ABSTRACT

Road safety is an important aspect which requires immediate attention in transportation engineering. Use of safety indicators/surrogate safety measures for traffic safety in transportation engineering has been increasing day to day. Safety analysis can be done in two ways – reactive point of view and preventive point of view. Researchers are more interested in traffic safety analysis with preventive point of view than reactive point of view. Reactive approach needs significant number of detailed crash data analysis, crash frequency, etc., which are quite expensive and also errors can occur while collecting crash data like understanding of crash failure mechanism, manual error in recording crash data, etc. In developing countries like India, it is quite difficult and expensive to get large and reliable crash data base due to lack of funds and technology. One of the objectives of safety analysis in preventive point of view is to derive safety indicators/surrogate safety measures which help to understand and analyze the crash phenomena. 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.

In the past, various works on identification of safety indicators has been carried out for homogeneous and lane discipline traffic in developed countries. However, such studies for heterogeneous and no lane disciplined traffic which exists in India is missing. This motivates to identify the suitable safety indicator for Indian Traffic. Three parameters like longitudinal headway, lateral headway and percentage overlap will be evaluated as their use as safety indicator for Indian Traffic. 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. Data collected from real world traffic stream is evaluated in order to determine the conflicts.

Keywords—Safety indicators, Time to collision, Lateral Headway, Traffic Conflict technique, Post Encroachment time.

I. 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. 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 inconclusive 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. 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. Surrogate safety measure means any conflict that can be correlated with crash rates, and used to measure the severity of conflict. 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. Conflict means a situation in which two road users approach towards each other in such a way that collision is imminent. 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. 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.

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. These surrogate safety measures available from simulation models are much more detailed than the subjective measures based on human observers.

**Motivation**

Most of researchers 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. 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.

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. 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. 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. 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.

**II. METHODOLOGY**

Field data has been collected 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 the 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.

4.1 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. 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. Threshold values consider to differentiate critical and very critical situation (i.e. serious conflict) of vehicle are 1 sec, 1.35 sec, 1.5 sec and 2 sec.

![A Traffic Conflict](image)

The safety pyramid
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. Therefore, drivers generally maintain lesser gap between vehicle to vehicle in comparison to homogeneous and lane 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. 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 the stagger between vehicles increases, threshold values of TTC decreases to define a conflict situation between vehicles. 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 in Figure 4.1). Value of maximum stagger depends on the follower and leader vehicle types and their speeds. With the increase in speed, maximum stagger value increases.

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                                           |
| Bikes                 | 0.1                                           | 0.7                                           |
| Bus                   | 0.4                                           | 1                                             |
| Car                   | 0.3                                           | 0.7                                           |
| GGV                   | 0.4                                           | 1                                             |
| Light commercial vehicle (LCV) | 0.3                     | 0.7                                           |
| Three Wheeler         | 0.2                                           | 0.7                                           |

III. PRIOR APPROACH

Richard van der Horst et al. (1993) had proposed that TTC is an effective measure for rating the severity of traffic conflicts and discriminating the critical from normal driver behavior and it can be directly used as a cue for decision-making in traffic safety. The TTC safety indicator is used in CAS (Collision Avoidance Systems) to define a proper Warning strategy; it warns the driver only when the driver is in danger position to take immediate action to avoid crashes. But too many false alarms may become a nuisance to the driver to avoid this exact threshold value of TTC was determined based on reaction time, deceleration behavior and breaking distance.

Ingrid et al. (2000) concluded that horizontal curves that require speed reductions have higher accident rates than curves that do not require speed reductions. Further, He found that there is a statistically significant relationship between the intervals means accident rate and mean speed 19 reductions on horizontal curves of the road. The mean accident rate increases approximately linearly with the mean speed reduction.

Katja Vogel et al (2002) had taken two safety indicators “headway” and “TTC” to determine the safety at different traffic situation. He had proposed that headway and TTC are independent to each other. The TTC and headway gives different values and it used for different purposes. The headway value can be used for tailgating, because it can easily observe and TTC value can be used to evaluate the actual safety situation. This TTC value can
also use to compare the different traffic conditions, comparing the same driver with and without intelligent transport systems (ITSs) etc. to evaluate safety. He recommended that time headway less than 1 sec and TTC less than 2 sec as critical values with respect to traffic safety.

Douglas et al. (2003) had investigated the potential for deriving surrogate safety measures from other micro simulation methods for intersections. Authors had presented a detailed literature review about modeling of safety at traffic facilities (specially the intersection) using surrogate measures. They had evaluated the capabilities of existing traffic simulation models (like CORSIM, SIMTRAFFIC, VISSIM, HUTSIM, PARAMICS, INTEGRATION, AIMSUNWATSIM, TEXAS) to support derivation of safety indicators. Analysis and validation procedure for surrogate measures of crash from simulation and field data were also devised.

Douglas Gettman et al. (2003) describes the importance of surrogate safety measure and briefly discussed about various safety indicators like Time to collision, Post encroachment time, Deceleration rate, Proportion of stopping distance, Red and yellow violation by phase, Speed variance, Speed differential between crossing movements, Merge area encroachments (freeway on ramp merging), Reaction to yellow, Variable driver reaction time, Variable acceleration and deceleration rate, Speed differential, Vehicle merge location, Traffic flow, Speed, Delay, Travel time, Approach speed, Percent stops, Queue length, Stop bar encroachments, Red violations etc.

