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Safety Indicators for Heterogeneous Non Lane Based Traffic- A Case Study at Outer Ring Road-Delhi

M. Bhargav Naidu* and Rishi Singh Chhabra

Department of Civil Engineering, Lovely Professional University Phagwara – 144401, Punjab, India; bhargav.naidu818@gmail.com, rishii.chhabra@gmail.com

Abstract

Objectives: The present research work concentrates on identification and evaluation of safety indicators for heterogeneous and non-lane based traffic. Explore the relationship of identified safety indicators with conflicts and crash potential. **Methods/Statistical Analysis**: Safety analysis is done in preventive point of view. Safety analysis in preventive point of view is to derive safety indicators which help to understand and analyze the crash phenomena. Some surrogate safety measures frequently used are Time to Collision (TTC), deceleration rate, Post Encroachment Time (PET) etc., Three parameters like longitudinal headway, lateral headway and percentage overlap will be evaluated as their use as safety indicator for Indian traffic. **Findings:** Due to heterogeneity and absence of lane discipline vehicle interact with other vehicles in its neighborhood not only in longitudinal direction but also in lateral direction. Using combination of safety indicators conflict event are evaluated. A relation between traffic flow (volume) and conflicts is proposed that is, when traffic flow increases conflicts also increase and vice versa. By drawing a relation between the lateral headway and time to collision in heterogeneous traffic conditions I have concluded that drivers maintaining larger lateral headway have less time to collision as they are not following the car following technique as this is not homogeneous traffic, similarly when the longitudinal headway between vehicles is high then their time to collision is more and hence they are maintaining less lateral headway between them, helping me to find out the no of conflicts being generated in any stretch of heterogeneous traffic, through this conflict data by studying the past accident or crash data a relation will be brought between conflicts and crash phenomena for further improvements. **Application/Improvements:** Safety Indicators applied for heterogeneous traffic conditions helps predicting the road accidents/crashes by analyzing the conflicts preventing the actual crashes and helping in further road safety improvements.

Keywords: Conflicts, Heterogeneous Traffic, Lateral Headway, Longitudinal Headway, Safety Indicators, Time to Collision

1. Introduction

Safety is characterized by the absence of accidents. The term "accident" is usually avoided in order to highlight their predictable and preventable nature: collision or crashes are preferred. Accident is defined as the number of collisions expected to occur at a given location per unit of time, the concept of risk associated with an event involves two dimensions, the probability of the event, and the consequences of the event[1]. For taking any innovative and new remedies for the traffic safety the main disadvantage is lack of predictive models of accident potential, small sample sizes leading to in conclusive results, due to the lack of details to improve understanding of crash failure mechanism, crash avoidance mechanism and manual error occurring while recording crash data, etc[2]. These problems are mainly faced by developing countries than developed countries due to lack of modern equipment or technology.

One of the objectives of safety analysis is to derive safety indicators/surrogate safety measures which help to understand and analyze the crash phenomena[3]. Surrogate safety measure means any conflict that can be correlated with crash rates, and used to measure the severity of con-

*Author for correspondence

flict. Because conflicts occur at a much greater frequency than crash rates, it is possible to assess the safety of a given location without waiting for a large number of crashes to occur[4]. Conflict means a situation in which two road users approach towards each other in such a way that collision is imminent as shown in Figure 1. It can also be defined as, two or more road users approach each other in time and space for such an extent that there is a risk of collision if their movements remain unchanged[5]. Additionally, these measures can be used with micro simulated road networks to assess the safety of proposed roadways and transit projects, experimental roadway designs, or operational strategies before they are built or implemented.

Figure 1. A traffic conflict.

These indicators usually based on threshold values which are calibrated initially. Some surrogate safety measures which are frequently used are Time to Collision (TTC), deceleration rate, Post Encroachment Time (PET), maximum speed, speed differential, merge area encroachments (freeway on ramp merging), variable driver reaction time, etc[6]. These surrogate safety measures available from simulation models are much more detailed than the subjective measures based on human observers.

1.1 Motivation

Most of researches carried out the traffic safety analysis using different statistical approaches, observing accident data, comparing the data before and after implementing the safety measure, anticipatory estimation studies based on safety audits etc. However, several problems have been documented by using these methods. The major drawback with the statistical models (like Regression model or Bayesian estimation) are that they fail to consider driver behavior and a number of related variables that influence the safety level other than the Average Annual Daily Traffic (AADT), speed, etc[7]. For comparisons of data before and after implementing the safety measure, a long observation period is necessary to gather the sufficient information on the occurrence of road accidents[8].

