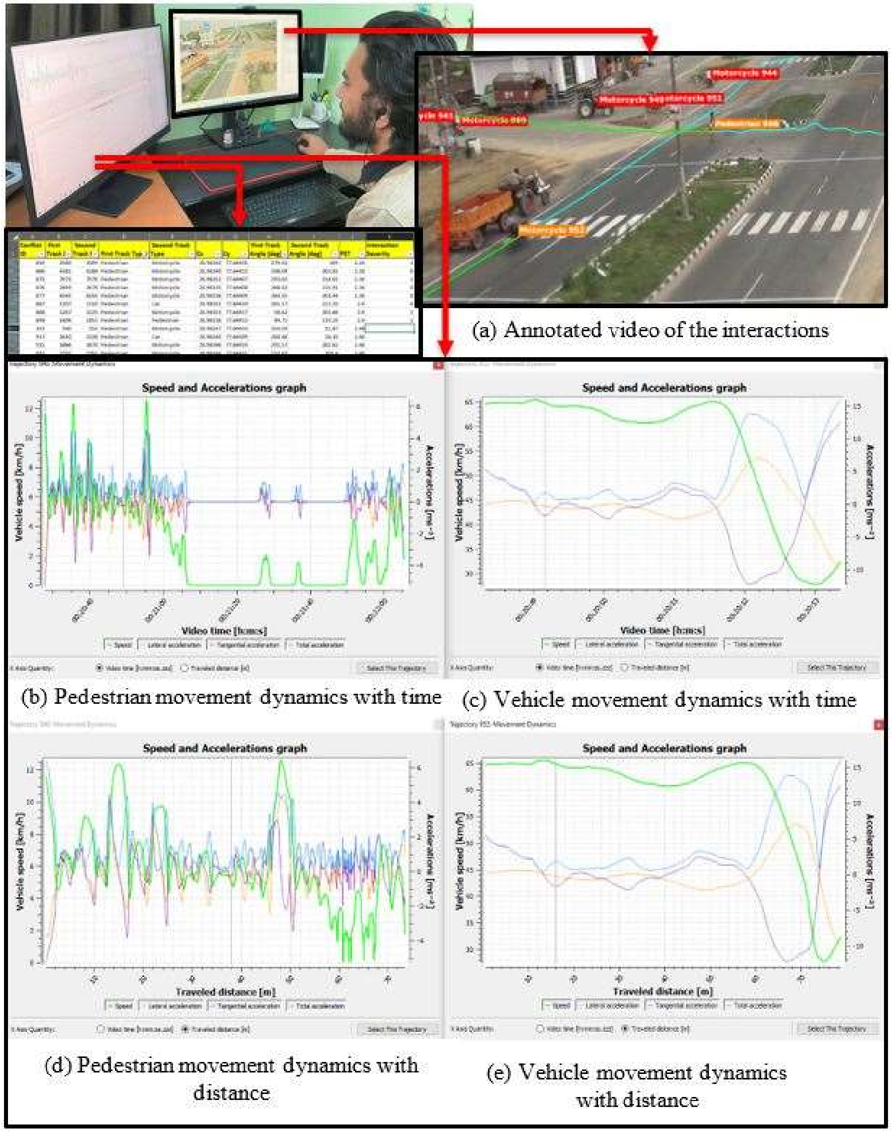
Hence,

Reaction Time = Decision Time + Execution Time

= 0.17+1.52 = 1.69 seconds (**Backward Avoidance Behavior**)

= 0.24+1.84 = 2.08 seconds (**Forward Avoidance Behavior**)

Muduli, K., & **Ghosh, I.** (2025). Predicting Pedestrian-Vehicle Interaction Severity at Unsignalized Intersections. *Traffic Injury Prevention.* Taylor & Francis, (Accepted; Manuscript ID: 249718806)



(a) Annotated video of the interactions

(b) Pedestrian movement dynamics with time

(c) Vehicle movement dynamics with time

(d) Pedestrian movement dynamics with distance

(e) Vehicle movement dynamics with distance

BEHAVIOR OBSERVATION AND INTERACTION SEVERITY ESTIMATION

An AI-powered tool (DataFromSky Viewer) for analyzing trajectories, speeds, and acceleration of road users was used to estimate severity levels.

