PREDICTION OF ACCIDENTS AT UNSIGNALIZED INTERSECTIONS AFTER SAFETY IMPROVEMENT

A DISSERTATION

submitted in the partial fulfillment of the

requirements for the award of degree

of

MASTER OF TECHNOLOGY

in

CIVIL ENGINEERING

(With specialization in Transportation Engineering)

Submitted By :

PRASHANK KUMAR

(Enrollment No. 17524012)

TRANSPORTATION ENGINEERING GROUP

DEPARTMENT OF CIVIL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY – ROORKEE

ROORKEE – 247667, UTTARAKHAND, INDIA

JUNE, 2019

CANDIDATE'S DECLARATION

I hereby declare that the work which is being presented in this dissertation report entitled, "**PREDICTION OF ACCIDENTS AT UNSIGNALIZED INTERSECTIONS AFTER SAFETY IMPROVEMENT**", is being submitted in partial fulfillment of the requirements for the award of the degree of "**Master of Technology**" in Civil Engineering with specialization in Transportation Engineering submitted to the Department of Civil Engineering, Indian Institute of Technology, Roorkee, is an authentic record of my own work carried out for a period of one year from June 2017 to June 2018 under the supervision of **Dr. Indrajit Ghosh,** Associate Professor, Department of Civil Engineering, IIT Roorkee.

IIT Roorkee **PRASHANK KUMAR**

JUNE, 2019 Enrollment No. 17524012

CERTIFICATE

This is to certify that the above statement made by the candidate is correct to the best of my knowledge and belief.

(Dr. Indrajit Ghosh)
Associate Professor
Transportation Engineering Group
Department of Civil Engineering
Indian Institute of Technology, Roorkee

ACKNOWLEDGEMENT

With immense pleasure I would like to express my sincere gratitude and thanks to my respected supervisor, **Dr. Indrajit Ghosh** Associate Professor, Transportation Engineering group, Department of Civil Engineering, Indian Institute of Technology, Roorkee, for his generosity, valuable guidance and consistent encouragement throughout the work. This work is simply the reflection of his thoughts, ideas, and concepts and all his efforts. I am highly obliged to him for his kind and valuable suggestions and of course his valuable time during the period of the work.

I am thankful to other faculty members of Transportation Engineering Group IIT Roorkee including **Professor S.S. Jain, Professor M. Parida, Professor Praveen Kumar, Professor Rajat Rastogi and Associate Professor G.D.R.N. Ransinchung** for their supporting attitude.

I would acknowledge my gratefulness to research student **Miss. MadhumitaPaul**for her valuable time when needed and my friends.

I am also grateful to the Accident Research Cell, Delhi Police: Traffic, Traffic Police (HQ), Todapur, Delhi for sharing accident data used in this research work.

Date: **(Prashank Kumar)**

Place: IIT Roorkee Enrollment No. 17524012

ABSTRACT

In any roadway system, intersections are the major bottleneck point. In India, in the year 2016, there was a total number of 1,39,389 accidents occurred at intersections and the uncontrolled ones contributed to a major portion of road accidents underscoring the importance of traffic control mechanism at junctions (MORTH 2016).The prime objective of this research is to develop a methodical exploration of the prospects for accepting a more mechanistic approach to unsignalized intersection's safety based on microscopic simulation of safety performance.For accomplishing the objectives proposed in this thesis, Simulation models of the intersection sites are developed for heterogenous non-lane-based traffic condition in PTV Vissim. A .trj file is then generated by running simulation in Vissim. This .trj file is then used as input to SSAM Software to find the number of conflicts possible in the developed simulation models. A conflict based accident prediction model (APM) is then developed by taking number of accidents as dependent variable and the conflicts generated as explanatory variable using negative binomial numerical method and Bayesian approach. Suitable countermeasures (e.g-speed tables, lane narrowing) for safety assessment was then applied in the developed simulated models in Vissim. Again by using SSAM software new conflicts were obtained and from these new conflicts changed number of accidents was calculated from the already developed conflict based APM to check the effectiveness of applied countermeasures. The results of the study show that speed tables prove to be more effective traffic calming measures than lane narrowing for unsignalized intersection.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1 General

Ever since the onset of automobile age about a century ago, a very big concern about traffic safety problems has been raised. As the attraction of general public towards motor vehicles has increased many folds during past two to three decades, a huge economic and human toll has been extorted. The extra costs generally implicated in movement of vehicles include that of air pollution, noise, and accidents. But due to the amount of loss, both in social and economic terms involved in an accident, it outweighs the other costs. The costs involved in an accident consist of the loss of property, injury, grief and death. As there is an annual increment in the vehicle miles travelled, there is a rising trend of loss of personal life. In the Global scenario, road accidents rank ninth in the causative factor for death and going by the current rate, may become seventh by 2030. In addition to having a high cost in terms of lives they cause huge cost in terms of financial losses too.

1.1.1 Intersections

An intersection is an area which is formed by the crossing of two or more roads and designed for turning of vehicles in different directions. It serves the main function of guiding vehicles to their corresponding direction. The condition at an intersection is such that vehicles which do not move in the same direction want to be at the same place and at the same time, besides pedestrians also look for some space to cross. Under such circumstances, the driver has to decide rather quickly taking into consideration his path, geometry of the intersection, speed and direction of the interacting vehicles, which may result into small error in judgment causing a severe accident. It calls for a specific concern about safety due to risky actions and maneuvers of drivers. Overall the performance of an intersection decides traffic flow which also impacts the capacity of the road.

Unsignalized Intersections

The most general type of intersections is an Unsignalized intersection which has the ability to cater for a large number of traffic if designed in a proper way. Basically Unsignalized intersections are categorized into two types **(Fig 1.1 & Fig 1.2):**

i) Uncontrolled intersections

ii) Controlled intersections

The controlled intersection being further classified into two types- a) All way stop controlled (AWSC), b) two-way stop-controlled (TWSC) intersection.

In a TSWC intersection, a common space is provided for certain flows on the basis of their priorities and at the same time other flows are forbidden from entry during that same time. Major roads are the roads which carry majority of the traffic flows and the roads which carry relatively lesser traffic are known as minor roads. AWSC intersections are used at a situation where all the legs of intersection carry traffic of equal importance and it is difficult to prioritize one leg to other. For such condition, stop signs are provided at all the approaches. Usually, the vehicle which arrives early has the priority.

The unsignalized intersections have more potential of being unsafe and liable to crashes due to the presence of comparatively limited controls as compared to a signalized intersection, which is evident from MORTH 2016 report.

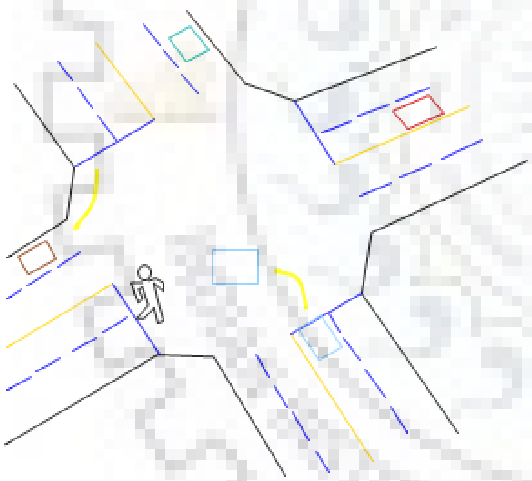



Fig 1.1 & Fig 1.2: Uncontrolled intersection

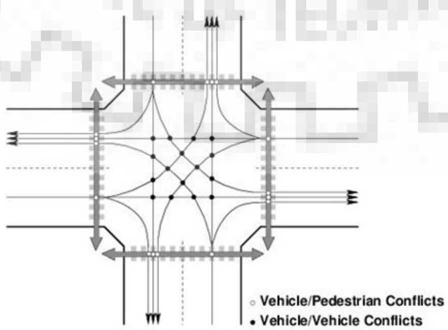


Fig 1.3:Conflicts for a four-legged intersection

1.1.2 Traffic Conflict Technique (TCT)

"The traffic conflict technique (TCT) was developed at the **Detroit General Motors Laboratory (Michigan, USA)** in the late 1960's for the recognition of safety-related problems in vehicles manufacturing.**(Perkins and Harris, 1967)"**. The idea of TCT evolved from the concept of recording the relatively not so safe interactions among vehicles based on the elusive action that a driver takes to evade the possibility of a collision. A traffic conflict is a situation which involves such an interaction of two or more vehicles, where one of the drivers or both have to take evasive action to avoid the probability of a crash. "A traffic conflict survey is a methodical method of observing and recording traffic conflicts and other events associated with safety operations."**(FHWA, 1989)**.

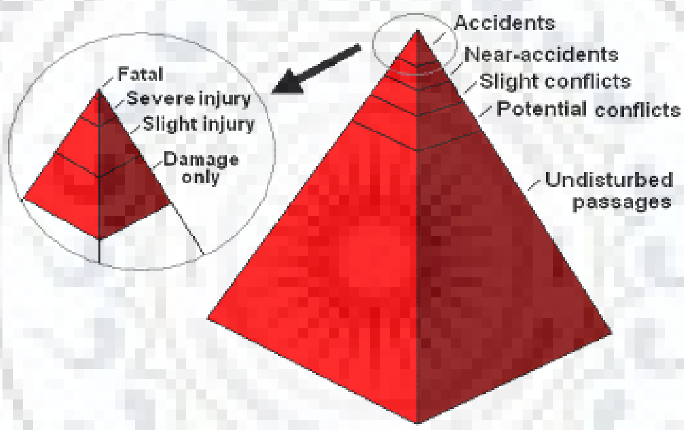


Fig 1.4: The Pyramid of safety (Hyden)

1.1.3 Swedish Traffic Conflict Technique (STCT)

University of Lund devised the methodology of Swedish traffic Conflict Technique, Sweden and defined it as: "An observable situation in which two or more road-users approach each other in time and space to such an extent that there is a risk of collision if their movements remain unchanged**(Amundsen and Hyden, 1977)"**. The conflicts were defined by using two terms, namely conflicting speed and time to the accident. There is a non-linear function which takes into account the average rate of deceleration which is needed for evading a clash of vehicles at differentiating speeds and a standard coefficient of friction. This function gives a line which further demarcates a serious and non serious conflict.

1.1.4 Traffic Microsimulation

The analysis of a traffic stream is a very complex problem primarily because of the difficulties involved in conducting the on field experiments. Thus there was a need for simulating the field condition in their original form and then perform its analysis. Thus Traffic Microsimulation became a popular mechanized tool for the analysis of intricate dynamic situations in traffic stream which are practically not possible to be analyzed by the age old and conventional methods used for evaluation of road safety. Microsimulation works by treating all the individual vehicles as well as the interaction amongst vehicles and road users as a single entity. In India the most commonly found traffic condition is an acute jam condition which can be simulated and analyzed by micro simulation. At present, many traffic microsimulation software are being used, such as “Aimsun, MITSIMLab,Cube Dynasim, PTV Vissim, Integration, Corsim, SUMO, Hutsim, Transmodeler,Sias Paramics, etc.”In this study PTV Vissim isbeing used.

1.1.5 *PTV Vissim*

It was developed by PTV planning Transport Verkehr AG in Karlsruhe, Germany. Using PTV Vissim, a vast range of components of traffic such as cars, trucks, buses, cyclists, pedestrians, etc can be simulated and that is why it is also known as multimodal micro simulation software and is most commonly used software by universities, public and private firms and researchers working in traffic area. PTV Vissim makes it possible to create and test distinct conditions pertaining to traffic before their actual realization. Various interactions among components of transportation networks such as pedestrians, signals and public transport are possible to be easily tested and analyzed. Being quite accurate and realistic in every detail combined with easy graphical user interface (GUI) makes PTV Vissim one of the best software for traffic micro simulation.

1.1.6 Conflict Based Accident Prediction Models

Accident Prediction Models are an important tool which can measure the impact of crashes on road safety. In the traditional development of accident prediction models, geometric and traffic variables such as traffic volume, road lane width, shoulder width, median width etc were used as response variables, but more recently these variables have been replaced by a single variable that is traffic conflicts. The arguments that have been put forward by researchers in favour of creating APMs based on conflicts is that conflicts may provide better prediction of crashes as they are based on interaction of vehicles. The majority of existing accident prediction models take the form of “accident frequency= constant* AADT^c_1” but the problem with making AADT or traffic volume as the major independent variable is that it assumes that all the vehicles entering the intersection interact in an unsafe manner and have the potential to cause accidents, which is not true. In a stream of traffic, there will be some vehicles which are not on the conflicting course and should most likely be excluded from the model for predicting accidents. Thus models based on conflicts can serve an advantage that it is the most closest and accurate analysis that is possible for prediction of accidents.

1.2Need of the Study

The Ministry of Road Transport and Highways (MORTH,2016) report says that the total count of road accidents reduced by 4.2 percent from 5,01,423 in 2015 to 4,80,652 in 2016 due to various safety campaigns of the Indian government. But, the total number of fatal casualty in road crashes also increased by 3.2 % from 1,46,130 in 2015 to 1,50,790 in 2016. On further analyzing the data of road accidents, it comes to picture that about 1,318 accidents and 412 deaths take place every day in Indian traffic, which further converts it into an hourly count of 52 accidents and 18 lives in the country. Road accidents in past 10 years have become the prime and most important area of concern and the same is reflected in the comparison of accident data available of the last 10 years. It shows that while the accident count has increased by about 15%, the casualties in form of death have increased by almost 48%.

In any roadway system, intersections are the major bottleneck point. “In India, in the year 2016, there was a total number of 1,39,389 accidents occurred at intersections and the uncontrolled ones contributed to a major portion of road accidents underscoring the importance of traffic control mechanism at junctions (MORTH 2016).” Thus, it can be concluded that intersections have unique concern with regard to safety due to unsafe actions of drivers and movements that result in conflict in traffic stream with a potential for crashes.

1.3Objective of the Study

The major objective of this research is to develop a systematic exploration of the prospects for accepting a more deterministic approach to unsignalized intersection's safety based on microscopic simulation. The objectives of this research are presented as below:

(i) Development of simulation models in PTV Vissim for fourteen Delhi-NCR based unsignalized intersections.

(ii) Generation of possible conflicts from the simulated models in PTV Vissim by SSAM Software.

(iii) Development of Conflict Based Accident Prediction Model.

(iv) Suggestion of measures for improving safety on at unsignalized intersections by applying suitable traffic calming measures in the developed simulation models and then checking their effectiveness by using Conflict Based Accident Prediction Model.

1.4Organization of Thesis

The thesis is documented in the following manner-

CHAPTER 1	i)Introduction ii)Need of study iii)Objective of the study iv)organization of study
CHAPTER 2	Literature review of the existing research on the use of PTV Vissim software in analysis of traffic safety, Traffic volume based and conflict based Accident Prediction Models, and Traffic calming measures.
CHAPTER 3	i)Methodology followed for this study, ii)Details of intersection sites used in this study, iii)Data collection and extraction methods.
CHAPTER 4	i) Development of microsimulation models in PTV Vissim for heterogeneous traffic condition. ii)Development of Conflict Based Accident Prediction Models. iii) Application of traffic calming measures in already developed models.
CHAPTER 5	Data Analysis, Results, and discussions.
CHAPTER 6	Conclusion, Recommendations and scope of future works.

LITERATURE REVIEW

2.1 General

In this chapter a review of previous research works conducted on the concerned topic has been done. It begins with the studies carried out across the world which includes the modeling methodology and various exposures that have been taken to predict crashes based on Traffic Volume as major explanatory variable, then followed by works related to conflict based APMs and the use of PTV Vissim for safety analysis of Intersections.

2.2Traffic Volume Based Accident Prediction Models

2.2.1 Van M.P. (1980)

The number of crashes per million conflicts was used as the major independent variable, and it was found that as compared to signalized intersections multi-lane unsignalized intersections have a lower number of crashes per million conflicts. The other conclusion drawn from the study was that intersections with a large distance between the two intersections had higher number of crashes per million conflicts than small intersections which are not signalized.

2.2.2 Sayed, T. et al. (1999)

For safety analysis at unsignalized intersections traffic conflict technique was used. For establishing the relation between conflict frequency and severity, standard values from 30 different survey data were collected. Further using an intersection conflict index, these standard values were later applied to compare the relative conflict risk rates between intersections. A predictive model which relates traffic conflicts to traffic volumes and crashes was developed.

2.2.3 Sayed, T. et al. (1999)

An accident prediction model was developed using the generalized linear model (GLM) formulation for determining safety at unsignalized intersections. They used the methodology of Bonneson and McCoy for estimating the model's parameters.

2.2.4Bauer, K.M. et al. (2000)

The study area consisted of 1,434 four-leg intersections and 2,692 three-leg intersections. A negative binomial model was used for investigating the relationship between traffic accidents and geometric design, traffic control and traffic volume variables. The dependent variable was total number of accidents. 5,631 accidents were studied on four-legged intersections of which 2,872 were fatal accidents and the remaining were non fatal. The time period of collection of accident and traffic data used in this study was from 1990 to 1992.

2.2.5Harnen, S. et al. (2003)

The study was concentrated on the crashes involving motorcycles at unsignalized intersections in Malaysia. The analysis of crash data revealed that about half of the registered motor vehicles were motorcycles which accounted for more than sixty percent of the total casualties. The collection of data was done from 1997-2000. The numerical method used for modeling was Poisson and negative binomial method.

2.2.6Salifu (2004)

A total of 91unsignalized intersections out of which 34 four legged and 57 three legged intersections in Ghana were considered for the study during the time period of 1996 to 1998. The crash counts during this period was of 355 at three legged and 239 at four legged intersections respectively. The major type of crash was of property damage and crash involving persons. Negative binomial approach for modeling was used with traffic flow and geometric variables as independent variables and number of crashes as dependent variables.

2.2.7Yan et al.(2005)

The multiple logistic regression technique was used for detecting the tendency of accidents at signalized intersections and identifying factors leading to risk of accidents caused due to the types of vehicles, characteristics of driver and traffic environment.

2.2.8Kim et al. (2007)

The study area which was selected for study was 90 two-lane intersections of rural areas from 38 counties in the state of Georgia and the study was conducted from 1996-1997. The crash was considered to happen at intersections only if they occurred within 250 ft of an intersection. A hierarchical study of intersection crashes was carried out for identification of certain causes of different types of accidents. A random effects binomial logistic regression model (random intercept model) was then developed for accident data which showed 540 crashes involving motor vehicles. Using these models, rear end, head on, side swipe and angle collisions were estimated.