To overcome the above drawbacks, a surrogate safety measures have been proposed based on Traffic Conflict Technique (TCT). Some studies have shown that there is a good correlation between crash rates and conflicts, with the latter occurring at a much higher frequency, given the opportunities to capture the dynamic characteristics on road[9]. Currently, some researchers are paying more attention to improve the traffic micro-simulation models and their capabilities to support TCT for determining surrogate safety measures[10]. Though there is a limited study conducted on surrogate safety measures, traffic micro simulation models have been proven to be a potential tools.

It has been determined that a single or individual safety indicator will not be sufficient to determine a conflict in a traffic stream. As there will be an absence of lanes on the road the vehicles would be continuously interacting with each other in longitudinal as well as lateral directions giving rise to heterogeneous traffic stream[11]. Therefore a combination of safety indicators would be necessary to determine the type of conflict aroused on the particular road stream i.e., an inter relation between safety indicators should be brought in such that the type of conflict arising on the road with heterogeneous traffic conditions will be determined.

2. Methodology

Field data has been collected during peak and non-peak hours of a day for one week and analyzed to explore the relationship between safety indicators (TTC and Stagger) considered for Indian traffic. This chapter is divided in three sections. The first section describes about identification of different parameters and describes how the threshold values of safety indicators are evaluated. Second section describes the details of location of field data collection while the last section describes detailed methodology about data analysis.

2.1 Identification of Suitable Parameters

- Time to collision.
- Post encroachment time.
- Proportion of stopping distance.
- Speed differential between crossing movements.
- Reaction to yellow.
- Variable driver reaction time.
- Variable acceleration and deceleration rate.
- Friendly merging.
- Super elevation.

These parameters (either individually or in a group) are used to define the relationship with traffic conflict in traffic streams considered in the respective study. In the Indian Traffic scenario, vehicles interact longitudinal as well as laterally with a group of vehicles present in its neighborhood. Therefore, vehicle has to maintain a safe distance in longitudinal direction as well as lateral direction with other neighboring vehicles.

Similarly the lateral clearance maintained by vehicles also varies with vehicles stagger. This indicates the relationship between distance gap vs. stagger and lateral clearance vs. stagger. Therefore, it is felt that the individual safety indicators (like TTC, Post encroachment time, and distance headway) might not be sufficient to describe the interaction between vehicles in such stream. Therefore, a combination of distance headway or time headway or TTC with stagger can be explored to describe the conflicts in the Indian traffic streams. Similarly a combination of lateral clearance with stagger is also explored to describe the conflict due to lateral interaction of vehicles.

2.2 Methodology for Evolution of Threshold Value for Conflicts and Serious Conflicts of Proposed Safety Indicators

A combination of safety indicators are required to replicate the Indian traffic safety analysis. So, in the present study, TTC and percentage stagger (safety indicators) are used to evaluate the conflicts between the interacting vehicles[12]. The main entity to determine the conflicts between the interacting vehicles is threshold values. These values play a vital role, which replicates the normal and critical or very critical situation of the vehicles. From the summary of literature review in Section 2.1, the threshold values considered for TTC safety indicator is 5 sec, 4 sec, 3.5 sec and 3 sec. These values considered to replicate normal and critical situation (i.e., conflict) between two vehicles[13]. Threshold values consider to differentiate critical and very critical situation (i.e., serious conflict) of vehicle are 1 sec, 1.35 sec, 1.5sec and 2 sec.

Most of these studies on the TTC safety indicator are done in homogenous and lane discipline traffic conditions. Due to these conditions drivers maintain car following behavior and longer gap between vehicles to vehicle. But in Indian traffic stream, there is no true car following behavior is observed due to weak lane discipline traffic, heterogeneous traffic[14]. Therefore, drivers generally maintain lesser gap between vehicle to vehicle in comparison to homogeneous and lane 29 discipline traffic. In car following situations drivers consistently peep out (i.e., stagger between following and leader vehicles is non-zero) for overtaking opportunity. Considering these conditions, a minimum threshold value of 3 sec is selected for TTC indicator and used to the conflict behavior[15]. To define the serious conflict, a threshold value of 1.5 sec is selected. These threshold values of TTC are valid for zero stagger conditions between leader and follower as shown in Figure 2. As the stagger between vehicles increases, threshold values of TTC decreases to define a conflict situation between vehicles.(10) At maximum stagger, threshold value of TTC leads to zero and vehicle will move on the side of leading vehicle with zero TTC (see the vehicle's position at Point D[16].

