Simulating Hazardous Traffic Condition for Urban Expressways

-A Micro-Simulation Approach

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APPROVAL

The thesis titled “Simulating Hazardous Traffic Condition for Urban Expressways-A Micro-Simulation Approach”submitted by Md. Nafis Imtiyaz St. No. 115438 has been found as satisfactory and accepted as partial fulfillment of the requirement for the degree of Bachelor of Science in Civil Engineering.

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DECLARATION OF CANDIDATE

I hereby declare that, undergraduate project work reported in this thesis has been performed by me under the supervision of Assistant Professor Moinul Hossain. Adequate care has been taken to ensure that the work is original and has not been taken from the work of others.

Md. Nafis Imtiyaz
ID: 115438
November, 2015

Dedicated to My Beloved Parents

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"In the name of Allah, Most Gracious, Most Merciful"

All praises belong to the Almighty Allah(SWT) for providing me with the strength and courage to successfully complete my B.Sc. thesis.

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ABSTRACT

The remarkable advancements in the field of Intelligent Transportation System (ITS) over the past two decades have promoted several studies on improving safety aspects of acess controlled roads. As many of the expressways in the developed world are instrumented to generate adequate amount of data on the traffic condition in real-time, it is possible to monitor traffic condition more closely and identify any anomaly that can evolve into a hazardous traffic condition. The result of which leads to the formation of real-time crash prediction model.

In present context ensuring pro-active road safety management plays a vital role in transportation modeling. To design a pro-active road safety management system, it is important to be able to devise a way to bring the hazardous traffic condition back to normal. In the past several studies have taken place where micro-simulation or driving simulator based approaches were adopted to achieve that. For the purpose of this study, a micro-simulation based approach was chosen. It is to be noted that driving simulator could capture individual driving behavior at a greater depth but as use of it involves a great deal of time as well as it depends on the respondents, it was avoided.

Micro-simulation approach is a profound tool used by researchers to determine and analyze traffic characteristics. Micro-simulation approach gives access to car following as well as lane changing behavior of individual vehicle and allows analyzing their interactions by changing the parameters. Existing studies provided very little insight into how to simulate hazardous traffic condition. So, in this study, a detailed and step-by-step explanation on how to simulate hazardous traffic condition has been incorporated.

CUBE Dynasim is a micro-simulation software developed by CITILABS which was used in this study. In CUBE Dynasim the normal traffic condition was created by using aggregated flow data obtained from Route 3 and Route 4 of Tokyo Metropolitan Expressway. The values of the parameters were altered to create hazardous traffic flow condition.

Best possible result was obtained by changing the values of car-following maximum threshold and mean of threshold value for car following rules. Again, in case of lane changing behavior changing of heavy vehicle threshold, light vehicle average time, light vehicle minimum time, light vehicle maximum time, light vehicle standard deviation, light vehicle minimum distance, heavy vehicle average time, heavy vehicle minimum time, heavy vehicle maximum time, heavy vehicle standard deviation, heavy vehicle minimum distance reflected best result. The outcome of the study was verified by comparing the field traffic flow variable data with that of the simulated data.

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Chapter 1 Introduction

1.1 Background

Objectives of urban expressways are to reduce travel time, mainly during the peak hour connecting major traffic attractions and productions. They are by design highly access controlled and can be quite expensive to construct. Urban expressways in general have fewer numbesr of lanes than freeways or surface roads. In many cases they are privately operated as well. Hence, when there is a crash occurring on the urban expressways, the consequences are high. A crash during peak hour on an urban expressway can heavily impact the travel time, which was the primary objective of building such structures. At the same time, it results in heavy loss of revenue and low accessibility can make rescue activity quite challenging as well.

Remarkable developments in the field of Intelligent Transportation System (ITS), is seen in past two decades. These have promoted several studies on improving safety aspects of access controlled roads. Now a day, many of the expressways in the developed world are instrumented which are generating a substantial amount of data on the current traffic condition in real-time. This has opened the door to monitor traffic condition closely and identify any anomaly that can evolve into a hazardous traffic condition elevating the probability to make driving errors. This one and a half decade old field in transportation deals with predicting crash probability in real-time and the resulting models is called real-time crash prediction models.

Speed variation was a prime variable on likelihood of occurrence of crash which was developed based on real data (Oh et al. 2001). By establishing relationships between coefficient of variation in speed, traffic density and speed difference to determine likelihood of crash occurrence, Lee et al. (2003) developed a log linear model. for freeway and ramp Separate real-time crash prediction model was developed by Hossain and Muromachi, (2011). Clustering analysis to establish connection between different traffic states and crash risks on freeways was used by Xu et al. (2012).

Crash prediction models were also developed using crash reports, real-time traffic and weather data (Yu and Abdel-Aty 2014).

For a proactive road safety management system, after predicting crashes, it is important to be able to identify how to bring the traffic condition back to normal. Several studies have shown that it is possible to bring the traffic condition back to normal by the implementation of different interventions.

Variable Message Signs have been incorporated in many metropolitan cities in the world (Van Eeden et al., 1996; Emmerink et al., 1996) in the hope that the information provided by these signs will alter drivers' behavior in appositive manner. Louma and Rama (2001) studied the comprehension of pictograms for VMS conducted on European drivers, demonstrated how difficult it is to find images which are readily understood. McManus (1997) reports that VMS receive information from loop detectors that calculate vehicle speed and length, have been used to improve safety at an accident-prone location.Messages with exact location of accidents and time lagging traffic information received high levels of response. On the basis of theoretical calculations and motorists' experience., Miller et al. (1995) reports that a VMS should not use more than two message screens. It also suggests that a single message screens is preferred and incorrect information can have disastrous consequences on VMS effectiveness.

The relationship between speed and accidents is a complex one. Worldwide 5 to 15% accidents occur due to over speed. Anderson and Nilsson (1997)reports that the reduction of speed by 1 mile/h (1.6 km/h) reduces the casualties by 5% and reduction of mean speed by 10% results in a reduction in fatalities by 40%. Finch et al. (1994) suggests that an increase in mean speed by 2 to 4 miles/h (approximately 3 to 6 km/h) results in an increase in fatalities by 19 to 34%. Variable speed limits are commonly used with variable message signs in order to reduce the speed of vehicles to relieve congestion or warn of an unseen danger downstream (Gayah et al., 2006). VSL are used to increase average headways and reduce variances in speed (Borrough, 1997; Ha et al., 2003; Pilli-Sivola,2004). This translates into fewer crashes (Smulders, 1990). Borrough (1997) found that the use of VSL and strong enforcement (video cameras) greatly reduce the number of crashes (28% over 18 months). The effect was attributed to not only a smoothing of traffic conditions through longer following distances, but also through reducing the number of lane changes during congestion (Borrough, 1997). Lee et al. (2004) used VSL to try and reduce crash potentials. Abdel-Aty et al. (2006) used a longer stretch of freeway from I-4 in Orlando to test the effect of VSL. Gayah et al.(2006) showed in their study that VSL had little to no effect on the crash risk index during the low-speed condition. This is most likely caused by the fact that during the low-speed scenario vehicles are travelling at congestion well below posted speed limit and, therefore, the change in speed limit on the roadway will not effectively change the speed the vehicles are travelling at.

The objective of ramp metering is to reduce delay and maintain capacity flow on a freeway by regulating access of ramp traffic to the mainline. Empirical studies have shown that ramp metering reduces turbulence in the merge zone, reduces variance in speed distributions, and thereby improves traffic safety i.e. reduces sideswipe and rear-end crashes (Lee et al., 2006). Ramp metering is used to reduce congestion by limiting the number of vehicles entering a freeway at a given time to avoid bottlenecks that typically occur at freeway on-ramps (Gayah et al., 2006). Piotrowicz and Robinson (1995) reported that ramp metering reduced crash rate by 24%-50% and increased capacity by 17%-25% on the basis of case studies of freeways in major U.S. cities. They also suggested that reductions in crash rate provide a further benefit by reducing crashinduced delay. Other empirical studies have supported the finding that ramp metering reduces crash rate (Cambridge Systematics, 2001) and more specifically rear-end and sideswipe crashes in the freeway mainline (Cleavenger and Upchurch, 1999). Many studies in North America and Europe have assessed the benefits of ramp metering quantitatively through field tests and simulation experiments. For example, Kang and Gillen (1999) considered fuel savings, time savings and the reduction in emission as the benefits of ramp metering. Thill et al. (2004) defined safety benefits of ramp metering as a decrease in crash frequency at the merging of ramp and freeway lanes from the baseline number of crashes.

Currently, ramp metering is used throughout the United States in California, Minnesota and New York, as well as many countries throughout Europe (Gayah et al., 2006).

Considering these opportunities, some new studies are now taking place to evaluate the effectiveness of these road safety improvement solutions in real-time, when coupled with real-time crash prediction models. These studies take various traffic flow variables as input and from that apply various traffic interventions to bring the hazardous traffic conditions back to normal. As due to safety reasons these studies cannot be conducted in real life, researchers opted for either microscopic traffic simulation (Lee et al., 2006; Abdel-Aty et al., 2006, 2007, 2008) or driving simulator (Lee and Abdel-Aty, 2008) based approaches. The recommended countermeasures so far have been posting warning message (Lee and Abdel-Aty, 2008), variable speed limits (Abdel-Aty et al., 2006, 2008; Lee and Abdel-Aty, 2008) and ramp metering (Lee et al., 2006;Abdel-Aty et al., 2007),which have proven track record as effective solutions as discussed in the aforementioned subsections.

1.2 Problem statement

Simulation based approach are favored because those could evaluate different scenarios as well as could reflect accuracies. For studies involving crash data it is not possible to recreate the environment in real field. That's why simulation based studies have been the key focus of the researchers. Methods like using a driving simulator or microscopic simulator are the prime method of such studies.

The use of driving simulator is not incorporated in this study because it would involve a lot of time as well as it would not be cost effective. Although it is to be noted that driving simulator could capture individual driving behavior at a greater depth. But again it will depend much on the respondents. So in this study a micro-simulation based approach was chosen. CUBE Dynasim was used as the micro-simulation software.

Micro-simulation models are built with real-life data from traffic streams. In micro-simulation models it is possible to calibrate those to represent the field scenario as closely as possible. For that reason, those are good at capturing the aggregated behavior of traffic stream.

In general, micro-simulation models are built to replicate normal traffic behavior. But for road safety related studies it is important to know how to simulate hazardous traffic condition. So this study is focused on the procedure of simulating hazardous traffic condition.

1.2 Purpose and Objective

The purpose of the study is to devise a way to simulate hazardous traffic condition in a micro-simulation environment. The specific objectives are:

- Identify and extract hazardous traffic conditions from matching detector and crash database, and,
- Calibrate car-following and lane changing models to reproduce the hazardous traffic condition in a micro-simulation environment.

1.3Thesis Outline

The rest of the thesis chapters will be organized as follows:

- Chapter 2: Literature Review; discusses about the past works on this subject, importance of such study, analysis of data on previous works.
- Chapter 3 – Methodology; discusses about the procedural steps of the study.
- Chapter 4 – Model Building and Analysis; discusses about the procedure to create a simulation model and procedure of analyzing it.
- Chapter 5 – Conclusion and Recommendation; discusses about the effectiveness of the study, and recommendations for future studies.

Chapter 2 Literature Review

2.1 General

This chapter contains all the knowledge collected from researchers who have contributed in simulation model building.

