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An impact of gap acceptance on road safety: A critical systematic review

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Abstract: An uncontrolled intersection is a critical area for crashes that depends on macroscopic traffic parameters. While the intersection is the potential of the center of crashes due to inappropriate decision of driver. Therefore, the study focuses on the effect of the gap acceptance parameter for the safety of drivers at an uncontrolled intersection. To examine, a systematic review of the literature is implemented to understand the different parameters, their impact, and models developed by the researchers. Additionally, it is demonstrated that the crashes are highly affected by the gap acceptance and the different models are formed to estimate the critical gap for different road sections under homogeneous and heterogeneous traffic conditions. However, it is not possible to definitively conclude the best model to evaluate the gap acceptance factor but can be preferred to reduce the severity of crashes. Nonetheless, most studies remain inconclusive, there is an emerging trend in the literature suggesting the increase of the crash risk at an uncontrolled intersection. Lastly, it is most important to mention the model suitability based on empirical studies commenced under the strong limitations. Consequently, there is a need for research in this area to correlate the gap acceptance with road safety to reduce the severity of accidents to improve the existing transportation system.

Keywords: Gap acceptance, uncontrolled intersection, critical gap, crashes, accidents.

1. Introduction

Intersections are the critical sections of any road network, where conflicts and delays frequently arise during the movements of vehicles or persons. There are different types of intersections depending upon the control and level which are priority intersection, space sharing intersection, time-sharing intersection, and uncontrolled intersection. As per FHWA (Federal Highway Administration) 2018, 2.5 million accidents occur at the intersection, out of which maximum crashes involve due to left-turn movement. The main reason behind the conflicts is to understand the travel behavior, behavior of age

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group, the experience of the driver, traffic control devices, atmospheric condition, geometrical features of intersection, etc. (Ashalatha & Chandra, 2011) have studied that 79.2 % of accidents occur at uncontrolled intersections, whereas 7.9 % and 12.9% of accidents take place at police-controlled and traffic signalized intersections respectively.

Further, accidents mainly depend on the gap retained between the vehicles during the crossing of the mainstream, smaller the gap, higher the chance of accident and vice-versa. Hence, the safety of vehicles and pedestrians on the road is analyzed by various means-road users, geometrical and vehicular features, climatic conditions, etc., which depends on the behavior of an individual vehicle in the stream concerning each other. An incorrect decision by the driver at an intersection may result in an accident, which accounts for around 24.4 % of crashes at uncontrolled intersections due to overspending of a vehicle.

1.1. Accident scenario of developed and developing countries

Accidents are killing more people in India than terrorism and natural disaster (S Elango et al., 2018). During the past decade, the natural cause of accidental death was lightning accounts for 10%; however, among the unnatural causes traffic accidents recorded as 42-45% of the unnatural deaths. As per the Institute of Health Metrics and Evaluation (IMHE), road traffic injuries are the 8th leading cause of death in India (2016) in which the health loss among the young (age between 15-49 years) is quite significant with the proportion of 68.7% as per Ministry of Road Transport and Highways (Ministry of Road Transport & Highways, 2020) (MoRTH) report. According to the World Health Organization (WHO), road traffic injuries caused an estimated 1.35 million deaths worldwide in the year 2016. However, India ranks first among the 199 countries for the number of road accidents as per world road statistics 2018. The data for road accidents for the last three years have been enumerated in Table 1.

Table 1: Road accident statistics in India from 2016-2018

Parameter	2016	2017	2018
Number of road accidents	4.80	4.64	4.67
Number of persons killed	1.50	1.47	1.51
Number of persons injured	4.94	4.70	4.69
Accident Severity (Persons killed per 100 accidents)	31.4 *	31.8*	32.4*

All units in lacs (lakh); * values per 100 accidents
Source: (MoRTH, 2018)

Among the different categories of roadways, more severe accidents are reported on rural roads. The leading cause of accidents on rural roads is geometry, road width, traffic volume, and type of intersections (Kadiyali et al.,1983). The local improvement suggested to reduce the traffic accidents on highways are correction of geometric curves, provision of paved shoulders, placing guard rails, removal of roadside hazards traffic barriers, advanced warning systems (Mirkazemi & Kar, 2014; Singh, 2017; Valli, 2010)

In India, accidents on the lower category roads have not been registered as frequent cases of hit and run, which suggests improving the features of the road, educating the road users, and improving the reporting of accidents to get the actual fatal and injuries to improvise the conflicts (MoRTH, 2018). One of the case studies of Vishakhapatnam specified the attributes for the accident were lack of signage, obstruction due to trees and bushes, improper visibility for pedestrians and drivers, median openings, and uncontrolled access for wrong side movements at NH 5 (Pandey et al., 2015). Moreover, the accident rate for a different classification of vehicles was noted as 35% for two-wheelers, 23% for goods vehicles followed by car, autos, and buses as 17%, 15%, and 9 % respectively. The authors suggested National Highway Authority of India (NHAI) close the median openings, remove the encroachments and improve the intersection geometrics at National Highways.