Figure 2. The safety pyramid.

Value of maximum stagger depends on the follower and leader vehicle types and their speeds. With the increase in speed, maximum stagger value increases[17].

Minimum Lateral Clearance (L.C.) or threshold values (to replicate normal and critical situation of two laterally interacted vehicles) based on vehicle type and speed characteristics of the interacting vehicles are presented in which were adopted. Similar relationship is also developed between TTC and stagger to define the threshold limits to define serious conflict situations[18]. After development of threshold values of conflicts and serious conflicts for the proposed safety indicators, combination of these threshold values are used to extract conflicts and serious conflicts situations in real world or simulated traffic streams as shown in Figure 3. Conflict and serious conflict situations are defined only when interacting vehicles are below threshold values of both critical situations according to both safety indicators simultaneously as shown in Table 1[19].

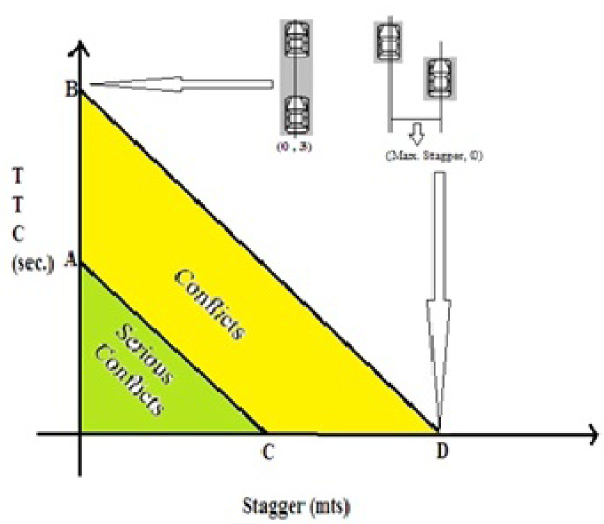

Figure 3. Definitions of conflicts and serious conflict.

3. Results and Discussion

3.1 Location of Field Data Study

Data of real world traffic stream has been collected in the month of March, 2015 at Outer Ring Road – New Delhi by M. Bhargav Naidu, which has six lane divided carriageway (three lanes i.e., 10.5 m width on each direction). The data is collected using video recording method during peak hours (8:00 am to 10:00 am and 5:00 pm to 7:00 pm) to ensure enough lateral interaction between vehicles on that road. A virtual section of 20 m length is marked on the road to obtain the vehicle speed.

A reconnaissance survey of all the road links will be made to see the actual site conditions and the geometrics. The exact survey locations will be frozen after ascertaining that the flow is even and the stretch is divided for a substantial length without any obstructions like bus stops, signals. The video recording technique will be used to collect the data. The place for fixing the camera will also be selected as shown in Figure 4. A longitudinal trap length of about 30 m will be adopted to capture the data for the measurement of speed. Markings were made with paint on the road to fix the trap length. The video camera was mounted on the tripod stand and was placed at a sufficiently high level so as to cover the full survey stretch. The data collection will be done on normal sunny days (working days between Mondays through Friday).

The surveys will be carried out for 1 hour sufficiently long duration to cover both peak and off peak traffic. The timer in the camera will be switched on to have the time recorded. In addition to the traffic data the physical data like carriageway width, footpath width, and adjoining land use will be collected at the survey locations[7].

Table 1. Minimum lateral clearance between interacting vehicles

Vehicle type	Minimum lateral clearance (in meter) at 0 kmph	Minimum lateral clearance (in meter) at 60 kmph
Bicycles	0.1	0.5
Bike	0.1	0.7
Bus	0.4	1
Car	0.3	0.7
HGV	0.4	1
Light Commercial Vehicle(LCV)	0.3	0.7
Three Wheeler	0.2	0.7

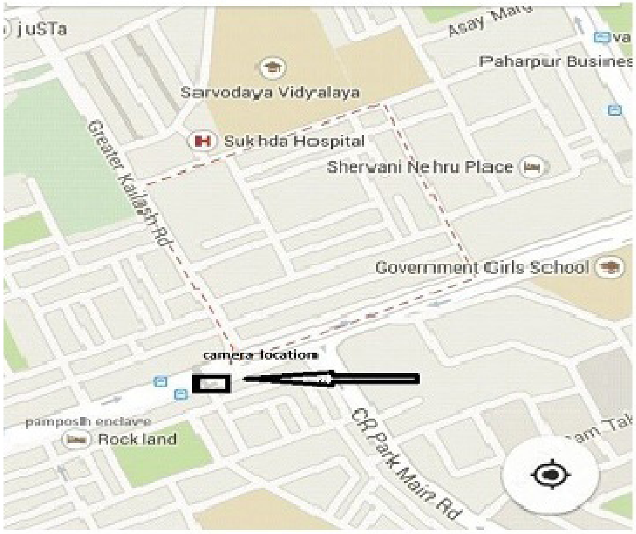

Figure 4. Selected mid-block section for field data collection on Outer Ring Road –Delhi.