2.2.9Cheng, L. et al.(2012)

The major objective of the study conducted in this paper was to compare the performance Poisson-Weibull generalized linear model and traditional Poisson Gamma model used for crash prediction. For accomplishing the objectives of this study, the performance of Poisson-Weibull model was tested by the use of simulated data set and then several other models were developed using Poisson Gamma and Poisson weibull regression analysis and the obtained results were used for comparison which showed that Poisson-Weibull model performed better that Poisson Gamma model.

2.2.10 Chikkakrishna, N.K., et al.(2013)

The study area selected for research was National Highway-58 of India. A relatively new concept of Bayesian modeling technique was used for the development of accident prediction model. The aim of study was to find the variables which influenced the safety of traffic at a section of four lane National Highway through statistical modeling which predicts frequency of occurrence of accidents.

2.2.11 Minachi, C. et al (2015)

This paper describes a study that aims at developing Accident Prediction Models for signalized four legged and three legged intersections in areas surrounding Chennai. For this purpose, 106 intersections in Chennai were chosen and their volume count data were obtained from the previous studies for the development of Accident Prediction Models. Accident Prediction Models were developed using the Negative Binomial regression analysis in statistical software. The dependent variable considered in the model was injury accidents at intersections per year. Independent variables considered were major and minor road Average Daily Traffic flow at intersections in PCUs.

2.3 Conflict Based Accident Prediction Models and the use of PTV Vissim

2.3.1 Hayward (1972)

The concept of time to collision was first proposed in this study, which is defined as "the time required for two vehicles to collide if they continue at their present speeds and on the same path". In case of commuters travelling in the same direction, TTC is mathematically defined by the following expression: "

$$TTCi,t = \frac{(X_{i-1,t} - X_{i,t}) - L_{i-1,t}}{V_{i,t} - V_{i-1,t}}$$

Where, P: the position of vehicles (i = leading vehicle, i-1 = following vehicle),

L: length of vehicles,

V = velocity

For vehicles crossing to each other, TTC can be defined as:

TTCi,t= $\frac{D_{i,t}}{V_{i,t}}$

Where, Di, t: Distance between the projected point of collision and initial point of vehicle I at time t;

Vi, t = The speed of vehicle i at time t."

The empirical curve of TTC is shown in **Fig 2.1** below.

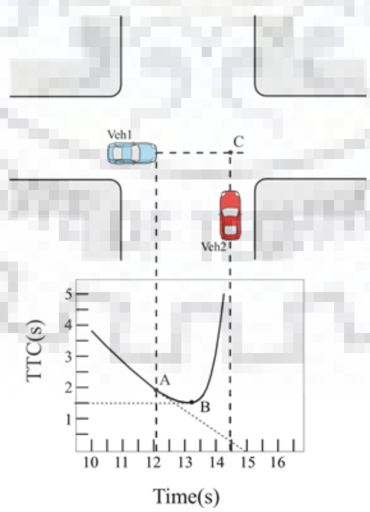


Fig 2.1: TTC (Time to Collision) empirical curve

2.3.2 Allen et.al. (1978)

The concept of Post Encroachment Time was introduced in this study which is defined as "the time difference between the moment an "offending" vehicle leaves the area of the potential collision and the moment the other vehicle arrives the collision area." Figure 2.2 describes the definition of the post-encroachment time for an angle conflict. Post Encroachment Time is different from the concept of Time to collision and Time to accident, as the path which the vehicle travels on the course of collision is not required to calculate thus making it easier to be calculated as data pertaining to relative speed and spacing between two vehicles is not required. But it has a limitation that it cannot measure the impact of speed on conflict because it eliminates the use of speed and distance. Therefore the accuracy of this indicator for estimating the accident frequency and severity involved becomes questionable. The main drawback in using PET is that it can be used only for movements where there are chances of crossing conflicts, their by limiting its application in smaller areas only. The mathematical expression of PET is defined as:

$$PET = t_2 - t_1 \tag{2.3}$$

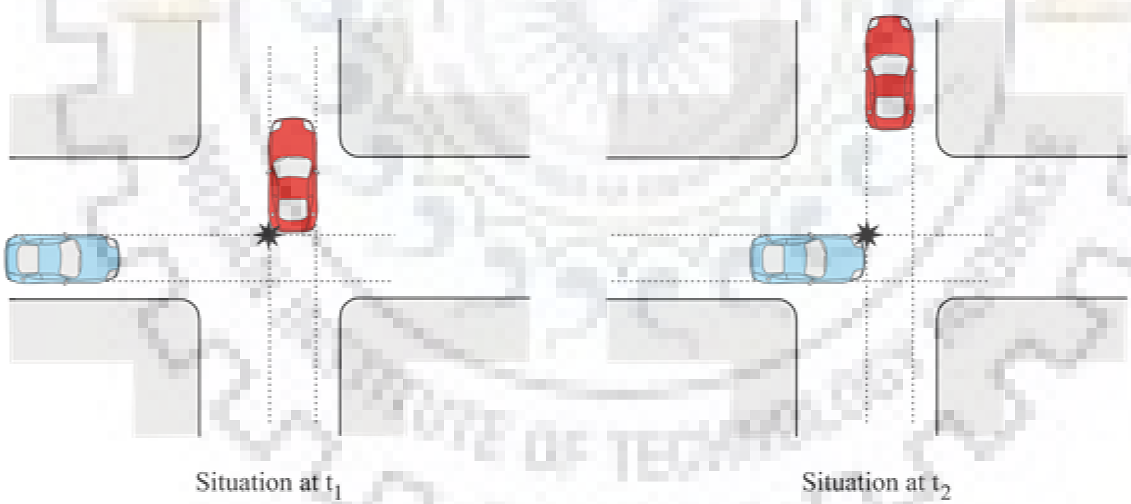


Fig 2.2:Post-encroachment time (PET)

2.3.3Hyden (1987)

The concept of Time to Accident was used which is defined as "the time that passes from the moment that one of the road users reacted and starts braking or swerving until the moment the involved road user had reached the point of collision if both road users had continued with unchanged speed and direction". In other words, in place of noting the Time to collision continuously, it is measured at the time the action to evade collision took place. Time to Accident is the subset of Time to Collision which is based on the action taken by one of the commuters to elude the collision. Thus, TTA can provide a better understanding in determination of severity of crashes as compared with Time to Collision. The severity zones defined by the Hyden (1987) shown in **Fig (2.3)**.

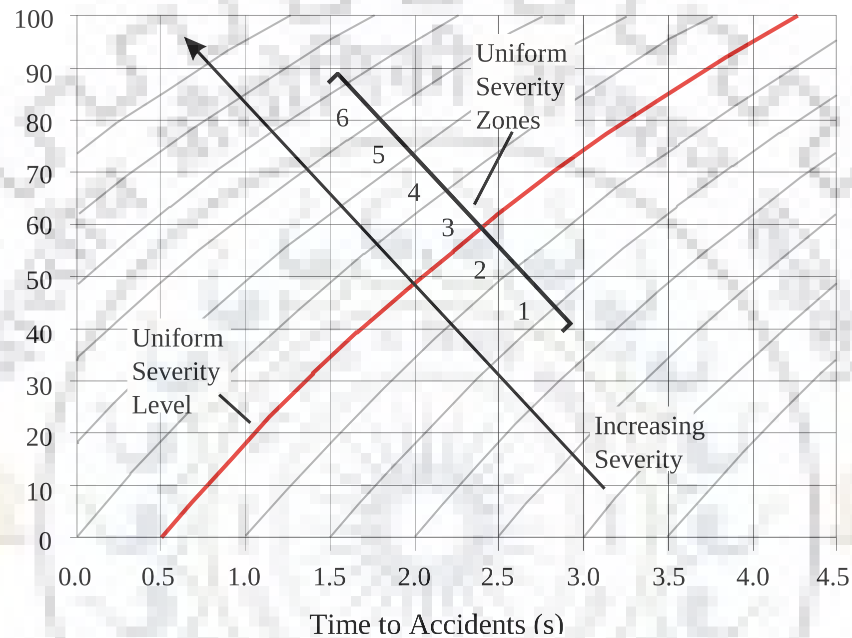


Fig 2.3: Time to Accident (TA)

2.3.4Sayed, T. et al. (2007)

Traffic conflict techniques and their application in estimating the safety at intersections forms the basic aim of this study. The standards for severity and traffic conflicts were established by the use of data which was collected from ninety four surveys. By using these standards, a relative comparison of the types of conflicts generated at different intersections can be done. There was the development of an Intersection Conflict Index (ICI) measure to give the idea about the risk due to traffic conflict and provide an indicator concerning the relative risk of involvement in crashes at an intersection. Besides a negative binomial regression analysis was used to develop APMs that gives a relation between the count of traffic conflicts and accidents. It was finally concluded that the average hourly conflict rate (AHC) and the average hourly severe conflict rate are correlated strongly with AADT as well as frequency of accidents.

2.3.5 Fan, R., et al. (2013)

There was the application of VISSIM software for simulating the field conditions at freeway merge areas and by the use of Surrogate Safety Assessment Model (SSAM), a new method of generating the conflicts involved was developed, replacing the traditional method of counting the conflicts manually from the in-field data. Then by the calibration of simulated and field measured conflicts, a consistency was established between the two data. For calibrating and validating VISSIM simulation model, a two stage process was developed. The performance of the two stage calibration process was noticed to be better than single stage one as reduced the MAPE for total conflicts from 78% to 33%. For studying the correlation between observed and VISSIM simulated conflicts, a linear regression model and spearman rank correlation coefficient was also developed. The results obtained from analysis of data indicated that there was a good enough consistency between observed and simulated conflicts.

2.3.6El-Basyouny, K. et al. (2013)

According to recent research results it has been shown that traffic conflicts have proven to be better indicator of the failure mechanism that causes crashes on roads. But before using traffic conflicts as alternative for analysis of safety at road intersections, collision and conflicts must be linked reasonably well. Development of a two phase model for investigating the association between conflicts and collision was proposed. The first phase was of implication of a lognormal model for prediction of conflicts by involving traffic volume, type of area, i.e, urban or sub-urban and other variables related to road geometry as independent variables. In the second phase, an accident prediction model was developed based on traffic conflict by the use of negative binomial regression analysis and using this APM, accident count was found. The data for developing model was collected from 51 signalized intersections in British Columbia. The results prove that a strong correlation exists between conflicts and collisions.

2.3.7 Zhang G., et.al (2017)

For the evaluation of safety at three legged intersection, the concept of traffic conflicts was implemented. The data was collected with the help of a video camera, and to remove the drawbacks of existing methods of analysis done on the basis of conflicts, 15 second time interval was used for every observation. For the classification of certain interactions among vehicles as conflicts, the parameter used was “Time to collision (TTC)”, which is the most widely used one. The numerical analysis which was considered for development of accident prediction model was Poisson regression. With the assumption that all other factors will remain constant it was observed that when the speed as well as time headway of the vehicles travelling on the major road which is crossed by vehicles turning left from minor road increases, the count of conflict decreases. On the other hand if the same case is reversed completely then number of conflicts increases.

2.4 Traffic Calming Measures:

The fundamental idea behind the use of traffic calming measures is to minimize the adverse impact caused by motorized vehicles in the built up as well as rural areas. The basic technique involved in almost all the traffic calming measures is to reduce the speed of vehicles, provision of adequate spaces for cyclists as well as pedestrians and simultaneously work for the betterment of the local environment. The guiding principles behind management of speed by design of road facility or traffic calming has the background coming from One of the aims of highway engineering which is to design the roads in accordance with the desired speeds of the vehicles moving on them. Some of the measures such as lane narrowing, rotaries and speed breakers minimize the negative effects of the use of motor vehicles, change the behavior of driver and improve the condition of non motorized road users as a result of which vehicles which travel at a speed below 30kmph can coexist with pedestrians relatively safely.

2.4.1Need for traffic calming measures:

Result of the researches show that implication of traffic calming measures can reduce level of accidents by 40 percent besides they have a significant impact on reduction of severity of crashes and financial loss. The biggest advantage that traffic calming measures have is that it eliminates the use of complex traffic regulation devices as most of them are self governing which makes it hugely cost effective. Also under the prevailing socio economic condition of India, it is almost impossible to restrict the non motorized vehicles from accessing highways. So in these circumstances to have a balance between efficient traffic movement and safety of the road users involved, traffic calming measures become the only option available.

2.4.1Classification of traffic calming measures:

The traffic calming measures can be classified as:

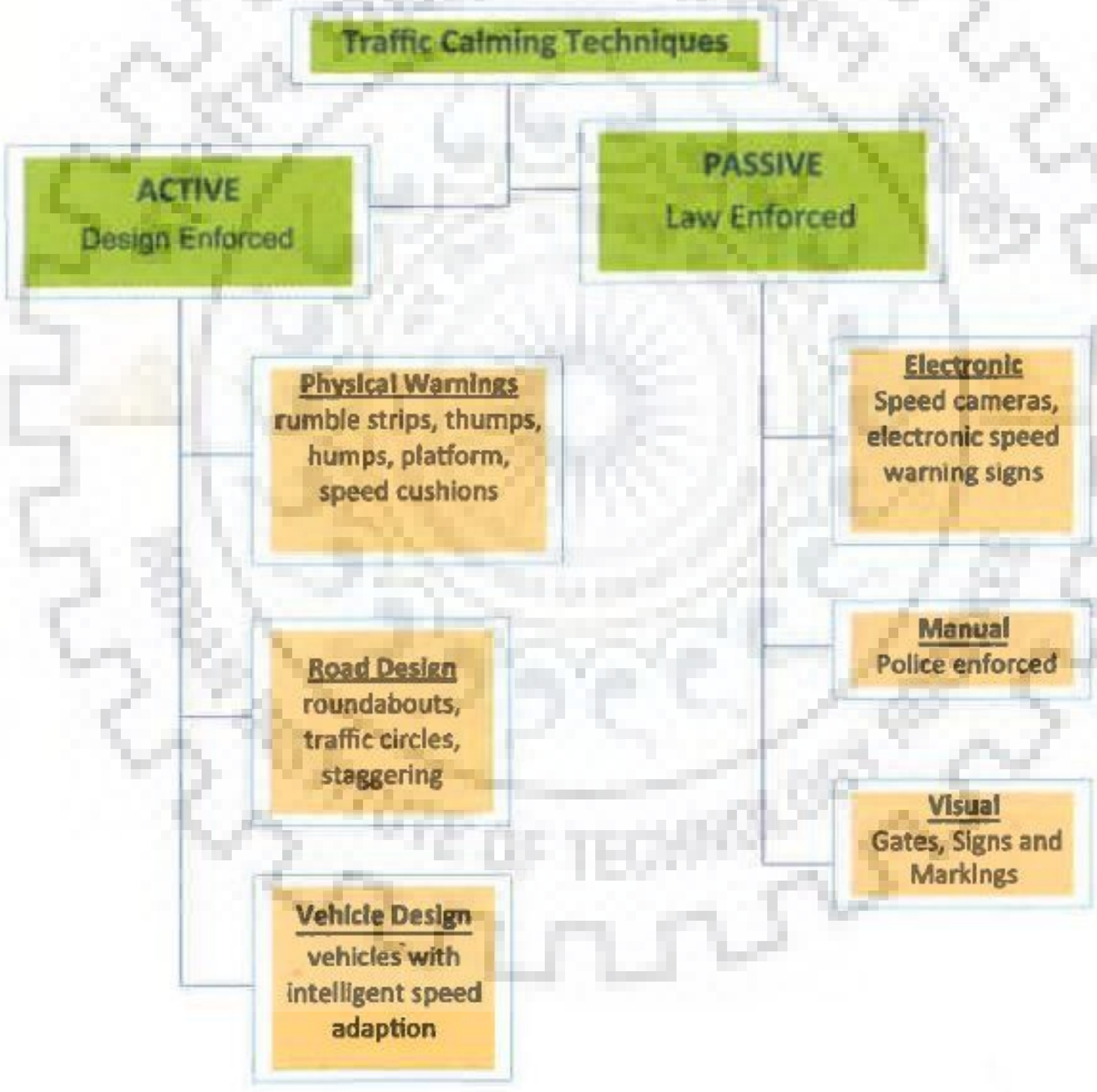


Fig 2.4: Classification of traffic calming measures

FIELD STUDY AND METHODOLOGY

3.1 General

The stepwise procedure followed for the accomplishment of objectives of this thesis has been summarized in form of methodology in **Fig 3.1**. The research starts with literature review of the works which have already been done in this area and further the gaps identified in those studies form the objective of the present study.

Once the objectives were defined, the next very important step was to collect field data from the already selected study area which consisted of fourteen unsignalized intersection in the National Capital Region (NCR), Delhi. The data was collected with the help of video camera. As the methodology required the work to be done in PTV Vissim software, the data required for input were traffic volume, relative flow, relative composition of vehicles and speed distribution of vehicles. A combination of Traffic data extractor software and a program which was written in Visual Basic(VBA) was used for extraction of the required data.

In PTV Vissim Simulation models of the intersections selected for study area were developed for heterogeneous traffic condition. A .trj file was then generated by running simulation in Vissim. This .trj file was then used as input to SSAM Software to find the number of conflicts possible in the developed simulation models. A conflict based accident prediction model (APM) was then developed by taking number of accidents as dependent variable and the conflicts generated as explanatory variable using negative binomial numerical method and Bayesian approach. Number of accidents was then found by this model.

Suitable countermeasures (e.g-speed breakers, lane narrowing) for safety assessment was then be applied in the already developed simulated models in Vissim. Again by using SSAM software new conflicts were obtained and from these new conflicts reduced number of accidents was calculated from the already developed conflict based APM to check the effectiveness of applied countermeasures.