INTERACTION CATEGORIES

1. **Safe Passage**:
   - No imminent risk, smooth interactions, high PET (>3 sec).
   - Low speeds (≤10 m/s), controlled trajectories.
   - Example: Vehicle yielding or negotiated passage.
2. **Critical Event**:
   - Moderate risk, closer temporal proximity, moderate PET (1-3 sec).
   - Speeds (5-10 m/s), evasive maneuvers, moderate acceleration.
   - Example: Pedestrian withdrawal or acceleration.
3. **Conflict**:
   - High risk, near-misses, low PET (<1 sec).
   - High speeds (>10 m/s), emergency maneuvers.
   - Example: Vehicle acceleration or emergency braking.

OBSERVER TRAINING AND RELIABILITY

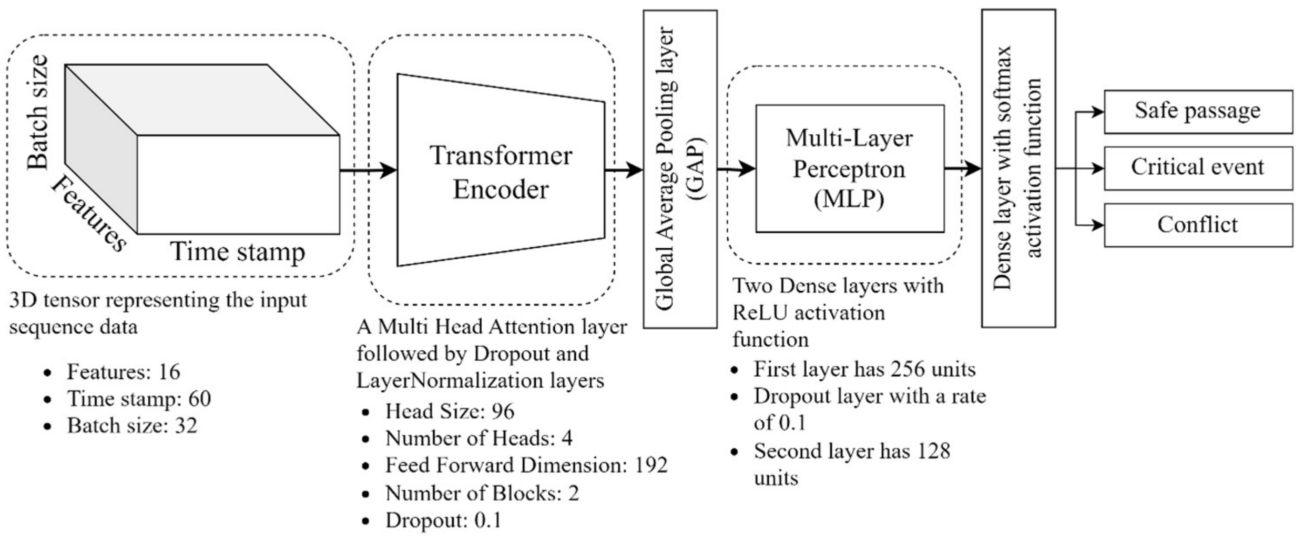
- 6 observers evaluated 4,315 interactions.

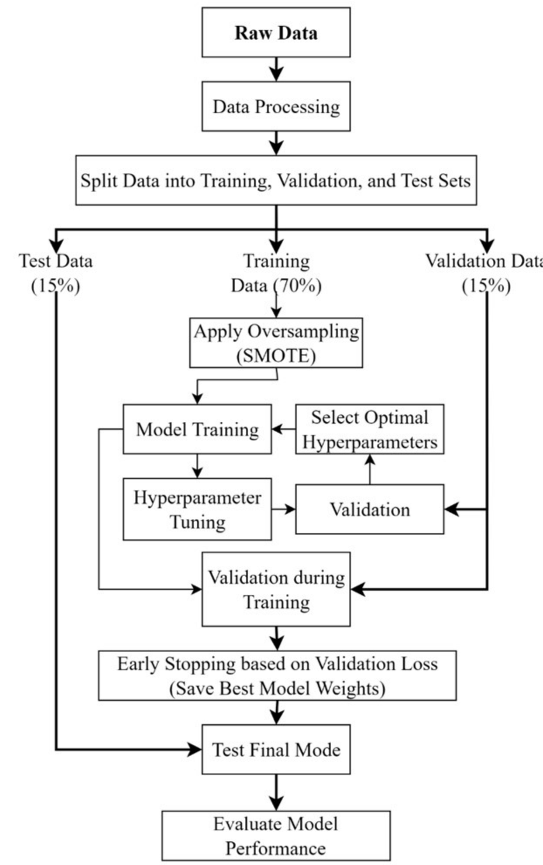
Inter-Rater Agreement:

- Measured using Fleiss Kappa (κ = 0.75)
- Demonstrated substantial agreement beyond chance

Muduli, K., & **Ghosh, I.** (2025). Predicting Pedestrian-Vehicle Interaction Severity at Unsignalized Intersections. *Traffic Injury Prevention*. Taylor & Francis, (Accepted; Manuscript ID: 249718806)

PROPOSED MODEL ARCHITECTURE AND TRAINING PROCESS



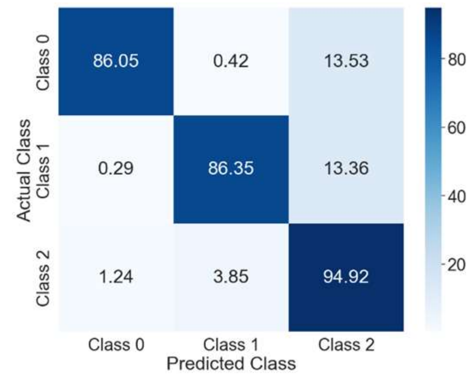


Parameter	Range/Search Space	Optimal Value
Head Size (*H*)	$32 \leq H \leq 128$, $\Delta H=32$	96
Number of Heads (N_h)	$2 \leq N_h \leq 8$, $\Delta N_h=2$	4
Feed Forward Dimension (*F*)	$64 \leq F \leq 256$, $\Delta F=64$	192
Number of Transformer Blocks (*B*)	$1 \leq B \leq 5$, $\Delta B=1$	2
MLP Units (*U*)	{'64_32', '128_64', '256_128'}	'256_128'
Dropout (*D*)	$0 \leq D \leq 0.5$, $\Delta D=0.1$	0.1
MLP Dropout (D_m)	$0 \leq D_m \leq 0.5$, $\Delta D_m=0.1$	0.1

Muduli, K., & **Ghosh, I.** (2025). Predicting Pedestrian-Vehicle Interaction Severity at Unsignalized Intersections. *Traffic Injury Prevention.* Taylor & Francis, (Accepted; Manuscript ID: 24971806)

RESULTS

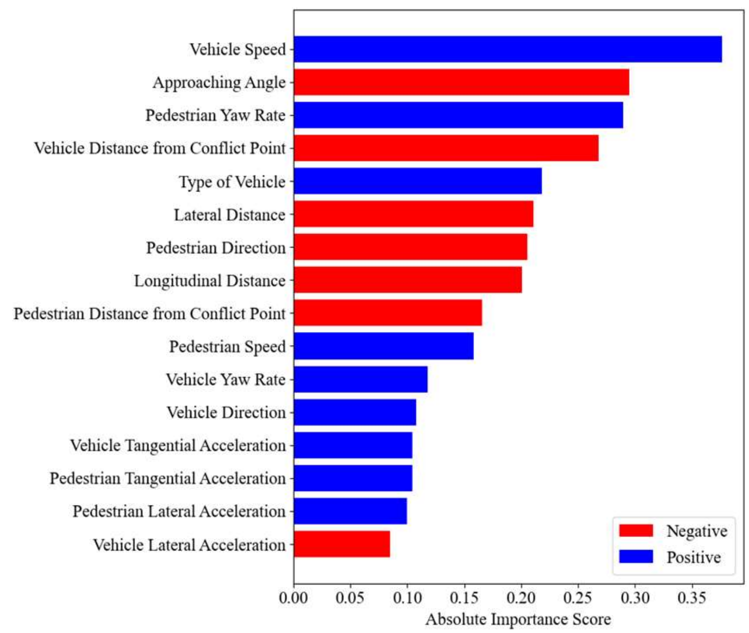
	Precision	Recall	F1-Score
Class 0 (Safe Passage)	0.78	0.91	0.84
Class 1 (Critical event)	0.93	0.85	0.89
Class 2 (Conflict)	0.95	0.86	0.90
Accuracy			**0.87**
Macro avg	0.89	0.87	0.88
Weighted avg	0.88	0.87	0.88