3.2 Data Analysis

The collected data from the field is processed manually for collection of data of safety indicators as TTC and percentage stagger. The data analysis was done by following process:

A grid was created which is equally spaced (0.2m) lines and parallel to the road and it is done by using on-screen marker software as shown in Figure 5. Marked grid is overlapped with recorded video such that it matches well with the road edges. Then video is played with grid over it.

Figure 5. Snap shot of analysis of field data by manual method
location near Pamposh Enclave
length of road stretch considered 30 M
width of road 10.5 m (3 Lanes)

Longitudinal and laterally interacting vehicle pair is identified manually and speed of vehicles are determined based on travel time method. Lateral clearance is measured directly by counting the gaps (with accuracy of 0.2 m) with of help of marked grid lines in longitudinal direction (refer Figure 5).

The speed of the vehicles was extracted by time difference between the entry and exit time of the vehicle in the marked section at known distance (20 meters).

The longitudinal headway data was collected by time difference between the two vehicles and it is multiplied with the velocity of following vehicle

$$V_B * (T_{A2} - T_{B2})$$

Where, V_B= Velocity of following vehicle
T_{A2}= Exit time of leading vehicle
T_{B2}= Exit time of following vehicle

The TTC safety indicator was computed based on longitudinal headway and speed difference of the following vehicle and leading vehicle.

$$TTC = \frac{\text{Longitudinal headway} - \text{length of leading vehicle}}{V_A - V_B}$$

Where, V_A= Velocity of leading vehicle
V_B= Velocity of following vehicle

The Stagger was computed based on difference between the lateral positions of interacting vehicles.
The percentage of overlap is computed beaded the following formula:

$$\%Stagger = \frac{Y_A - Y_B}{W + L.C} \times 100$$

Where, Y_A = Lateral position of leading vehicle
Y_B = Lateral position of following vehicle
W = Average width of leading vehicle and following vehicle
L.C = Lateral clearance

From the above process data of safety indicators were extracted from field data.

3.3 Results and Analysis

The traffic safety indicators for heterogeneous and no lane discipline traffic has been identified and Behavior of selected safety indicators are evaluated based on field data. The relationships between safety parameters are also explored.

This chapter is divided into four sections. First section presents the comparisons of speed-flow-density relationship and speed distribution of different vehicle types respectively obtained from field traffic stream. Next section presents the relationship between TTC and percentage stagger values obtained from the field results. Third section discusses the effect of road on safety indicators and last section describes the relationship between traffic flow and conflicts from the field data.

3.4 Comparisons of Speed-Flow-Density Relationship and Speed Distribution of Different Vehicle Types Respectively Obtained from Field Traffic Stream

Various traffic parameters (like speed-flow-density relationships and speed distribution of different vehicle types) are extracted from real world traffic streams characteristics collected from the field. Following two subsections presents the comparisons between speed-flow-density relationship and speed distribution of different vehicle types respectively obtained from field traffic stream.

The basic relations of traffic flow characteristic are density-speed, density-flow and flow-speed relationships which are plotted in Figure 6 based on field. Relation of density-speed is, as the density of traffic stream increases speed of vehicle tends to decreases. A similar trend was observed from

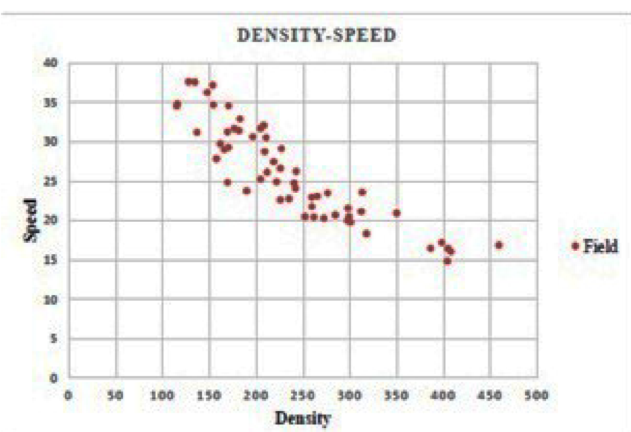

Figure 6. Density – Speed relation from field data.

