An Innovative Methodology for Evaluation of Signalized Intersection Safety

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Abstract: Signalized intersections are the important points or nodes inside a system of highways and streets. To explain some measure of effectiveness to evaluate a signalized intersection or to explain the standard of operations could be a tough task. Saturation flow is a very important parameter within the capacity analysis of signalized intersection. The ability to predict saturation flows is important to the design of signalized intersections to avoid congestion from occurring. Saturation flows are often measured directly in the field using standard strategies or expected from other known factors for a new signal installation. As the project could be a large health campus including emergency services, it's necessary to assess its accessibility at these intersections by determining the levels of service (LOS), which is that the objective of this study. The estimation of LOS for a signalized intersection needs the determination of management delay which has uniform, incremental and initial queue delays.

***Index Terms* – signalized intersection, control delay measurement, level of service.**

Introduction

In the race of development in every sector all over the world, lack of safety may cause huge loss of wealth and people. India is the second largest developing economy of the world. Among all the sectors, transportation sector plays important role in the development of any country. Three modes of transportation are generally used for the movement of people and goods viz. Rail, road, and airways. In this study we are interested to discuss the various problems and their solutions related to road safety. Intersections are the most dangerous locations in any road network. Especially in any urban road network, functioning of signalized intersection affects the overall efficiency of the entire transport system of the city. Hence it is necessary to identify all the major and minor factors which are responsible for enhancing the road safety at these locations. Many studies have shown that intersections are among the most dangerous locations of a roadway network, since intersections are the planned point of conflict in any roadway system, hence it is required to ensure all the safety aspects at these locations.

1.1Signalized Intersections

Due to the rapid increase in number of vehicles, number of accidents also increased. Frequent traffic jam causes the unwanted delay. At the junction such type of situation creates problems to not only the motorized road user but also to pedestrians. To overcome from such type of problems signalization of the junction is introduced. Signalization of intersection provides safe opportunity to the pedestrians and cyclists to cross over the road. Signalized intersection is the common space of all the crossing roads at an any location which is controlled by providing the electrically operated traffic control devices. The primary purpose of providing signals is to enhance the traffic movement at the junction and to ensure the traffic safety at conflict points over common space by enabling right of way and shared use of road space to all the road users (e.g.-Pedestrians, Bicyclists, Motorists and transit users). If this space is left uncontrolled than there is a major chances of conflicting the different traffic streams. Signalization is one of the ways to control this space. Basic terms related to signalized intersections are signals, stop line, cross walk, traffic lanes, green phase, red phase, amber phase, signal cycle, divider, channelization etc. Since timings of movements of different streams are separated at signalized intersection, the chances of their conflicting gets reduce. Provision of different traffic lanes allows us to design the signalized intersection for accommodating different varities of vehicles. Off road path separates the cyclists and pedestrians from the motorized traffic queue as shown in the figure 1 below. Right turning traffic creates dangerous situation on a general unsignalized intersection which ultimately increases the chances of accidents and frequent traffic jam. Provision of different turning lanes and separation of movement timings, reduces such types of problems at signalized intersections. Figure 1 shows a typical four leg signalized intersection. Safe path for cyclists and pedestrians can be seen in the figure below. Among different types of intersections, signalized intersections are expected to provide efficient traffic movement and to improve traffic safety. Nevertheless, severe crashes still occur at signalized intersections. (Polders E. et al 2015). Various crash patterns that occur at signalized intersections are rare end collision, side sweep; right angled collision and right turn collisions. Different crash patterns and the conditions of their occurrence are discussed below.

I. CRASH PATTERN AT SIGNALISED INTERSECTIONS

Among deferent types of intersections, signalized intersections are expected to provide efficient traffic movement and to improve traffic safety. Nevertheless, severe crashes still occur at signalized intersections. (Polders E. et al 2015). Various crash patterns that occur at signalized intersections are rare end collision, side sweep; right angled collision and right turn collisions. Different crash patterns and the conditions of their occurrence are discussed below.