$$A_{ij} = \frac{e^{S_{ij}}}{\sum e^{S_{ik}}}$$

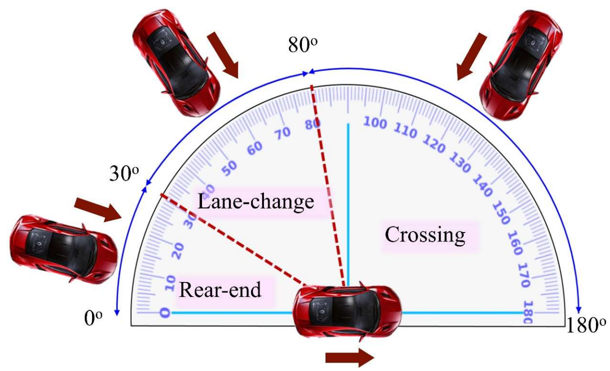
$$S_{ij} = \frac{Q_i . K_j}{\sqrt{d_K}}$$

$$Importance(i) = \frac{\sum A_{ij}}{N}$$

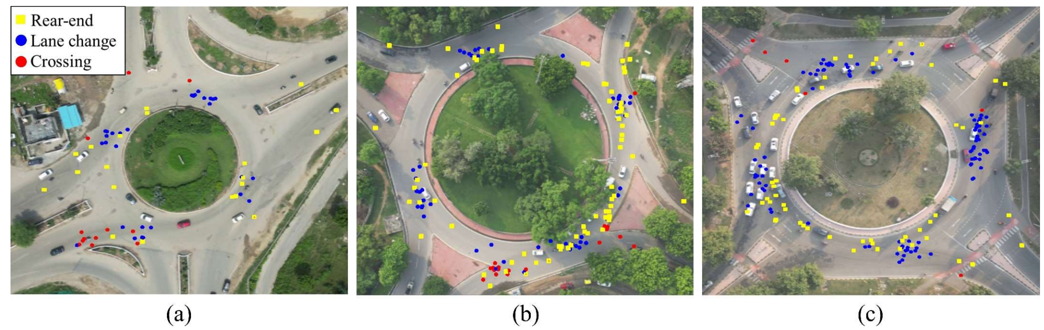


Muduli, K., & **Ghosh, I.** (2025). Predicting Pedestrian-Vehicle Interaction Severity at Unsignalized Intersections. *Traffic Injury Prevention*. Taylor & Francis, (Accepted; Manuscript ID: 249718806)

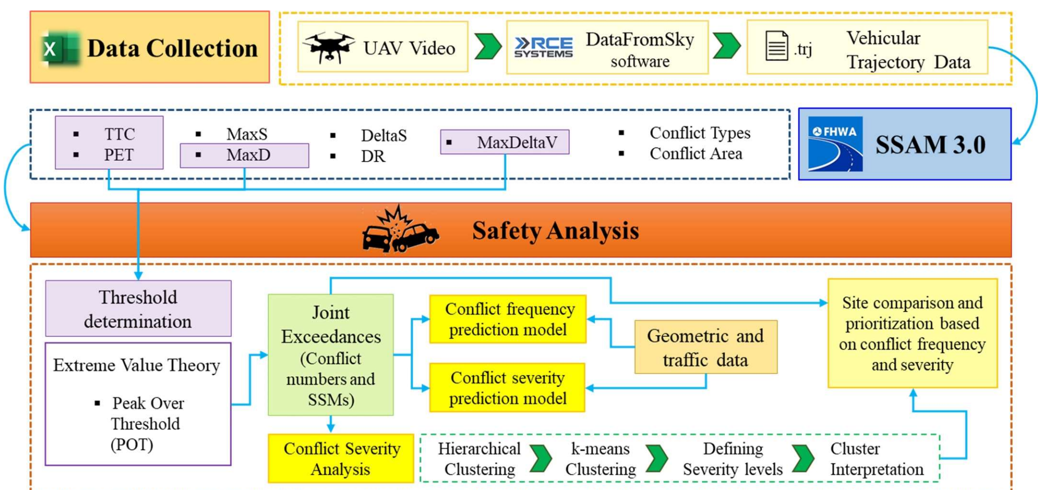
Safety evaluation at roundabout and unsignalized intersections