This shows density-speed relation of field data. The relation density-flow is, as density of traffic stream increases, flow of vehicle tends to 36 increases up to a point and then decreases and, the same was observed from which shows density-flow relation of field data as shown in Figure 6. Flow of vehicle tends to increases up to a point and then decreases trend has not shown because the field data has captured at uncongested traffic conditions. Basic flow-speed relationship shows, as when traffic flow increases speed of the vehicles decreases till it reaches capacity condition of a road for non-congested traffic condition as shown in Figure 7.

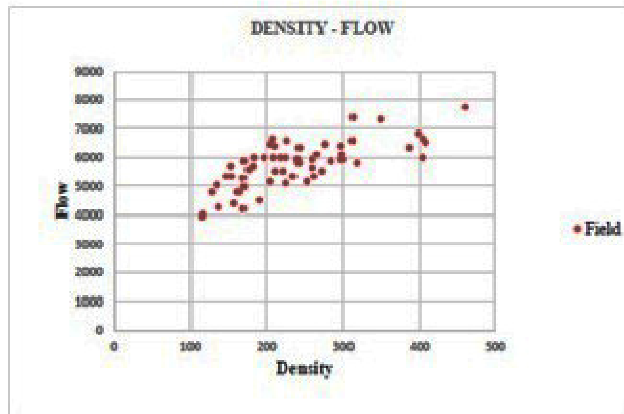

Figure 7. Flow – Speed relation from field data.

3.5 Speed Distribution of Different Vehicle Types using Field Data

Speed distribution analysis of each vehicle types have been carried out from field data and the speed distribution of all the vehicles is plotted having average frequency between 20-40 kmph as shown in Figure 8.

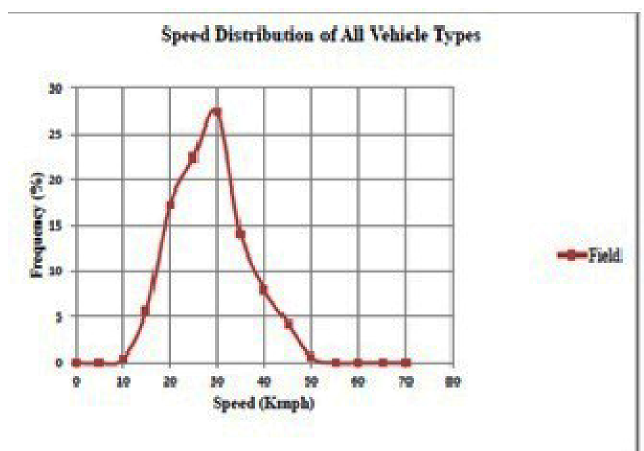

Figure 8. Speed distribution of all vehicle types from field data.

Speed distributions of vehicles from field data are plotted for each vehicle. In speed distribution of cars the frequency is in between 20-30 kmph as shown in Figure 9. In the speed distribution of three wheelers from field data the maximum frequency is in between 20-40 kmph as shown in Figure 10. In the speed distribution of bikes from field data the maximum frequency is in between 20-35 kmph as shown in Figure 11. In the speed distribution of heavy vehicles the maximum frequency is in between 20-40 kmph as shown in Figure 12.

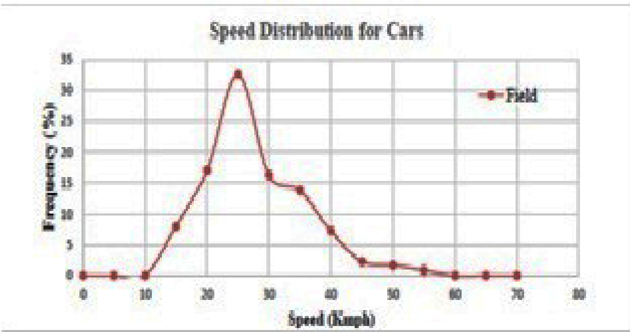

Figure 9. Speed distribution of cars from field data.