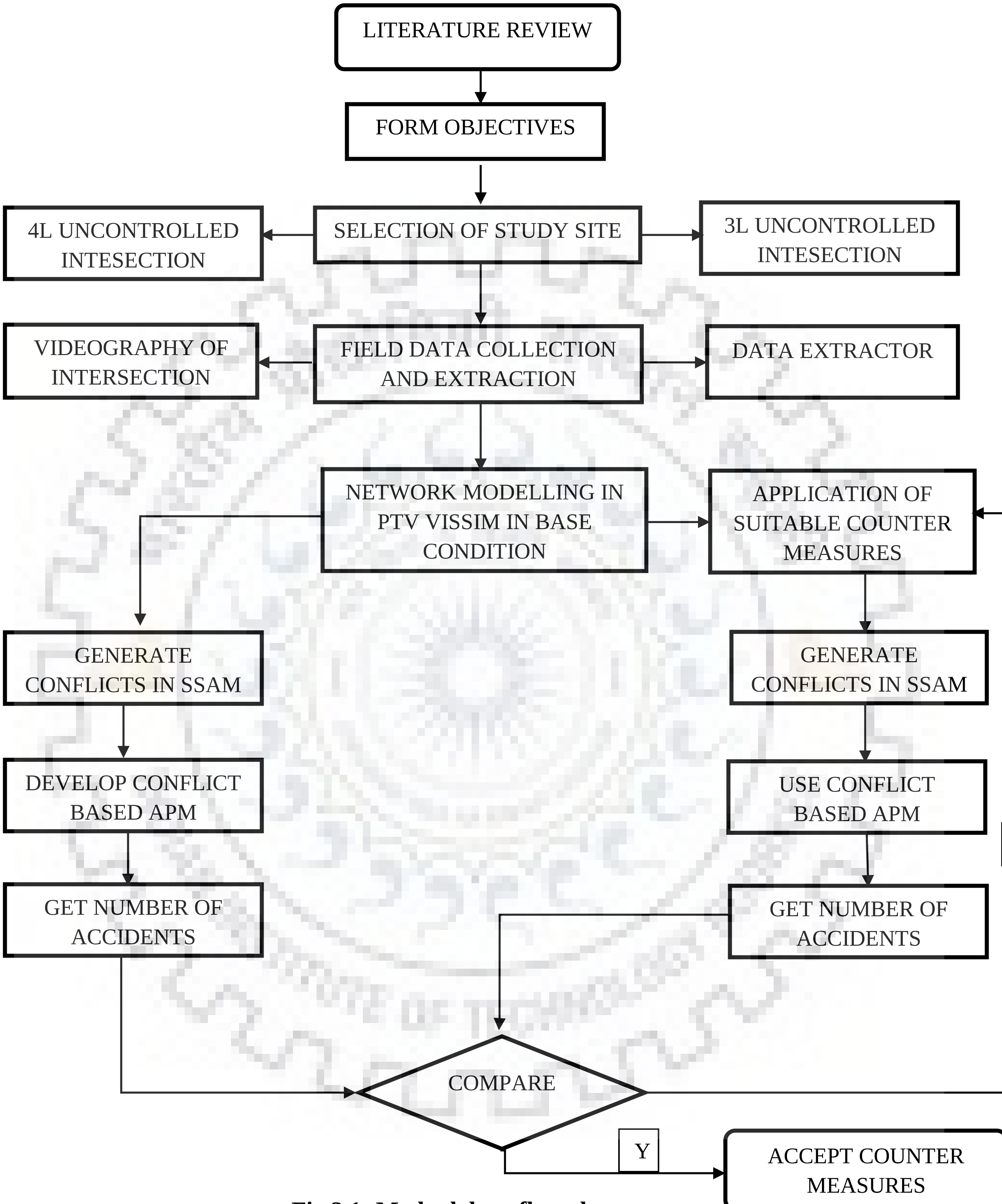


Fig 3.1: Methodology flow chart.

3.2 Study Area Characteristics

Proper selection of study area intersection sites is a vital part of the research for which fourteen unsignalized intersections were selected from the national capital region (NCR), Delhi, India. The selected intersection sites followed the following basic criteria:

i) Presence of enough traffic volume at each approach for observing traffic conflicts.
ii) The travel speed of vehicles must be so high that they are able to cause issues related to safety of the intersections which were selected.
iii) For studying the effect of various classes of vehicles on safety issues, heterogeneous condition of traffic must be present.

The stretch from chainage 75.00 km to chainage 130.00 km of NCR, India had been selected for the study. The study area stretch which had been selected was reconstructed recently and upgraded from two lanes to four lanes. Major portion of the study stretch comes in the rural areas (approximately 80%). The important urban areas lying in the study stretch are Muzaffarnagar, Khatauli, Meerut and Delhi. The cross slope of the selected stretch comes under category of flat and rolling terrain with settlement around stretch mostly consisting of mix of agricultural and urban activities. National Highway-58 from Northern India is shown in **Fig 3.2**

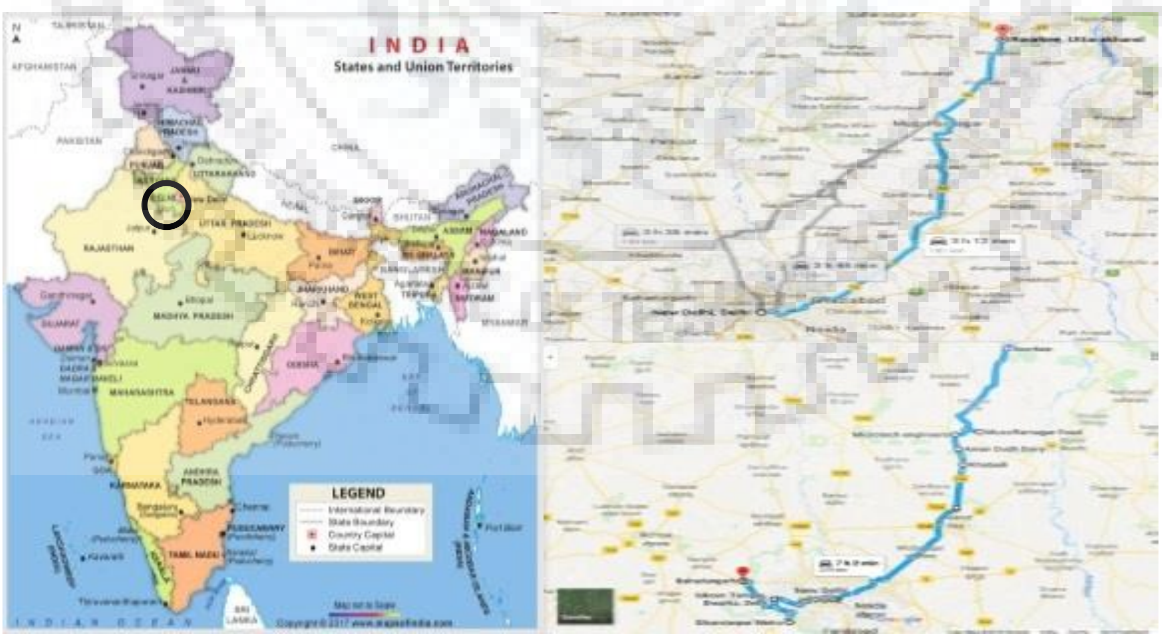


Fig 3.2: Route Map of study area.

Table 3.1: Details of Selected Unsignalized Intersections

S.No	CHAINAGE	INTERSECTION SITES	TYPE OF INTERSECTION
IS1	50.0	NayaGaon, Bahadurgarh New Delhi, Haryana	4 legged
IS2	55.0	IskconChowk, DwarkaNew delhi, Delhi	4 legged
IS3	56.3	Dwarka AIFF New Delhi, Delhi	3 legged
IS4	58.0	Gurgaon Sikenderpur Faridabad Gurgaon, Haryana	3 legged
IS5	60.0	DwarkaKargilChowk New Delhi, Delhi	4 legged
IS6	65.9	V S Gas Ggency NH 58 Meerut	4 legged
IS7	71.4	Modi International School,Modipuram Meerut	3legged
IS8	72.0	Pandit Sweet Corner Modipuram	3legged
IS9	96.0	Meerut KhatauliPathanpuraMaliyana	4 legged
IS10	105.8	Aman Dairy NH58 Meerut	3legged
IS11	108.0	SaraswatiGurukulVidyaMadir School Mansorpur	3legged
IS12	113.8	Microtech Engineers Delhi-Haridwar Road, Sujroo, UP	3legged
IS13	124.2	PanditjiDhaba, Royal Academy Palhada bypass ,Muzzafarnagar	3legged
IS14	126.7	VaishnoDhabaGurukulNarson, Muzzafarnagar	3legged

Fig3.3: Camera view of Bahadurgarh-Nayagaon-Balaur intersection

Fig 3.4: Bird’s Eye view of Bahadurgarh-Nayagaon-Balaur intersection

Fig 3.5: Camera view of the Dwarka-Kargil intersection

Fig 3.6: Bird's Eye view of the Dwarka-Kargil intersection

Fig 3.7: Camera view of Faridabad-Gurugram-Sikenderpur intersection

Fig 3.8: Bird's Eye view of Faridabad-Gurugram-Sikenderpur intersection

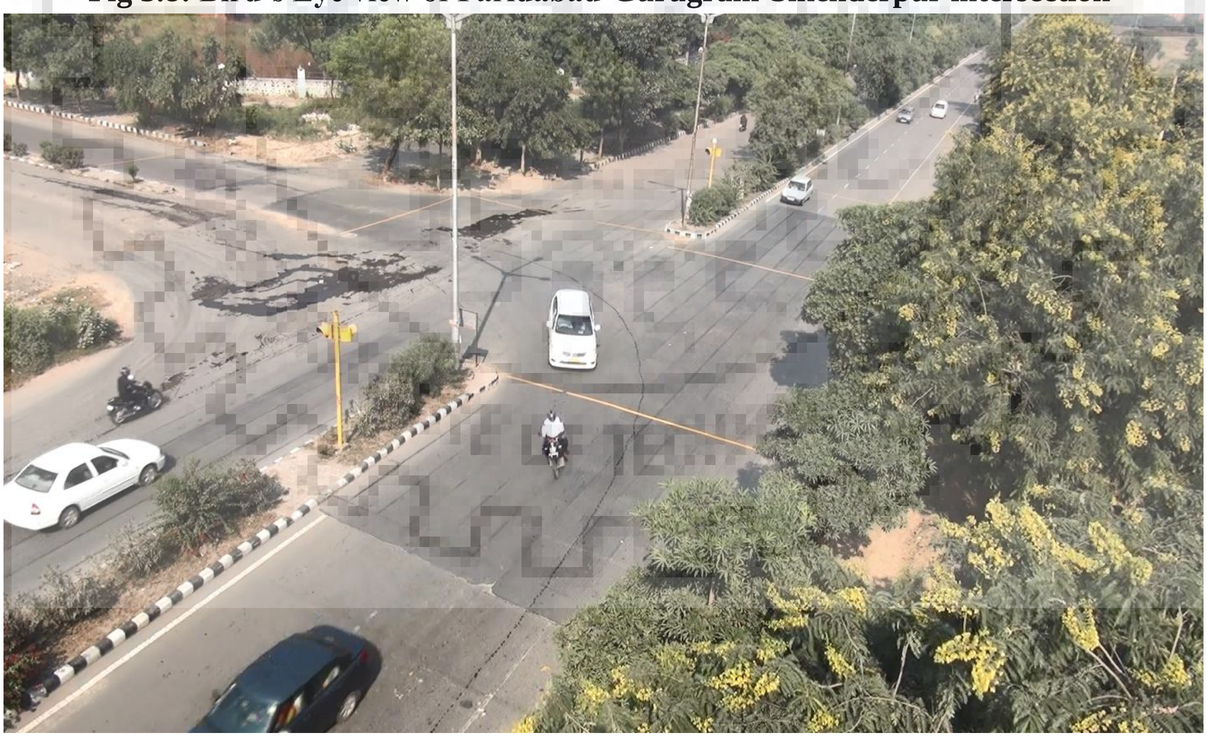


Fig 3.9: Camera view of Airport-NHAI-AIFF intersection

Fig 3.10: Bird's Eye View of Dwarka-AIFF-NHAI intersection

3.3. Data Collection and Extraction

3.3.1 .Traffic Data

For the collection of traffic data, video recording of the selected sites was done. Then with the help of a program which was written in Visual Basic for Application in excel environment and object detection algorithms (CNTK Toolkit) the required data for input in Vissim was extracted. The concerned data included volume of traffic, relative flow at each approach and relative composition of vehicles. Active X is a software developed by Microsoft which helps in design of precise set of functions to be defined by users in excel with the help of VBA platform. It becomes basically a macro program where a specific button is designated for different kinds of vehicles like cars, SUVs, LCVs, Autos, Bikes, Buses, etc. Each time a vehicle crosses the concerned line on the video, the user is required to press the designated button of the specific vehicle class and the total number of vehicles on that particular approach increases by one. Once data extraction from one video is over, a reset button is pressed which resets the whole system to be used for extracting data from another video. Finally a result button is pressed to generate the result and display it on screen.

The relative flow and relative composition of each approaches of the intersection is finally displayed as result.

The GUI of vehicle counter is shown in **Fig 3.11** below:

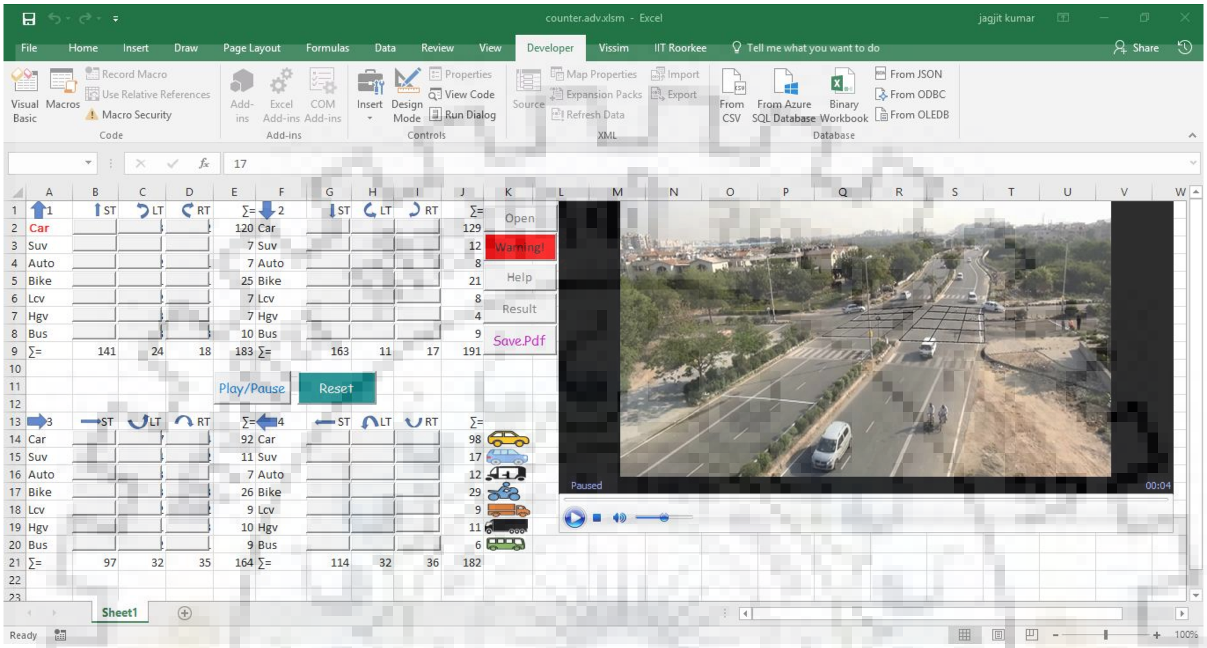


Fig: 3.11: VBA program GUI for vehicle counting at intersections

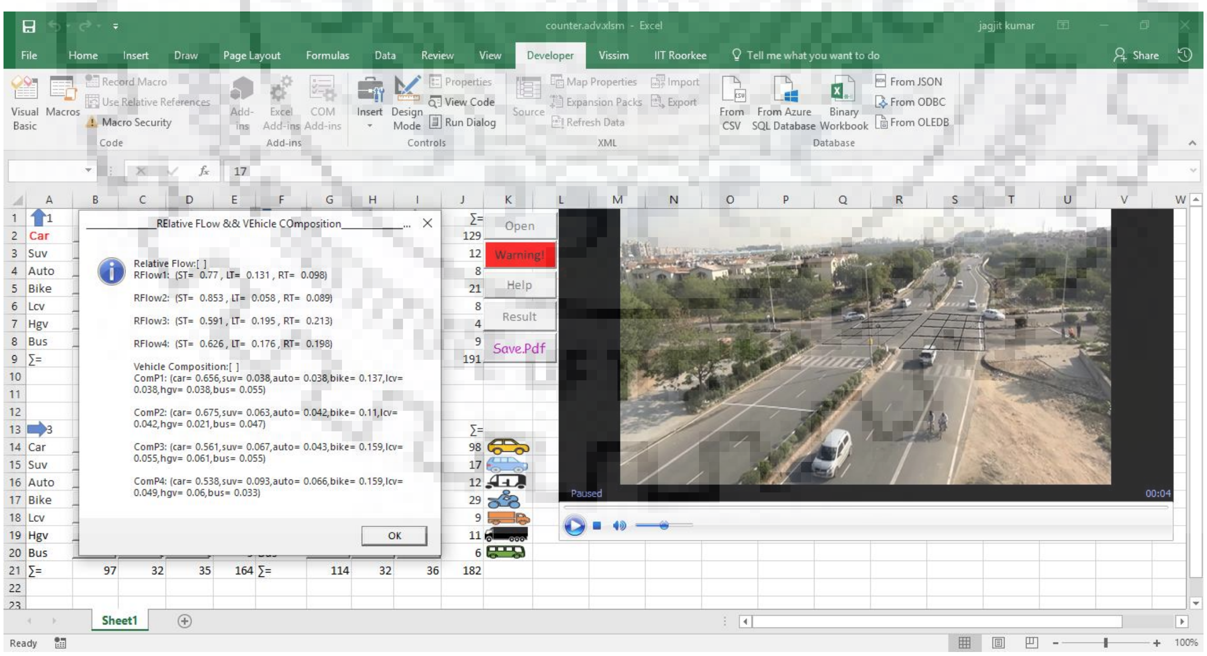


Fig 3.12: Output window of vehicle counter

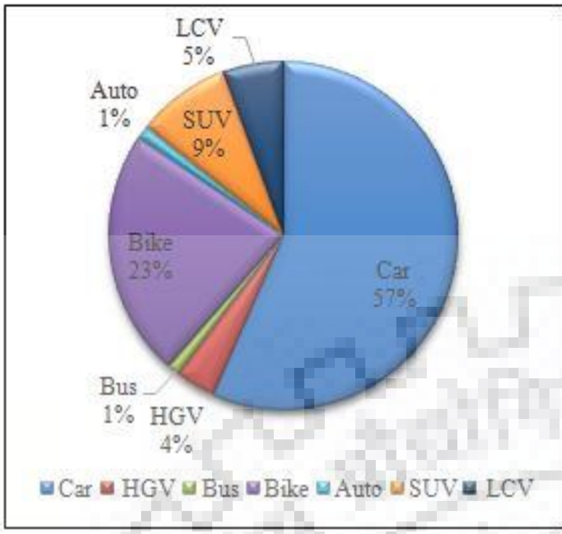
3.3.1.1. Vehicle Classification

For further complete and exhaustive analysis of data which was collected, the vehicles were further categorized into seven classes on the basis of their physical characteristics, maximum speed and acceleration and de-acceleration properties. The vehicles were classified as "car, SUV, Light Commercial Vehicle (LCV), bus, two-wheelers, three-wheelers, and HCV". This categorization is also needed for further study where models for selected models will be developed in PTV Vissim. The classification of vehicle categories is presented in table 3.2 below:

Table 3.2 Classification of Vehicles

S no.	Vehicles Grouped Together	Group Designation
1	Sedans and Hatch Backs such as Swift Dzire	Car
2	Trucks, commercial vehicles	HCV
3	Mini-Trucks and Vans	LCV
4	SUVs and MUVs such as Scorpio, Xylo, and Bolero	SUV
5	Motor-bikes, Scooters, and Mopeds	2w
6	Three-wheelers such as Auto, Vikram	3w
7	Passenger Buses, School Bus	Bus

As discussed earlier, for the present study, vehicles were classified in seven categories (Table 3.2). The composition of vehicles for four of the selected sites is shown in **Fig 3.14 to Fig 3.16**. It was noticed that nearly half of the total volume at all the approaches of intersection sites consisted of cars (up to 55 percent), which was followed by bikes (up to30 percent) showing resemblance to the expected Indian traffic conditions which are typical of Indian road conditions. With an exception at Bahadurgarh-Nayagaon intersection, where HCVs and LCVs constituted 10 percent of the total volume, they mostly constituted minor portion of less than 5 percent for all other intersections. The proportion of SUVs varied from 6 to10 percent of total volume for all approaches at all intersections.