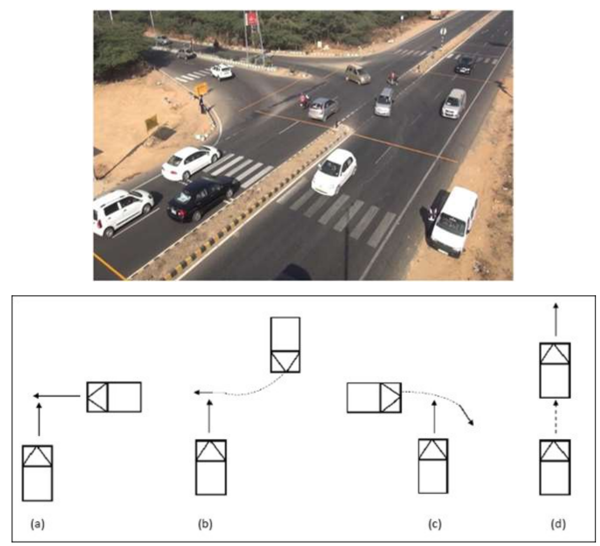


Ranges of conflict angles for different conflict types



Conflict points and their types at (a) Site 1, (b) Site 2, and (c) Site 13





Different types of traffic conflicts at unsignalized junctions on NHs

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Post encroachment time threshold identification for right-turn related crashes at unsignalized intersections on intercity highways under mixed traffic

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ABSTRACT

Unsignalized intersections in developing countries experience many serious conflicts between cross-traffic due to indiscipline traffic manoeuvrability. Historically, Post Encroachment Time (PET) has gained attention as a proximal indicator to analyze crossing conflicts. However, identifying an appropriate PET threshold to classify critical conflicts for highly heterogeneous traffic scenario is still an unexplored area. Consequently, this study proposes a novel approach of PET threshold identification with proof of application by collecting data from ten intersections located on four-lane intercity highways in the National Capital Region (NCR), India. Both crossing conflicts and right-turn related crash data (for the left-hand drive) are collected. Their correlations are thoroughly studied for each PET threshold using a quantitative technique considering all and individual vehicle categories. Finally, a qualitative analysis is done by ranking the sites based on cumulative PET and related crashes to verify the proposed quantitative technique. A PET threshold of 1 s is obtained from both the techniques which can be used to identify critical conflicts for unsignalized intersections located on four-lane intercity highways. The proposed methodology will serve as an alternative, faster and effective tool to evaluate the hazardousness of unsignalized intersections located on intercity highways under highly heterogeneous traffic condition.

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KEYWORDS
Unsignalized intersections; post encroachment time; threshold; crash

Introduction

In the developing economies like India, safety evaluation is a critical task due to highly heterogeneous traffic mix, traffic indiscipline, as well as the absence of standard guidelines for assessing the safety of various traffic facilities. These often lead to less consideration of safety aspects resulting into an excessive number of crashes. With about 1,50,000 deaths annually, India presently has the worst road traffic crash rate worldwide (MoRTH, 2017; WHO, 2018). Although, India is a signatory to Brasilia Declaration and committed to reducing the number of road accidents and fatalities by 50% at the end of this decade, unsignalized intersections are such locations which have consistently proved themselves very unsafe traffic facilities. As per the latest statistics, unsignalized intersections accounted for about 83% of the 1,75,853 crashes and 85% of 53,975 deaths that took place at intersection locations (MoRTH, 2017). These intersections see more traffic conflicts as traffic signals are not present and drivers of self-organizing traffic flow need to take appropriate decision for carrying out various maneuvers. Interestingly, for developing countries, these intersections behave quite differently in comparison to their western counterparts (Paul & Ghosh, 2018). The non-prioritized traffic, that is, minor road traffic, as well as right turning vehicles (for the left-hand drive) from the major road, do not yield to the right-of-way vehicles and undertake risky crossing or turning maneuvers by accepting smaller gaps in between through traffic along major roads. The priorities are basically established by the situations drivers perceive (Ashalatha & Chandra, 2011; Patil & Pawar, 2014; Paul & Ghosh, 2018) and thus these junctions essentially function as uncontrolled ones where vehicles from all the directions attempt crossing and turning at the same time, increasing the probability of crashes. Hence, ensuring safety at such locations is really a critical and challenging task due to the complex nature of traffic.