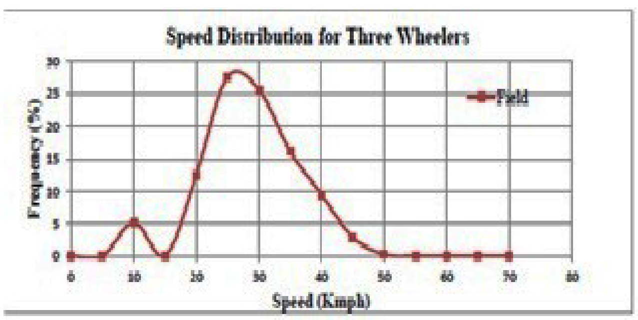

Figure 10. Speed distribution of three wheelers from field data.

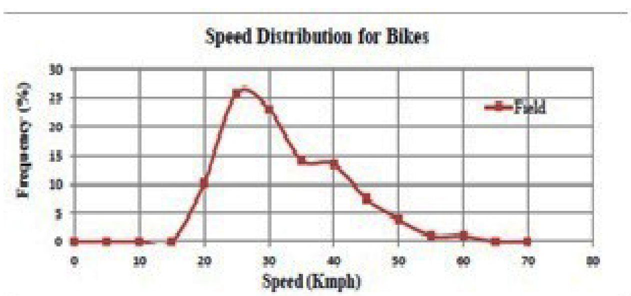

Figure 11. Speed distribution of bikes from field data.

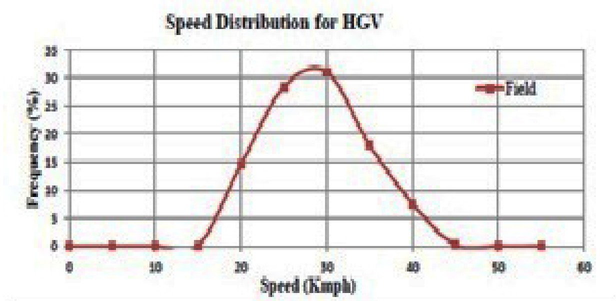

Figure 12. Speed distribution of HGV from field data.

3.6 Relationship between TTC and Percentage Stagger

In previous chapter, it is observed that there is a relation between the TTC and percentage stagger safety indicators. To verify this relationship, various analysis results from field study are determined.

3.7 Relation between TTC and percentage stagger from field data

It is expected that vehicle maintains higher TTC when vehicles are in exact car-following mode (i.e., stagger is zero). As the stagger increases, the TTC maintained between leading and following vehicle reduces[20]. Similar observation is made by. The relationship between TTC and percentage stagger of interacting vehicles of car-car combination[21]. It can be observed that at lower stagger (i.e., near 0% stagger) driver maintains higher TTC in comparison to higher stagger case. It can be seen that at lower percentage of stagger, TTC maintained by the driver increases[22]. This analysis has been done for different interacting vehicle combinations like car-bike, bike-car, auto-car, car-auto, bike-bike etc., All combinations of interacting vehicles are showing similar pattern as in car-car combination, i.e. when percentage stagger is 80-100%, drivers maintain lower TTC value. Similarly when percentage stagger is 0-25%, drivers maintain higher TTC value[23]. This implies that driver of a following vehicle feels safer at higher percentage of stagger and lower TTC value as shown in Figure 13. As the percentage stagger increases, drivers are in better position to veer away from that leading vehicle in a conflicting situation. Therefore, there is lesser threat to their safety in these cases and also keep driving at lesser TTC values[13] also observed the similar trend.

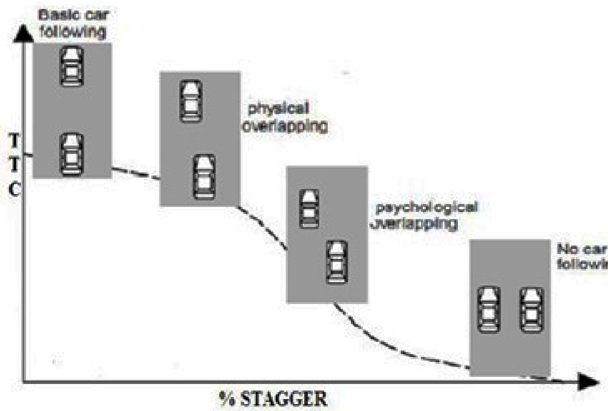

Figure 13. A typical trend of the relationship between horizontal separations of the two consecutive vehicles and the following distance between them.

Similar behavior is observer between TTC and Stagger for all vehicle pair cases.