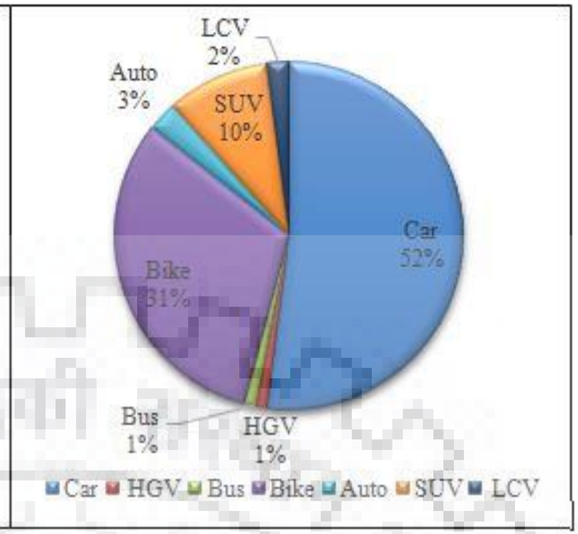
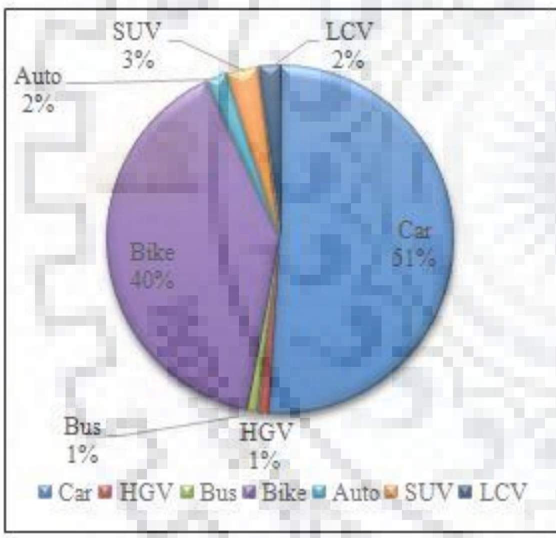


Fig 3.13:Bahadurgarh(IS1) intersection **Fig 3.14:Dwarka-Kargil(IS5) intersection**



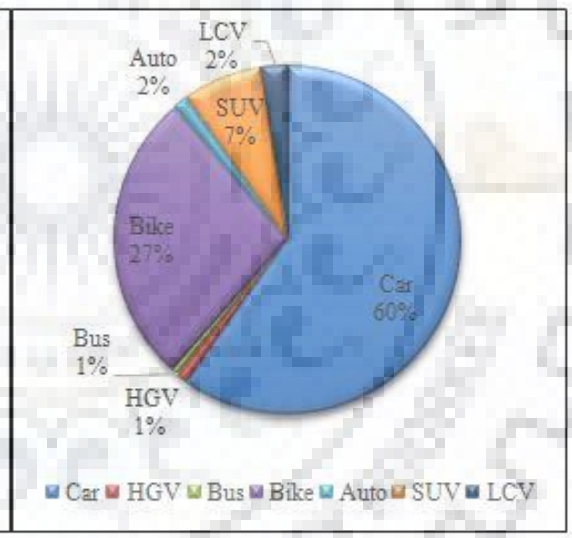
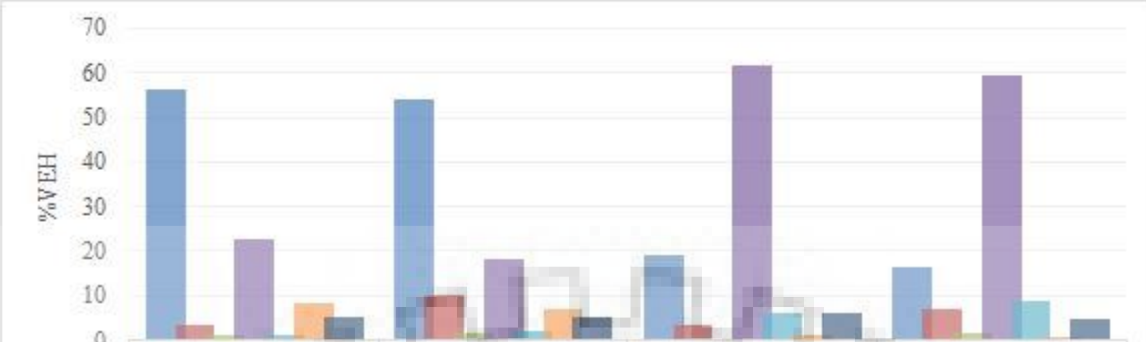


Fig 3.15: Faridabad (IS4) intersection **Fig 3.16: Dwarka-AIFF (IS3) intersection**

3.3.3. Relative Composition of Approaches

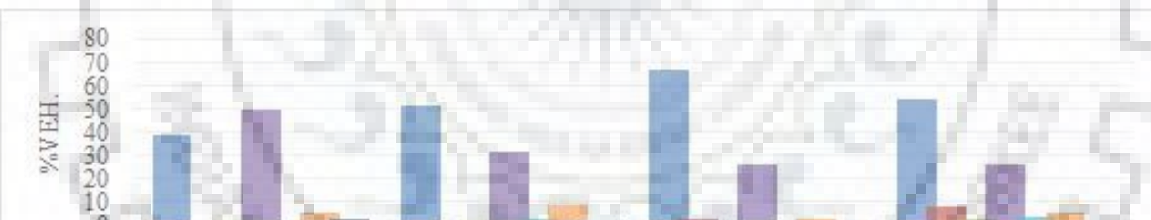
The relative vehicular composition of all approaches of intersections are extracted by "vehicle counter" VBA program and shown in **Fig 3.17** to **Fig 3.20**.



	^Dehi	V Rohtak	>Badli	<Bahadurgarh
Car	56.6	54.5	19.5	16.8
HGV	3.7	10.1	3.7	7.2
Bus	1.15	1.9	0.5	1.8
Bike	23	18.5	61.8	59.6
Auto	1.25	2.3	6.5	9
SUV	8.7	7.4	1.5	0.8
LCV	5.6	5.3	6.5	4.8

Car HGV Bus Bike Auto SUV LCV

Fig 3.17: Relative composition of Bahadurgarh (IS1) intersection



	^Golf Course road	V 205 Delhi road	>Sector 18A	<Sector 19
Car	39.3	52	67.3	54.2
HGV	1	1.03	2.3	8.4
Bus	1.1	1.14	0.4	1.8
Bike	50.15	31.44	26.2	26.6
Auto	1	2.8	1.1	3.7
SUV	5.05	9.53	2.3	5.1
LCV	2.5	2.06	0.4	0.2

Car HGV Bus Bike Auto SUV LCV

Fig 3.18: Relative composition of Dwarka-Kargil (IS5) intersection

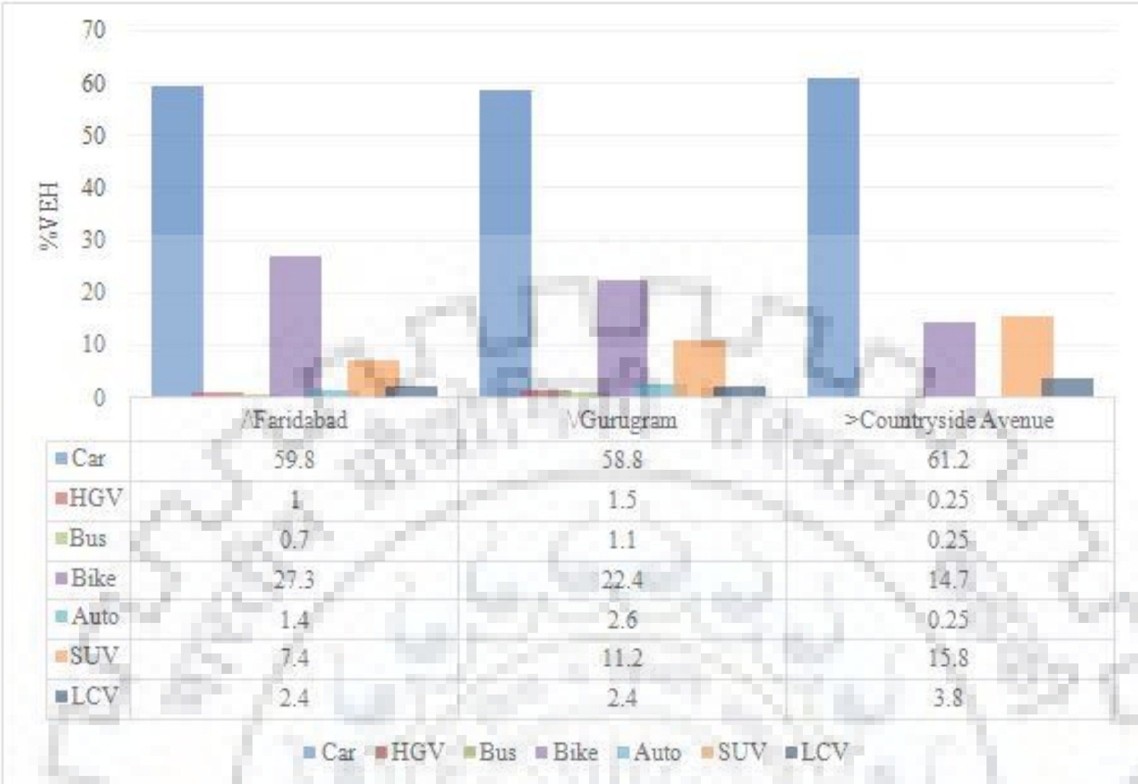


Fig 3.19: Relative composition of Faridabad (IS4) intersection

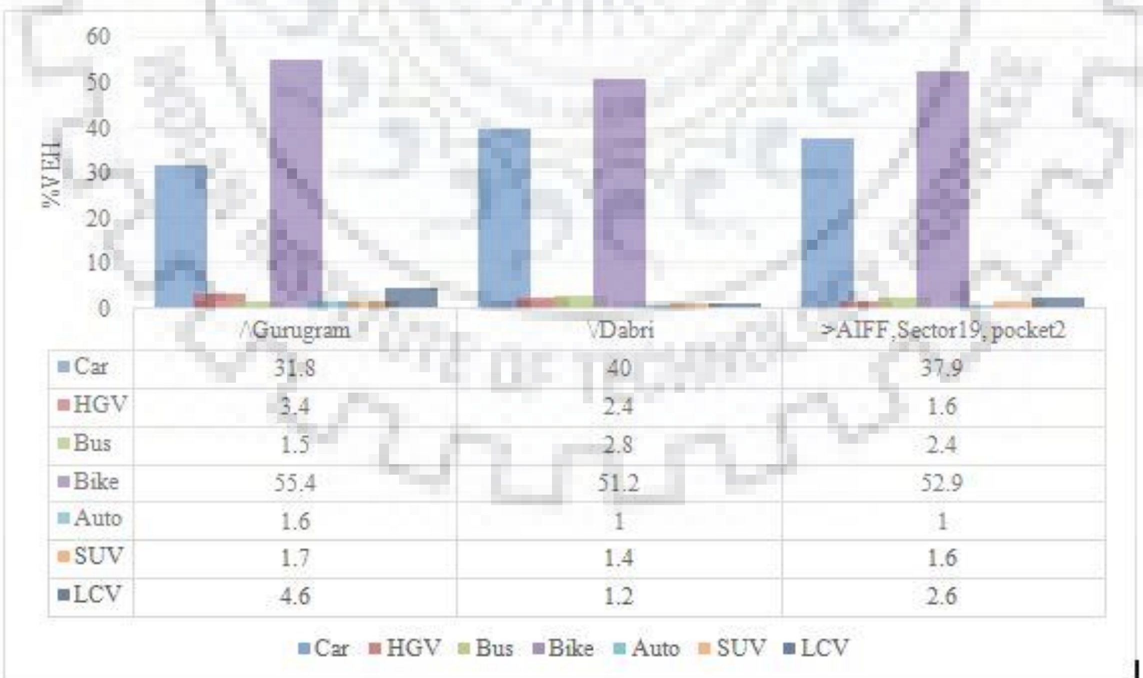


Fig 3.20: Relative composition of Dwarka-AIFF (IS3) intersection

3.3.1.2 Traffic Volume Composition (Veh/h) of intersections

The details of traffic volume composition of each site and details of geometric design parameters are shown in table 3.3 and table 34 respectively:

Table 3.3: Site Details and total volume

S.No	CHAINAGE	SITES	MAJOR ROAD VOLUME(Veh/hr)	MINOR ROAD VOLUME(Veh/hr)
IS1	50	Naya Gaon, Bahadurgarh New Delhi, Haryana	2107	1087
IS2	55	Iskcon Chowk, DwarkaNew delhi, Delhi	2869	1087
IS3	56.32	Dwarka AIFF New Delhi, Delhi	10551	2062
IS4	58	Gurgaon Sikenderpur Faridabad Gurgaon, Haryana	6092	1065
IS5	60	Dwarka Kargil Chowk New Delhi, Delhi	2662	1059
IS6	65.9	V S Gas Ggency NH 58 Meerut	1093	628
IS7	71.4	Modi International School,Modipuram Meerut	3580	457
IS8	72	Pandit Sweet Corner Modipuram	3498	340
IS9	96	Meerut Khatauli Pathanpura Maliyana	2750	461
IS10	105.8	Aman Dairy NH58 Meerut	1882	768
IS11	108	Saraswati Gurukul Vidya Madir School Mansorpur	2442	344
IS12	113.82	Microtech Engineers Delhi-Haridwar Road, Sujroo, UP	1981	199
IS13	124.2	Pandit ji Dhaba, Royal Academy Palhada bypass ,Muzzafarnagar	2980	267
IS14	126.7	Vaishno Dhaba Gurukul Narson, Muzzafarnagar	1637	763

Table 3.4: Details of geometric design parameter

S.NO	TYPE OF INTERSECTION	MEDIAN WIDTH(m)	SHOULDER WIDTH(m)	MAJOR ROAD CW WIDTH(m)	MINOR ROAD CW WIDTH(m)
IS1	4 legged	4.3	4.3	7.25	7.3
IS2	4 legged	3	3	9	7.94
IS3	3 legged	2	2	9	5.12
IS5	4 legged	2.5	2.5	9	7.9
IS6	4 legged	3.2	3.2	8.6	6.8
IS7	3legged	4.2	3	9	6.9
IS8	3legged	3.5	1.2	8.4	5.6
IS9	4 legged	1.3	1.3	13.3	3.93
IS10	3legged	2.5	2.5	9	7.2
IS11	3legged	4	1.4	8.8	3.8
IS12	3legged	3.8	1.4	8.6	7.2
IS13	3legged	3.4	2.1	8.2	6.2
IS14	3legged	4	2.6	8	7.4

3.3.2 Collection Of Accident Data

The main source of accident data are police record, hospitals, insurance agencies. For this particular study the data of road accident has been extracted from the police records with the permission of the concerned police officials.

Accident data for the last 5 years (2012-2016) has been collected from the police stations of NCR locations and UP Western Toll Plaza.