Figure 1 A typical 4 leg Signalized Intersection

Rare end collision

Rare end collisions generally occur near the stop line. Since during red phase of signal all vehicles are forced to stop behind the stop line in such condition there is a possibility that a free moving vehicle may collide with the already stopped vehicle. Another condition of rare end collision arises when there is a gradient on the approach road. Figure 2 shows the rare end collision.

Figure 2 Rare end collisions

Right angled collision

This type of crash generally occurs during the amber phase of any one traffic stream. Some times during the last few seconds of amber time driver tries to cross the intersection at the same time vehicle of other stream starts moving towards the junction in such situation there are major chances of right angled collisions. Figure 3 shows the right angled collision.

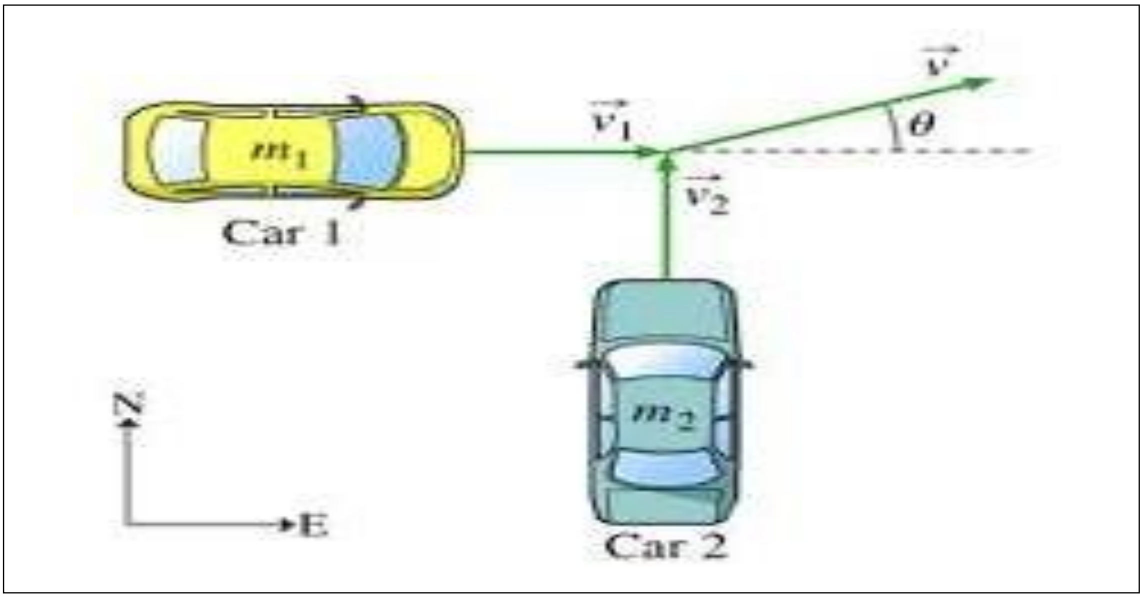

Figure 3 Right angled collision

Sideswipe collision

During the red phase of signal every vehicle is forced to stop behind the stop line. As the green light turns on all the vehicles starts moving simultaneously. In such situation there is a possibility of side sweep collision. Figure 4 shows the side sweep collision.