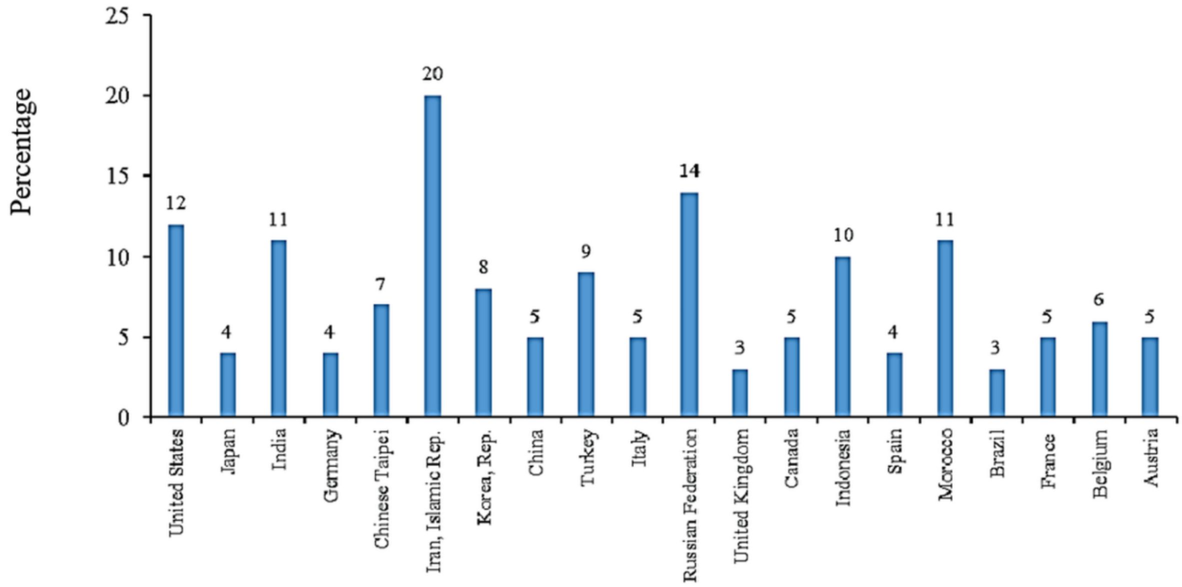
Sarin et.al., (2005) had suggested low cost-effective improvements to reduce the accidents and increase safety concerning USA and UK i.e. roadway and roadside, and operational improvements by providing traffic signs, markings, minor alterations in the layout of intersections, and drainage improvements. Other finding shows that front to rear collision involves buses and heavy vehicles due to slowing down or stopping or overtaking, which accounts for 59% of the accidents, which can be mitigated by implementing acceleration and deceleration lanes, warning and information signs (Baviskar, 1998; Mohan, 1984) examined 76 crashes on National Highways where the 58% of the accidents was at intersections. Besides the shift of crash pattern from a head-on collision on the 2-lane undivided highway to a front-rear collision on a 4-lane divided highway. Proper signage facilities, warning systems need to be introduced and appropriate design and location of intersections and median openings to diminish the collisions. Based on random parameter modeling for two-lane undivided highways in India, the factors influencing the accidents at the day time and night time are compared which illustrates an increase in the proportion of cars and shoulder-width decreases the accident frequencies at day time, whereas the proportion of cars and trucks increases, the rate of accident decreases in night time (Raichur, et.al., 1993).

A road safety audit suggested to provide a service road at highways to bifurcate the fast and slow-moving traffic as it creates hazards and all the major and minor intersections to be developed with adequate lighting as maximum collisions were observed at these locations (Ogallo and Jha, 2014). A road safety report of 2018 (MoRTH), for a two-lane single carriageway rural network for four states i.e. Karnataka, Andhra Pradesh, Gujarat, and Assam was generated in 2012 which stated to upgrades the intersection with roundabouts, signalization, turn lanes and upgrade road features like paved shoulders, shoulders widening. The combined investment for all four states will prevent 1, 25,000 deaths and serious injuries which will reduce 40% of deaths based on the estimates (Kanchan, et. al, 2012).

The accident rate at NH 6, the accident rate can be reduced by 50% by increasing the shoulder width by 1m as the crash rate of 1.62 accidents per year per km and additional access point per km per road length may increase the road accidents especially for the pedestrians (Singh and Mishra, 2001). An investigation on 167 accidents was carried out in Coimbatore (Tamil Nadu), including 71 fatal accidents involving 80 fatalities (66 vehicle occupants and 14 pedestrians) which accounts for 43 % of all accidents investigated and the injury severity MAIS from 3-6 and fatalities MAIS is 4 (Dinu and Veeraragavan, 2011). Median opening and access to roads have a major influence on the occurrence of crashes as per realistic experience (Prajapati and Tiwari, 2013). The buses are involved in about 10- 35 % of the road accidents in different states of India, in which the accident rate for straight roads, curves, and intersections for buses is 81%, 11 %, and 5 % respectively to reduce the accident rate road safety education and effective driver training is recommended (Singh et.al, 2015).

In developing countries like India, the rate of accidents is significant as compared to other countries (Figure 2). Moreover, the number of motor vehicles has also been increased from 1401 to 230031 (in thousands) from 1970 to 2016 and accidents increased from 114 to 464 (in thousands) from 1970 -2017. The national average accident severity (persons killed per 100 accidents) increased from 28.5 in 2014 to 31.5 in 2017. Various preventive measures have been recommended including lane bifurcation, pedestrian safety, traffic rules regulations, enforcement, and education.

Figure 1: Country wise number of persons killed per one lakh population in 2018



Source: (MoRTH, 2018)

Moreover, globally the death rate due to accidents is increasing and the major cause for the accident is identified as speed, not using preventive measures like a helmet or seat belt, and drinking and driving. The safety measures are taken into account by improving the road infrastructure and design standards as per the laws in 112 countries around the world to reduce the crashes on road (Dandona & Mishra, 2003).

The fatality rate of different countries along with the growth in the vehicles and risk of fatality is shown in Table 2. It shows that the fatality rate and risk are higher in India (11.2) though the motorization rate is lowest, whereas, in the USA, fatality risk is 10.7 followed by New Zealand (6.9) where the maximum growth rate of the vehicle is in the USA i.e. 846 trailed by New Zealand (733). Hence, Table 2, reveals that the Indian roads are unsafe than the other countries as the motorization rate is low.

Table 2: Comparison of fatalities for different countries

Country	Motorization Rate (No. of Vehicles per 1,000 People)	Fatality Rate (No. of Fatalities per 10,000 Vehicles	Fatality Risk (No. of Fatalities per 100,000 People)
India (2012)	130	8.6	11.2
Germany (2012)	657	0.67	4.4
Japan (2012)	651	0.63	4.1
New Zealand (2012)	733	0.91	6.9
Sweden (2012)	599	0.50	3.0
United Kingdom (2012)	599	0.51	2.8
United States of America (2012)	846	1.26	10.7

Source: (Singh, 2017)

In Turkey, the total number of accidents in the urban area accounts for 36% whereas it is 65 % in the case of rural areas. One of the research studies developed a model to analyze the accident retaining the variables of traffic safety and types of collision. The policies were implemented based on the results. The road accidents are due to different reasons, as in the case of Iran, youngsters have more exposure to crashes on roads and deaths as compared to other diseases.

The driver's related factors are studied to suggest the preventive measures and a major association among the type and time of the accident, gender, education level are allied (Hingorani and Sarna, 1978). Whereas one of the research in Indonesia has proved that the human factors have a strong effect for ascending leaning for the accident on-road and another influencing parameter is lack of road infrastructure. The accident severity and probability of injuries were predicted using a multiple logistic regression model for a total distance of 207 km and a record of 2194 crashes at expressways of Thailand taking into consideration the diverse variables as speed, traffic volume, time, weather condition, and physical characteristics of the accident area. Hence the outcome revealed the speed of the vehicle increases the accident severity; suggested that further research be on roadway geometric features for driver's safety at highways(Mishra et al., 1984).