2.1 Real-time crash prediction model

The study of Kolisetty et al. (2005)was targeted on how effective traffic advisory information could be so that drivers could avoid potentially dangerous conditions. In reducing driver’s perception and perceptual judgment adverse weather conditions have great impact. They used a driving simulator to measure the effect of VMS on behavior of drivers. PC-based simulation program was used by Vaughn et al. (1992). They tried to find out choice of route due to Advanced Traveler Information System. They concluded that if the change of route was a freeway it was more likely that the driver will follow the information. In the study of Kolisetty et al.(2005) analytical results of speed behavior of each subject were categorized. The categories were effective, marginal effect and no effect of Variable message sign. In their study performance of sign conditions was analyzed using repeated measures model ANOVA. ANOVA results of the study showed that 7, 11 and 15 km/h reductions of speed in case before, at and after VMS locations respectively in with VMS compared to without VMS. However, this study was limited to the considered situation and found that provision of traffic advisory information through VMS can affect driver speed behavior and in turn reduce road accidents and fatalities.

The study of Lee et al. (2004,2006), was focused on presenting a real-time crash prediction model and uses this model to investigate the effect of the local traffic-responsive ramp metering strategy on freeway safety. Using a micro-simulation approach driver response to ramp metering and the consequent traffic flow changes were observed. To propose a method of quantifying the effect of a traffic-responsive ramp metering strategy on crash reduction as well as to evaluate the performance of ramp metering in terms of improving freeway safety under various traffic conditions were the objectives of this study. The concept of ALINEA ramp metering was used. They stated that through field tests and simulation experiments it was found ALINEA can stabilize traffic flow and reduce the risk of flow breakdown while making effective use of freeway capacity. Three crash precursors that contribute to the variation of crash potential prior to the crash occurrence were identified and included in their model as independent variable. Those were coefficient of variation of speed upstream of a specific location, average speed difference between the upstream and downstream of a specific location and average covariance of volume difference between the upstream and downstream of a specific location between adjacent lanes. The model was also calibrated for actual crash, traffic and road geometry data. As a result of the calibration, it was found that the model tended to predict high crash potential in high turbulence of traffic flow. Those hazardous traffic conditions were reflected by high values of precursors like high variation of speed over time and frequent lane changing. The study also concluded that the difference in average speed between upstream and downstream locations has the most dominant effect on crash potential among the three crash precursors. PARAMICS microscopic traffic simulator was used in the study. The simulation model was calibrated by comparing flow, density and travel time between actual conditions and simulations. Using two fitness functions the comparisons were made. The first function calculates the sum of absolute errors in 1-minute average flow and density in each detector station during each time interval. Calculation of the sum of squares of errors in travel time for selected routes during each time period was the second function. The crash prediction modelling logic was incorporated in PARAMICS through the application programming interface (API). The results of the study stated that the ALINEA ramp metering strategy can reduce total crash potential by 5-37% compared to the no-control case. The crash potential reduction was most noticeable under the traffic condition when congestion was caused by high ramp traffic volume in the absence of a queue downstream of the ramp. It was also found that the ability of ramp metering to make significant safety would be limited if a queue already exists downstream of the ramp. The limitation of this study were first, the simulation model needed to be calibrated for the real freeway sections not only in terms of aggregated flows and speeds, but also individual vehicle movements like merge or diverge, car following and lane changing, which would be the basis of the proposed safety measures. Second, it must be noted that car-following models ensure that follower vehicles always maintain safe headways and consequently, crashes do not take place in the simulation models. Third, the simulation results tend to be demand specific and they may change for different demand levels on the mainline and the ramp which may demand that sensitivity of the results in terms of both congestion and crash potential needs to be analyzed.

The model developed by Abdel-Aty et al. (2005) was used for the simulated network to analyze the likelihood of crash in another study by Abdel-Aty et al. (2006). Also, real-time crash prediction models were developed separately for a moderate-to-high-speed and low-speed traffic speed regime and the threshold for separating the two regimes was set at 37.5 mph based on visual examination of traffic speed distributions. Above this speed, a moderate-to-high speed model was used whereas below this speed, a low-speed model was adapted. For the moderate-to-high-speed model average occupancy, flow and for low-speed model average volume, occupancy, and the coefficient of variation in speed variations were used as inputs. The calibration was done by techniques and values that have been used in previous studies as stated in it. In studies of Bertini et al. (2002), Abdulhai et al. (2002), Trapp (2002), and Stewart(2001), the multiple factors used to calibrate their networks are laid out. Each mentions the use of flow as well as travel time. But only Bertani et al. (2002) showed the calibration values used in simulating their network, and mentioned adjusting two parameters, neither of which directly affects queuing behavior. Abdullahi et al. (2002) mentioned that they calibrated for vehicle bunching, which based on their description is excessive queuing, by decreasing the memory speed, furthering the idea that queuing behavior is an important factor to consider. Cheu et al (2002) and Bertini et al. (2002) noted that in PARAMICS the mean target headway and mean driver’s reaction time need to be calibrated based on the area’s drivers for accurate flow characteristics. Other factors involved in calibrating PARAMICS are the time step, aggressiveness, and minimum gap values. Initially, the mean target headway and mean driver’s reaction time were changed to values found in different literature. The PARAMICS runs were inspected with different values of core parameters: target headway, mean reaction time, queuing speed, and queuing distance. Behavior characteristics, aggressiveness and awareness, were also tested, but no effect was seen changing their values. The results showed that queuing distance does not have a major effect on flows except for the case with low mean target headways. The resulting speeds were inspected to determine if it was possible to determine whether the detector is experiencing heavy, mild or no congestion. Mean headway of 1.0 second, a mean reaction time of 0.42 second, a queuing speed of 8 miles/hr, and a queuing distance of 9 ft were the values that produced the best results in terms of flow and speeds. The objective of the study was fulfilled for the moderate-to-high-speed case. But the low-speed case did not show clear improvement.

Abdel-Aty et al. (2007) investigated various ALINEA ramp metering strategies to mitigate crash risk on freeways under congested traffic. The study was targeted to show the effective performance of the ALINEA ramp metering algorithm and draw conclusions towards the effective implementation of an ALINEA system on a network wide level on an urban freeway to reduce the risk of crash occurrence in real time. PARAMICS was used as it was used in previous similar studies like by Lee et al. (2004, 2006). In this study the driver behavior parameters, origin destination matrix and release profiles were the key parameters to be calibrated. Speed, flow and the parameters were used in statistical measures at a 5 minutes resolution so the calibration was done at the same resolution. The experimental design consisted of a total 48 runs to test for the entire variables critical occupancy, signal cycle length, number of ramps to be controlled and regulator parameter (Kr). The primary effects that were tested using the experimental design were effect of signal cycles of metered ramps, effect of number of metered ramps, effect of ALINEA parameters. During analysis it was proved that Kr has very little impact on the safety of the freeway. First, the result of the study was the general trend which showed higher values of the critical occupancy provided slightly better results. Second, metering more ramps tends to provide greater benefits than metering fewer ramps. Third, Kr is an insignificant factor in the comparison of cases. Fourth, longer signal cycles tend to provide better results than shorter signal cycles when a single ramp is metered in the network. Subsequently, shorter signal cycle tends to provide better results than longer signal cycles when multiple ramps are metered. The main conclusions of the study for the implementation of ramp metering algorithm ALINEA in order to improve safety was safety benefits of metering increase with increase in number of meters as well as shorter signal cycles work better in multiple ramp metering implementations.

2.2 Real-time crash prediction interventions

Interventions can be used to turn hazardous traffic back to normal. Various studies have proved effectiveness of VMS in doing so. Kolisetty et al. (2005) studied effect of VMS on driver speed behavior. They stated that for providing dynamic information and also to show different speed limits at different conditions VMS are used. In that study, categorization was done based on average speeds estimated before and after messages in with VMS. The subjects would receive VMS effectively if the average speed difference was more than 10 km/hr; marginal effect of VMS was observed if difference was in the range of 5-10 km/hr; and for a difference of 5 km/hr speed there was no effect of VMS on the subject. Results found were classified in to four cases. Entire section’s mean speed, maximum speed, minimum speed and speed deviation in without VMS and with VMS was case 1 whereas case 2 was before VMS locations in without VMS and with VMS. Case 3 was at VMS locations in without VMS and with VMS and finally case 4 was after VMS locations in without VMS and with VMS. In their study they concluded that VMS had an effect on subjects with an average speed changing behavior of 2 to 15 km/hr with VMS as compared to without VMS. Variation in speed deviation was also found in without VMS and the reason was provision of traffic advisory information through VMS.

In another study of Abdel-Aty et al. (2006), variable speed limits (VSL) for real-time freeway safety improvement was evaluated. In this study the final recommendations for implementing VSL were first, gradually introducing speed limit changes over time (5 miles/hr every 10 min), second, abruptly changing speed limit (no gap distance) and third, reducing speed limits upstream and increasing speed limits downstream of location of interest. And finally, the speed limit changes in upstream and downstream should be large in magnitude (15 miles/hr) and implemented within short distances (2 miles) of the location of interest. The recommendations were made through the use of multiple microscopic traffic simulations by determining best practices. PARAMICS was used as the simulation software.

Gayah et al. (2006) conducted a study to evaluate ITS strategies for real-time freeway safety improvement. The ITS strategies that were examined were variable speed limit (VSL) and ramp metering. The roadway corridor chosen for the study was a segment of Interstate-4 (I-4) in Orlando, Florida. This research also addressed two situations- one representing low-speed and the other the moderate-to-high-speed situation. A micro-simulation approach was adopted because it replicates the interaction of individual vehicles as traffic flow progresses. Since the crash prevention techniques deal specifically with the movement of individual vehicles, this type of analysis was ideal. And also this approach was cheaper and safer than field testing. PARAMICS micro-simulation software package was used in the study. The calibration was done based on previous studies. It was observed in the preliminary runs that variable speed limits had little to no effect on the crash risk index during the low-speed condition. The likely cause indicated in the study was during the low-speed scenario vehicles are travelling at congestion well below the posted speed limit. This causes the change in speed limit on the roadway having no significant effect on the speed the vehicles are moving at. The moderate-to-high-speed implementation of VSL considered the upstream lowering of the speed limit, the downstream raising of the speed limit and the combination of the two. Now, as variable speed limit did not show any effect at lowering the crash potential in the low-speed situation, ramp metering was considered as a suitable option in the study. To simulate the effect of meters on ramps in PARAMICS traffic signals were placed at on-ramp entrances. The simulation was viewed by turning the metered ramp on and off manually based on the level of congestion on the main line. Fixed ramp metering was considered for the test cases where pre-timed traffic signals were used at the ramp entrances to the freeway in order to control the number of vehicles that enter the main line. Overall, the improvement in the crash risk was found to be minimal when metering only one ramp. Only a 3.6% decrease in the crash potential at the station of interest was observed. But, at the station upstream of the ramp an added 6.3% decrease in crash potential was observed. It was also observed that when metering was employed on 7 ramps the crash potential reduction became more. Besides, when the crash risk for a single station was observed for the duration of the ramp metering implementation at 30 sec intervals, the best case showed that there were periods where the crash risk became higher than the actual case. So it was concluded that though fixed ramp metering shows a potential to mitigate probability of crashes occurring overall there might be time where this type of metering increases the crash potential as well. According to the study this was most likely due to the fact that fixed ramp metering does not consider the mainline traffic while allowing vehicles to enter the freeway. In this study driver compliances with the ITS strategies was considered to be 100%. But in practical this would not be the case which promoted the need of a further study to be performed in order to analyze the effect of varying degrees of driver compliance on best crash reduction strategies.