Jungwook Jun et al. (2006) evaluated the individual driving behavior activity patterns based on crash involvement status using safety indicators travel mileage, speed patterns, and acceleration 20 activities. Driving activity of large fleets of vehicles over long-time data was collected by mobile technology and global positioning systems (GPS). It is concluded that crash-group drivers usually had traveled longer mileage, had traveled at higher speeds than non-crash drivers, and had frequently engaged in hard deceleration events compared to non-crash group drivers.

Gerdien et al. (2006) describes an ongoing research project at TNO in the Netherlands for assessing the safety of intersection traffic using micro-simulation techniques. In this micro simulation models explains relationship between microscopic traffic flow characteristics and accidents, can be established using the concept of surrogate safety measures. Surrogate safety measures rely on the idea that accidents evolve from conflicts. Surrogate safety measures used for this are the time to collision (TTC) and post encroachment time (PET). Surrogate safety measures reflect the safety of a facility. Overall study describes that as the critical gap decreases the TTC decreases and PET decreases.

Francesco Bella et al. (2011) had created a new algorithm for Collision warning and collision avoidance systems to assist drivers to avoid rear-end collisions. Its main function is when the vehicle was in danger or critical position the alarm will on and alerts the driver, by giving enough time to driver to avoid the crash. For effectiveness of this algorithm and avoid the false alarms he had analyzed the driver’s behavior by taking a sample of 32 drivers according to CRIS Driving Simulator. He took their behaviours at different traffic conditions at two-lane rural road. Based on the risk perception by driver’s (deceleration, speed and reaction time) he had proposed the critical value of TTC 1.35 sec.

Richard van der Horst explained the use of safety indicators, advantages of time relates safety measures and develop sound criteria for the distinction between normal and critical behavior. He had proposed TTI (Time to Interaction) safety indicator based on TTC. This safety indicator used at intersections. He used videotapes for analysis to distinguish between normal and critical behavior. He proposed if TTC is less than 1.5 sec as critical behavior based on deceleration and speed.

Beshr Sultan et al. (2012) had observed driver behavior at emergency braking situations and proposed threshold value of TTC as 4 sec to autonomous ACAS warning system. The threshold value of TTC proposed based on, reaction time of driver, deceleration behavior and braking system of vehicles. For this experiment 6 experienced drivers with TRG instrumented vehicle had used and instructed to follow a ‘dummy’ vehicle and subjected to brake suddenly at three different speed levels (60, 45 and 30 mph). Through this he collected the detailed information about driver behavior like relative speed, spacing distance, pedal movement, and speed and deceleration levels and proposed the threshold value.

IV. OUR APPROACH

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). Figure 4.2 presents line map of the location. 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. 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.

| Length of Road Stretch Considered | 30 M |
|----------------------------------|------|
| Width of Road                    | 10.5 m (3 Lanes) |

**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 4.3. Marked grid is overlapped with recorded video such that it matches well with the road edges. Then video is played with grid over it.
- 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 help of marked grid lines in longitudinal direction (refer Figure 4.3).
- 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

\[
\text{Longitudinal headway} = V_f \times (T_{42} - T_{52})
\]

Where, \( V_f \) = velocity of following vehicle.
\( T_{42} \) = exit time of leading vehicle.
\( T_{52} \) = 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.

\[
\text{TTC} = \frac{\text{Longitudinal headway}}{V_4 - V_5} = \frac{V_4 - V_5}{V_4 - V_5} = 1
\]

Where, \( V_4 \) = velocity of leading vehicle.
\( V_5 \) = 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:

\[
\% \text{Stagger} = \frac{W - L.C}{W} \times 100
\]

Where, \( L.C \) = lateral clearance.
From the above process data of safety indicators were extracted from field data.

**Results & 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.

**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 7.1, 7.2 and 7.3 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 7.1 which 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 Figure 7.2, which shows density – flow relation of field data. 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.

**Speed Distribution of different vehicle types using field data**

Speed distribution analysis of each vehicle types have been carried out from field data. In Figure speed distributions of vehicles from field data are plotted for each vehicle types.
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.

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. Similar observation is made by Gunay (2007). The relationship between TTC and percentage stagger of interacting vehicles of car-car combination. 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. 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. This implies that driver of a following vehicle feels safer at higher percentage of stagger and lower TTC value. 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. Gunay (2007) also observed the similar trend as shown in Figure 7.1. 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. Therefore, the relationship 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.
shown in following Figures. 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.

**Relation between TTC and % Stagger from Field Data for Car - Car Combination**

**Relation between TTC and % Stagger from Field Data for Car - Bike Combination**

**Relation between TTC and % Stagger from Field Data for Bike – Car Combination**

**Relation between TTC and % Stagger from Field Data for Bike – Bike Combination**

**Relation between TTC and % Stagger from Field Data for Three Wheeler – Car Combination**

**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. Figure 6.34 shows that 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.
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 conflicts, 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.

V. CONCLUSION

The goal of this project is to identify the safety indicators for heterogeneous and no lane discipline traffic stream and evaluate the conflicts from the safety indicators. Literature review yields many safety indicators like time to collision (TTC), deceleration rate, post encroachment time (PET), maximum speed, speed differential, merge area encroachments, variable driver reaction time, etc. which are generally used for homogeneous traffic stream with lane discipline. Therefore, in such streams, vehicles interact not only with their leading vehicle but also with the vehicles presents on their sides. In the present study, suitable safety indicators to define the conflicts for such stream 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.
- With the increase in traffic flow, number of conflicts 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.

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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