In Jordan, a traffic accident is correlated accident type with several variables age, speed, time, day of the week, month, weather, pavement surface condition, and severity level, which foreseen that accident due to wrong turning (2.7%) and pedestrian (6.3%) has a decreasing tendency and 88% collision type has an accumulative tendency for the accident data of 13 years (1998-2010) (Mittal and Sarin, 2001). Several research for accident study was conducted for developed and developing countries considering various statistical analyses and different variables; which predicts the severity of the accident, crash trends, factors affecting the accident- human and vehicle characteristics, road geometrics which suggested safety measures like improvement in road geometric, infrastructure, design standards. Therefore, to reduce the accident rate and severity on the road section different variables are studied individually as well with the combination of either variable.

1.2. Safety measures

For two decades' researchers are focusing on road safety and its affecting parameters. (Baviskar, 1998) carried out the survey in Delhi, India, particularly for two-wheelers accident crashes, and found that the collision pattern, age, experience, average severity index of admitted patients is different from the reported in industrialized countries. Moreover, the majority of the accidents were recorded for two-wheelers (83%) occurred on straight roads whereas only 16 out of 87 were recorded as collisions with cars, buses, or trucks. A large proportion of fatalities occurred at T-intersection (51%) and four arm intersection (28%) and a total of 79% at the uncontrolled intersection (Sharma, A. and Dua, 2000). A study on the accident statistics of Vadodara city, Gujarat, India, proposes several safety measures for different causes of accidents as engineering measures, intersection improvement, enforcement measures, traffic education to road users, and safety enhancement at accident blackspots (Sharma, A. and Landge, 2012). Pedestrians and two-wheeler riders are the vulnerable users and 60% of victims died before reaching the hospital. It needs intervention strategies to improve the safety of road users (Narayan et al., 2011; Victor and Vasudevan, 1989; Chikkakrishna et al., 2013). To avoid collision segregation of traffic is being recommended for reducing accidents (Chand, 1999). The various parameters affect the injuries, the maximum occurrence of the injuries is for the age group of 15-30, males, students, and workers found using univariate analysis for 14 administrative wards for Pune, India (Jain et.al, 2011).

For urban arterial mid-block of medium-sized city based on traffic level and road network for the fatal crashes. The presence of medians results in higher speed of vehicles and the absence of pedestrian and bicyclist facilities leads to more crashes (Rogers, 2012). The rate of accidents for two-wheeler increased from 18 % (1978) to 39 % (2013), the best solution is to include road safety issues in the school curriculum to reduce the severity of crashes and ensure that the vehicles follow the speed limits (Sarin et.al, 2005). Epidemiological trends of the accidents arose that 84% occurs in urban areas and mainly 46.7% on National Highways. The auto-rickshaws have low fatal crashes as compared to the other vehicle class as their speed is limited to 40 kmph when carrying passengers (Narayan et al., 2011).In Sweden and Paris, the safety guidelines have been implemented and speed is restricted to 30 mph which has reduced the fatalities by 30%.

In developed countries, like the UK fine is charged for violation of the traffic rules, and few countries like the Netherland, Germany, and Oman, road infrastructure design, standards are modified as per the traffic scenario. As per the study of different developed and developing countries for road accidents and safety; the measures provided are enforcement of laws by the public; improvising the road design and standards. However, they are not being incorporated as per the guidelines and foremost crashes are due to violation of rules and regulation and design standards. Additionally, accidents and speed has a strong statistical linear relationship between vehicle speed and road accidents presented that the relationship may not be necessarily linear but chances of road crash upturns exponentially with an increase in speed. Hence, reducing the speed has decreased the rate of fatalities by around 30-40% which can further be implemented in different countries like India where the rate of accidents is quite higher. The decision to be taken at the road section while the vehicle is above the speed limit is rather problematic. The drivers' perception can be studied using gap acceptance behavior to increase the safety on road.

1.3. Gap acceptance influence for crashes

Gap acceptance is an important parameter in traffic characteristics to study the relevant features related to capacity, delay, and road safety concerns to driver's performance at road section. Gap acceptance behavior is to accept or reject the gap which depends on the decision process of a driver. It generally depends on the critical gap and follow-up time whereas the critical gap value is a changing parameter for each case which is predicted with the assistance of several models on the base of altered experimentations by researchers. Due to inadequate headway between the vehicles and inappropriate judgment of the driver at the road section results in accidents (Mohan, 2009). Road accidents are affected by the inappropriate movements of the vehicles, between the vehicles and other road users or roadway features.

The gap acceptance is an important parameter to study the driver's behavior and analyze safety on road. Estimation of the critical gap is one of the most common parameters to analyze the gap acceptance. An incorrect estimate of the critical gap leads to an unsuitable design decision of the road elements. Moreover, 95 % of crashes are occurring due to the driver's error which is inadequate gaps that may be due to aggressiveness (Tupper & Hurwitz, 2011a). The driver's gap acceptance depends on various factors like age, gender, type of vehicles driving, presence of the number of passengers, month(Elango et al., 2018) whereas the factors associated with site condition are the number of lanes, speed, traffic volume at the major and minor street and type of traffic control device (Ashalatha & Chandra, 2011; Narayan et al., 2011; Ogallo & Jha, 2014; Tupper & Hurwitz, 2011b)

Several researchers have worked upon the effects of drivers' behavior on crashes due to gap acceptance which concluded that male and teen drivers have more aggressive behavior as compared to females and adults respectively (Tupper & Hurwitz, 2011b). When a driver makes a wrong gap acceptance decision there is a strong probability of crash as a result (Elango et al., 2018). Based on the available literature, it is concluded that the accident analysis and safety on road; gap acceptance parameter need to be concentrated for further research as the maximum accident occurs due to driver's error.