Abdel-Aty et al. (2007) stated that the problem of discriminating crash prone conditions from normal freeway traffic could be set up as a classification problem, in their research. They collected ‘non-crash’ loop detector data representing ‘normal’ traffic conditions. Traffic parameters were used as inputs to binary regression logistics models. Relative measure of crash risk for observed traffic conditions were found as outputs from the logistic regression models. From their preliminary analysis they concluded the need for two separate models. The first model was set for average speed at station less than or equal to 37.5 miles/hr and the second was for others. As those regression models provide them with a measure of relative risk under moderate- to high-speed and low-speed traffic conditions in their study they also used those to evaluate effectiveness of ITS strategies such as ramp metering and variable speed limits towards the reduction of real-time risk. They defined ramp crashes as the crashes that physically occurred on ramps and at the ramp intersections. Crashes occurring on auxiliary lanes were not included in their research. Ramp crashes were classified by two ramp types (off-ramp and on-ramp) and four ramp configurations (diamond, loop, outer connection and directional or semi-directional connection). By developing a two-level nested logit model they estimated the effect of traffic flow on the probabilities of ramp crashes. Ramp configurations were compared separately within each ramp because of the substantial difference in typical traffic movement and associated crash risk between off- and on-ramps. The result of the study reflected that when a driver exits at higher speed under low volume on ramps, they tend to lose control which leads to crashes on ramps. Besides high traffic turbulence and crash potential upstream of off-ramps made drivers diverge from the mainline line earlier when the downstream speed remained lower. The probability of on-ramp crashes seemed to be increased as the upstream speed is lower and the downstream speed is higher which reflected that the drivers pass the merging area at higher speed. This driver behavior potentially reduced merging vehicles, which increases the delay of merging from on-ramps which consequently induces the aggressiveness of drivers who wait in a queue on ramp and increases crash potential. They also made analysis involving VSL by lowering the upstream speed limit near a detector for 30 minutes during the simulation. The effects of ramp metering and VSL were simulated by PARAMICS micro-simulation. For VSL, abrupt reduction in speed limit by 15 miles/hr two miles directly upstream and raising of the speed limit by 15 miles/hr two miles directly downstream of the station of interest reduces the potential most efficiently for moderate-to high-speed situations. For low-speed situations, allowing vehicles to enter the mainline using smaller amounts of green time during shorter cycle lengths for seven consecutive on-ramps in the network provided the best results. But using a fixed ramp metering system does not react to the changing flow of traffic. The ramp metering proposed in their study aimed at reducing congestion and improving safety in the mainline, not on freeway ramps.

Chapter 3 Methodology

3.1 General

This section describes the method to be followed in the study to simulate hazardous traffic conditions using CUBE Dynasim which is a micro-simulation tool. Figure 3.1 illustrates the overall workflow and the subsequent sections briefly describe each of the steps.

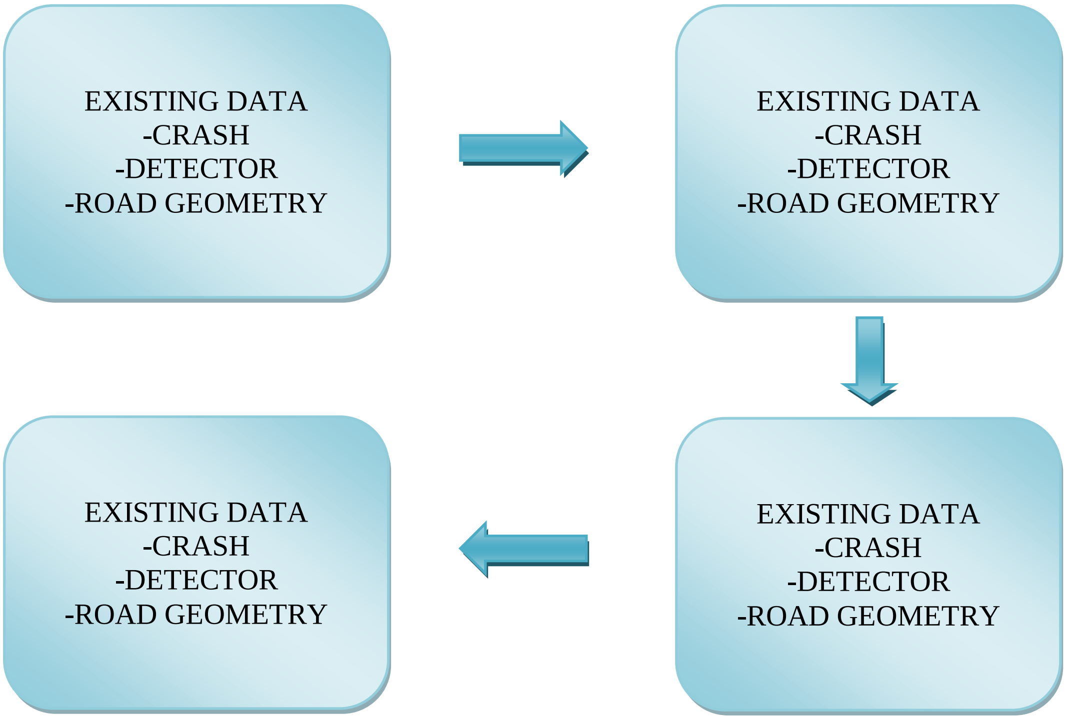


Figure 3.1: Overall workflow diagram

3.2 Study area and the data

It is necessary to select such an area where it is possible to observe substantial amount of crash as well as means to collect crash data along with high resolution traffic flow data. Besides, high accuracy is also a requirement.

The data used in this study was collected from two parts of the Tokyo metropolitan expressways. The first one is Shibuya and the other one is Shinjuku 4 expressways. They were collected for a period of months from May to August on the year of 2014.

The total length of the two expressways are 25.4 km. Shibuya Route(also known as theRoute 3) is one of the radial routes of the expressway system in the Tokyo area. Route 3 runs southwest from Tanimachi Junction (with the Inner Circular route) in Minato-ku and runs for 12 kilometers through Shibuya-ku, Meguro-ku, and Setagaya-ku. The Route 3 designation ends at the Yoga Rampway (Tokyo Interchange) and the expressway continues as the intercity Tomei Expressway to Nagoya. Whereas, Route 4 (also known as the Shinjuku Route) is another radial routes of the Expressway system in the Tokyo area. It runs west from Miyakezaka Junction (with the Inner Circular Route) in Chiyoda-ku and runs for 13.5 kilometers through Shinjuku-ku, Shibuya-ku, and Suginami-ku. The Route 4 designation ends at the Takaido Interchange and the expressway continues as the intercity Chūō Expressway to Nagoya via Yamanashi and Nagano Prefecture.

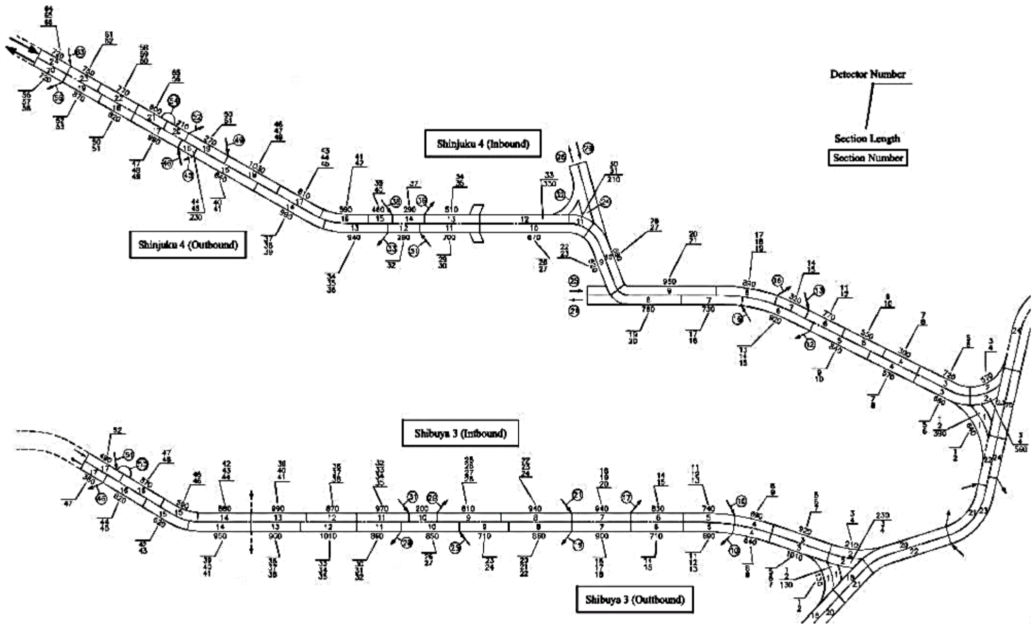


Figure 3.2: Schematic diagram of Route 3 and 4 of Tokyo Metropolitan Expressways (diagram not drawn to scale)

Source: Provided by Tokyo Metropolitan Expressway Company Limited

A total no. of 24 ramps are present in the selected study area and approximately a total of 210 loop detectors were established there. A total 610 crashes were observed during the study period. Three classes of data were collected. These are detector data, crash data and road geometry data. The parameters set for collecting detector data were speed, flow, occupancy, number of heavy vehicles for each lane and ramps. Date, time, location, vehicles involved, types of lane were the parameters for collecting crash data. Road geometry data was focused on location of ramps, position of detectors and section length.

3.3 Experimental setup

Data are preserved for each detector for every eight mili-seconds in Tokyo Metropolitan Expressways. Data is also stored for each lane covering information on speed, flow, occupancy and no. of heavy vehicles. Data for every one minute for each detector were aggregated and provided for the purpose of this study. Crash data including information on date, time, location, vehicles involved and types of lane were also added.

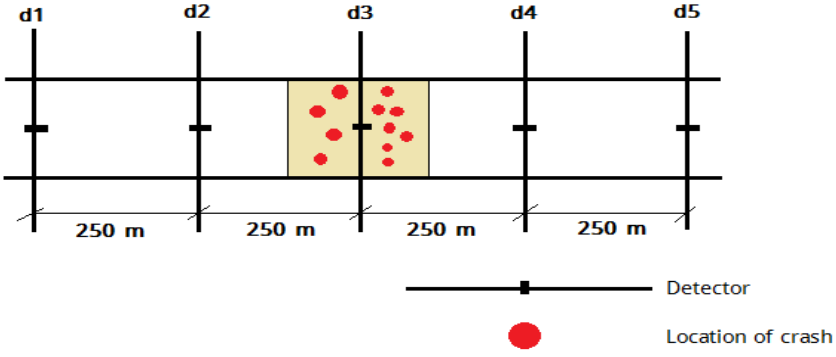


Figure 3.3: Position of detector and location of crash

The experimental setup was made as shown in the figure 3.3. Each crash points were associated with its corresponding 250meter section. For every section two upstream detectors, two downstream detectors and the detector within the section were identified. Two traffic conditions were identified hazardous traffic condition and normal traffic condition. For hazardous traffic condition (D_H^{ij}) 1 minute aggregated data for all lanes before i (i=1, 2, 3, 4, 5) minutes crash at j (upstream or downstream) junction were collected. On the other hand, for normal traffic random sampling of 1-minute aggregated data from any timeslot where no crash took place before or after that time period. The data collected from the detectors were then sorted and organized so that it can be easily incorporated in analysis. Each crash was given a single identification no. and speed, flow, occupancy data for 5 detectors as mentioned in the next segment was sorted.