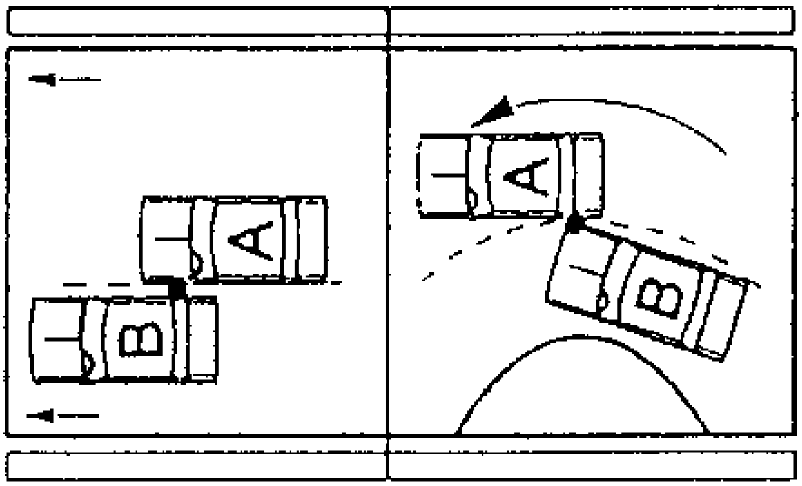

Figure 4 Sideswipe collision

Right turn collision

Right turning collision is the most frequently occurring crash at the signalized intersection. Since right turning traffic directly affects the movement of straight through traffic and generates the conflict points. To avoid such type of crash a separate lane should be provided towards left side of the approaching lane so that right turning traffic does not affect the movement of straight through traffic. Figure 5 shows the right turn collision.

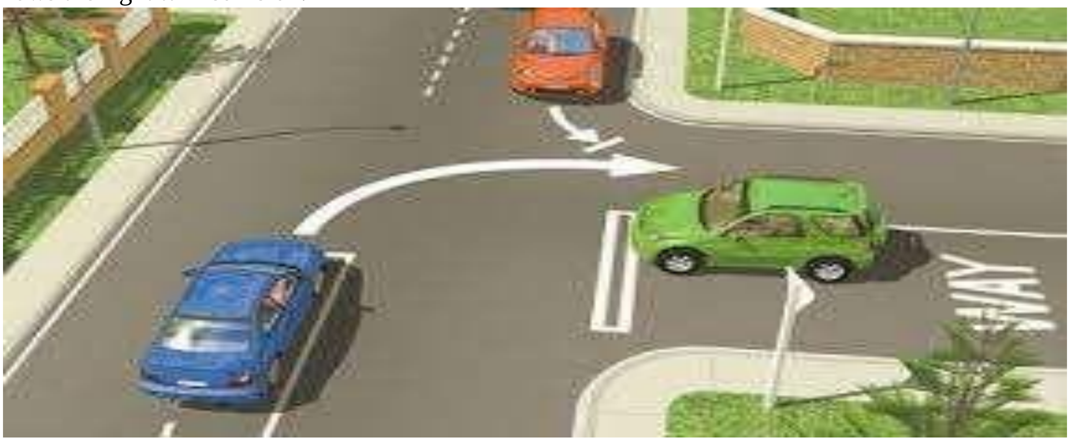

Figure 5 Right turn collision

II. METHODOLOGY

Evaluation of Safety at Signalized Intersection

The main objective of this section is to develop a methodology for evaluation of safety at signalized intersection. To achieve this objective with minimum complexity and easier way of presentation the work is divided into three major steps viz. Identification of factors, Evaluation of factors affecting safety at signalized intersections and Development of safety index. The breakdown of the work is discussed below in detail with the help of Framework. Developed methodology will be useful for evaluation of safety of new proposed signalized intersection and it can also be used for comparing two or more signalized intersections as far as safety is concern.

Framework for Proposed Methodology

There is a need to develop a comprehensive methodology for evaluation of safety at signalized intersection. The objective of this section is to develop a framework for the proposed methodology for evaluation of safety at signalized intersections, also the brief introduction and details of each stage is discussed in this section. Figure 6 presents the framework for proposed methodology.

Based on the framework four major stages identified to evaluate the safety at signalized intersections are summarized as follows:

- Stage I: Development of a hierarchical Structure to identify critical factors affecting safety at signalized intersections.
- Stage II: Determination of relative importance of identified hazardous factors.
- Stage III: Assessment of signalized intersection safety hazardous factors.
- Stage IV: Evaluation of overall weighted hazardous factors at signalized intersection by developing signalized intersection Safety Index (SISI).