1.4. Estimation of critical gap

The critical gap is one of the most important metric parameters that can be calculated for the study of gap acceptance performance. The standard critical gap is estimated through the theoretical formulae given in HCM 2017 (Indo-HCM, 2017) along with the suitable corrections. However, as per the analyses, it is applicable only for small-scale studies for an ideal situation. For the field application, evaluating the value of the critical gap using various models under certain assumptions and limitations has been deliberated by some of the researchers. In general, 15 models are identified to date based on the available literature, to evaluate the value of critical gap based on gap, lag, and conflicting traffic volume for different section and vehicle classes. Whereas, the models have certain limitations either for the section, type of traffic, vehicle classes, type of intersection, etc. The mathematical and statistical models with the data required, procedure, and limitation have been shown in Table 3. Several models, distributions are developed by different researchers based on traffic scenario, capacity, field condition, vehicle parameters, human behavior, and many more for developed and developing countries.

In Table 3, the models have compared in which the Raff's method is the first model developed in 1972 by Miller which estimates the value by accepted gap and lag. However, the limitation of this model is; it is biased towards cautious drivers and depends on conflicting traffic volume which is relatively complex. Further, research on estimating the critical gap lead to the development of other models like the acceptance curve method, lag method, the harder method which estimates the values either by accepted and rejected gap or lag or both though model restraint the behavior of the driver, saturated condition of traffic (which is practically not feasible).

Greenshield method developed a histogram however, it was unsuitable for a small set of field data. Even a few statistical distributions were also taken into account like the probit method, logit model. As of certain, they restraint for only gap data, gap follows a normal distribution, overestimates the value and maximum likelihood method can only be used for homogeneous traffic conditions. Henceforth, the other methods namely the clearing time approach method, occupancy time method, and minimizing the sum of absolute difference are advanced for heterogeneous traffic conditions which somehow estimate the value based on accepted and rejected gap, lag; occupancy time, clearing time at the intersection. The estimated value of the critical gap for different sections has been discussed further to select the best method based on past literature studied.

Therefore, all the methods have their significance for site conditions and field data collected with certain restraints. Moreover, precisely for mixed traffic conditions like India three models are been applicable i.e., minimizing the sum of absolute difference, clearing time approach method, and occupancy time method.

Table 3: Comparative methods for estimation of critical gap

No.	Method	Methodology	Data Required	Advantages	Limitations
1	Siegloch Method (Brilon & Miltner, 2005; M. Mohan & Chandra, 2016)	Linear Regression $t_c = t_o + t_f/2$	Number of vehicles entering into each gap	Closely related to Siegloch's capacity formula Estimates the value of critical gap and follow-up time The critical gap value obtained is stochastic	Only suitable for saturated conditions Depends on headway distribution of major streets from minor streets
2	Greenshields Method (Amin & Maurya, 2015)	Histogram for the time gap	Accepted and rejected gaps	Based on histograms	Not suitable for small sets of data
3	Acceptance Curve Method(Amin & Maurya, 2015; M. Mohan & Chandra, 2016)	$P_i = d_i/N$ (0 < P < 1)	Accepted gaps	Simpler estimation process	Bias towards cautious drivers P = 0.5 (always)
4	Lag Method (Ashalatha & Chandra, 2011; Brilon & Wu, 2001; Chandra & Mohan, 2018)	$F_c(t_i) = A_i/N_i$	Accepted and rejected lags	Lag data is free from any bias Simpler estimation process	Wastage of large valuable gap data Longer observation periods are required for obtaining lag data
5	Harder's method (Amin & Maurya, 2015; Ashalatha & Chandra, 2011; Brilon et al., 1999)	$p_i = a_i/n_i$ $tc = \sum_{i=1}^{n} ti * pi$	Accepted and rejected gaps	Simpler estimation process	Require large data size for accurate estimation Depending on the volume of conflicting traffic Curve obtained provides floating values
6	Ashworth method (Ahmad et al., 2015; Brilon & Miltner, 2005)	$t_c = \mu - p\sigma_a{}^2$	Accepted gaps	No bias in the estimated result	Depending on the volume of conflicting traffic The consecutive gap is independent Assumes gap is exponentially distributed and critical gap to be normally distributed
7	Raff's Method (Ashalatha & Chandra, 2011; Bargegol et al., 2017; Brilon & Miltner, 2005)	$F_a + F_r = 1$	Accepted and rejected gaps and/or Lags	Simpler estimation process Satisfactory for small bias low traffic volume	Bias towards cautious drivers Depending on the volume of conflicting traffic
8	Logit Model (Brilon & Wu, 2002)	$P = 1/\{1 + e - (\beta_0 + \beta_1 x)\}$	Accepted gaps	Closely related to driver's gap acceptance decisions Used to study the effect of waiting time on the critical gap Good results for only gap data	Depending on the volume of conflicting traffic Underestimated results for the combination of lag and gap data
9	Probit Model (M. Mohan & Chandra, 2016)	$Y = 5 + \frac{(X - \mu)}{\sigma}$	Accepted gaps	Closely related to driver's gap acceptance decisions	Assumes critical gap to be normally distributed Less reliability
10	Hewitt Method	Iterative Approach	Accepted and rejected gaps and lags	Independent of conflicting traffic volume	Involves complex iterative procedure Difficult to accomplish without a computer Gap acceptance is established by lag or probit method
11	Maximum Likelihood Method (Ashalatha & Chandra, 2011; Brilon & Miltner, 2005; Brilon & Wu, 2001)	$L *= \prod_{g=1}^{n} [Fa(ag) - Fr(rg)]$ $L = \sum_{g=1}^{n} \ln[Fa(ag) - Fr(rg)]$	Accepted and maximum rejected gaps	Gives parameters of the distribution Independent of conflicting traffic volume	Assume lognormal distribution for critical gap Overestimated values for cautious driver

					Drivers are assumed to be homogeneous and consistent Difficult to accomplish without using a computer Not applicable for heterogeneous traffic conditions.
13	Clearing Time Approach Method (Ashalatha & Chandra, 2011)	Cumulative percentage graph for the time gap	Accepted gaps and clearing time	Useful in heterogeneous traffic conditions	Uncertainty regarding the influence area(conflict area)
14	Occupancy Time Method (Chandra & Mohan, 2018)	$P(t_a > t) \geq P(t_o \leq t)$	Accepted gaps and occupancy time	Useful in heterogeneous and homogeneous traffic conditions	Extraction of occupancy time data is time-consuming
15	Minimum absolute difference of accepted and rejected gap (Ahmad et al., 2015)	$f = [Abs\ (Tc - Ri\ ) + Abs(\ Ai - Tc\ )]$	Accepted gap and Rejected gap	Can be used universally	

2. Discussion

Based on the available literature, safety has been analyzed considering gap acceptance parameters relating to crashes. After the review of the literature, certain concerns need to be focused on considering the safety point of view. In this section, the issues related to the methodology of existing work carried out till now is been compared under the different criteria.