3.4 Data preparation

As it was mentioned, a total 210 detectors are placed in the two routes, when both directions are considered. The primary task was to identify nearest detector, upstream detector and downstream detector for each crash point, a sample of which is shown in table 3.1.

Table 3.1: Crash data with unique ID and detector located near crash (sample)

Cra-sh Id	Date	Time	Day of week	Kms	Segments	Kilo post	D2D	D1D	D0	D1U	D2U
481	4/30	06:46 pm	Wed	0	1	0.10	04	01	03	-	-
482	6/14	11:24 am	Sat			0.20	02	04	01	03	-
483	3/27	07:03 pm	Thurs			0.20	02	04	01	03	-
484	3/21	07:13 pm	Fri		2	0.30	02	04	01	03	-
485	7/7	11:15 am	Mon			0.30	02	04	01	03	-
486	3/30	07:54 pm	Sun		3	0.60	06	05	02	04	01
487	5/23	09:53 am	Fri			0.60	06	05	02	04	01
488	6/7	02:02 am	Sat	1	1	1.00	08	07	06	05	02
489	7/1	12:37 am	Tues			1.00	08	07	06	05	02
490	8/14	10:48 pm	Thurs			1.10	08	07	06	05	02
491	7/24	07:12 pm	Thurs		3	1.60	09	08	07	06	05
492	3/14	07:24 pm	Fri		4	1.80	10	09	08	07	06
493	6/14	10:43 am	Sat	2	1	2.00	13	10	09	08	07

Here,

D0 = Detector in the segment

D1D = First detector in the downstream

D2D = Second detector in the downstream

D1U = First detector in the upstream

D2U = Second detector in the upstream

Then it was needed to sort the data from all detector and combine them together so that it can be easily found and used during the course if this study. A sample of such work is shown in table 3.2.

Table 3.2: Flow data after sorting with unique crash id (sample)

Crash ID	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Date	6/7	6/10	6/29	3/21	8/15	8/18	6/29	3/13	8/7
Time	21:25	02:28	03:26	17:47	08:01	16:22	11:06	21:25	17:58
Kilo post	0.00	0.10	0.10	0.10	0.10	0.10	0.20	0.20	0.20
D1D_f_15	4	13	3	2	18	7	28	11	21
D1D_f_14	10	8	2	2	23	16	22	12	9
D1D_f_13	13	4	1	2	27	19	21	9	18
D1D_f_12	12	8	3	5	20	16	29	9	18
D1D_f_11	10	8	2	2	19	17	25	14	15
D1D_f_10	10	11	7	1	20	22	19	4	20
D1D_f_9	11	13	2	2	20	8	25	16	15
D1D_f_8	14	18	0	1	23	19	23	15	17
D1D_f_7	12	4	5	4	22	19	22	7	12
D1D_f_6	16	7	4	3	21	16	23	7	10
D1D_f_5	5	3	7	2	19	16	22	8	21
D1D_f_4	11	3	2	2	21	14	23	17	22

Here,
D1D_f_t = flow data of detector at time t minutes before crash

After finishing of sorting the data looked like the above figure. speed, flow, occupancy data for 5 minutes after the crash and 15 minutes before the crash were considered.

3.5 Microscopic traffic simulation with CUBE Dynasim

In microscopic traffic simulation it is possible to model traffic behavior by calibrating car following and lane changing parameters. The methodology followed to calibrate these parameters are discussed in detail in the next sections.

3.5.1 Car following

There are two car following rules followed in CUBE Dynasim. First one is MGA, which is acronym for General Motors Ahmed and the other one is PLP7. The car following depends on speed, space headway, density, relative speed, free-flow acceleration, headway threshold and reaction time distribution. Most algorithm used in MGA was taken from a paper written by Kazi Iftekhar Ahmed in 1999.

Whereas, PLP7 is a simple acceleration model. In it only three parameters are considered. This is very useful in modelling congestion in urban traffic. The acceleration of vehicle 2 which follows vehicle 1 is determined by the speed and the distance from the vehicle which precedes it according to the formula:

$A2(t+0.25) = *\alpha* [\ V1(t) - V2(t)] + *\beta* [\ X1(t) - X2(t) - *\tau*\ V2(t) - L\ ]$ **….(3.1)**

Here,
A1 = Acceleration of vehicle 1
A2 = Acceleration of vehicle 2
t = Time at any instant
V1 = Velocity of vehicle 1
V2 = Velocity of vehicle 2
X1 = Position of vehicle 1
X2 = Position of vehicle 2

Table 3.3: value of α, β, τ

A1(t)	α	β	τ
< -0.6 m/s2	0.7	0.03	1.82
[-0.6 ; 0.6]	1.1	0.2	0.52
> 0.6 m/s2	0.36	0.03	1.82

3.5.2 Lane changing

In CUBE Dynasim two types of situations that lead to a lane change. The first one is a lane change imposed by the path the vehicle takes to reach its destination, conditioned by “Insertion gaps” and a the other one is a lane change due to the vehicle’s behavior usually conditioned by “Behavior associated with lane satisfaction”. Insertion gaps determine whether the vehicle will be able to change lanes depending on the traffic in its target lane. Behavior associated with lane satisfaction can be of two sorts. First one is current lane satisfaction, which determines whether or not a vehicle is satisfied with the traffic conditions in the current lane. Whereas, target lane satisfaction determines whether a vehicle wants to change lanes depending on the traffic in adjacent lanes.

A vehicle that wants or needs to change lanes must make sure, in terms of safety, that the vehicles in front and behind in its target lane are at a sufficient distance from its front and rear bumpers. This is done using lag and lead insertion gaps. In CUBE Dynasim the calculated acceptable gap distance depend on the instant speed of the vehicle V(t), the speed of the vehicle in the target lane $V_C(t)$.

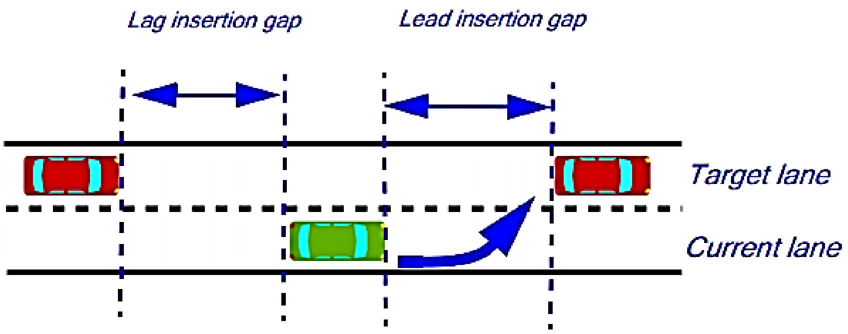


Figure 3.4: Insertion gaps

Source: CUBE Dynasim Reference Guide Version-5

The minimum acceptable gap for changing lanes is given by:

$$G\ (t) = \exp\ (C_1 + C_2\boldsymbol{Max}(0,\ V_c(t) - V(t))) + C_3\boldsymbol{Min}(0,\ V_c(t) - V(t))) + C_4 n + N(0,\ C_5^2)) \quad \textbf{..... (3.2)}$$

Here,

C_1 = Constant

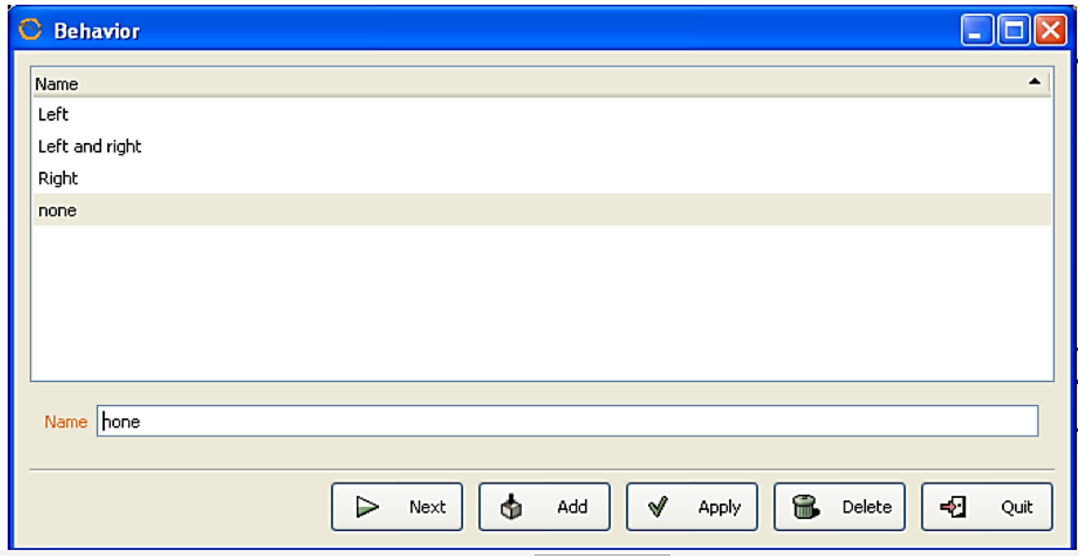
C_2 = Positive speed differences (***dv+***), i.e. the difference between the instant speed of the vehicle in the current lane V(t) and the speed of the vehicle in the target lane $V_c(t)$

C_3 = negative speed differences parameter (***dv-***), i.e. the difference between the instant speed of the vehicle in the current lane V(t) and the speed of the vehicle in the target lane $V_c(t)$

C_4 = Aggressiveness parameter associated with a random selection n which serves to reflect different types of driving

C_5 = Standard deviation of the normal distribution centered on 0

It is very important to note that in CUBE Dynasim a lane change, not imposed by a vehicle's destination depends on the lane satisfaction in the current and adjacent lanes. The behavior assigned to a lane in a trajectory will define the conditions in which the vehicles concerned will want to move to the target lane. In fact, if a vehicle does not satisfy the lane satisfaction condition on its current lane, but satisfies the condition on the target lane it will change lanes.