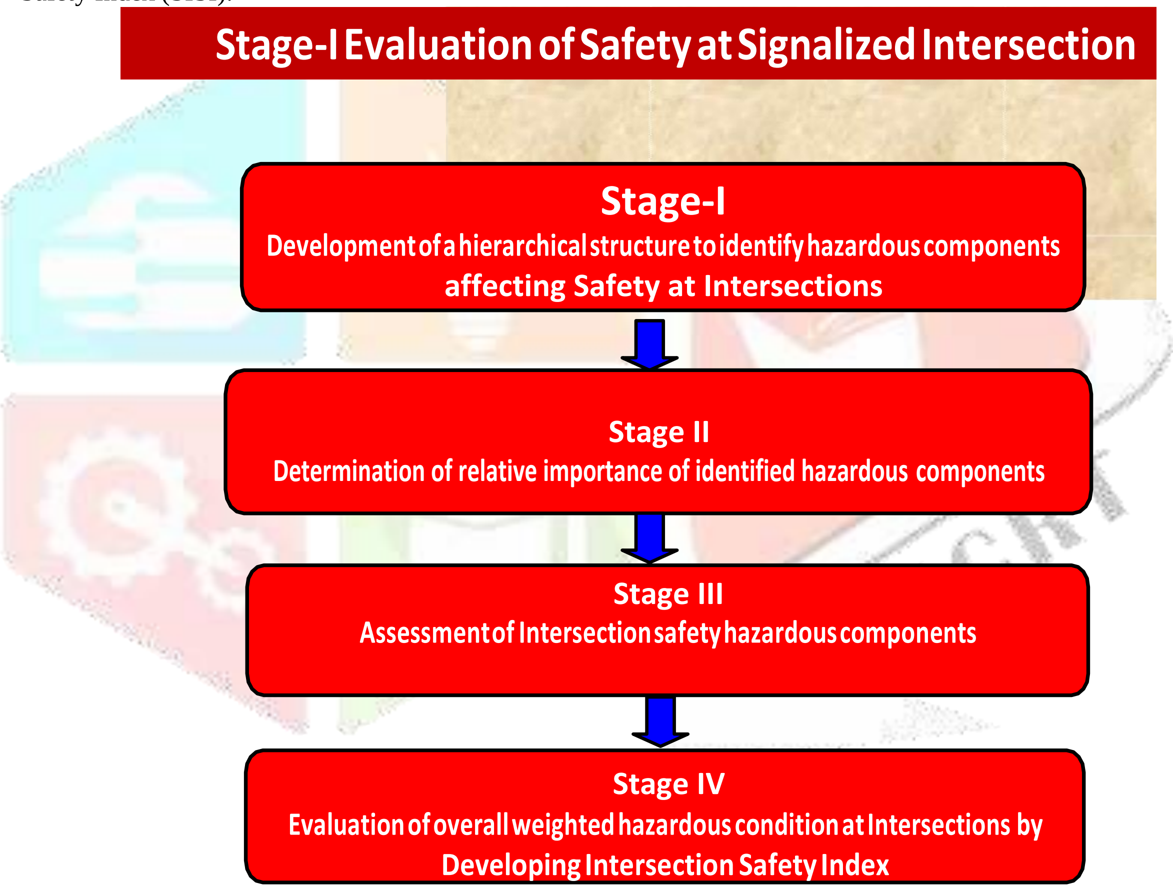

Figure 6: A Framework for Proposed Methodology for Ranking Road Safety Hazardous Locations

Stage I: Development of a hierarchical structure to identify hazardous factors affecting Intersection Safety

The first stage of this proposed methodology is to develop a hierarchical structure to identify hazardous factors affecting safety at Intersections. A hierarchical structure is needed to be developed to identify hazardous factors affecting Intersections safety in a well-defined hierarchy manner so that all hazardous components can be identified. An overall hierarchical structure is developed to identify hazardous components in Intersections. Therefore, first an Intersection is decomposed in to different factors i.e. (i) Geometrical Safety Hazards (ii) Traffic Operational Safety Hazards. Further, separate hierarchical structures are developed at each condition factors in a comprehensive manner so that all hazardous factors affecting Intersections can be identified. This stage of this proposed methodology is to identify hazardous factors affecting Intersections safety. The basic purpose of this stage is to provide lists of hazardous factors to guide highway engineers to evaluate the condition of these identified hazardous factors to improve safety at Intersections.