3. Methodological approaches and issues

The methodology for evaluating the value of the critical gap is possible only by calculation as it cannot be directly attained from the field data. Based on the above comparison table, only 3 out of 15 models, enable us to identify the value for Indian traffic conditions. Moreover, most of the model's critical gap value estimation is based on accepted and rejected gaps and lags, conflicting traffic volume, clearing time, and occupancy time. The calculation of conflicting traffic volume for an uncontrolled intersection calculation is relatively lengthy and a complex process. A minor error in calculation leads to variation in the value of the estimated critical gap resulting in an inappropriate decision that has a clear implication on safety. Figure 3 shows the estimated value of the critical gap for two-wheelers and four-wheelers by different models. Based on the value of standard deviation, mean and root mean square error, the clearing time approach method is a model that overestimates the value of the critical gap, out of all statistical models available in the literature for estimation of the critical gap. Therefore, for Indian traffic conditions, two methods can be used for the attainment of optimum values of the critical gap at four-arm uncontrolled intersections. Based on the literature studied, the values estimated for the critical gap utilizing models for different categories of vehicles are listed in Table 4.

Figure 2: Comparison of methods for estimation of the critical gap for different vehicle types

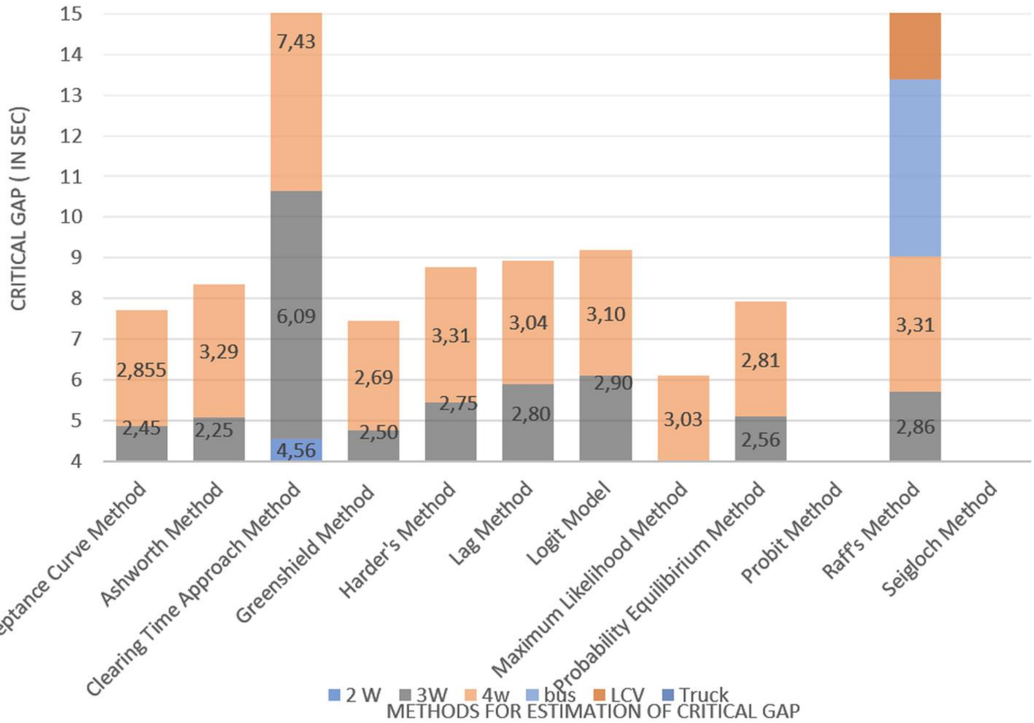
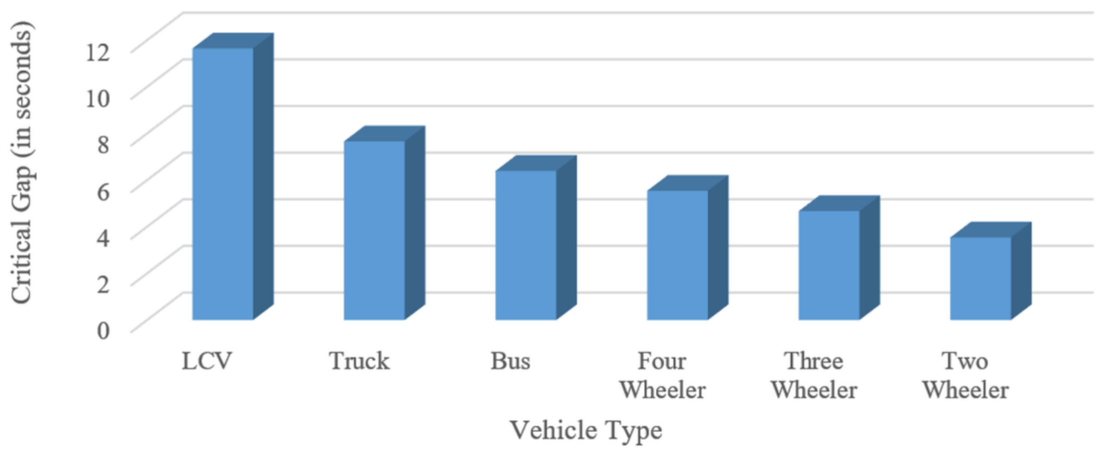


Table 4: Critical gap values for four-arm uncontrolled intersection for heterogeneous traffic condition