Behavior

Name

Left

Left and right

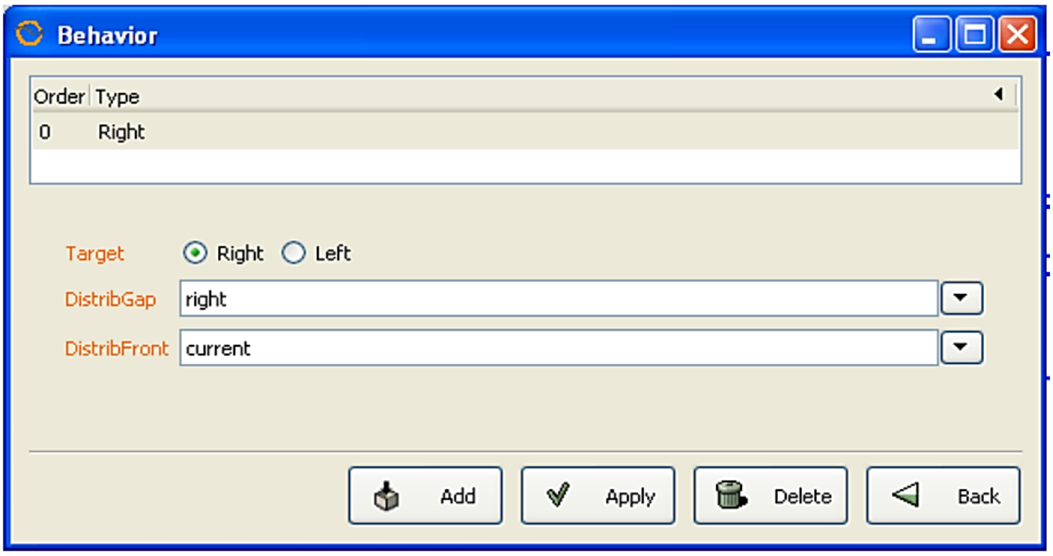
Right

none

Name: none

Figure 3.5: Behavior definition window in CUBE Dynasim

Source: CUBE Dynasim Reference Guide Version-5



Order	Type
0	Right

Target ● Right ○ Left
DistribGap right
DistribFront current

Figure 3.6: Behavior entry window in CUBE Dynasim

Source: CUBE Dynasim Reference Guide Version-5

Current lane satisfaction depends on the instant speed of the vehicle V(t) and the desired maximum speed of the vehicle $V_1(t)$. The probability that a vehicle is not satisfied in its current lane is as follows:

$$P(t) = \frac{1}{1+e^{(C_1+C_2(V(t)-V_1(t))+C_3\delta_{PL}+C_4\delta_{PA})}} \qquad \text{...............(3.3)}$$

Here,

C_1 : Constant

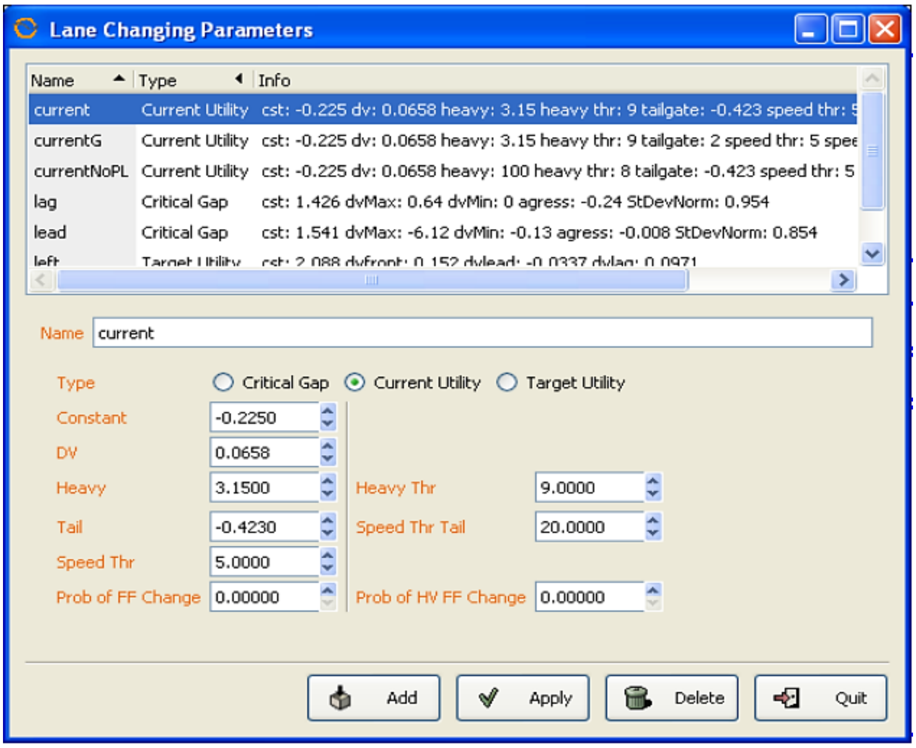
C_2 : A ***dV*** maximum parameter relative to the difference between the instant speed of the vehicle V (t) and the desired maximum speed of the vehicle $V_1(t)$

C_3 : An ***HV*** penalty parameter, used for vehicles whose length in m exceeds the threshold specified in the ***Heavy thr*** field

C_4: A tailgate parameter (TG) relative to the distance between the vehicle and the vehicle directly behind it, used for vehicles whose speed is greater than the tailgate speed threshold specified in the ***Speed thr*** tail field

δ_{PL}= 1, If the length of the vehicle considered is greater than the value specified in the ***Heavy Thr*** field

δ_{PA}= 0, if the distance between the vehicle considered and the vehicle directly behind it is less than 10 m



Name	Type	Info
current	Current Utility	cst: -0.225 dv: 0.0658 heavy: 3.15 heavy thr: 9 tailgate: -0.423 speed thr:
currentG	Current Utility	cst: -0.225 dv: 0.0658 heavy: 3.15 heavy thr: 9 tailgate: 2 speed thr: 5 spee
currentNoPL	Current Utility	cst: -0.225 dv: 0.0658 heavy: 100 heavy thr: 8 tailgate: -0.423 speed thr: 5
lag	Critical Gap	cst: 1.426 dvMax: 0.64 dvMin: 0 agress: -0.24 StDevNorm: 0.954
lead	Critical Gap	cst: 1.541 dvMax: -6.12 dvMin: -0.13 agress: -0.008 StDevNorm: 0.854
left	Target Utility	cst: 2.088 dvfront: 0.152 dvlead: -0.0337 dvlag: 0.0971

Name: current

Type: ○ Critical Gap ● Current Utility ○ Target Utility

Constant: -0.2250
DV: 0.0658
Heavy: 3.1500
Heavy Thr: 9.0000
Tail: -0.4230
Speed Thr Tail: 20.0000
Speed Thr: 5.0000
Prob of FF Change: 0.00000
Prob of HV FF Change: 0.00000

Figure 3.7: Lane changing parameters for current lane satisfaction

Source: CUBE Dynasim Reference Guide Version-5

Target lane satisfaction depends on the instant speed of the vehicle $V(t)$, the maximum desired speed of the vehicle $V_1(t)$, the speed of the lag vehicle $V_P(t)$, in the current lane the speed of the lag vehicle and of the lead vehicle in the target lane $V_{CP}(t)$ and $V_{CS}(t)$ respectively.

The probability that a vehicle will want to change to a target lane is as follows:

$$P(t) = \frac{1}{1 + e^{(C_1 + C_2(V_P(t) - V_1(t))) + C_3\,(V_{CP}(t) - V_1(t)) + C_4(V_{CS}(t) - V_1(t))}}$$

…(3.4)

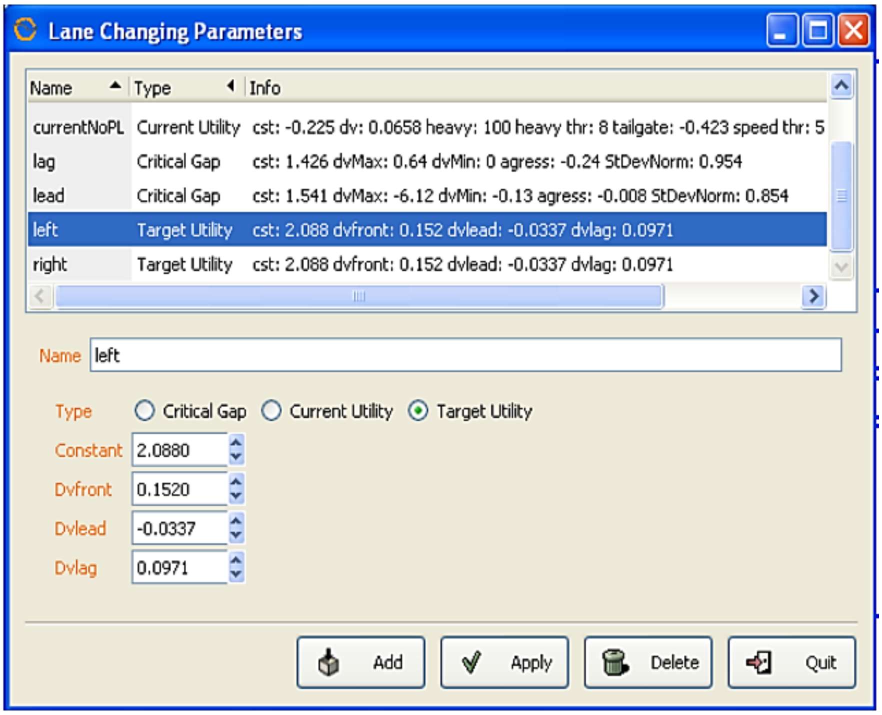
Here,

C_1: Constant

C_2: A ***Dvfront*** parameter relative to the difference between the speed the vehicle wants to reach $V_1(t)$and that of the vehicle in front $V_P(t)$

C_3: A **Dvlead** parameter relative to the difference between the speed the vehicle wants to reach $V_1(t)$and that of the vehicle in front in the adjacent lane$V_{CP}(t)$

C_4: A **Dvlag** parameter relative to the difference between the speed vehicle V (t)and that of the vehicle behind in the adjacent laneV_{CS} (t)



Name	Type	Info
currentNoPL	Current Utility	cst: -0.225 dv: 0.0658 heavy: 100 heavy thr: 8 tailgate: -0.423 speed thr: 5
lag	Critical Gap	cst: 1.426 dvMax: 0.64 dvMin: 0 agress: -0.24 StDevNorm: 0.954
lead	Critical Gap	cst: 1.541 dvMax: -6.12 dvMin: -0.13 agress: -0.008 StDevNorm: 0.854
left	Target Utility	cst: 2.088 dvfront: 0.152 dvlead: -0.0337 dvlag: 0.0971
right	Target Utility	cst: 2.088 dvfront: 0.152 dvlead: -0.0337 dvlag: 0.0971

Name left

Type ○ Critical Gap ○ Current Utility ● Target Utility

Constant 2.0880

Dvfront 0.1520

Dvlead -0.0337

Dvlag 0.0971

Figure 3.8: Lane change parameters for target lane satisfaction

Source: CUBE Dynasim Reference Guide Version-5

Chapter 4 Model Building and Analysis

4.1 General

This chapter will reflect upon how to build a model in CUBE Dynasim step by step as well as how to calibrate the parameters to find out the expected flow-occupancy relationship. Figure 5.1 shows in a diagram the steps to follow for model building in CUBE Dynasim. Detail procedure of each step will be discussed in the following sections of this chapter.