Stage II: Determination of Relative Importance of Hazardous Components

Second stage of the proposed methodology is to determine the relative importance of hazardous factors affecting Intersections safety. The hazardous factors may not equally affect the safety of Intersections. The relative weight of each hazardous factor is determined using expert opinion using questionnaire survey by Analytical Hierarchical Process. Method of determining the relative weight of different factors is explained in previous chapter. A system of weights therefore needs to be introduced to reflect the contribution to the Intersections safety. Therefore the objective of this stage is to determination of relative importance of identified performance indicators using Analytical Hierarchical Process.

Stage III: Assessment of Intersections safety Hazardous components

Third stage of the anticipated methodology is to assess the hazardous condition of different hazardous factors affecting Intersections safety. In this stage, safety hazardous condition index is developed for each hazardous component at Intersections. Condition indices for each hazardous factor are developed in such an approach so that the value obtained should be lie between zero to one. Where zero indicates the safety at its highest level and one indicates minimum safety.

Stage IV: Evaluation of Overall Weighted Hazardous Condition at Intersections by Developing Intersections Safety Index

Fourth stage of the proposed methodology is to evaluate the overall safety hazardous condition at Intersections. In this stage an overall Intersections Safety Index ($RSI_{ER,)}$) is developed at existing Intersections to evaluate the safety level at a particular intersections. Intersections Safety Index lies between zero to one. Value of Intersections Safety Index equal to one shows the least safe Intersections. And value of Intersections Safety Index equal to zero shows the safest Intersections.

Table 1: List of identified Signalized intersection Safety Hazardous Components

S.No.	Hazardous Component ID	Hazardous Component	Notation
1.	IHC-1	Gaps-in-median	GM
2.	IHC-2	Inadequate Entry Angle	IEA
3.	IHC-3	Inadequate Entry Radius	IER
4.	IHC-4	Level of Service	LOS
5.	IHC-5	Poor Lighting	PL
6.	IHC-6	Slow Moving Vehicle Composition	SMVC
7.	IHC-7	Non-Motorized Transport Composition	NMTC
8.	IHC-8	Traffic Signs	TS
9.	IHC-9	Absence of Cross Walk	ACW
10.	IHC-10	Narrow/No shoulder	NS

Assessment of Hazardous Condition of Different Hazardous Component at Signalized intersection

In this section, a methodology is developed to evaluate hazardous condition of different hazardous components. In the view of simple methodology, condition indices are developed to measure hazardous condition of different components. Condition indices are developed in such a manner so that field engineers can evaluate hazardous condition without using sophisticated equipment. The value obtained from the condition indices lies between Zero to one. Concept of value obtained between Zero to One is to compare the condition of a hazardous component at different locations. "One" value presents least safety at Signalized intersection and "Zero" suggests safest condition at signalized intersection.