In order to reduce crashes, safety evaluation has traditionally been carried out based upon police-reported crash data. Traffic crash data analysis can help to understand the overall trend of crash occurrence and identify the major contributory factors that can be valuable to implement relevant countermeasures. However, besides various shortcomings associated with conventional approach (i.e. long observation period, reactive nature, etc.), unavailability of crash data and improper information related to the crash pattern as well as location are quite common for developing countries. In order to address these issues, several researchers have advocated the use of indirect, short-term traffic safety measures which are 'proactive' in nature and being used as an alternative to historical crash data for the reliable and faster safety evaluation (Allen, Shin, & Cooper, 1978; Hayward, 1972; Parker & Zegger, 1989; Perkins & Bowman, 1986). Among various such surrogate road safety measures, traffic conflict has been drawing enormous attention, as

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Development of conflict severity index for safety evaluation of severe crash types at unsignalized intersections under mixed traffic

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ARTICLE INFO

Keywords:
Critical conflict
Severity
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Rear-end crash
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ABSTRACT

Existing proximal indicators lack the capability of addressing the severe implications of a possible collision. This study proposes a conflict severity index (CSI) based on crash risk and expected collision severity for severe crash types at unsignalized intersections on intercity highways. CSI is estimated for critical crossing and rear-end conflicts observed at ten unsignalized junctions using Post Encroachment Time (PET), Delta t (Δt) and the expected loss in kinetic energy (ΔKE). Δt is a newly proposed indicator reflecting the rear-end collision probability, which is the difference between Modified Time to Collision (MTTC) and Time-to-Stop (T_s). To get critical crossing and rear-end conflicts, 'critical speed' and 1.5 s threshold value of Δt are used respectively. The study concept postulates that with the decreasing PET and Δt or an increasing ΔKE, the CSI value increases. The sensitivity analysis shows that for a specific PET or Δt value, CSI increases with the increasing speed of right-of-way vehicle/follower, vehicular mass difference and conflict angle. For crossing conflicts, angle between involved vehicles plays a major role in increasing ΔKE and resulting CSI. Finally, relationships between CSI values of critical crossing/rear-end conflicts and related severe crash types (for left-hand traffic) demonstrate that the proposed index is an appropriate measure to reflect the probable collision severity. This index will be very useful in network screening for safety improvement and reducing the number of crash victims at hazardous locations.

1. Introduction

Reducing the severity of road crashes has been a critical concern for many years. Despite several studies aimed at identifying factors that affect crash injury severity, a thorough evaluation of severity consequences of potential collisions remains difficult using traditional crash data-based methods (Pai and Saleh, 2007; Pai 2009; Das and Abdel-Aty, 2011; Arteaga et al., 2020). Safety research using crash data is logically rational and reliable, but it has some limitations such as i) well-recognized availability and quality issues, ii) a longer observational period, iii) random and rare nature of crashes in a statistical sense, and iv) technique is reactive in nature (Chin and Quek, 1997; de Leur and Sayed (2003); Oh et al., 2010; El-Basyouny and Sayed, 2013; Sacchi and Sayed, 2016; Paul and Ghosh, 2018; Uzondu et al., 2018). These have led to an increased interest in safety diagnosis using traffic conflict technique (TCT) based on several proximal indicators for any roadway facility, including intersections (Sayed et al., 1994; Archer, 2005; Pirdavani et al., 2010; Huang et al., 2013). TCT has several statistical benefits, including a large sample size, short duration, and proactive nature (Amundsen and Hyden, 1977). At present, the majority of proximal safety indicators are utilized to detect traffic conflicts and determine the proximity of crash occurrence in terms of time and space. A few of them are Time to Accident (TA), Time to Collision (TTC), Post-Encroachment Time (PET), Deceleration Rate (DR), Proportion of stopping distance (PSD), etc. These indicators are limited to depict the severity consequences of possible collisions caused by vehicular interactions (Laureshyn et al., 2017). For example, a small TTC or PET value represents a minimal time to collide and a high propensity to convert a conflict in the collision. A similar TTC/PET value for various conflicts represents the same probability of collision occurrence. However, a crash involving small vehicles is very different from a collision resulting in injuries caused by buses or trucks, even though their TTC/PET values are the same. Thus, the severity outcomes of potential collisions should be taken into account.