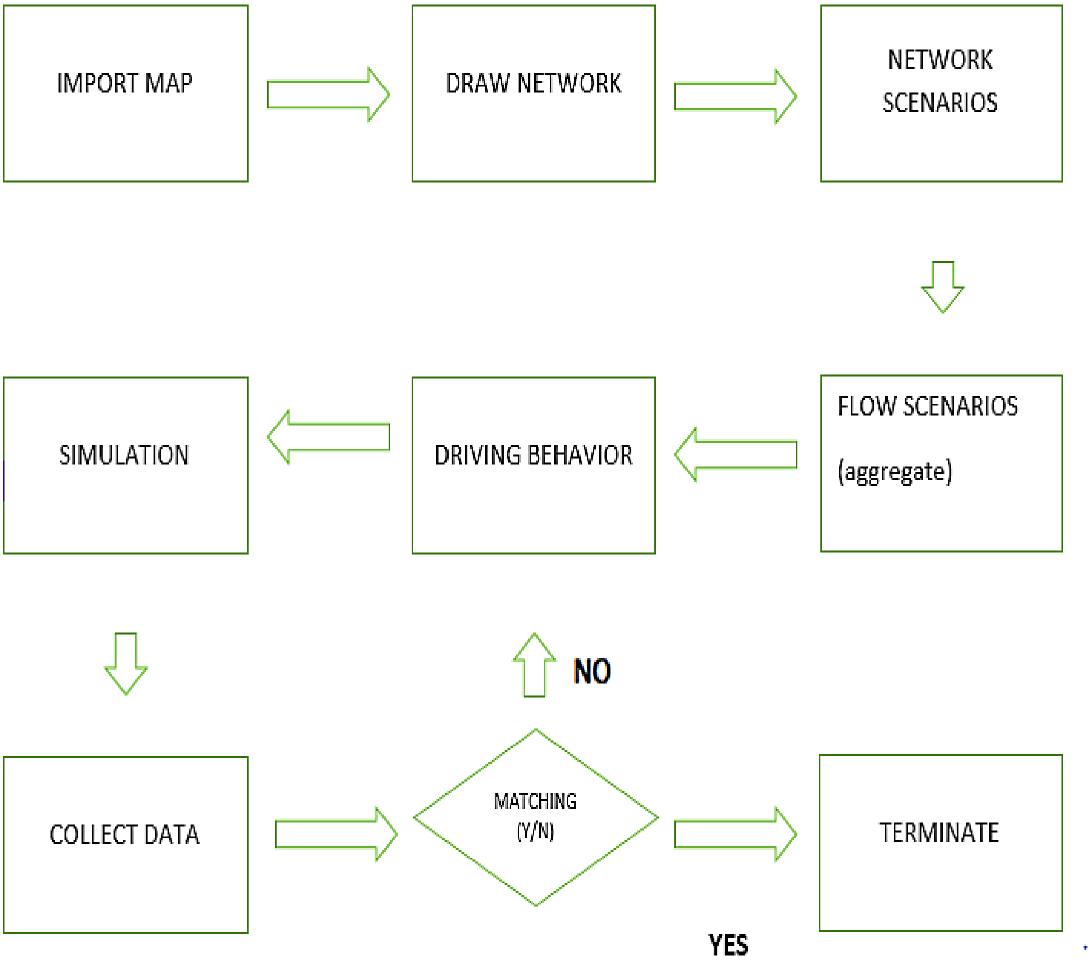


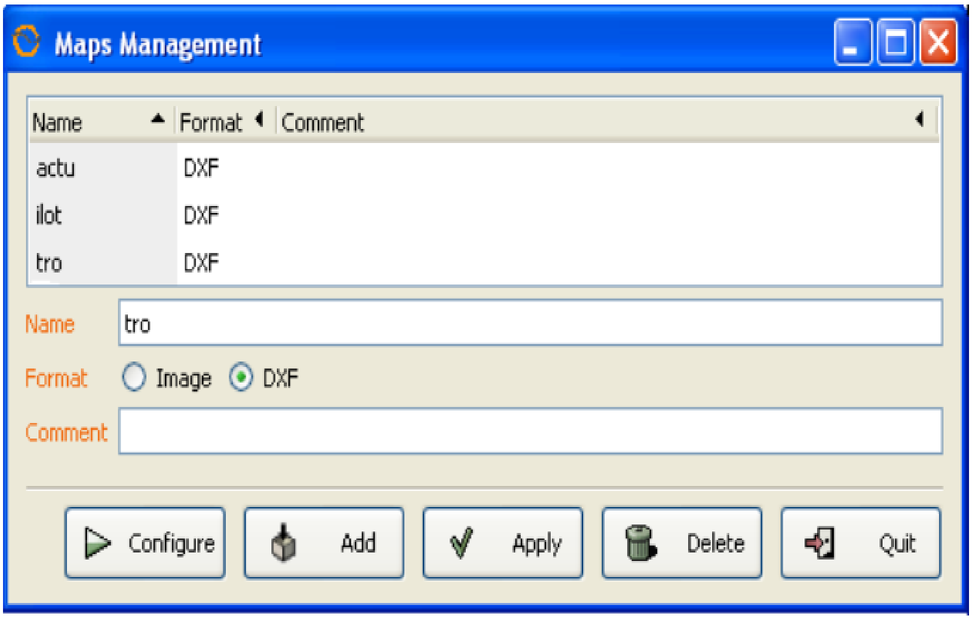
Figure 4.1: Framework of analysis

4.2 Import map

The first step in modelling with CUBE Dynasim is to select and input the map in the software. The map could be in two formats. These are:

1. Vector maps with DXF format
2. Bitmaps in formats BMP, JPEG and GIF

Background maps files are copied to the maps directory. The maps management window in CUBE Dynasim is shown figure 4.2.



Name	Format	Comment
actu	DXF	
ilot	DXF	
tro	DXF	

Name: tro

Format: ○ Image ● DXF

Comment:

Figure 4.2: Map management window

Source: CUBE Dynasim Reference Guide Version-5

4.3 Draw network

In CUBE Dynasim network are drawn with handles and trajectories. Handles are defined by its position, its orientation and its number of attachment points. On the other hand, a trajectory is defined between two different handles. It can link one or more attachment points on the handles. A single lane is modeled by a trajectory that links a single attachment point on each handle. In certain conditions, the vehicles can change lanes depending on their behavior, or to reach their destination.

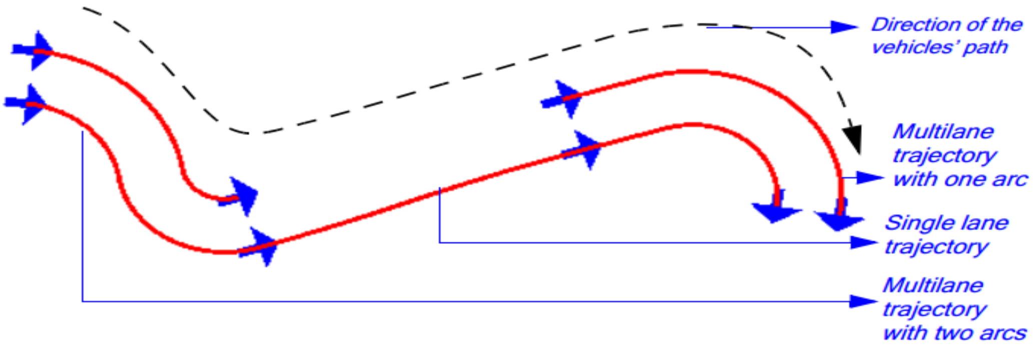
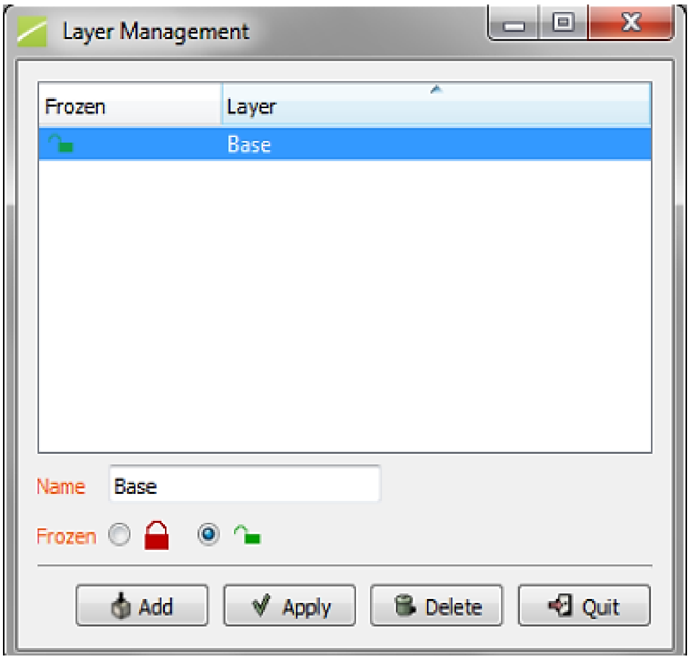


Figure 4.3: Representation of handles and trajectories

Source: CUBE Dynasim Reference Guide Version-5

4.4 Network scenarios

The first step to take in defining a network scenario is to make a layer. Usually the very first layer is defined as Base. Figure 4.4 shows the layer management window.


Layer Management

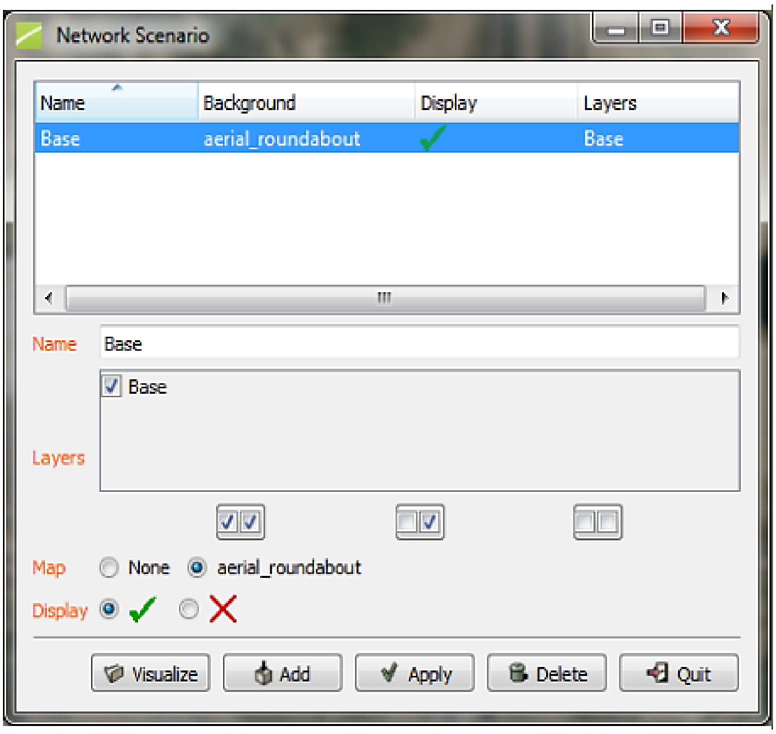
Frozen	Layer
🔓	Base

Name: Base

Frozen: ○ 🔒 ● 🔓

Figure 4.4: Layer management window

After a layer is created the next step to take is to define the network scenario. In the new network the created layer, input maps are selected.



Name	Background	Display	Layers
Base	aerial_roundabout	✓	Base

Name: Base

Layers: ☑ Base

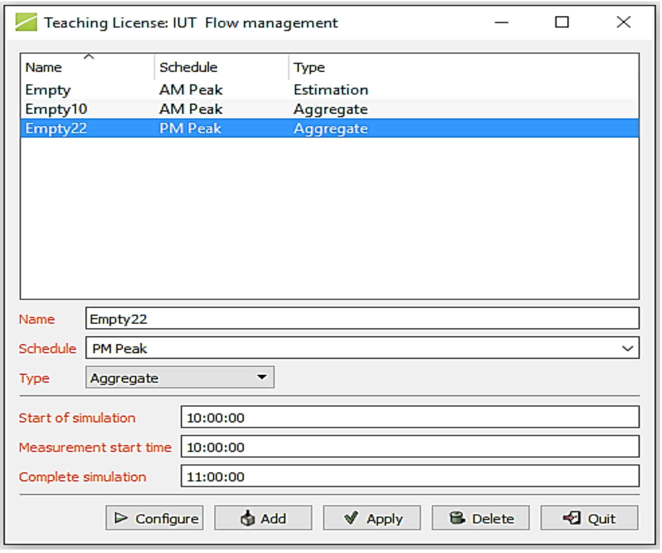
Map: ○ None ● aerial_roundabout

Display: ● ✓ ○ ✗

Figure 4.5: Network management window

4.5 Flow scenarios

In CUBE Dynasim different types of flow scenarios are included. These are aggregate, generator, assignment, estimation, export-import, subnetwork etc. and for the purpose of this study aggregate flow type was used. Aggregate flow was used as aggregate flow value of 15 minutes was introduced as input. Figure 4.6 illustrates the flow scenario window.