Table 2 Related Weights Obtained for Safety Hazardous Components at Signalized Intersections

S. No.	Hazardous Component ID	Hazardous Component	Notation	Local Weight	Global Weight
1.	IHC-1	Gaps-in-median	GM	0.42	0.092
2.	IHC-2	Inadequate Entry Angle	IEA	0.58	0.382
3.	IHC-3	Inadequate Entry Radius	IER	0.25	0.077
4.	IHC-4	Level of Service	LOS	0.36	0.066
5.	IHC-5	Poor Lighting	PL	0.32	0.096
6.	IHC-6	Slow Moving Vehicle Composition	SMVC	0.36	0.090
7.	IHC-7	Non-Motorized Transport Composition	NMTC	0.15	0.054
8.	IHC-8	Traffic Signs	TS	0.29	0.023
9.	IHC-9	Absence of Cross Walk	ACW	0.68	0.090
10.	IHC-10	Narrow/No shoulder	NS	0.39	0.030
Total				3.8	1.00

IHC-1Gaps-in-median

In different road sections like signalized intersection, gap between lanes and pedestrian and crosswalk and given the median serves as a storage space for the left turning and the through movement traffic from the minor road. U-turns at median openings are utilized as an option to administer left turns keeping in mind the end goal to lessen clashes and enhance movement operation along divided arterial streets when the volumes on both directions are high. At median openings has been broadly utilized as a part of the outline of a divided arterial road. Left turn departure onto the main street is disallowed in a few outlines of the arterial roads. As an option, turn bays at medians ahead of time of signalized intersection is provided to oblige these developments.

$$GM_{ESI} = \left|\frac{DGM - AGM}{DGM}\right| \text{……………………..………Equation 1}$$

Where:-

GM_{ESI} = Gaps in median at existing signalized intersection.
DGM = Desired Gaps in Medians in meter.
AGM= Available Gaps in Medians in meter.

IHC-2 Entry Angle Index

Entry angle is the angle between the path of approaching vehicle and the vehicle in circulatory motion. An ideal entry angle should be less than 75^0 for all type of signalized intersection. Entry angle less than recommended value make the crossing of vehicle more susceptible to collision. Hence entry angle should always keep in mind while designing the Signalized intersection. To evaluate the safety hazardous condition at Signalized intersection due to inadequate entry angle, a condition index is developed. That is represented in equation 2. Index is developed in such a way that “Zero” values of proposed index shows the safest condition and “One” value of Index presents the least safety condition at existing Signalized intersection.

$$EAI_{ESI} = \left|\frac{DEA - AEA}{DEA}\right| \text{………………………………..Equation 2}$$

Where:

EAI_{ESI} = Entry angle index at existing signalized intersection.
DEA = Desired entry angle in radians.
AEA = Available minimum entry angle in radians of all approaches.

IHC-3 Entry Radius Index

The entry curve is one of the most important geometric parameters that affect the safety at Signalized intersection. The provision of an appropriate radius on the entry curve encourages drivers to slow down before reaching the Signalized intersection. A lower value of entry radius produce a sharp curvature at entry hence makes it more accident prone section. A condition index is developed to evaluate the safety hazardous condition due to the inadequate entry radius. That can be determined using equation 3.

Index is developed in such a way that “Zero” values of proposed index shows the safest condition and “One” value of index presents the least safety condition at existing Signalized intersection.

$$ERI_{ESI} = \left|\frac{DER-AER}{DER}\right| \quad \textbf{Equation 3}$$

Where:

ERI_{ESI}= Entry radius index at existing Signalized intersection.
DER = Desired entry radius in meter.
AER = Available minimum entry radius in meter.

IHC-4Level of Services

Height Signalized intersection level of service (LOS) is defined in terms of a weighted average control delay for the entire Signalized intersection. Control delay quantifies the increase in travel time that a vehicle experiences due to the traffic signal control as well as provides a surrogate measure for driver discomfort and fuel consumption. Signalized intersection LOS is stated in terms of average control delay per vehicle (in seconds) during a specified time period (e.g., week day PM peak hour). Signalized intersection LOS criteria can be further reduced into three Signalized intersection types: all-way stop, two-way stop, and roundabout control. All-way stop and Signalized intersection LOS is expressed in terms of the weighted average control delay of the overall Signalized intersection or by approach. Two-way stop-controlled Signalized intersection LOS is defined in terms of the average control delay for each minor-street movement (or shared movement) as well as major-street left-turns.

$$LOSI_{ESI} = \left|\frac{DLSI-ALSI}{DLSI}\right| \quad \textit{Equation 4}$$

Where:

$LOSI_{ESI}$= Level of Service at existing Signalized intersection.
DLSI = Desired level of service at Signalized intersection.
ALSI = Available level of service at Signalized intersection.