When the TTC value falls below certain threshold at a particular stagger, it may pose threat for safety i.e., conflict may occur. Conflict and crash rate is having a relation as conflicts in the traffic stream increases, crash rate increases and vice versa[24]. Therefore, the relationship 42 between TTC and percentage stagger can be used to define the conflict events in a traffic stream. This helps in assessing the safety level in a traffic stream which is desired in any safety analysis.

As shown in Figure 14 the relationship between TTC and percentage stagger for a car-car combination

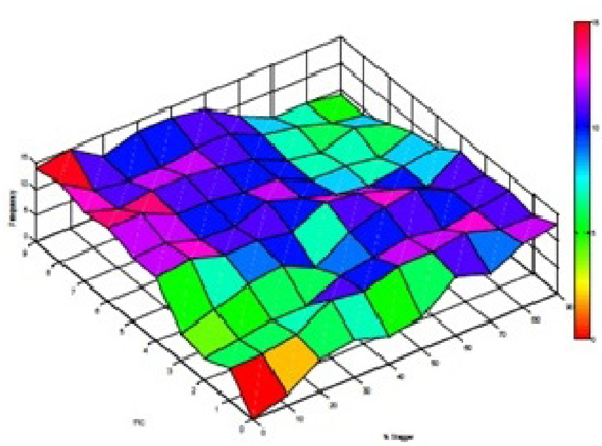

Figure 14. Relation between TTC and % stagger from field data for car-car combination.

interacting vehicles obtained from field data. It can be seen that vehicles maintain higher TTC with lower percentage stagger. Due to less field data, the analysis has done for four other combinations of interacting vehicles, as Car – Bike as shown in Figure 15, Bike – Car as shown in Figure 16, Bike – Bike as shown in Figure 17and Three Wheeler – Car combinations as shown in Figure 18[4] the results for the four combinations are shown in following

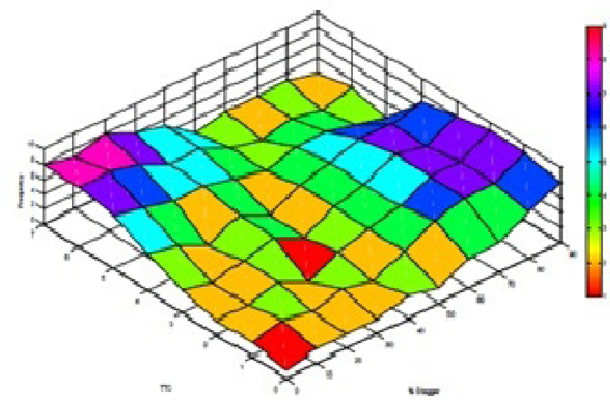

Figure 15. Relation between TTC and % stagger from field data for car-bike combination.

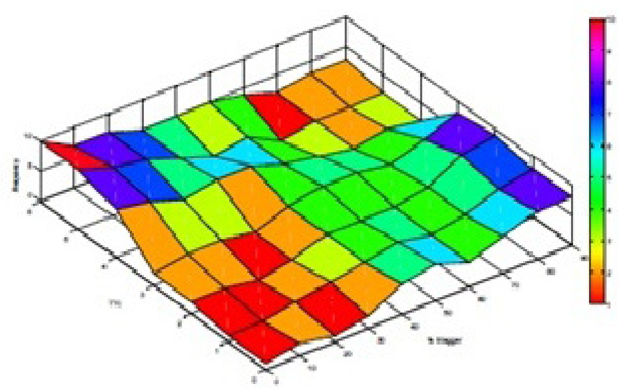

Figure 16. Relation between TTC and % stagger from field data for bike-car combination.

This justifies that there is a relation between these two safety indicators. So, the conflicts can be evaluated by considering both lateral and longitudinal interaction of vehicles in the Indian traffic stream.

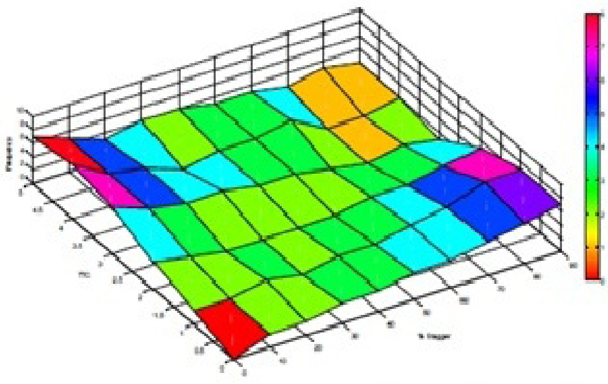

Figure 17. Relation between TTC and % Stagger from field data for bike-bike combination.