Teaching License: IUT Flow management

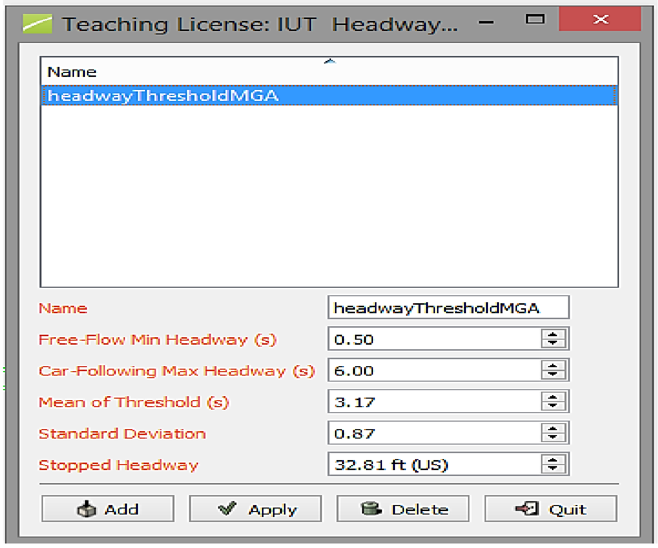
Name	Schedule	Type
Empty	AM Peak	Estimation
Empty10	AM Peak	Aggregate
Empty22	PM Peak	Aggregate

Name: Empty22
Schedule: PM Peak
Type: Aggregate
Start of simulation: 10:00:00
Measurement start time: 10:00:00
Complete simulation: 11:00:00

Figure 4.6: Flow management window

4.6 Driving behavior

In microscopic traffic simulation individual driving behavior is influenced by car following and lane changing parameters. A detail discussion of car following and lane changing is done in the previous chapters. In this section only the parameters which were changed from default value toobtain the hazardous traffic condition is shown.In the following figure software specific car following parameters are shown.



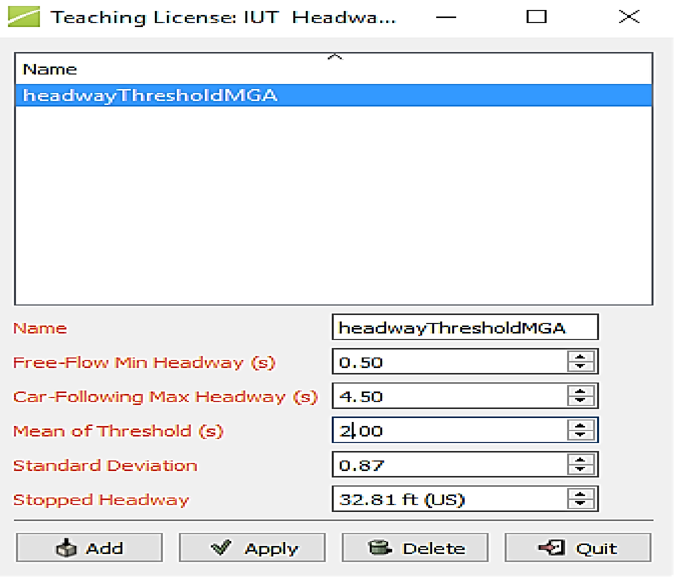
Teaching License: IUT Headway...

Name
headwayThresholdMGA

Name: headwayThresholdMGA
Free-Flow Min Headway (s): 0.50
Car-Following Max Headway (s): 6.00
Mean of Threshold (s): 3.17
Standard Deviation: 0.87
Stopped Headway: 32.81 ft (US)

Figure 4.7: Car following parameters (software specified)

The following figure shows car following parameters that are calibrated.

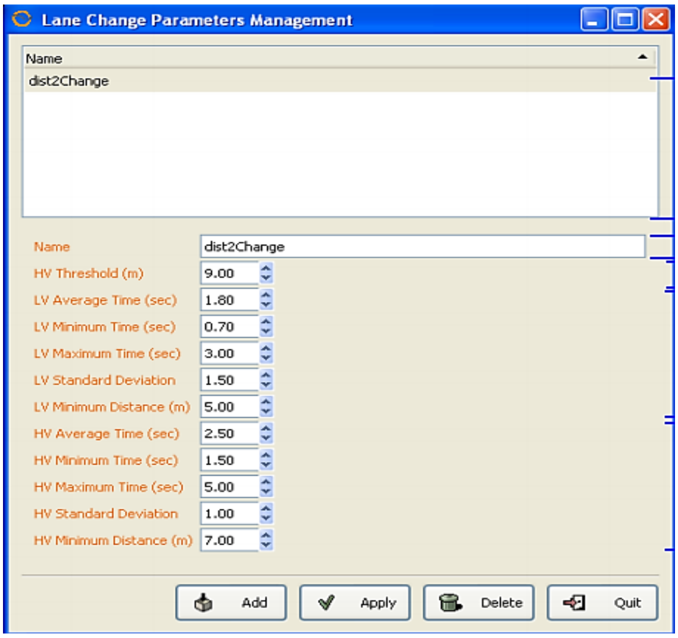


Name
headwayThresholdMGA

Name	headwayThresholdMGA
Free-Flow Min Headway (s)	0.50
Car-Following Max Headway (s)	4.50
Mean of Threshold (s)	2.00
Standard Deviation	0.87
Stopped Headway	32.81 ft (US)

Figure 4.8: Car following parameters (calibrated)

As it is observed from the two figures that car following maximum headway was changed from 6 s to 4.5 s and mean of threshold was changed from 3.17 to 2.In the following figure software specific lane changing parameters are shown.



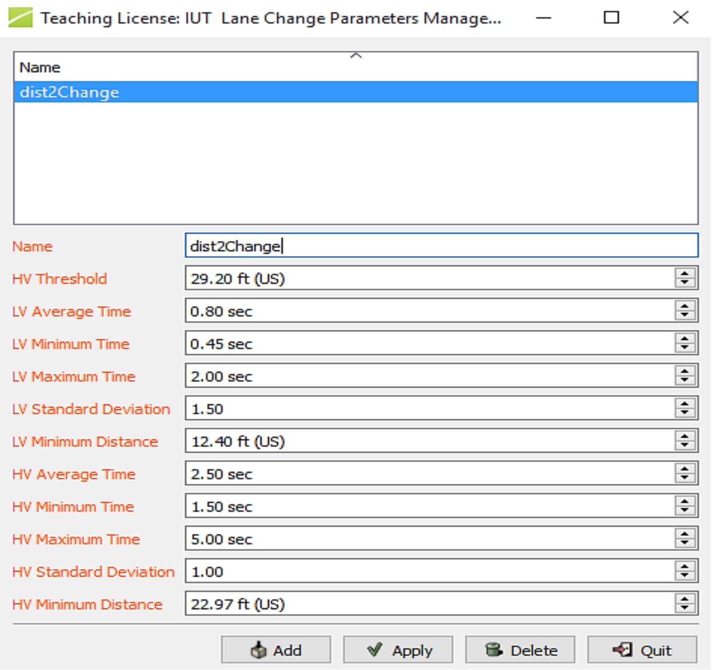
Name
dist2Change

Name	dist2Change
HV Threshold (m)	9.00
LV Average Time (sec)	1.80
LV Minimum Time (sec)	0.70
LV Maximum Time (sec)	3.00
LV Standard Deviation	1.50
LV Minimum Distance (m)	5.00
HV Average Time (sec)	2.50
HV Minimum Time (sec)	1.50
HV Maximum Time (sec)	5.00
HV Standard Deviation	1.00
HV Minimum Distance (m)	7.00

Figure 4.9: Lane changing parameters (software specified)

Source: CUBE Dynasim Reference Guide Version-5

The following figure shows lane changing parameters that are calibrated.



Name	dist2Change
HV Threshold	29.20 ft (US)
LV Average Time	0.80 sec
LV Minimum Time	0.45 sec
LV Maximum Time	2.00 sec
LV Standard Deviation	1.50
LV Minimum Distance	12.40 ft (US)
HV Average Time	2.50 sec
HV Minimum Time	1.50 sec
HV Maximum Time	5.00 sec
HV Standard Deviation	1.00
HV Minimum Distance	22.97 ft (US)

Figure 4.10: Lane changing parameters (calibrated)

It is observed from the two figures that light vehicle average time, light vehicle minimum time and light vehicle maximum time values were changed from the software specified values.

The reason for changing those values was to see how the speed, flow and occupancy relationships change with change in such values.

4.7 Result analysis

The following graph was obtained after the first simulation run. It is seen that most of the vehicles are operating at a very high speed rather than giving a good speed-flow relationship.

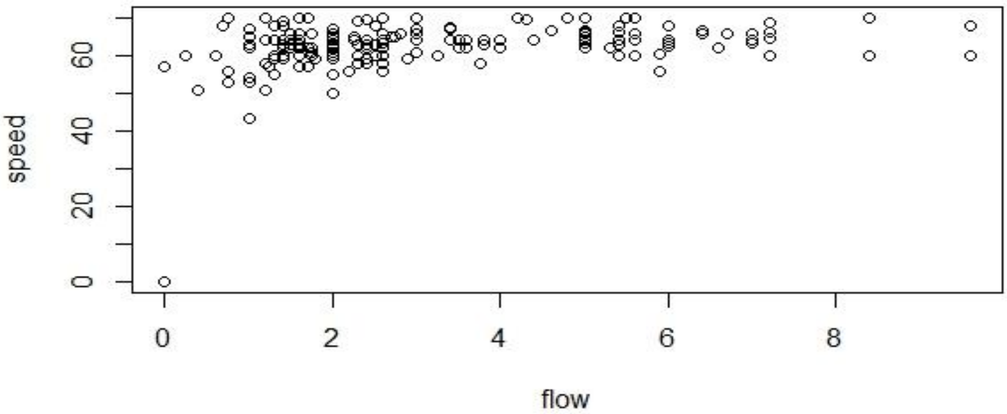


Figure 4.11: Flow vs Speed relationship with software specific value

The relationship drawn between speed versus flow was done with the software specific value. Thus a normal flow model was created.

After the calibration of the parameter the relationship changed a lot and became close to expected outcome.