Collected parameters from the police records are-

1)Accident location

2)Intersection type

3)Accident nature

4)Total no. of accidents

The total number of accidents at the selected intersections during the period of 5 years is summarized in table 3.5:

TABLE3.5: Accident Detail Summary of Study area intersections:

S.No	CHAINAGE	INTERSECTION SITES	Total Accidents in 5 years.
IS1	50.0	NayaGaon, Bahadurgarh New Delhi, Haryana	17
IS2	55.0	IskconChowk, DwarkaNew delhi, Delhi	23
IS3	56.3	Dwarka AIFF New Delhi, Delhi	24
IS4	58.0	Gurgaon Sikenderpur Faridabad Gurgaon, Haryana	18
IS5	60.0	DwarkaKargilChowk New Delhi, Delhi	16
IS6	65.9	V S Gas Ggency NH 58 Meerut	18
IS7	71.4	Modi International School,Modipuram Meerut	21
IS8	72.0	Pandit Sweet Corner Modipuram	19
IS9	96.0	Meerut Khatauli Pathanpura Maliyana	16
IS10	105.8	Aman Dairy NH58 Meerut	24
IS11	108.0	Saraswati Gurukul VidyaMadir School Mansorpur	15
IS12	113.8	Microtech Engineers Delhi-Haridwar Road, Sujroo, UP	20
IS13	124.2	PanditjiDhaba, Royal Academy Palhada bypass ,Muzzafarnagar	25
IS14	126.7	VaishnoDhaba GurukulNarson, Muzzafarnagar	24

A general trend of number of accidents in NCR in the time period 2012 to 2016 has been summarized in table 3.6:

TABLE3.6: Accident Detail Summary of NCR

Year	Total number of accidents	Total number of deaths	Total number of injuries
2012	137	78	168
2013	115	44	135
2014	113	59	102
2015	106	56	101
2016	101	52	97

NETWORK MODELLING AND ACCIDENT PREDICTION MODEL

4.1 Network Modelling

4.1.1 General

After analysis and extraction of traffic and crash data, the next step according to the methodology was to simulate the study area intersections in PTV Vissim. By the use of links, connectors and the field data, fourteen of the selected intersections were simulated in Vissim. After the simulation was run, the trajectory (.trj*) of the model was generated which was then analyzed with SSAM software for obtaining number of conflicts.

4.1.2 Defining Model Parameters

4.1.2.1 Vehicle Models

The default model that is already present in VISSIM generally takes care of homogenous condition of traffic, therefore for taking into consideration the heterogeneous condition of traffic, new models of vehicles are needed to be added. Heterogeneous condition of traffic consists of a blend of vehicles which have very distinct static as well as dynamic properties.Hence there is a need of adding the vehicles such as TATA 407 (Light commercial vehicle), cycle rickshaw, for more accurate simulation. Models in 3D were directly available for TATA truck, Delhi Green Bus, cycle rickshaw and Auto rickshaw and so were added directly to the .exe directory of vissim. The procedure to add vehicles is:

"**Base Data > 2D/3D Model >Add** (if 3D model is available)

Base Data > 2D/3D Model > Add without file (if 3D model is not available)"

4.1.2.2. Desired Speed Distribution

The capacity of a particular link as well as time of travel on the link is affected largely by desired speed distribution function making it an important parameter. The driver whose desired speed is more than his current travelling speed will always be looking for the opportunity to perform overtaking operation safely. Traffic Data Extractor (TDE), a software which was developed by IIT Bombay for the purpose of counting of traffic volume, extraction of vehicle trajectory and extraction of speed of vehicles was used for extracting the speed distribution of all types of vehicles for all approach roads of an intersection. In Vissim, it is possible to add a new distribution of speed by adding middle points as spline points to the cumulative speed frequency distribution curve. Generally by the use of two nodes only, S-shaped distribution curve is achieved accurately and thus as achieving precise mean value. Minimum speed, 50th percentile speed, 85th percentile speed and maximum speed play an important role in accurate running of simulation. The data which was extracted from video of intersections was added to the model using the following command:

"Base Data > Distributions > Desired Speed > Add"

After entering the command, a window for desired speed distribution opens as shown in **Fig 4.1**. By the help of speed data corresponding to 15th, 50th, 85th percentile speed with maximum and minimum speed, a curve is drawn:

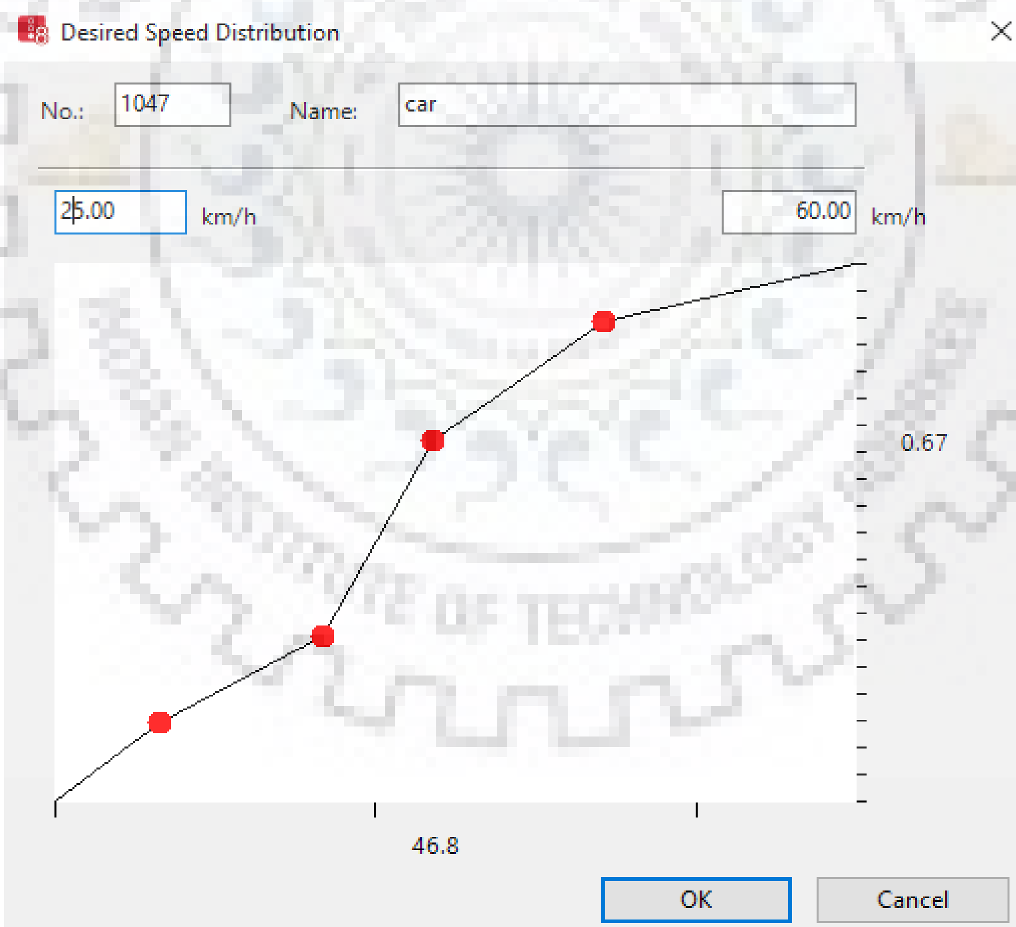


Fig 4.1: Speed distribution window

4.1.2.3. Vehicle Composition

The data required for vehicle composition consisted of type of vehicle, relative volume and desired speed distribution of the particular vehicle type. For a specific approach of an intersection, the data for composition of vehicles was extracted by VBA program and then added in the Vissim simulated network by the following command:

"Lists > Private Network > Vehicle Composition > Add, or
Traffic > Vehicle Composition > Add"

The vehicle composition of 205 **Delhi road** and **Golf-course road** approach of Dwarka-Kargilintersection is shown in **Fig 4.2** and **Fig 4.3** respectively as **Cm(a)** and **Cm(b)**.

Count: 7	VehType	DesSpeedDistr	RelFlow
1	100: Car	1047: Car	52.000
2	200: HGV	1050: Hgv	1.030
3	300: Bus	1050: Hgv	1.140
4	600: Bike	1048: Bike	31.440
5	610: Auto	1049: Auto	2.800
6	620: SUV	1047: Car	9.530
7	630: ICV	1051: Lcv	2.060

Fig 4.2: Cm(a) for Dwarka-Kargil

Count: 7	VehType	DesSpeedDistr	RelFlow
1	100: Car	1047: Car	39.300
2	200: HGV	1050: Hgv	1.000
3	300: Bus	1050: Hgv	1.100
4	600: Bike	1048: Bike	50.150
5	610: Auto	1049: Auto	1.000
6	620: SUV	1047: Car	5.050
7	630: ICV	1051: Lcv	2.500

Fig 4.3: Cm(b) for Dwarka-Kargil

4.1.2.4. Acceleration and Deceleration Rates

The acceleration and deceleration rates for all vehicle classes were taken from a recent (Acceleration-Deceleration) study for Indian heterogenous condition entitled "**Acceleration-Deceleration Behaviour of Various Vehicle Types**" on Indian intersections by **IIT Bhubaneswar** which is very similar to intersection sites used in the present study. Vissim does not use individual acceleration or de-acceleration data points for accounting for different driving behavior of various drivers along with mixed vehicle properties at the time of acceleration or de-acceleration. It rather uses functions in place of discrete data points. The limitation of the acceleration and de-acceleration data which was implemented in the present research was that it could not cover a vast range of values of speed. So for a few particular cases, default values stored in vissim was used for maintaining uniformity.

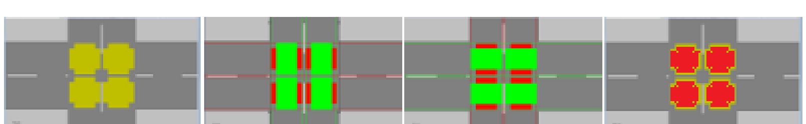
Table 4.1: Vehicle characteristics used for simulation

Vehicle Type	Length (m)	Width (m)	Desired Speed (km/h)	Acceleration (m/s2)		Deceleration (m/s2)	
				Maximum	Desired	Maximum	Desired
Two-Wheeler	1.8	0.5	40	2.5	1.7	1.7	1.2
Auto Rickshaw	3.2	1.4	25	1.2	0.9	1.1	0.8
Car/SUV	4.4	1.5	50	2.23	1.2	4.3	1
Bus/HGV	11.54	2.5	20	1.3	0.8	1.4	0.6
LCV	6.1	2.2	25	0.8	0.7	1.2	0.6

4.1.2.5. Conflict Areas

The behavior of drivers on an unsignalized intersection is modeled on the basis of his behavior in conflict areas. Before the decision of a vehicle which is yielding about entering on the major road and crossing the conflict area is made, it has to watch the traffic on major road very carefully. Then depending on the situation perceived by the driver on whether he will get sufficient time to cross the conflict area or not, he has to accelerate or de-accelerate accordingly. If the driver sees that the flow on the major road is considerably high, he can decide to wait further more or to take more time and cross the conflicting area. Vehicles travelling in the major traffic stream also respond to the conflict areas. If under a circumstance, the vehicle from minor road misjudges the situation and is caught in between and is unable to cross the conflicting area then vehicles from the major traffic will have to apply brake or even completely stop sometimes. The various status of Vissim conflict is represented in **Fig 4.4** below:

- "Green: main flow (right of way, [2] in Fig 4.4)
- Red: minor flow (yield, [2] in Fig 4.4)
- Both red: (for branching conflicts so that vehicles can see each other [4] in Fig 4.4)
- Both yellow: (passive conflict area without right of way [1] in Fig 4.4)"



1 2 3 4

Fig 4.4: Conflict status in Vissim

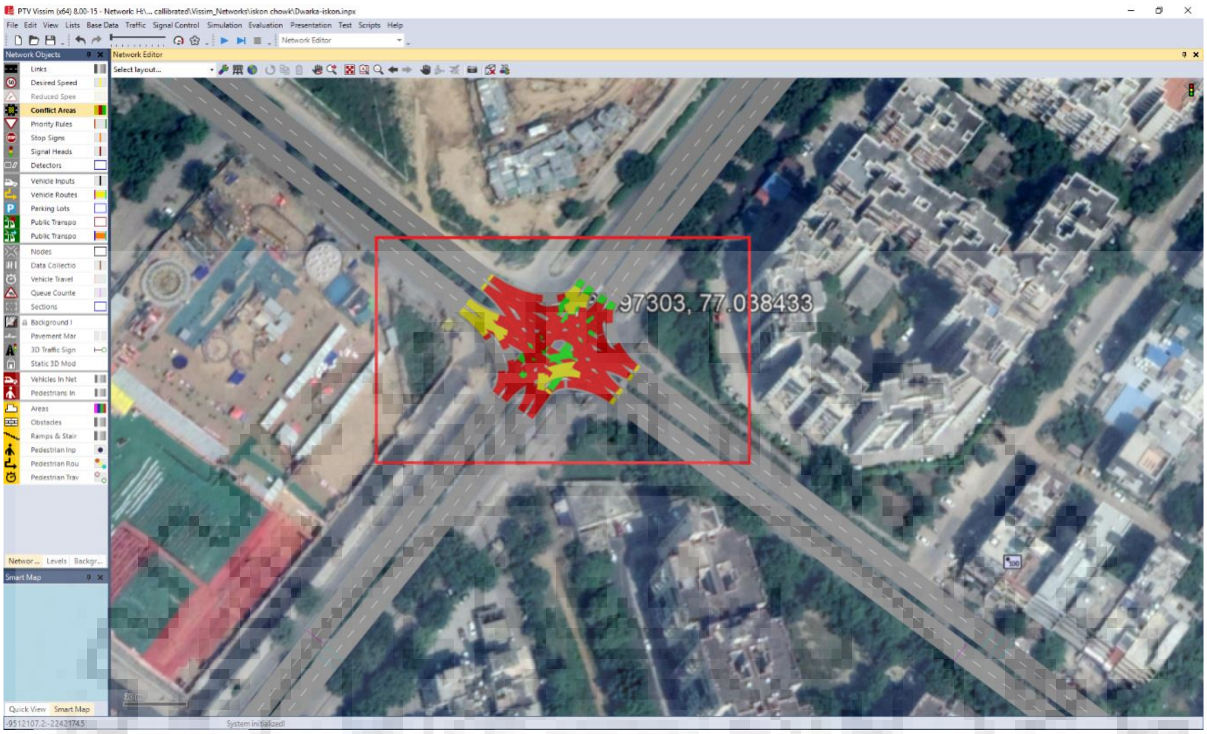


Fig 4.5: Conflict area modeling in networks

4.1.2.6. Evaluation Configuration

When a simulation is run in Vissim, then depending on the usage of objects used in network, different raw and aggregate data is produced which can be configured in the evaluation menu of Vissim. Depending on the further utilization and type of data, it is possible to get evaluations in the form of lists and/or windows and save them to text files and/or database files**(*db)**.For the present study, one type of data output is required for the analysis.

1. SSAM: It contains binary trajectories (*.trj) and describes the course of the vehicle position throughout the network.

4.1.3 Creating Base Network

Making a model of existing network in Vissim is a very complicated process but if done carefully can create a situation where it will be difficult to differentiate between real field condition and virtual traffic condition. The process of modeling started with importing image of the required intersection either from Google Earth or from Bing maps which is already inbuilt. After importing the image, links and connectors were drawn and superimposed over the imported image for getting the geometry of the required intersection as accurate as possible. Roads were represented by links and two links were connected by connectors.

Once the network was developed, next task was to input the exact data pertaining to traffic composition, volume and relative flow of every individual approach of a specific intersection which was extracted from video recording. After developing network and incorporating traffic data, the next step was to set up routing decisions which would simulate the field condition where the vehicles have a choice of moving in any particular direction. Based on turning movement counts of all approaches and options available to choose from dynamic, partial static or static routing decision, static routing one was chosen. Although the practice of priority rules is not common in countries like India, but still it has to be followed in the software for avoiding some unusual situations like cars going straight through each other. So the next process was setting up priority rules in Vissim.

After completing the first phase of completely developing the physical characteristics of a network, next most important part was definition of parameters to run simulation. Some of the parameters were simulation resolution, simulation ID, period of simulation, random seed, etc. The result of simulation run differs by changing simulation resolution because it impacts the behavior of vehicles that move during a simulation by specifying the count of time steps. For differentiating flow of traffic in multi-simulation runs in the same network, a random number generator which is at outcome of a stochastic function is required. Random seed fulfills this requirement. The simulation speed indicates time-lapse factor which corresponds to simulation seconds per real-time second, however simulation results are unaffected by simulation speeds. The models developed in Vissim are represented in **Fig 4.6 and Fig 4.7.**

An automated calibration was used for the preset study, with the help of Morris Elementary Effect of sensitivity analysis, COM interface of Vissim and Genetic Algorithm tool for optimization.

Fig 4.6: Representation of network at Bahadurgarh-Nayagaon-Balaur intersection.

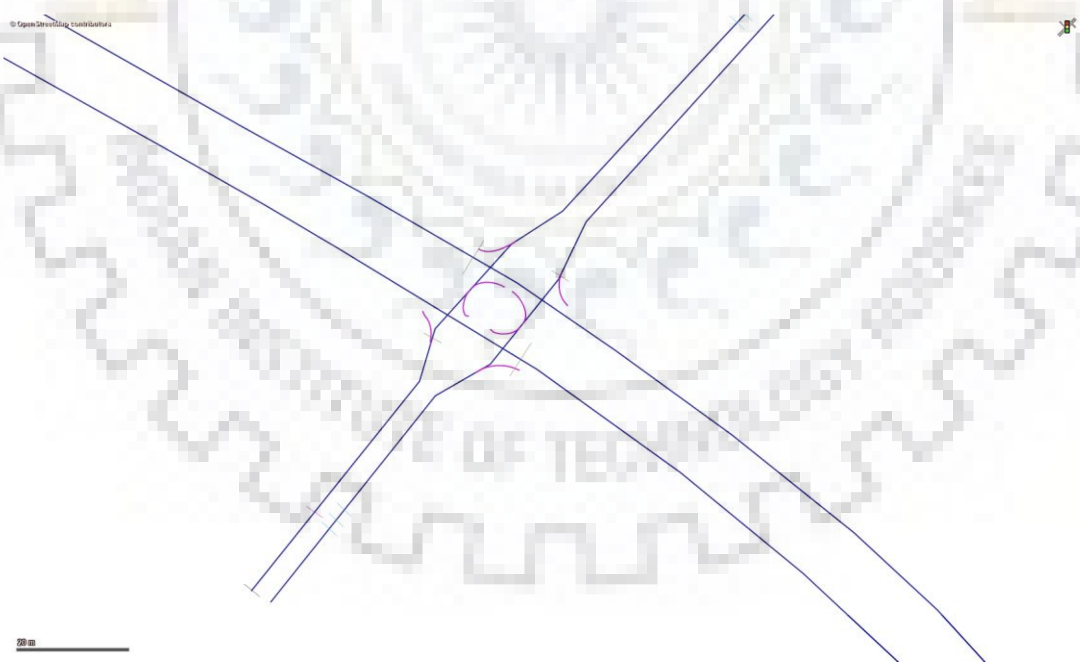


Fig 4.7: Representation of links and connectors at Bahadurgarh-Nayagaon-Balaur intersection.