S No.	Method	Authors	2W	3W	4W	Bus	LCV	Truck
1	Raff's Method	(Venkata et al., 2018)	2.75	4.05	4.80	4.50	3.95	4.60
2	Raff's Method		2.60	2.27	2.80	4.20	3.40	3.85
3	Clearing Time Approach Method		4.84	7.08	8.59		19.90	11.48
4	Clearing Time Approach Method		4.03	6.53	7.69	8.60	6.97	9.98
5	Raff's Method	(Patil & Pawar, 2014)	3.80	--	--	--	--	--
6	Lag Method		3.60	--	--	--	--	--
7	Ashworth Method		3.35	--	--	--	--	--
8	Maximum Likelihood Method		3.60	--	--	--	--	--
9	Logit Model		3.70	--	--	--	--	--
10	Acceptance Curve Method	(Amin & Maurya, 2015)	2.40	2.45	2.80	--	--	--
11	Clearing Time Approach Method		4.80	4.65	5.00	--	--	--
12	Greenshield Method		2.25	2.50	2.50	--	--	--
13	Raff's Method		2.30	2.25	2.65	--	--	--
14	Probability Equilibrium Method		2.55	2.58	2.97	--	--	--
15	Logit Model		2.70	2.90	3.10	--	--	--
16	Ashworth Method		2.30	2.25	2.65	--	--	--
17	Lag Method		2.60	2.80	3.04	--	--	--
18	Harder's Method		2.70	2.75	3.20	--	--	--
19	Raff's Method	(Mohan & Chandra, 2016)	--	--	2.98	--	--	--
20	Harder's Method		--	--	3.42	--	--	--
21	Ashworth Method		--	--	3.92	--	--	--
22	Maximum Likelihood Method		--	--	3.03	--	--	--
23	Logit Model		--	--	3.42	--	--	--
24	Seigloch Method		--	--	2.93	--	--	--
25	Greenshields Method		--	--	2.88	--	--	--
26	Acceptance Curve Method		--	--	2.91	--	--	--
27	Probability Equilibrium Method		--	--	2.65	--	--	--
28	Probit Method		--	--	2.98	--	--	--

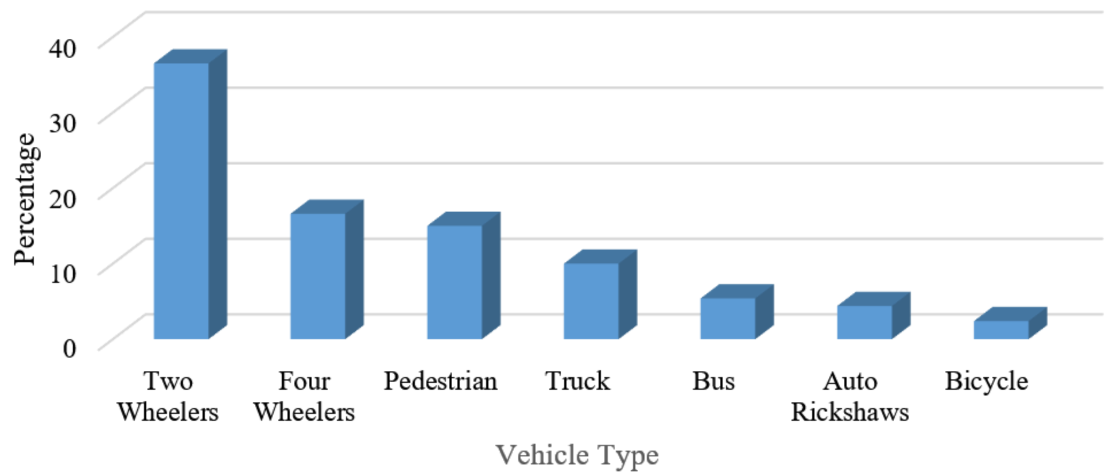
The critical gap values obtained by the different researchers for various intersections for various classes of vehicles are demarcated in Table 4. It is perceived that for large and commercial vehicles the values are very less as related to two-wheelers, cars, and auto rickshaws. Thus, advanced research needs to emphasize large vehicles as the range for their perception varies with an enormous difference. Besides, the value attained from past research is used for the relative analysis concerning the fatalities. Figure 3, depicts the average value of the critical gap acquired by the literature for the four-arm uncontrolled intersection. The range of critical gap for the different classes of the vehicle varies however, in the case of large vehicles like LCV, truck, and bus; has a large variation from 6.4 to 11.65 sec which may be due to fatigue and long route journey the drivers are more procuring more gap as compared to two-wheelers (3.54 sec) and four-wheelers (4.675 sec).

Figure 3: Critical gap for different classes of vehicles at a four-arm uncontrolled intersection



As per the road statistics of India in 2018, the crash rate for trucks and buses is lower relative to other personalized vehicle classes. The highest proportion of accidents is recorded for two-wheelers which is near about 36.5 % trailed by four-wheelers and pedestrians as 16.6% and 15% respectively which is presented graphically in Figure 4.

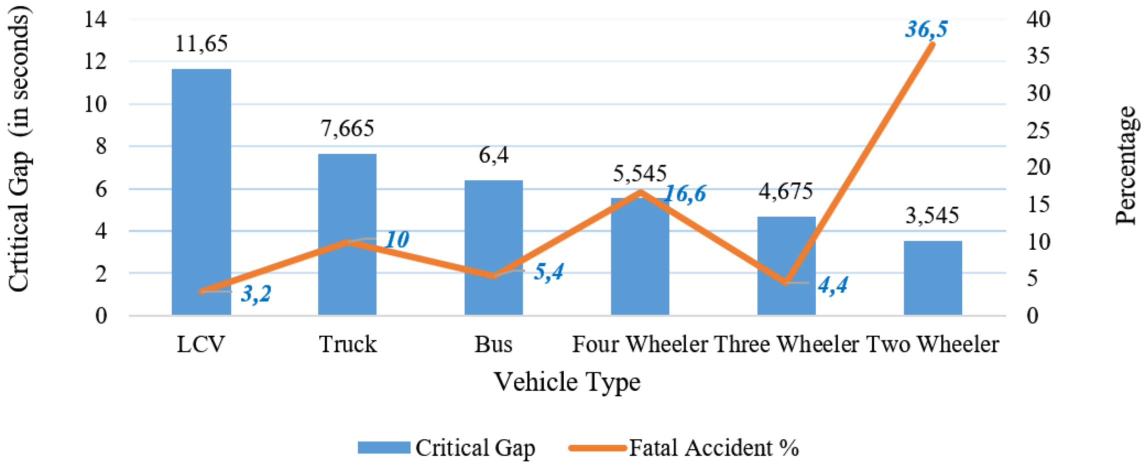
Figure 4: Persons killed in terms of road user category



Source: MoRTH Road Accident Statistics 2018

The accident and gap acceptance can be interrelated and has an inverse relationship which is depicted in Figure 5. The larger the gap value lessen the chance of accidents and vice versa. Considering the fatality rate for trucks is 10% and the value of gap is 7.6 sec. On the contrary, the value of the gap is 3.5 sec for two-wheelers has a fatality rate of 36.5%. Therefore, crashes increase with the decrease in the value of the gap, similarly inappropriate decision of gap acceptance leads to conflicts at the intersection.