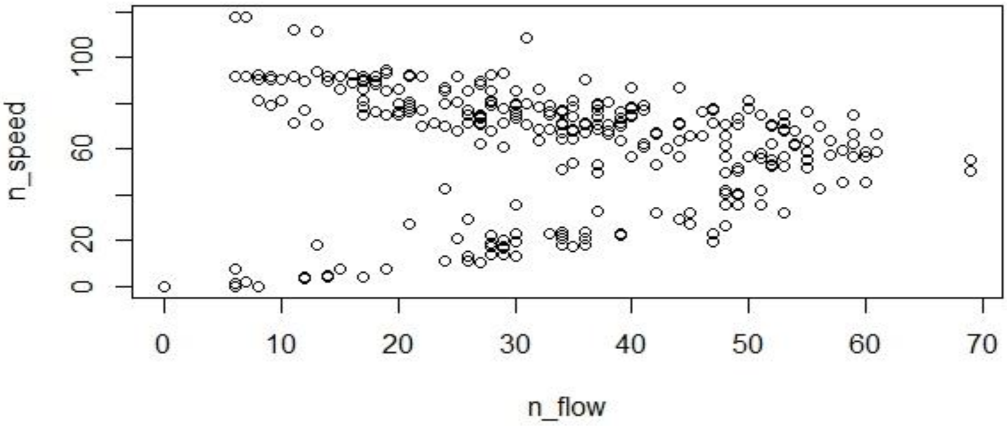


Figure 4.12: Flow vs Speed relationship with calibrated value

The expected relationship should be like following figure,

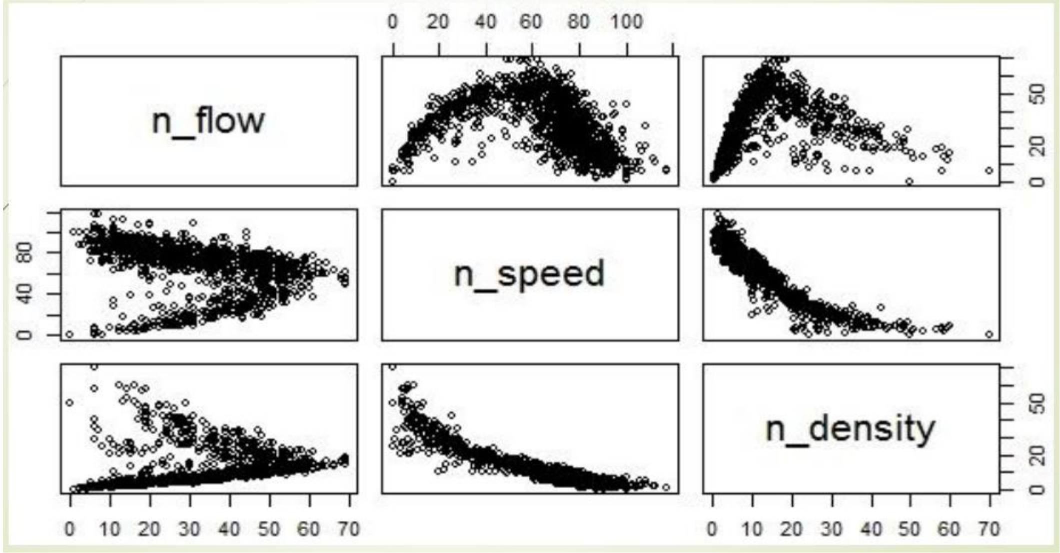


Figure 4.13: Relationship between flow, speed and density

So it is seen that the relationship obtained after calibrating the parameters are much more satisfactory than that of the earlier

Chapter 5 Conclusion

5.1 General

To find out realistic solution to ensure road safety is very important in transportation sector. Now, in this regard it is needed to define normal and hazardous traffic condition with a micro-simulation approach. As micro-simulation approach is less time consuming and dangerous in defining hazardous traffic condition.

5.2 Key findings

In CUBE Dynasim car following and lane changing behavior can be altered to create different flow pattern. The parameters for car following behavior are free flow minimum headway, car-following maximum headway, mean of threshold, standard deviation, stopped headway. Best possible result was obtained by changing the values of car-following maximum threshold and mean of threshold value.

In case of lane changing behavior the parameters are heavy vehicle (hv) threshold, light vehicle (lv) average time, lv minimum time, lv maximum time, lv standard deviation, lv minimum distance, hv average time, hv minimum time, hv maximum time, hv standard deviation, hv minimum distance. Best result was found by changing the values of lv average time, lv minimum time, lv maximum time.

5.2 Limitation and future scope

The limitation of the study was only 300 data was used as input in CUBE Dynasim. This was done owing to limitation of time. Besides, no relationship between density and flow was formulated. This relationship was not formulated because from CUBE Dynasim density data is not shown as output.

The constriction of time during analysis was there because of the fact that a huge amount of time was spent for learning the software and simulation model building.

In future this study could be further used to find out the inclusion of interventions and their effects to turn a hazardous traffic condition back to normal. This study was done based on data of Japan if adequate data could be formulated such study could be carried out for expressways in Bangladesh as well.

References

Abdel-Aty, M. & Gayah, V. (2010). Real-Time Crash Reduction on Freeways Using Coordinated and Uncoordinated Ramp Metering Approaches. Journal of Transportation Engineering, 136(5), 410-423.

Abdel-Aty, M., Cunningham, R.J., Gayah, V. & Hsia, L. (2008). Dynamic Variable Speed Limit Strategies for Real-Time Crash Risk Reduction on Freeways. Journal of the Transportation Reseasrch Board, 2078, Transportation Research Board of the National Academics, Washington, D.C., 108-116.

Abdel-Aty, M., Pande, A., Lee, C., Gayah, V. & Dos Santos, C. (2007). Crash Risk Assessment Using Intelligent Transportation Systems Data and Real-Time Intervention Strategies to Improve Safety on Freeways. Journal of Intelligent Transportation Systems, 11(3), 107-120.

Abdel-Aty, M., Dhindsa, A. & Gayah, V. (2007). Considering Various ALINEA Ramp Metering Strategies for Crash Risk Mitigation on Freeway under Congested Regime. Transportation Research Part C, 15, 113-134.

Abdel-Aty, M., Dilmore, J. & Dhindsa, A. (2006). Evaluation of Variable Speed Limits for Real-Time Freeway Safety Improvement. Accident Analysis and Prevention, 38, 335-345.

Abdel-Aty, M. & Dilmore, J. (2006). Applying Variable Speed Limits and the Potential for Crash Mitigation. In: Presented at 85th Annual Meeting of Transportation Research Board, Washington, D.C.

Andersson, G. & Nilsson, G. (1997). Speed Management in Sweden, Linkoping: Swedish National Road and Transport Institute, VTI.

Bohenger, K. & May, A. (1999). Advanced Coordinated Traffic Responsive Ramp Metering Strtegies. PATH Rep. No. UCB-ITS-PWP-99-19, University of California, Barkley.

Borrough, P. (1997). Variable Speed Limits Reduce Crashes Significantly in the U.K. The Urban Transportation Monitor.

Cambridge Symentics. (2001). Twin Cities Ramp Meter Evaluation. Final Report Prepared for Minnesota DOT, Cambridge Symantics, Cambridge, Massachussets.

Reference

Dhindsa, A. (2006). Evaluating Ramp Metering and Variable Speed Limits to Reduce Crash Potential on Congested Freeways Using Micro-Simulation. MS Thesis, University of Central Florida, Orlando.

Finch, D.J., Kompfner., Lockwood, C.R.P. & Maycock, G. (1994). Speed, Speed Limits and Accidents, TRL Project Report 58, Transport Research Laboratory, Crowthorne.

Gayah, V., Dos Santos, C., Abdel-aty, M., Dhindsa, A. & Dilmore, J. (2006). Evaluating ITS Strategies for Real-Time Freeway Safety Improvement. IEEE Inteligent Transportation Systems Conference, Toronto, Canada.

Ha, T., Kamg, J. & Park, J. (2003). The Effects of Automated Speed Enforcement Systems on Traffic-Flow Characteristics and Crashes in Korea. Institute of Transportation Engineers Journal. 28-31.

Hossain, M. & Muromachi, Y.(2011). Understanding Crash Mechanism and Selecting Appropriate Interventions for Real-Time Hazard Mitigation on Urban Expressways. Transportation Research Record, 2213, 53–62.

Kolisetty, V.G.B., Iryo, T., Asakura, Y. & Kuroda, K. (2005). Effect of Variable Message Signs on Driver Speed Behavior on a Section of Expressway under Adverse Fog Conditions- A Driving Simulator Approach. Journal of Advanced Transportation, 40(1), 47-74.

Lee, C. & Abdel-Aty, M. (2008). Testing Effects of Warning Messages and Variable Speed Limits on Driver Behavior Using Driving Simulator. Journal of the Transportation Research Board, 2069, Transportation Research Board of the National Academics, Washington, D.C., 55-64.

Lee, C., Helinga, B. & Ozbay, K. (2006). Quantifying the effects of Ramp Metering.On Freeway Safety. Accident Analysis and Prevention, 38, 279-288.

Lee, C. (2004). Proactive Vehicle Crash Prevention on Instrumented Freeway Using Real-Time Traffic Control. Ph.D. Thesis, University of Waterloo, Ontario, Canada.

Lee, C., Hellinga, B. & Saccomanno, F. (2004). Assesing Safety Benefits of Variable Speed Limits. In: Presented at the 83rd Annual Meeting of Transportation Research Board, (Paper No. 04-4835).

Reference

Lee, C., Saccomanno, F. & Hellinga, B., (2003). Real-Time Crash Prediction Model for the Application to Crash Prevention in Freeway Traffic. Transportation Research Record, 1840, 67–77.

Levinson, D., Zhang, L., Das, S. & Sheikh, A. (2002). Evaluating Ramp Meters: Evidence from the Twin Cities Ramp Meter Shut-off. 81st Annual Meeting of the Transportation Research Board, Washington, D.C.

Louma, J. & Rama, P. (2001). Comprehension of Pictograms for Variable Message Signs. Traffic Engineering & Control 42:53-58.

McManus, S. (1997). Beating Blind Spots: Variable Message Signshave a Valuable Part to Play in Preventing Collisions at a Notorious Accident Black Spot in the UK. ITS International 10:67.

Miller, J.S., Smith, B.L., Newman, B.R. & Demetsky, M.J. (1995). Effective Use of Variable Message Signs: Lessons Learned Through Development of User's Manual. Transportation Research Record 1495:1-8.

Oh, C., Oh, J. & Ritchie, S. (2001). Real-Time Estimation of Freeway Accident Likelihood. In: Presented at the 80th Annual Meeting of the Transportation Research Board, Washington, D.C.

Pande, A., Abdel-Aty, M. & Hsia, L. (2005). Spatio-Temporal Variation of Risk Preceding Crash Occurance on Freeways. In: Presented at the 84th Annual Meeting of Transportation Research Board, Washington, DC.

Pilli-Sivola, Y. (2000). State of the Art in Finland Concerning RWIS and Variable Massage Signs. Finnish National Road Administration.

Smulders, S. (1990). Control of Freeway Traffic Flow by Variable Speed Signs. Transportation Research, 24B, 111-132.

Van Eeden, P., Van Lieshout, M., Van Der Mede, P., Van Ruermonde, A. & Schouten, W. (1996). Dynamic Route Information in the Netherlands: Effects and Research. 8th International Conference on Road Traffic Monitoring and Control, 145-149.

Xu, C., Liu, P., Wang, W., Li, Z. (2012). Evaluation of the Impacts of Traffic States on Crash Risks on Freeways. Accident Analysis and Prevention 47, 162–171.

Reference

Yu, R. & Abdel-Aty, M. (2013). Analyzing Crash Injury Severity for a Mountainous Freeway Incorporating Real-Time Traffic and Weather Data. Safety Science 63, 50–56.