IHC-5 Poor Lighting Index

In view of safety and security, streets should be well lighted. The Signalized intersection must not be left unlit with one or more approaches being lit. Otherwise the driver may not be able to see the unlit Signalized intersection while coming from a lit up approach arm. A condition Index is developed to evaluate the hazardous safety condition at Signalized intersection due to poor lighting. That can be determined using equation 5. Index is developed in such a way that “Zero” values of proposed index shows the safest condition and “One” value of index presents the least safety condition at existing Signalized intersection.

$$PLI_{ESI} = = \left|\frac{DLP-ALP}{DLP}\right| \quad \textbf{Equation 5}$$

Where:

PLI_{ESI} = Poor lighting index
DLP = Desired number of light poles
ALP = Available number of light poles

IHC-6Slow Moving Vehicle Composition Index

Composition of slow moving vehicle is a major safety hazardous condition of mix traffic condition. More percentage of slow moving vehicles increases the relative speed of vehicles that decrease the safety at signalized intersection. Some slow moving vehicles are Trucks, Tractors, Trolley, Cycle Rickshaw, Hand/Bull Cart etc. Hence a condition Index is developed to evaluate the safety hazardous condition due to the Slow Moving Vehicle Composition. Index is developed in such a way that “Zero” values of proposed Index shows the safest condition and “One” value of Index presents the least safety condition at existing Signalized intersection.

$$\text{Percentage of slow moving vehicles} = \left|\frac{VSMV}{VFMV+VSMV}\right| \times \mathbf{100} \quad \textbf{Equation 6}$$

Where:

$SMVCI_{ESI}$= Slow moving vehicle composition index at existing Signalized intersection.
VSMV = Volume of slow moving vehicles at peak hour in Vehicles/hr.
VFMV = Volume of fast moving vehicles at peak hour in Vehicles/hr.

IHC-7 Non-Motorized Transport Composition Index

Non-motorized transport vehicles are totally different with motorized transport in their behavior. Pedestrians, Cyclists, Hand Cart, Buffalo Card, and Cycle Rickshaw etc. are the type of non motorized transport. More percentage of non-motorized transport is an example of hazardous mix traffic condition. Hence a condition index is developed to evaluate the hazardous safety condition at Signalized intersection due to non-motorized transport composition. Index is developed in such a way that “Zero” values of proposed index shows the safest condition and “One” value of index presents the least safety condition at existing Signalized intersection.

$$\textbf{Percentage of non-motorized transport} = \left|\frac{VNMT}{VMT+VNMT}\right| \times \mathbf{100} \quad \textbf{Equation 7}$$

Where:

$NMTCI_{ESI}$ = Non-motorized transport composition index at existing Signalized intersection.
VNMT = Volume of non-motorized at peak hour in vehicles/hr.
VMT = Volume of motorized transport at peak hour in vehicles/hr.

IHC-8Traffic Sign Index

Traffic signs are major traffic regulation devices at signalized intersection to control and regulate the traffic flow. Most of the traffic signs provided at Signalized intersection also affect the safety. A condition Index is developed to evaluate the hazardous safety condition at Signalized intersection due to absence of traffic signs. That can be determined using equation 8. Index is developed in such a way that “Zero” values of proposed index shows the safest condition and “One” value of index presents the least safety condition at existing Signalized intersection.

$$\mathbf{TSI_{ESI}} = \left|\frac{DTS-ATS}{DTS}\right| \text{.......... } \textbf{Equation 8}$$

Where:

TSI_{ESI} = Traffic sign index at existing Signalized intersection.
DTS = Desired number of traffic sign.
ATS = Available number of traffic sign.