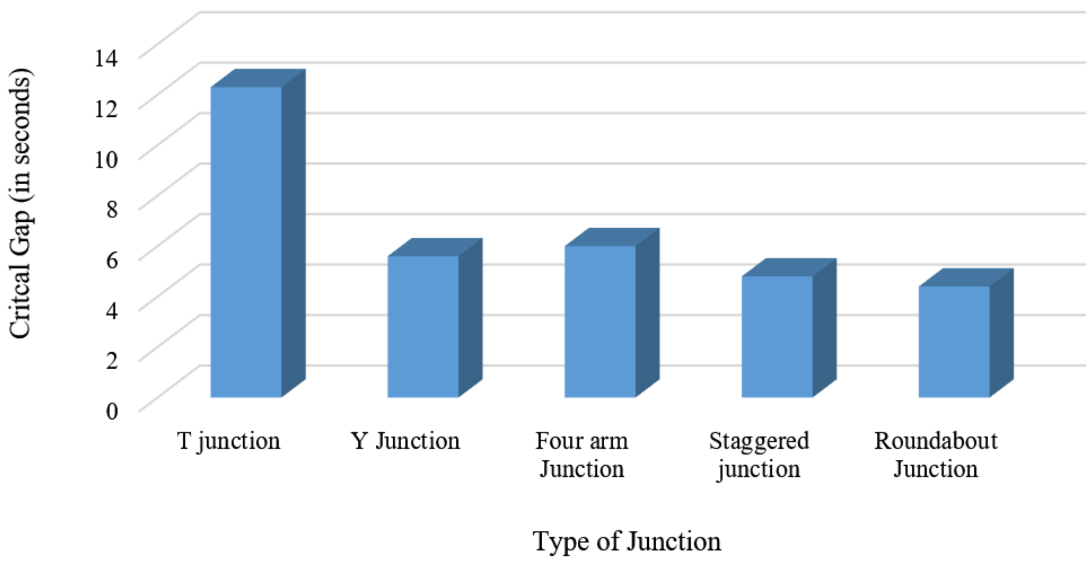
Figure 5: Comparison of critical gap values and fatal accident for different road user categories



Nevertheless, increasing the gap without any prior limitation may lead to delay at the section of the road. Therefore, appropriate gaps need to be specified for different vehicle types and road intersections. If a driver is over-aggressive, gap acceptance behavior assumes that it will require a smaller critical gap which results in estimating insufficient capacity for turning movements and there will be a strong likelihood of occurring an accident (Tupper & Hurwitz, 2011a).

Out of 33% known accidents at the junction, 12.3% crashes at occur at T–intersection documented under Road accident statistics-2018 by MoRTH which is represented in Figure 6. Moreover, the rate of an accident increases at the intersection due to an unsuitable gap between the vehicles at turning movements.

Figure 6: Percentage of accidents for different road intersections



Source: MoRTH Road Accident Statistics 2018

Therefore, the critical gap at turning movement is an important factor to be studied for reducing the rate of accidents. As T-intersection and four-arm intersection are the critical areas for the crashes due to turning movements. So, analyses on the previous research works are done which is presented in Table 5.

Table 5: Critical gap values for different classes of vehicles

S No	Section (Uncontrolled)	Vehicle Type	Category	Critical gap values (in seconds)
1	T section	Two Wheeler	Personalized	2.91-3.84
2	Four arm	Two Wheeler	Personalized	2.25-4.84
3	Four arm	Three Wheeler	Commercial	2.27-7.08
4	Four arm	Four Wheeler	Personalised/commercial	2.50-8.59
5	Four arm	LCV	Commercial	3.40-19.90
6	Four arm	Bus	Commercial	4.20-8.60
7	Four arm	Truck	Commercial	3.85-11.48

The range of the critical gap for two-wheeler is around 2.25 to 4.84 sec for T-intersection and four-arm intersection which does not have any large variation but in the case of large vehicles like bus, LCV, trucks due to large size the time required to cross the conflict area of an intersection; the values have very large difference i.e. from 3.40 to 11.48 seconds, during a particular time of crossing judgment by the drivers of other vehicles is of prime importance as that incorrect perception leads to an accident at the intersection due to different turning movements. Additionally, the research on T-intersection is limited to two-wheelers which need to be advanced for other classes of vehicles. Correspondingly, in further section, the critical gap value is discussed for the turning moments for developed and developing countries.

4. Gap acceptance for developed and developing country

The foremost variance fact in the case of a developed and developing country is about the traffic composition i.e. for developing country like India, has a mixed traffic condition whereas developed countries have homogeneous traffic. From the collected research work, 55 study area is deliberated out of which 6 was for uncontrolled T-intersection under mixed traffic condition, 39 for four-arm uncontrolled intersection for different class of vehicles 11 for developing countries, and 10 for developed countries for different turning movements as summarized in table 6 and table 7 respectively.

Table 6: Critical gap values for four-arm uncontrolled intersection for turning movements for heterogeneous traffic condition in developing country

S No.	Method	Authors	Right turn from major	Right turn from minor	Through from minor
1	Raff's Method		3.20	4.50	3.30
2	Lag Method		3.79	3.50	--
3	Harder's Method		4.00	4.00	3.93
4	Maximum Likelihood Method	(Saha et al., 2017)	3.19	4.10	--
5	Logit Model		--	--	3.75
6	Probability Equilibrium Method		3.24	3.95	3.46
7	Occupancy Time Method		5.10	4.30	4.30
8	Maximum Likelihood Method		2.23	3.14	--
9	Maximum Likelihood Method	(Ashalatha &	2.71	2.97	--
10	Maximum Likelihood Method	Chandra, 2011)	3.29	3.38	4.36
11	Maximum Likelihood Method		2.32	2.68	2.78

In the case of developing countries, mixed traffic is observed at the road section whereas the study area observed has a free left turn at an intersection. So, the above table shows three tuning movements i.e. right turn from a major and minor road and though from minor. As it is clear that at the four-arm uncontrolled intersection the range varies between 2.23-5.10 sec for right turn from major; 2.68-4.50 sec for right turn from minor and 2.78-4.36 sec for through from minor. In general gap value for turning does not have a large variation as per the road type. Together the value lies among 2.23 to 5.10 sec for all movements under heterogeneous traffic conditions. To have a comparative analysis for developed and developing countries homogeneous traffic movements are analyzed and summarised in Table 7.