4.2 Accident Prediction Modelling Techniques

4.2.1 General

The approach for development of a statistical equation linking accident frequency to average hourly conflict is the main objective of this section. An accident prediction model is a mathematical equation which is used to find the number of accidents in response to certain dependent variables (average hourly conflict in present study).

4.2.2 Negative Binomial Model

Negative binomial regression is a specific type of model belonging to Poisson regression family which is used when the dependent variable to be modeled is discrete rather than continuous. It is an improvement over Poisson model which does not account for the over dispersion present in data, that is the situation where mean of data is not equal to the variance of data. Even though the mean structure of negative binomial model is same as that of Poisson model, but it possesses an extra parameter to account for over dispersion. The confidence interval of negative binomial model become comparatively narrower than Poisson model in case of over dispersed dataset. The general equation for estimator is given as "

$$P(y) = P\ (Y = y) = \Gamma \frac{\Gamma\ (y + 1/\alpha)}{\Gamma\ (y + 1)\Gamma\ (1/\alpha)} \left(\frac{1}{1+\alpha\mu}\right)^{1/\alpha} \left(\frac{\alpha\mu}{1+\alpha\mu}\right)^{y} \quad \text{...........(4.1)}$$

Where $\mu > 0$ is the mean of Y and $\alpha > 0$ is the heterogeneity parameter."

The traditional negative binomial regression model, designated as "

$$\ln\mu = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots\ldots + \beta_p X_p\ , \quad \text{..................(4.2)}$$

where the predictor variables x_1 , x_2, ..., x_p are given, and regression coefficients β_0, β_1, β_2,...., β_p are to be estimated."

4.2.3. Bayesian Estimation of Model Parameters

According to traditional freqentist theories, the parameters of a regression equation are constants which are obtained by maximizing the most likelihood function. The Bayesian technique on the other hand requires the computation of a set of prior distributions for a parameter whose value is to be estimated. This prior distribution gives the summary of any prior information about the parameters that might be available before observation of any data is made. After the analysis of prior distribution, a posterior distribution is then formulated with the help of sampling methods. So basically Bayesian technique is a two stage process of determination of parameters of regression equation. It is proposed to use BayES software for carrying out Bayesian Estimation of model parameters. The Baseline model function is expected to come in the form of:

$$E(Y)=C_o * (AHC)^{C1} \quad \text{………(4.3)}$$

Where, E(Y)- No. of accidents; AHC- Average Hourly Conflict.

4.2.4 Model Performance Measures

The reliability of formulated models is checked through performance measurement methods involving statistics. These performance measures are also known as the test of 'goodness of fit' of model.

a.) Mean Absolute Deviance (MAD)

Mean Absolute Deviance is a statistical tool which is used for assessment of how accurately the model fits to the data and also give an idea of the average miss-predictions possible by the model. It is obtained by subtracting observed data (O) from estimated data (E) and then taking its absolute value. MAD is defined as: "

$$\text{MAD} = \frac{1}{n}\sum_{i=1}^{n} | Ei - Oi| \quad \text{……..(4.6)}$$

where, O_i = Observed crash frequency at site *i*.

E_i = Estimated crash frequency at site *i*."

b.) Mean Squared Predictive Error (MSPE)

MSPE is used to calculate the error which is associated with the validation of external data set of model. It measures the expected squared distance between predicted and true value. It can be assessed as: "

$$\text{MSPE} = \frac{1}{n}\sum_{i=1}^{n}(Ei - Oi)^2 \quad \text{………(4.7)}$$

where, O_i = Observed crash frequency at site *i*.

E_i = Estimated crash frequency at site *i*."

4.3 Traffic Calming measures:

Lane narrowing and speed tables are the two traffic calming measures used in this study.

4.3.1.Lane narrowing:

Lane narrowing was implemented as one of the traffic calming measures for increasing level of safety at an intersection. The lane width was reduced by 10% of the original width at almost 100m before the intersection began.

4.3.2.Speed Tables:

Speed tables are traffic calming measures that are used to reduce the traffic speed by raising the entire wheel base of a vehicle. Speed tables were placed 10m before junction on all the minor roads at the junction. As per IRC 99-2018 guidelines, the following specifications were used for speed tables:

i)Desired speed = 40kmph

ii)Length of ramp = 1.7m

iii)Gradient = 6%

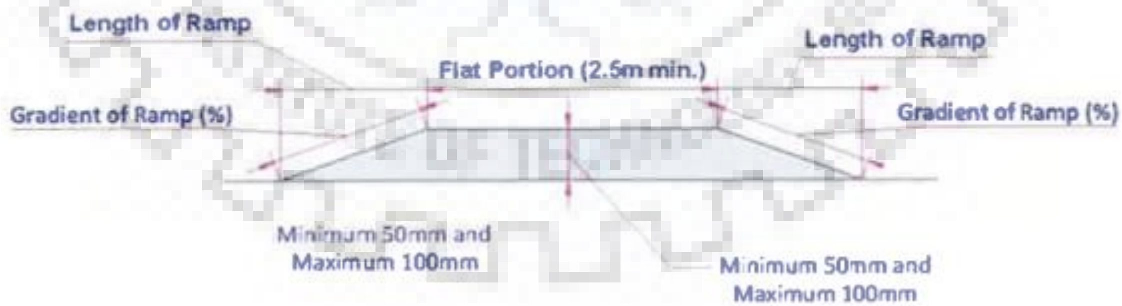


Fig 4.8: Representation of Speed Table used in Vissim

The models developed in Vissim after incorporating these traffic calming measures are shown in Fig 4.9 and Fig 4.10:

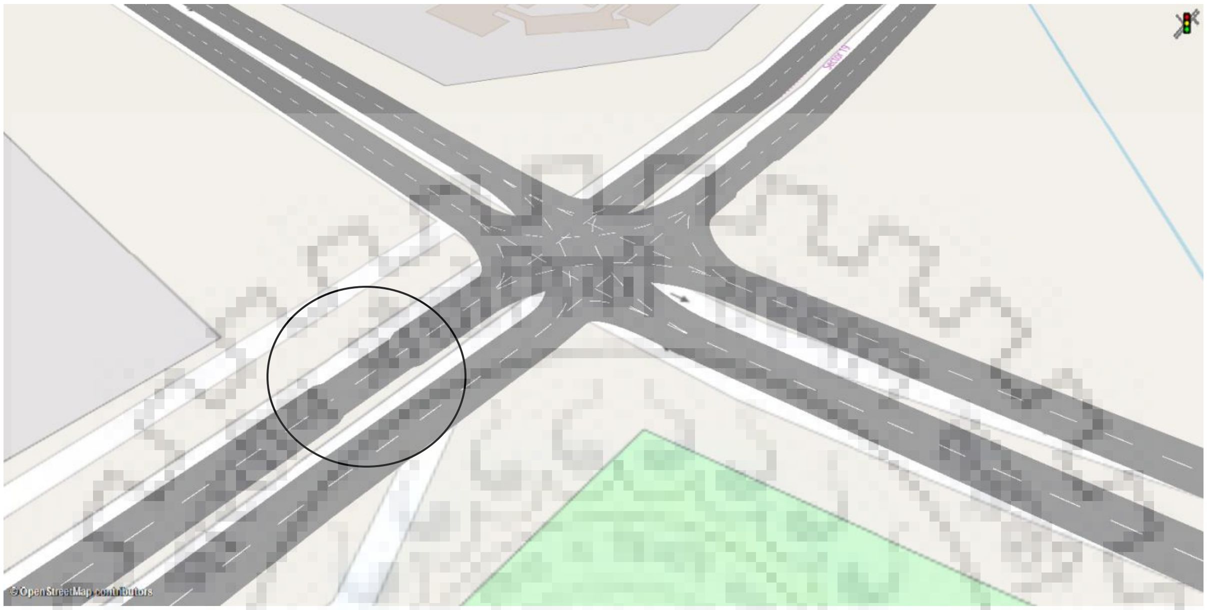


Fig 4.9: Representation of network at Dwarka Kargil intersection after lane narrowing

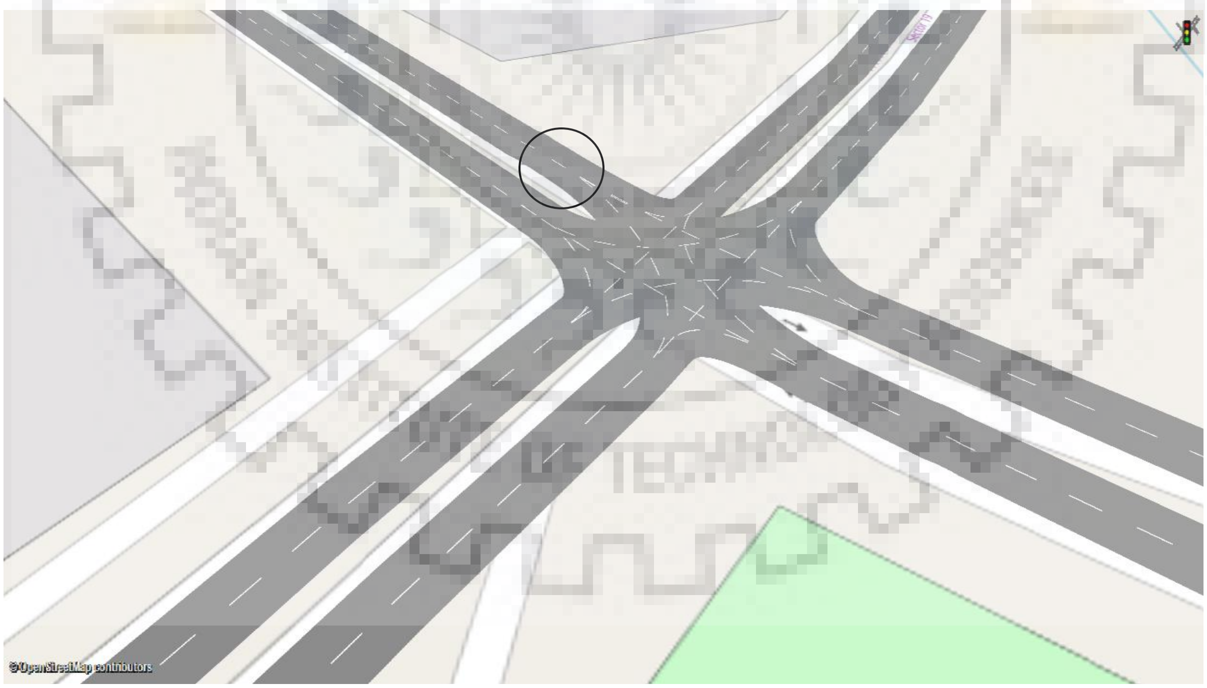


Fig 4.10: Representation of network at Dwarka Kargil intersection after constructing speed table

DATA ANALYSIS, RESULTS AND DISCUSSIONS

5.1 Number of conflicts at Intersections

The number of conflicts generated in PTV Vissim simulated models in base condition is shown in Table 5.1:

Table 5.1: No. of conflicts/hr in base condition

S.No	Total Conflicts/hr			
	Rear End	Crossing	Lane change	Total
IS1	70	72	15	157
IS2	80	81	20	181
IS3	79	88	17	184
IS4	58	60	20	138
IS5	55	62	15	132
IS6	62	65	18	145
IS7	76	79	17	172
IS8	72	75	18	165
IS9	58	63	15	136
IS10	85	88	14	187
IS11	50	53	18	121
IS12	73	77	19	169
IS13	86	89	18	193
IS14	84	88	17	189

5.2 Accident Prediction Model developed

The accident prediction model developed in BaYES software takes the form of:

$$Y = e^{\alpha} * X^{\beta}$$

Where, Y= Total Number of accidents, X= Total conflicts/hr;

α, β=Regression coefficients.

Coefficients	Value
α	-3.5656
β	0.9726
R^2	0.878
MAD	0.19
MSPE	0.037

Based on the accident prediction model developed, the predicted number of accidents are computed and shown in Table 5.2:

Table 5.2: Observed and predicted No. of accidents/yr

S.No	Observed No of accidents in 5 years	Observed No of accidents/yr	Predicted No of accidents/yr
IS1	17	3.4	3.9
IS2	23	4.6	4.4
IS3	24	4.8	4.5
IS4	18	3.6	3.4
IS5	16	3.2	3.3
IS6	18	3.6	3.6
IS7	21	4.2	4.2
IS8	19	3.8	4.1
IS9	16	3.2	3.4
IS10	24	4.8	4.6
IS11	15	3.0	3.0
IS12	20	4.0	4.2
IS13	25	5.0	4.7
IS14	24	4.8	4.6

5.3 Effect of Traffic calming measures

5.3.1 Lane Narrowing

The number of conflicts and predicted number of accidents after reducing the lane width are shown in Table 5.3

Table 5.3: No. of conflicts/hr and predicted no. of accidents after narrowing the lane

S.No	Total Conflicts/hr				Predicted No. of Accidents
	Rear End	Crossing	Lane change	Total	
IS1	75	69	15	159	3.9
IS2	91	78	18	187	4.6
IS3	88	87	16	191	4.7
IS4	67	58	18	143	3.5
IS5	61	59	14	134	3.3
IS6	72	64	17	153	3.8
IS7	82	76	16	174	4.3
IS8	80	73	18	171	4.2
IS9	67	62	14	143	3.5
IS10	97	88	13	198	4.8
IS11	54	52	17	123	3.0
IS12	80	75	18	173	4.2
IS13	93	85	17	195	4.8
IS14	90	88	15	193	4.7

5.3.2 Speed Table

The number of conflicts and predicted number of accidents after constructing speed tables are shown in Table 5.4:

Table 5.4: No. of conflicts/hr and predicted no. of accidents by constructing speed tables

S.No	Total Conflicts/hr				Predicted No of Accidents
	Rear End	Crossing	Lane change	Total	
IS1	61	68	15	144	3.6
IS2	65	73	20	158	3.9
IS3	64	84	17	165	4.1
IS4	53	54	19	126	3.1
IS5	47	58	15	120	3.0
IS6	56	62	18	136	3.4
IS7	66	71	17	154	3.8
IS8	60	72	18	150	3.7
IS9	47	55	15	117	2.9
IS10	73	85	14	172	4.2
IS11	41	51	18	110	2.7
IS12	55	68	19	142	3.5
IS13	75	84	18	177	4.3
IS14	72	79	17	168	4.1

5.4 Data Analysis:

5.4.1 Effect of Lane Narrowing on Rear End Conflicts

The effect of lane narrowing on number of Rear End conflicts are shown in Table 5.5 and Fig 5.1 :

Table 5.5: Percentage change in rear end conflicts by lane narrowing

S.NO	Rear end conflicts/hr		
	BASE CONDITION	LANE NARROWING	% CHANGE
IS 1	70	75	(+)7.14
IS 2	80	91	(+)13.75
IS 3	79	88	(+)11.39
IS 4	58	67	(+)15.52
IS 5	55	61	(+)10.91
IS 6	62	72	(+)16.13
IS 7	76	82	(+)7.89
IS 8	72	80	(+)11.11
IS 9	58	67	(+)15.52
IS 10	85	97	(+)14.12
IS 11	50	54	(+)8.00
IS 12	73	80	(+)9.59
IS 13	86	93	(+)8.14
IS 14	84	90	(+)7.14

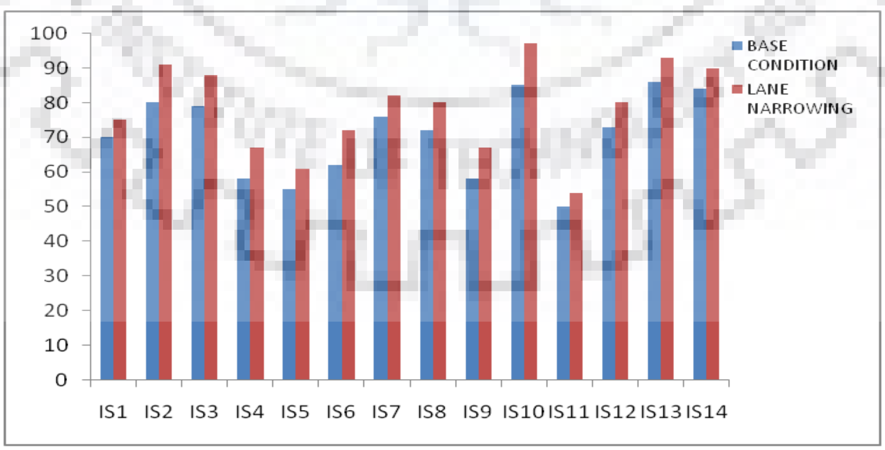


Fig 5.1: Effect of Lane Narrowing on Rear End Conflicts.

- It can be inferred from Table 5.5 and Fig 5.1 that because of reducing the lane width near intersections, Rear end conflicts increase on an average by 11%.