IHC-9 Cross Walk Index

Cross walk is one of the major pedestrians facility provided at Signalized intersection for the safety of pedestrians. Absence of cross walk or poor condition of cross walk affects safety of pedestrians at Signalized intersection. A condition Index is developed to evaluate the hazardous safety condition at Signalized intersection due to poor condition of cross walk. That can be determined using equation 9.Index is developed in such a way that “Zero” values of proposed index shows the safest condition and “One” value of index presents the least safety condition at existing Signalized intersection.

$$*CWI_{ESI} = \left|\frac{DCW-ACW}{DCW}\right| \text{.......... } \textbf{Equation 9}$$

Where:

CWI_{ESI} = Cross Walk Index
DCW = Desired number of cross walk
ACW = Available number of cross walk
*In this equation ACW cannot be greater than DCW.

IHC-10Narrow/No shoulder

Approach for improving the safety from collision, this strategy can be used in conjunction with most others for improving safety at signalized intersection. It is, however, an alternative to providing a left-turn lane. At three-legged signalized intersection on two-lane highways, shoulder bypass lanes can provide an effective substitute for a left-turn lane on the major road where provision of a left-turn lane is economically infeasible. Instead of providing a left-turn lane for drivers turning left from the major road, part of the shoulder may be marked as a travel lane to encourage following through drivers to use this shoulder lane to bypass vehicles waiting to turn left. That can be determined using equation 10. Index is developed in such a way that “Zero” values of proposed index shows the safest condition and “One” value of index presents the least safety condition at existing Signalized intersection.

$$\mathbf{NSI_{ESI}} = \left|\frac{DNSW-ANSW}{DNSW}\right| \text{.......... } \textbf{Equation 10}$$

Where:

NSI_{ESI} = Approach width index at existing signalized intersection.
DNSW = Desired approach width in meter.
ANSW = Available minimum approach width in meter.

Ranking of road safety for signalized intersections at hazardous locations

This stage presents a methodology to rank road safety hazardous locations. The Safety Hazardous Index is developed using weight of safety factors and condition rating of safety factors. The Safety Hazardous Index is developed separately to evaluate safety at straight section, safety at curve section and safety at intersection and presented in equation 11. Ranking of road safety hazardous locations is evaluated by determination of safety hazardous index at straight sections, curve sections and intersections.

Ranking of Road Safety Hazardous Location at Signalized Intersections

$$SHI_{SI} = \sum_{i=SF} W_{SFI} \times R_{SFI} \qquad \text{Equation........(11)}$$

Where,

SHI_{SI} = Safety Hazardous Index at Signalized intersection
W_{SFI} = Weight of safety factors at intersection
R_{SFI} = Condition rating of safety factors at intersection

Further, Safety hazardous index for entire road section (SHI_{SRS}) can be obtain by summation of safety hazardous index at straight section, curve section and intersections as presented in equation (12).

$$SHI_{SRS} = \sum_{i=1}^{n} SHI_{S_n I_n} \qquad \text{Equation........(12)}$$

Where,

SHI_{SRS} = Safety Hazardous Index at Signalized entire road section
$SHI_{S_n I_n}$ = Safety Hazardous Index at Multiple points Signalized intersection

Further, it is to be noted that higher safety hazardous index at a particular location indicates more safety hazardous conditions at that particular location.

IV. CONCLUSION

The main objective of this paper is to develop a methodology for evaluation of the safety at signalized intersections. Further this study is also helpful in comparing the level of safety among different identified signalized intersections. Following are the main conclusions drawn from the study. All around the world, road accidents are considered as one of the major factors causes death. Intersections are the most dangerous location of any roadway network. Further signalized intersections are supposed to be safe and efficient traffic movement nevertheless still many sever crashes occurs at these locations.

Various types of crash pattern occurred at signalized intersection has shown in this study and cause of their occurrence is also discussed.

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