Few studies have explored the severity consequences of traffic conflicts. Hyden (1987) had first talked about the conflict severity in TCT

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Influence of green signal countdown timer on severe crash types at signalized intersections due to red light violations

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ABSTRACT

Traffic conflicts at signalized intersections caused by red light violations (RLVs) present an enormous danger for severe crashes. This study proactively evaluates the efficacy of Green Signal Countdown Timer (GSCT) on RLVs and resulting right-angle and right turn related crashes (for left-hand driving) using Post Encroachment Time (PET). A before-after (B-A) with comparison group analysis is done considering five 4-legged signalized intersections from Delhi, India comprising of with and without SCT installations. RLV occurrences and maximum violation time during initial 10 s of red are more in the absence of GSCT. Considering various RLV-related characteristics, Powered Two Wheelers (P2W) are found to have the highest exposure in crash involvement for both timer conditions. Finally, B-A method shows 57.74% reduction in crossing conflicts due to the presence of GSCT at the sites. . Accordingly, SCT's installation can be recommended as a cost-effective engineering countermeasure to reduce severe crash types at signalized intersections.

KEYWORDS

Signalized intersection; red light violation; green signal countdown timer; before-after study; post encroachment time

Introduction

Red light violation (RLV) is one of the major factors contributing to motor vehicle crashes at urban signalized intersections. It takes places when a driver intentionally or unintentionally enters into the intersection from one of its approaches at the onset of red and involves in crash with another road user who has the right-of-way (Baratian-Ghorghi, Zhou, and Zech 2016). As per the recent statistics of the USA, an average of 719 people died each year between 2011 and 2015 in RLV-related crashes (American Traffic Solutions [ATSOL] 2017). In Thailand, 1702 red light running crashes at intersections were caused by drivers violating the red light (Kanitpong et al. 2015; Jensupakarn and Kanitpong 2018).

To reduce this non-compliant driving behavior and resulting crashes, several mitigation measures related to geometric changes, change in signal timings, installations of contemporary traffic control devices, e.g. red light cameras (RLCs) have been implemented during the last few decades. Although RLCs have increasingly been used to enforce violations at intersections and discourage a driver running the red light, their presence is found to be associated with a higher number of minor rear-end collisions (Council et al. 2005; Persaud et al. 2005; Baratian-Ghorghi, Zhou, and Zech 2016). In addition, RLCs are not always cost-effectiveness considering their installations and maintenance (Chen and Warburton 2006).

The application of driver warning indicators in terms of distance and time reference aids is currently quite common to help drivers to make their decisions at signalized intersections. In recent years, a cost-effective technological implementation, namely, signal countdown timer (SCT), has become increasingly popular in numerous Asian including India, which operates as a time-warning system. Interestingly, this device was installed in India with the objective of saving valuable fossil fuel when motorists are stuck at the red light. However, their installations at major signalized intersections of several Indian cities have been taken up without examining the safety aspects. SCT's green component, i.e. Green signal countdown timer (GSCT) is found to alter the driving behavior at the end of the green signal (Devalla, Biswas, and Ghosh 2015; Limanond, Prabjabok, and Tippayawong 2010; Chiou and Chang 2010; Fu et al. 2016; Biswas, Ghosh, and Chandra 2017). Simultaneously, its absence or presence may affect the occurrences of RLVs at the starting of red and thereby create the potentials for severe crash types. Among such crashes, the most severe ones are the right-angle and right turn related crashes (for left-hand drive) (Wang and Abdel-Aty 2007; Jin, Wang, and Chen 2010). In this context, the goal of the present research is to assess the safety impacts of GSCT on severe crash types at major urban signalized intersections. For this purpose, this study adopts the before–after (B-A) with comparison group study design based on Traffic Conflict Technique (TCT), which includes five signalized intersections located in Delhi, consisting of both treatment and control sites (i.e. sites with and without SCT respectively).