5.4.2 Effect of Lane Narrowing on Crossing Conflicts

The effect of lane narrowing on number of crossing conflicts are shown in Table 5.6 and Fig 5.2:

Table 5.6: Percentage change in crossing conflicts by lane narrowing

S.NO	Crossing conflicts/hr		
	BASE CONDITION	LANE NARROWING	% CHANGE
IS 1	72	69	-4.17
IS 2	81	78	-3.70
IS 3	88	87	-1.14
IS 4	60	58	-3.33
IS 5	62	59	-4.84
IS 6	65	64	-1.54
IS 7	79	76	-3.80
IS 8	75	73	-2.67
IS 9	63	62	-1.59
IS 10	88	88	0.00
IS 11	53	52	-1.89
IS 12	77	75	-2.60
IS 13	89	85	-4.49
IS 14	88	88	0.00

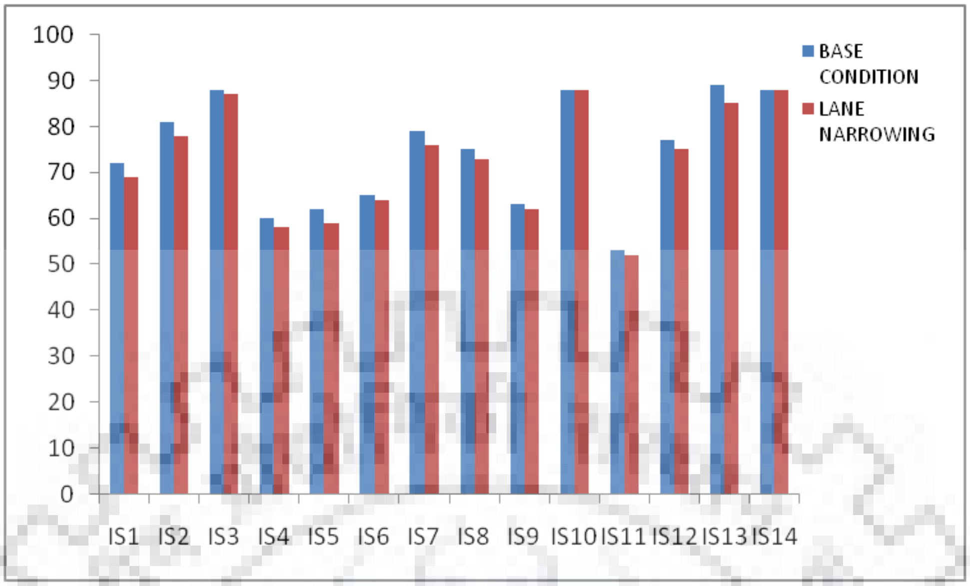


Fig 5.2: Effect of Lane Narrowing on crossing conflicts.

- It can be inferred from Table 5.6 and Fig 5.2 that because of reducing the lane width near intersections, Crossing conflicts decrease on an average by 2.5%.

5.4.3 Effect of Lane Narrowing on Lane changing Conflicts

The effect of lane narrowing on number of Lane changing conflicts are shown in Table 5.7 and Fig 5.3:

Table 5.7: Percentage change in Lane changing conflicts by lane narrowing

S.NO	Lane Changing conflicts/hr		
	BASE CONDITION	LANE NARROWING	% CHANGE
IS 1	15	15	0.00
IS 2	20	18	-10.00
IS 3	17	16	-5.88
IS 4	20	18	-10.00
IS 5	15	14	-6.67
IS 6	18	17	-5.56
IS 7	17	16	-5.88
IS 8	18	18	0.00
IS 9	15	14	-6.67
IS 10	14	13	-7.14

IS 11	18	17	-5.56
IS 12	19	18	-5.26
IS 13	18	17	-5.56
IS 14	17	15	-11.76

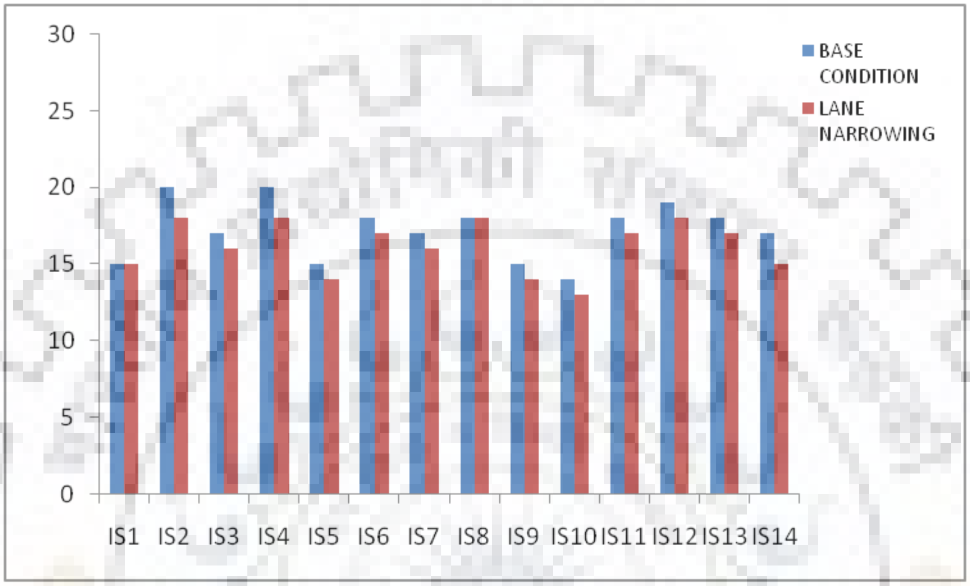


Fig 5.3: Effect of Lane Narrowing on Lane Changing conflicts.

- It can be inferred from Table 5.7 and Fig 5.3 that because of reducing the lane width near intersections, Lane changing conflicts decrease on an average by 6.15%.

5.4.4 Effect of Lane Narrowing on Total Conflicts

The effect of lane narrowing on Total number of conflicts are shown in Table 5.8 and Fig 5.4:

Table 5.8: Percentage change in Total conflicts by lane narrowing

S.NO	Total conflicts/hr		
	BASE CONDITION	LANE NARROWING	% CHANGE
IS 1	157	159	(+)1.27
IS 2	181	187	(+)3.31
IS 3	184	191	(+)3.80
IS 4	138	143	(+)3.62
IS 5	132	134	(+)1.52

IS 6	145	153	(+)5.52
IS 7	172	174	(+)1.16
IS 8	165	171	(+)3.64
IS 9	136	143	(+)5.15
IS 10	187	198	(+)5.88
IS 11	121	123	(+)1.65
IS 12	169	173	(+)2.37
IS 13	193	195	(+)1.04
IS 14	189	193	(+)2.12

Fig 5.4: Effect of Lane Narrowing on Total conflicts.

- It can be inferred from Table 5.8 and Fig 5.4 that because of reducing the lane width near intersections, Total conflicts increase on an average by 3%.

5.4.5 Effect of Lane Narrowing on total number of accidents

The effect of lane narrowing on Total number of Accidents are shown in Table 5.9 and Fig 5.5:

Table 5.9: Percentage change in predicted accidents by lane narrowing

S.NO	Predicted accidents/yr		
	BASE CONDITION	LANE NARROWING	% CHANGE
IS 1	3.9	3.9	0.00
IS 2	4.4	4.6	(+)4.55
IS 3	4.5	4.7	(+)4.44
IS 4	3.4	3.5	(+)2.94
IS 5	3.3	3.3	0.00
IS 6	3.6	3.8	(+)5.56
IS 7	4.2	4.3	(+)2.38
IS 8	4.1	4.2	(+)2.44
IS 9	3.4	3.5	(+)2.94
IS 10	4.6	4.8	(+)4.35
IS 11	3.0	3.0	0.00
IS 12	4.2	4.2	0.00
IS 13	4.7	4.8	(+)2.13
IS 14	4.6	4.7	(+)2.17

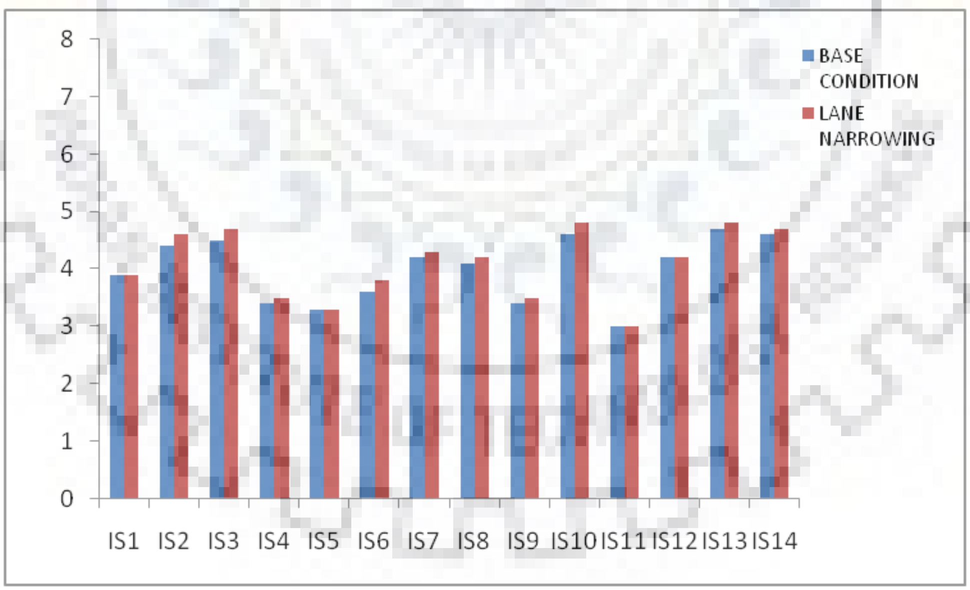


Fig 5.5: Effect of Lane Narrowing on Accidents/yr.

- It can be inferred from Table 5.9 and Fig 5.5 that because of reducing the lane width near intersections, Total accidents per year increase on an average by 2.4%.

5.4.6 Effect of Speed Tables on Rear End conflicts

The effect of Speed Table on number of Rear End conflicts are shown in Table 5.10 and Fig 5.6:

Table 5.10: Percentage change in rear end conflicts by Speed Table

S.NO	Rear end conflicts/hr		
	BASE CONDITION	SPEED TABLE	% CHANGE
IS 1	70	61	-12.86
IS 2	80	65	-18.75
IS 3	79	64	-18.99
IS 4	58	53	-8.62
IS 5	55	47	-14.55
IS 6	62	56	-9.68
IS 7	76	66	-13.16
IS 8	72	60	-16.67
IS 9	58	47	-18.97
IS 10	85	73	-14.12
IS 11	50	41	-18.00
IS 12	73	55	-24.66
IS 13	86	75	-12.79
IS 14	84	72	-14.29

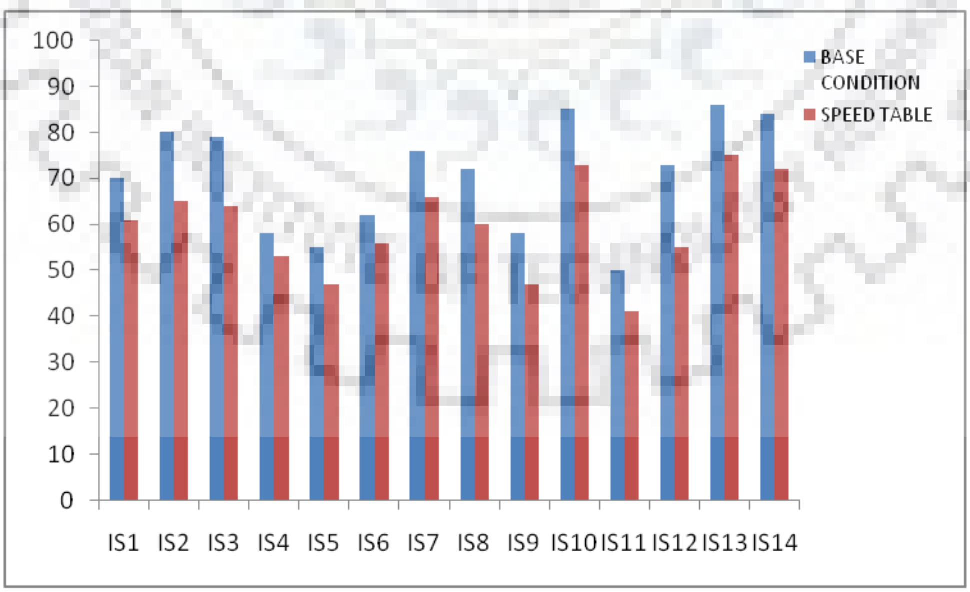


Fig 5.6: Effect of Speed Table on Rear End Conflicts.

- It can be inferred from Table 5.10 and Fig 5.6 that because of constructing speed table near intersections, rear end conflicts decrease on an average by 15.4%.

5.4.7 Effect of Speed Tables on crossing conflicts

The effect of Speed Table on number of crossing conflicts are shown in Table 5.11 and Fig 5.7:

Table 5.11: Percentage change in crossing conflicts by Speed Table

S.NO	Crossing conflicts/hr		
	BASE CONDITION	SPEED TABLE	% CHANGE
IS 1	72	68	-5.56
IS 2	81	73	-9.88
IS 3	88	84	-4.55
IS 4	60	54	-10.00
IS 5	62	58	-6.45
IS 6	65	62	-4.62
IS 7	79	71	-10.13
IS 8	75	72	-4.00
IS 9	63	55	-12.70
IS 10	88	85	-3.41
IS 11	53	51	-3.77
IS 12	77	68	-11.69
IS 13	89	84	-5.62
IS 14	88	79	-10.23

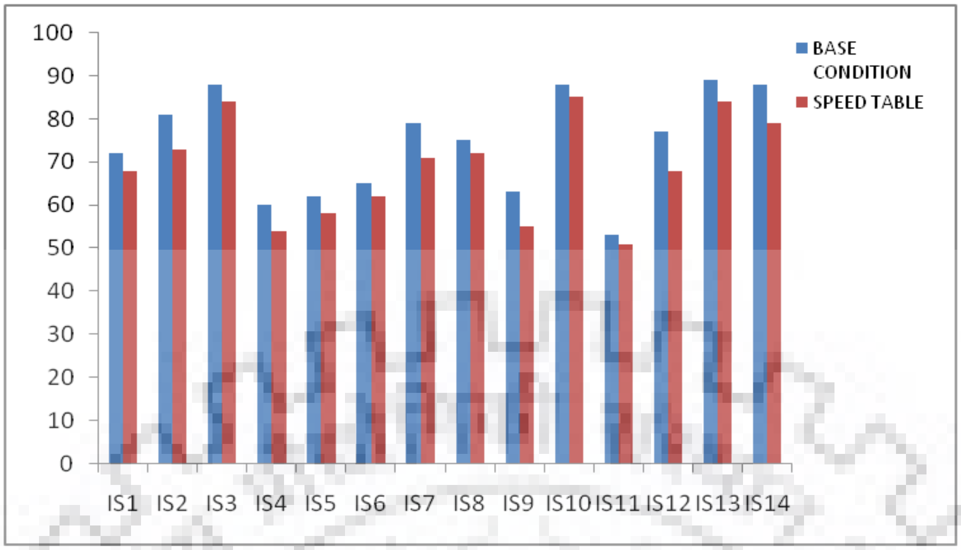


Fig 5.7: Effect of Speed Table on crossing conflicts.

- It can be inferred from Table 5.11 and Fig 5.7 that because of constructing speed table near intersections, crossing conflicts decrease on an average by 7.3%.

5.4.8 Effect of Speed Tables on Lane changing conflicts

The effect of Speed Table on number of Lane changing conflicts are shown in Table 5.12 and Fig 5.8:

Table 5.12: Percentage change in Lane changing conflicts by Speed Table

S.NO	Lane Changing conflicts/hr		
	BASE CONDITION	SPEED TABLE	% CHANGE
IS 1	15	15	0.00
IS 2	20	19	-5.00
IS 3	17	17	0.00
IS 4	20	19	-5.00
IS 5	15	14	-6.67
IS 6	18	18	0.00
IS 7	17	17	0.00
IS 8	18	18	0.00
IS 9	15	13	-13.33
IS 10	14	14	0.00
IS 11	18	18	0.00
IS 12	19	19	0.00
IS 13	18	18	0.00
IS 14	17	17	0.00

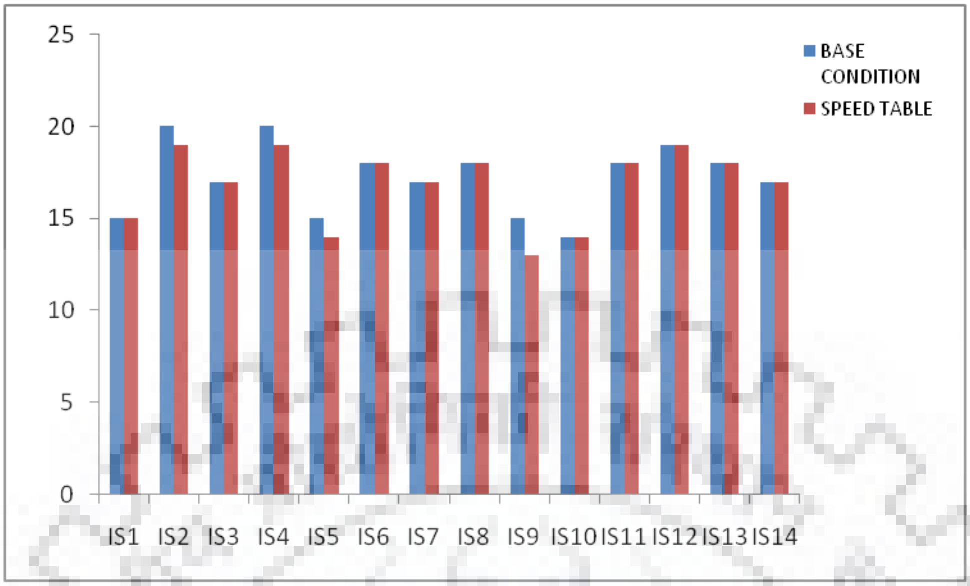


Fig 5.8: Effect of Speed Table on Lane Changing Conflicts.

- It can be inferred from Table 5.12 and Fig 5.8 that because of constructing speed table near intersections, Lane changing conflicts decrease on an average by 2%.