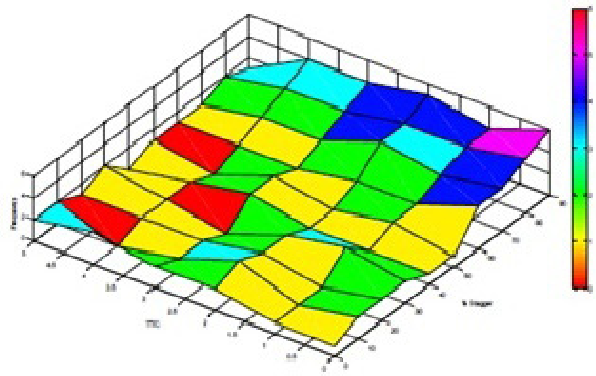

Figure 18. Relation between TTC and % stagger from field data for three wheeler-car combination.

3.8 Relation between Traffic Flow and Conflicts for heterogeneous and Weak Lane Discipline Traffic from Field Data

Similar to relationship observed between flow and number of conflicts in homogeneous traffic condition, the same relationship is explored in heterogeneous traffic condition with vehicle type's cars, bike, HGV, three wheelers, etc. Traffic composition chosen was similar to the field condition.Here, due to heterogeneous traffic the analysis has done for different combinations of interacting vehicles like Car – Car, Car – HGV, Bike – Car, Bike – Bike etc., and after completion of analysis for all combinations of interacted vehicles, the evaluated conflicts and serious conflicts of results are pooled or added.

As traffic flow increases conflicts among interacting vehicles also increase monotonically similar to homogenous traffic case. Because of heterogeneous vehicles, it can be observed that the numbers of conflicts are more at a particular flow level than a homogeneous traffic case as shown in Figure 19.

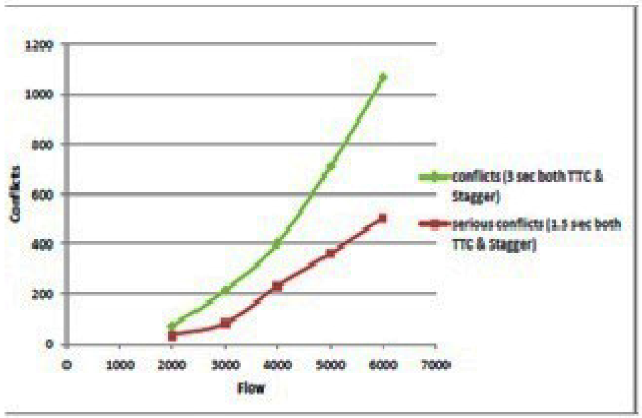

Figure 19. Relationship between traffic flow and conflicts for heterogeneous and weak lane discipline traffic obtained from field data.

It can be seen that the number of conflicts is related to traffic parameter (like traffic volume) and choice of surrogate safety measure used to define the conflicts. With the help of number of conflict, one can do the following:

- By knowing the conflicts of traffic streams, one can develop the accident prediction model for Indian traffic streams by using the relationship between accidents and conflict.
- From these safety parameters, conflicts from the traffic streams can be evaluated and traffic safety can compare between road sections.
- These SSM (Surrogate Safety Measures) not only used for traffic safety analysis, but also used to solve economic problems also.

4. Conclusion

In the present study, suitable safety indicators to define the conflicts are identified and analyzed for different scenarios. Following observations can be made from this study:

- To define the conflict in Indian traffic stream, single safety indicator is not adequate. Therefore, a combination of safety indicator like TTC and stagger are used to define the conflicts in Indian traffic scenario. Combination of TTC and stagger safety indicators is able to account the longitudinal and lateral interaction of vehicle in Indian traffic streams.

- To define the conflict situations, threshold value of TTC reduces with the increase in stagger between participating vehicle pair. Similar behavior is also observed from field data. Threshold values of TTC as 3 seconds and 1.5 seconds at near zero stagger are found suitable to define the conflict and serious conflict scenarios respectively as shown in Figure 19.
- With the increase in traffic flow, number of conflict also increases. It is observed that for 10.5 m wide road, conflicts are less sensitive initially with the increase in traffic flow (up to 4000 veh/hr). However, number of conflicts increases very rapidly with further increase in flow.

5. Future Scope

- Further, more field can be collected to develop a robust relationship between chosen safety indicators.
- After evolution of conflicts and serious conflicts from combination of identified safety indicators, a relation can explore between conflicts and crashes.

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