Of late, TCT has been drawing enormous attention owing to its proactive nature and several drawbacks associated with traditional crash data based assessment (Gettman and Head 2003; Zheng, Ismail, and Meng 2014; Sacchi and Sayed 2016; Paul and Ghosh 2018). TCT monitors the real-time traffic interactions even before the crashes occur and has the benefit of determining the propensity of resulting collisions at any road network including intersections. Its use for short term safety evaluation is well accepted worldwide, although TCT does not show the general trend of crashes and the associated contributory variables. Furthermore, for certain types of conflict, the crash conflict relationship is ambiguous and the correctness of the conversion to expected crash frequencies is doubtful. (Williams 1981; Laureshyn and Varhelyi 2018). Another significant point is that the police record does not always enable for the correct identification of severe RLV crashes. There may be few crashes per year but hundreds of RLV could have occurred at an intersection. Hence, it is essential to

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The effects of green signal countdown timer and retiming of signal intervals on dilemma zone related crash risk at signalized intersections under heterogeneous traffic conditions

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A R T I C L E I N F O

Keywords:
Signalized intersections
Dilemma zone
Green signal countdown timer
Yellow interval
All red
Microsimulation

A B S T R A C T

During yellow intervals, dilemma zones (DZ) often trigger red light violations (RLV) and unexpected stoppings near stop lines, causing severe collisions at signalized intersections. While several studies in developed countries have tested various countermeasures to eliminate DZ, this aspect is not well explored for developing countries. This study investigated a green signal countdown timer's (GSCT) efficacy in reducing DZ at signalized intersections. Based on historical crash data, 10 signalized junctions in Delhi, India, 5 with GSCT and 5 without, were chosen. Although India has a permissive yellow law, all the study sites have a flat 5 s yellow change interval with no provision of all-red (AR) intervals, which might have resulted in severe crashes at these locations. Empirical assessments revealed that GSCT minimizes the length of type-I DZ, which refers to a situation when drivers can neither stop nor proceed to the intersection during the yellow signal. Interestingly, GSCT also minimizes the length of type-II DZ, which is an indecision zone based on drivers' 10% and 90% stopping probabilities. Summation of yellow and all-red intervals (Y + AR) obtained using Institute of Transportation Engineers (ITE) equations was found to be longer than field-allocated 5 s change interval at GSCT-enabled sites. Consequently, GSCT's effectiveness across various yellow and all-red intervals was investigated in the PTV-VISSIM microsimulation tool, and crossing and rear-end conflicts were extracted using Surrogate Safety Assessment Model (SSAM). Results suggest that GSCT's presence, along with estimated yellow and all-red intervals, reduces crossing and rear-end conflicts due to RLVs and inconsistent stoppings, respectively.

1. Introduction

Signalized intersections are critical locations of urban road networks which account for a significant number of severe road crashes. The yellow interval at signalized intersections often produces a dilemma zone (DZ) along the intersection approaches. Within DZ, a vehicle 'cannot cross' the entire intersection with its traveling speed without violating red light or 'cannot stop' safely with a comfortable deceleration (i.e., must stop suddenly). These often result in right-angle, right turn related crashes (for left-hand traffic) and rear-end collisions at signalized intersections. For the yellow interval, different countries have different legal requirements. In the nations where restrictive yellow law exists, ideally, only a yellow interval is given with no provision for an all-red interval prohibiting the entry of drivers at an intersection. However, in regions where the yellow permissive law is followed, drivers can enter the intersection during a yellow light. In the case of permissive yellow law, it is also customary to have an all-red (AR) interval as it provides an extra buffer for vehicles to cross the intersections during the red time (NCUTLO, 1992).

In India, 9,712 crashes took place at signalized intersections in 2019, claiming 2,839 lives, of whom 541 died in crashes due to red light jumping (MoRTH, 2020). Besides red-light violations (RLVs), another prime reason for crashes is found to be sudden stoppings of vehicles along the intersection approaches. RLVs at the starting of the red often induce severe injury/fatal crashes between vehicles violating the red and vehicles from the conflicting traffic stream that recently received

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Suvam Banerjee
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- 1 Joint (Project)

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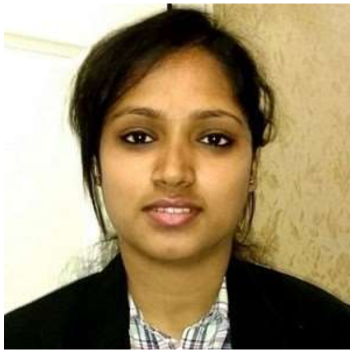

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