Table 7: Critical gap values for four arms uncontrolled intersection for homogeneous traffic condition in a developed country

S No.	Method	Authors	Right turn from major	Right turn from minor	Through from minor	Left turn from minor	Left turn from major
1	Maximum Likelihood Method	(M. Mohan & Chandra, 2016)	5.75	5.99	5.35	--	--
2	Raff's Method	(Tupper & Hurwitz, 2011a)	--	--	--	--	--
3	Acceptance Curve Method		--	--	--	--	--
4	Raff's Method	(Saha et al., 2017)	--	4.60	5.90	6.10	5.90
5	Lag Method		--	6.55	7.50	6.83	4.83
6	Harder's Method		--	7.27	6.52	6.72	6.25
7	Maximum Likelihood Method		--	6.09	5.98	5.99	--
8	Logit Model		--	8.69	6.70	6.60	6.00
9	Probability Equilibrium Method		--	5.69	5.54	5.71	5.95
10	Occupancy Time Method		--	4.80	5.60	5.70	6.00

In developed countries, as per traffic rules, there are no free-turning movements as in developing countries. Therefore, in total five turning movements are categorized as right turn from major and minor; left turn from major and minor, and through from minor. The past research is reviewed and analyzed the following results which show that value varies among 4.60-7.70 sec for turning movements. Henceforth, the value is quite higher as compared to the developing countries which are presented in Table 8.

Table 8: Comparative critical gap (in seconds) range for turning movement for developed and developing countries

Section	Left turn from minor	Right turn from minor	Through from minor	Left turn from major	Right turn from major
Four-Arm (Heterogeneous condition)	-	2.68 - 4.50	2.78 - 4.36	-	2.23 - 5.10
Four-Arm (Homogeneous condition)	5.70 - 6.83	4.60 - 8.69	5.35-7.70	4.83 - 6.25	5.75

On relative analysis of critical gap for a developed and developing country, the range is as double in case of a developed country concerning to a developing country. This is one of the reasons for higher safety on roads in developed countries and less fatality risk even after a high vehicle growth rate.

The range for the uncontrolled four-arm intersection for the heterogeneous condition in developing countries varies from 2 - 5 seconds whereas, in the case of homogeneous traffic movements of a developed country it varies from 5 - 9 seconds. Therefore, the gap acceptance plays a major role to study the effect of conflicts at the intersection for various classes of vehicles with their turning movements. Besides, the analysis for T- intersection for heterogeneous traffic conditions is also studied which is quite limited and shown in Table 9.

Table 9: Critical gap values for T-intersection for heterogeneous traffic condition

S No.	Method	Authors	Two-Wheeler	Left Turn	Right Turn	Through
1	Seigloch Method	(Gattis and Low, 1999)	--	6.60	7.80	3.30
2	Raff's Method	(Patil & Pawar, 2014)	3.18	--	--	--
3	Lag Method		3.20	--	--	--
4	Ashworth Method		3.84	--	--	--
5	Maximum Likelihood Method		2.91	--	--	--
6	Logit Model		3.26	--	--	--

However, the T-intersection in the critical area of road section for crashes still there are limited study performed for estimation of the critical gap. The values obtained from the literature studied were restraint to only a single class of vehicle i.e. two-wheeler by five different methods whose value varies between 2.91-3.84 secs which does not have a large variation. Besides this, an ancient study has reflected the value of turning movements for T-intersection. However, due to lesser data, it cannot be concluded that the best suitable method for T intersection. Therefore, from the study, it is foreseen that estimation of the critical gap is an important parameter for the safety on road.

5. Conclusions

The paper presents an in-depth review of the past research conducted on the various parameters of safety measures for accidents, fatalities, injuries, and critical gap estimation at an intersection. This segment precisely emphasizes the safety measures recommended to reduce the accident rate and different methods for estimation of critical gaps at an intersection to avoid conflicts. Furthermore, an understanding of various methods adopted to estimate the value of critical gap by different researchers is presented and the research gap along the future scope is underlined.

Out of various literature studied, the major conflicts occur due to incorrect judgment taken by the driver for crossing the approach which depends on the various factors. Out of which, road and vehicular characteristics need to be studied and estimate the value of gap on certain significant parameters to obtain a value of safe gap for the road users to eliminate the chance of accidents at uncontrolled intersections. Gap acceptance is the key factor in the crash analysis and is also complex, hence, it needs further research and a multi-layered mitigation approach if significant improvement in safety for road users is to be concluded.

6. Key findings

Accidents have an increasing trend for both developed and developing countries; several research has been conducted to reduce the severity of accidents on basis of human, vehicle, and road characteristics (age, gender, traffic volume, time, weather, day, week, month and climatic condition). However, additional research can be conducted to identify the safe gap to avoid a crash at an intersection using the gap acceptance parameter.

The growth rate of vehicles in India is quite low however, the roads are unsafe for the users due to high fatality risk compared to other countries.

Gap acceptance behavior of driver plays a vital role for the safety as 95% of road accidents are occurring due to human fault.

For mixed traffic conditions, the two models – minimizing the sum of absolute difference of accepted and rejected gap and occupancy time method can be used based on comparative analysis as clearing time approach method overestimates the value of critical gap.

A comparative analysis of fatality rate and critical gap demonstrated that the lesser the gap value more is the fatality rate for vehicle class; therefore, minimum value for each type of vehicle is crucial to be assimilated to reduce the conflicts.

The range of critical gap varies from 2.91 to 3.84 sec for two-wheelers nevertheless, none of the studies carried out for the other vehicle classes for T-intersection where the percentage of accidents is maximum.

In the case of four-arm uncontrolled intersection large variation in the critical gap value of LCV and truck i.e. 3.4 to 19.90 sec and 3.85 to 11.48 sec respectively.

In developed countries the gap for turning is large (4.80-8.69 sec) as compared to developing countries (2.68-4.50 sec) which may be one of the causes for accidents at the intersection.

The gap acceptance parameter can be used to reduce the conflict rate by developing an index of safety using a statistical model to identify the safe gap for road users. As the study for the gap and lag between the different combinations of vehicles at intersections enables to reduce the crashes at intersections.

Inclusion of the quantitative measures for the improvement of road safety based on different traffic parameters to suggest the warrants for the road users at an uncontrolled intersection.

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