5.4.9 Effect of Speed Tables on Total conflicts

The effect of Speed Table on Total number of conflicts are shown in Table 5.13 and Fig 5.9:

Table 5.13: Percentage change in total conflicts by Speed Table

S.NO	Total conflicts/hr		
	BASE CONDITION	SPEED TABLE	% CHANGE
IS 1	157	144	-8.28
IS 2	181	158	-12.71
IS 3	184	165	-10.33
IS 4	138	126	-8.70
IS 5	132	120	-9.09
IS 6	145	136	-6.21
IS 7	172	154	-10.47
IS 8	165	150	-9.09
IS 9	136	117	-13.97
IS 10	187	172	-8.02
IS 11	121	110	-9.09
IS 12	169	142	-15.98
IS 13	193	177	-8.29
IS 14	189	168	-11.11

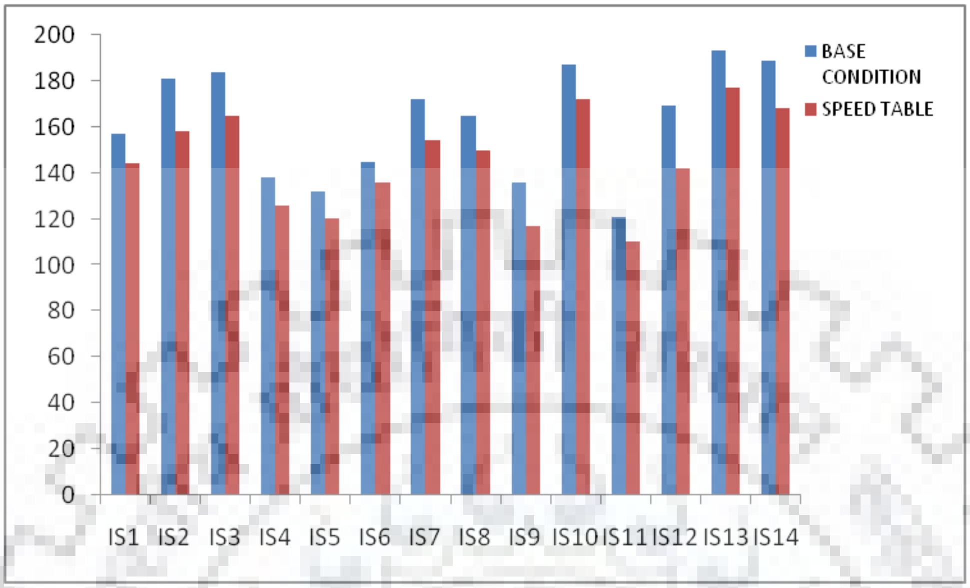


Fig 5.9: Effect of Speed Table on Total Conflicts.

- It can be inferred from Table 5.13 and Fig 5.9 that because of constructing speed table near intersections, total conflicts decrease on an average by 10%.

5.4.10 Effect of Speed Tables on total number of accidents

The effect of Speed tables on Total number of Accidents are shown in Table 5.14 and Fig 5.10:

Table 5.14: Percentage change in predicted accidents by Speed Table

S.NO	Predicted Accidents/yr		
	BASE CONDITION	SPEED TABLE	% CHANGE
IS 1	3.9	3.6	-7.69
IS 2	4.4	3.9	-11.36
IS 3	4.5	4.1	-8.89
IS 4	3.4	3.1	-8.82
IS 5	3.3	3	-9.09
IS 6	3.6	3.4	-5.56
IS 7	4.2	3.8	-9.52
IS 8	4.1	3.7	-9.76

IS 9	3.4	2.9	-14.71
IS 10	4.6	4.2	-8.70
IS 11	3	2.7	-10.00
IS 12	4.2	3.5	-16.67
IS 13	4.7	4.3	-8.51
IS 14	4.6	4.1	-10.87

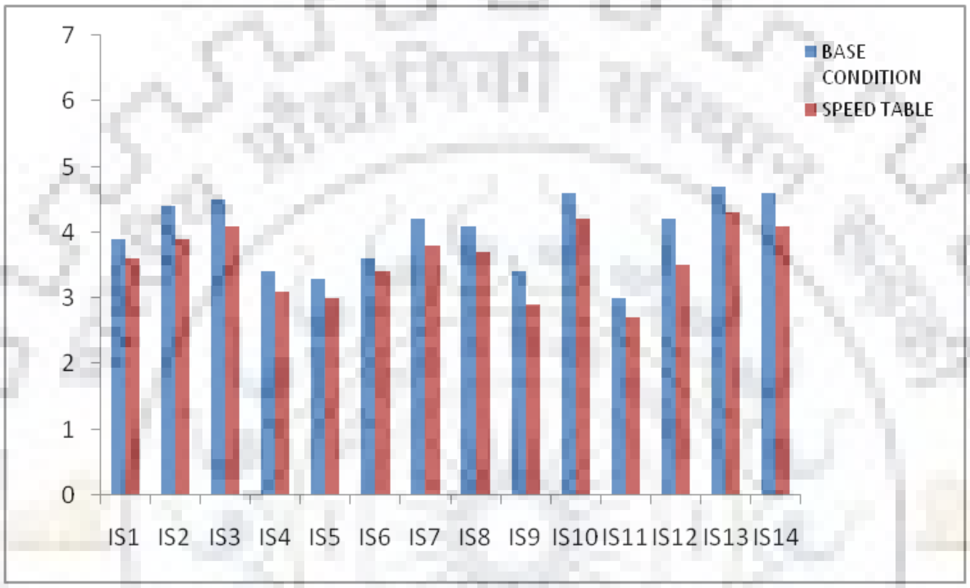


Fig 5.10: Effect of Speed Table on Accidents/yr.

- It can be inferred from Table 5.14 and Fig 5.10 that because of constructing speed table near intersections, total accidents/yr decrease on an average by 10%.

5.4.11Average effect of Traffic calming measures on conflicts and number of accidents.

The average effect of Lane narrowing and speed table on Rear End Conflicts, Crossing conflicts, Lane Changing conflicts, total conflicts and number of accidents/yr is shown in Fig. 5.11 and Fig. 5.12. It can be observed from the results that on an average reducing the width of carriageway results in increase in number of conflicts as well as number of accidents/yr while application of speed tables can cause reduction in both conflicts as well as number of accidents.

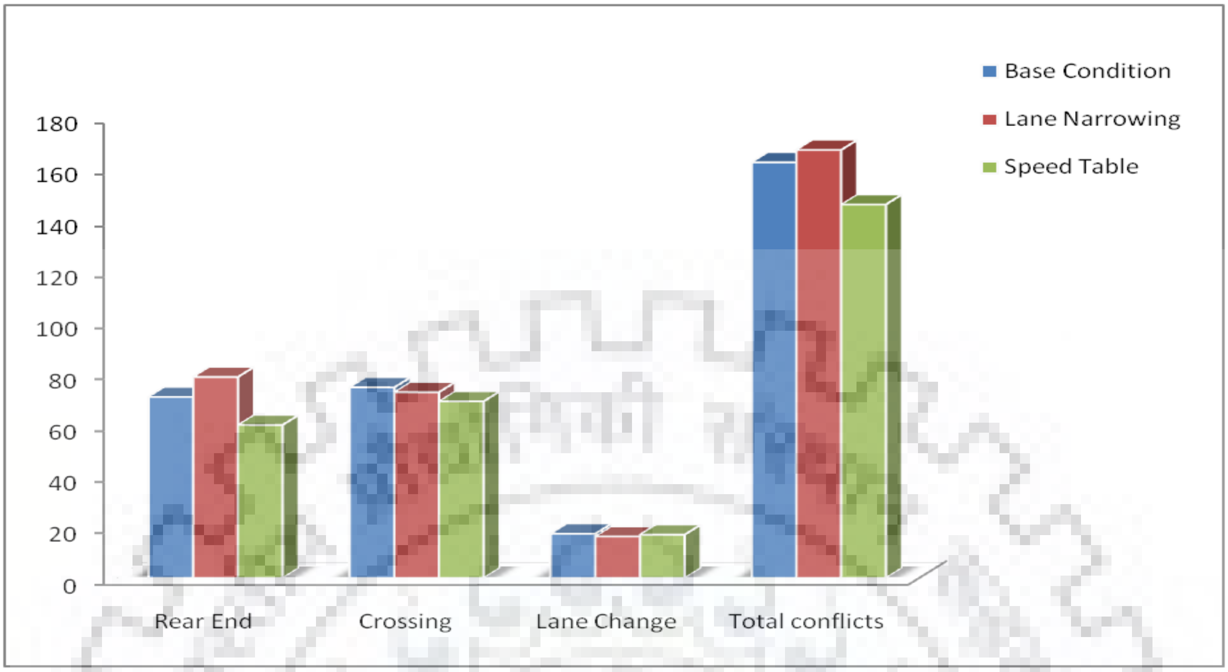


Fig 5.11: Effect of Lane narrowing and Speed Table on Various Conflicts

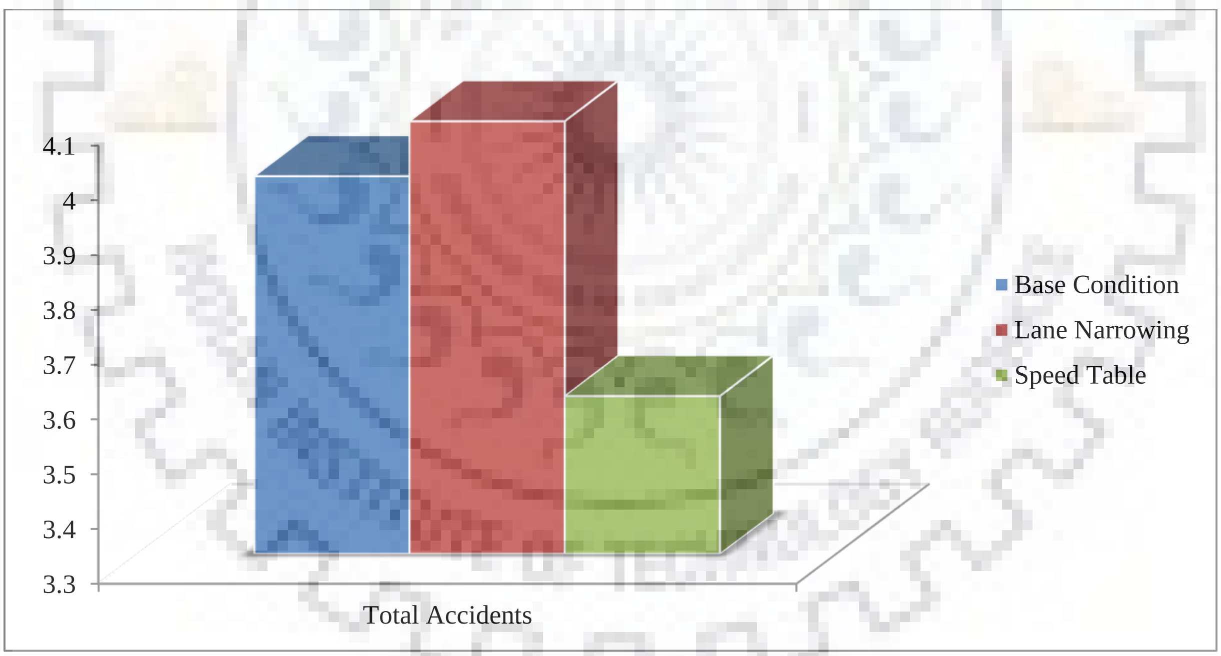


Fig 5.12: Effect of Lane narrowing and Speed Table on No. of accidents

CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions:

Simulation models of the intersection sites were developed for heterogenous traffic condition in PTV Vissim. SSAM Software was then used to find the number of conflicts in the developed simulation models. After that a conflict based accident prediction model (APM) was developed using negative binomial numerical method and Bayesian approach. Suitable traffic calming measures (e.g-speed tables and lane reduction) for safety assessment were then applied in the developed simulated models in Vissim. New number of conflicts was obtained then and from these new conflicts, changed number of accidents was calculated from the already developed conflict based APM to check the effectiveness of applied countermeasures. Based on the results of above study following conclusions can be drawn:

1. In base condition, the proportion of lane changing conflicts was considerably smaller than the crossing and rear end conflicts. Also the number of rear end and crossing conflicts is not significantly different.
2. On reducing the width of lanes near intersection, it was expected that the number of conflicts should have reduced due to reduction in speed of the vehicles but the results show a contradictory behavior and primarily due to increase in rear end conflicts, the total number of conflicts after lane narrowing increased.
3. Lane narrowing had a positive impact in reducing the number of lane changing conflicts.
4. Overall lane narrowing had a negative impact on reducing the total number of accidents.
5. Speed tables showed considerable reduction in rear end conflicts as well as crossing conflicts but had a negligible effect on lane changing conflicts but overall they had a positive impact in reducing the number of accidents.

6.2. Recommendations and scope for future works:

- Since speed tables show an overall positive impact on reducing the number of conflicts as well as number of accidents, they should be used more in place of lane narrowing for unsignalized intersections.
- Other than the two traffic calming measures which are used in the study namely speed tables and lane narrowing, various other measures can be tried.
- For getting more accurate results, data from as many intersection sites as possible can be collected and used for developing the accident prediction model.
- The trajectory of microsimulation models isin binary format which is unable to provide information about the type of vehicles involved in a certain conflict situation.In this report, information about the type of vehicle in a conflict situation is missing. So, it is highly recommended to update the trajectory format which contains information about vehicles in a conflict situation.
- While getting the number of conflicts from SSAM software, the default value of parameters was used which can be varied and the corresponding variation in results can be observed.

REFERENCES:

1. Allen,B.L., Shin,B.T., and Cooper,P.J., 1978. Analysis of traffic conflicts and collisions.*Accident Analysis & Prevention*, *74*, pp.21-33.
2. Almqvist,S., Hyden,C., and Risser,R., 1991. Use of speed limiters in cars for increased safety and a better environment. *Transportation Research Record*, 1318, pp.10-13.
3. Archer,J., 2004. Methods for the Assessment and Prediction of Traffic Safety at Urban Intersections and their Application in Micro-simulation Modelling (Academic Thesis). Royal Institute of Technology, Stockholm, 2004.pp.123-127.
4. Archer,J., 2005. Indicators for traffic safety assessment and prediction and their application in micro-simulation modeling: A study of urban and suburban intersections (Doctoral dissertation, KTH).pp.11-25.
5. Bauer,K.M., and Harwood,D.W., 2000. Statistical models of at-grade intersections accidents-addendum. Publication FHWA-RD-99-094, FHWA, Washington D.C.
6. Bokare,P.S., andMaurya,A.K., 2017. Acceleration-deceleration behavior of various vehicle types. *Transportation research procedia*, 25, pp.4733-4749.
7. Chan,C.Y., 2006. Defining safety performance measures of driver-assistance systems for intersection left-turn conflicts. *In Intelligent Vehicles Symposium*, 2006, pp. 25-30.
8. Cheng,L., Reddy,S.G., Lord,D., 2012. The Poisson–Weibull generalized linear model for analyzing motor vehicle crash data. *Safety science*, 37(1), pp. 38-42.
9. Chikkakrishna N.K., Parida, M. and Jain, S.S., 2013. Poisson family regression techniques for prediction of crash counts using Bayesian inference. *Procedia-Social and Behavioral Sciences*, 104, pp.982-991.
10. Cooper,D.F., andFerguson,N., 1976. Traffic studies at T-junctions - a conflict simulation model. *Traffic Engineering and Control* 17, pp.306–309.
11. Cunto,F.J.C., andSaccomanno,F.F., 2007. Micro-level traffic simulation method for assessing crash potential at intersections. Transportation Research Board 86th Annual Meeting (No. 07-2180). Washington D.C., USA.
12. El-Basyouny,K., and Sayed,T., 2013.Safety performance function using traffic conflicts. *Safety Science*.51, pp. 160-164.
13. Essa,M., and Sayed,T., 2015. Simulated traffic conflicts: do they accurately represent field-measured conflicts. *Transportation Research Record*, 2514, pp.48-57.

14. Fan,R., Yu,H., Liu,P., Wang,W., 2013. Using VISSIM simulation model and Surrogate Safety Assessment Model for estimating field measured traffic conflicts at freeway merge areas. *IET Intelligent Transport Systems*. 7, pp.68-77.
15. FHWA 1989. Traffic Conflict Techniques for Safety and Operations. Observers Manual, Publication No FHWA-IP-88-027, Federal Highway Administration, USA.
16. Gettman,D., and Head, L., 2003. Surrogate safety measures from traffic simulation models. *Transportation Research Record*, 1840, pp.104-115.
17. Harnen,S., Radin,U.R.S., Wong,S.V., and Hashim,W.W.I.,2003. Motorcycle crash prediction model for non-signalized intersections. *IATSS Research*. 27(2), pp. 58-65.
18. Hayward,J.C.,1972. Near-miss determination through use of a scale of danger. *Highway Research Record*, 384, pp. 24–34.
19. Hunter,J.D., 2007. Matplotlib: A 2D graphics environment. *Computing in science & engineering*, 9(3), pp.90-95.
20. Hyden,C., 1987. The development of a method for traffic safety evaluation: The Swedish Traffic Conflicts Technique. Bulletin Lund Institute of Technology, Department, (70), pp.13-21.
21. IRC:99-2018. Guidelines for Traffic Calming measures in urban and rural areas.
22. Kim,D., Lee,Y., Washington,S., and Choi,K.,2007. Modeling crash outcome probabilities at rural intersections. *Application of hierarchical binomial logistic models*. 39, pp. 125-134.
23. Minachi,C., Gladsen,J., Kalaanidhi,S., and Gunasekaran,K.,2015.Development of accident prediction models for safety evaluation of urban intersections. *Indian Highways*.51, pp. 37-42.
24. MORTH 2017 "Road Accidents in India 2016". Ministry of Road Transport and Highways, Government of India.pp. 10-41.
25. Sacchi,E., Sayed,T.,DeLeur,P., 2013. A comparison of collision-based and conflict-based safety evaluations: The case of right-turn smart channels. *Accident Analysis and prevention*.59, pp. 260-266.
26. Salifu,M., 2004. Accident prediction models for unsignalized urban junctions in Ghana. *IATSS Research*. 28(1), pp.68-81.
27. Sayed,T., and Zein,S., 2007. Traffic conflict standards for Intersections. *Transportation Planning and Technology*.22, pp. 309-323.
28. Sayed,T., Vahidi,H. and Rodriguez,F., 1999. Advance warning flashers: Do they improve safety. *Transportation Research Record*,1692, pp.30-38.

29. Siddharth,S.M.P.,and Ramadurai,G.,2013. Calibration of VISSIM for Indian heterogeneous traffic conditions. *Procedia-Social and Behavioral Sciences*, 104, pp.380-389.

30. Van, M.P., 1977. Correlation of design and control characteristics with accidents at rural multi-lane highway intersections in Indiana: interim report.

31. Yan,X., Radwan,E., and Abdel-Aty,M., 2005. Characteristics of rear-end accidents at signalized intersections using multiple logistic regression model. *Accident Analysis & Prevention.* 37, pp. 983-995.

32. Zhang, G., Chen, J.,and Zhao, J., 2017. Safety Performance Evaluation of a Three Leg Unsignalized Intersection Using Traffic Conflict Analysis.*Mathematical Problems in Engineering*,2017, pp. 177-183.