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Traffic Conflict Analysis Under Fog Conditions Using Computer Simulation

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TRAFFIC CONFLICT ANALYSIS UNDER FOG CONDITIONS USING COMPUTER SIMULATION

by

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ABSTRACT

The weather condition is a crucial influence factor on road safety issues. Fog is one of the most noticeable weather conditions, which has a significant impact on traffic safety. Such condition reduces the road's visibility and consequently can affect drivers' vision, perception, and judgments. The statistical data shows that many crashes are directly or indirectly caused by the low-visibility weather condition. Hence, it is necessary for road traffic engineers to study the relationship of road traffic accidents and their influence factors. Among these factors, the traffic volume and the speed limits in poor visibility areas are the primary reasons that can affect the types and occurring locations of road accidents.

In this thesis, microscopic traffic simulation, through the use of VISSIM software, was used to study the road safety issue and its influencing factors due to limited visibility. A basic simulation model was built based on previously collected field data to simulate Interstate 4 (I-4)'s environment, geometry characteristics, and the basic traffic volume composition conditions.

On the foundation of the basic simulation model, an experimental model was built to study the conflicts' types and distribution places under several different scenarios. Taking into consideration the entire 4-mile study area on I-4, this area was divided into 3 segments: section 1 with clear visibility, fog area of low visibility, and section 2 with clear visibility. Lower speed limits in the fog area, which were less than the limits in no-fog areas, were set to investigate the different speed limits' influence on the two main types of traffic conflicts: lane-change conflicts and rear-end conflicts.

The experimental model generated several groups of traffic trajectory data files. The vehicle conflicts data were stored in these trajectory data files which, contains the conflict locations' coordinates, conflict time, time-to-conflict, and post-encroachment-time among other measures. The Surrogate Safety Assessment Model (SSAM), developed by the Federal Highway Administration, was applied to analyze these conflict data.

From the analysis results, it is found that the traffic volume is an important factor, which has a large effect on the number of conflicts. The number of lane-change and rear-end conflicts increases along with the traffic volume growth. Another finding is that the difference between the speed limits in the fog area and in the no-fog areas is another significant factor that impacts the conflicts' frequency. Larger difference between the speed limits in two nearing road sections always leads to more accidents due to the inadequate reaction time for vehicle drivers to brake in time. And comparing to the scenarios that with the reduced speed limits in the low visibility zone, the condition that without the reduced speed limit has higher conflict number, which indicates that the it is necessary to put a lower speed limit in the fog zone which has a lower visibility.

The results of this research have a certain reference value for studying the relationship between the road traffic conflicts and the impacts of different speed limits under fog condition. Overall, the findings of this research suggest follow up studies to further investigate possible relationships between conflicts as observed by simulation models and reported crashes in fog areas.

TO MY PARENTS

for making me who I am

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CHAPTER 1. INTRODUCTION

1.1 Motivation for the Study of Fog-related Conflict with Variable Speed Limits

Weather conditions are rising urban and suburban accidents risks, and fog is one of the most significant factors impacting the road traffic safety and efficiency due to its effect on reducing drivers' visibility. In the study of road traffic system, increasing influence is being focused on the relationship between the visibility and the traffic conflicts in fog, and the impact of the variable speed limits in fog areas.

Safety and efficiency are the key purposes of road traffic systems. Safety means that by taking certain methods and measures, the risks of road users' injury and fatality can be kept at a lower level. Efficiency indicates that drivers and vehicles can arrive at their destinations in the shortest possible time. Drivers tend to spend less time on the road by enhancing their speed. But driving in a high speed in fog with the lower visibility can often lead to a lower safety level and cause traffic accidents. Due to this statistical data, it can be known that both the weather condition and visibility are crucial factors influencing road traffic crashes. The data of fog and other weather condition-related fatal crashes from 2002 to 2012 is shown in Table 1-1. In the United States, the data of weather and visibility related accidents from 2008 to 2012 is shown in Table 1-2 (National Highway Traffic Safety Administration, 2008-2012).

Besides weather and visibility condition, the speed limit is also a mentionable factor which influences the road accidents' types, severity and locations. The speed limit is used to give the maximum or minimum speed requirement at which road users should follow up legally while travelling on this road segment. Speed limit setting is based on road geometry, the road application, road types, and the road level of service. However, other than these factors that do not change dynamically, weather condition is a factor that can vary randomly. Considering its important influence to drivers' perception and judgment, it is necessary to set the speed limit value that can change in accordance with the weather condition. So the variable speed limits' influence on road safety problems and traffic conflict issue should be studied.

Table 1-1 Fatal Crashes by Weather Condition and Light Condition from 2002-2012

Weather conditions	Year	Light Condition					Total
		Daylight	Dark, but Lighted	Dark	Dawn or Dusk	Unknown	
Fog, Smog, Smoke; Severe Crosswinds; Blowing Sand, Soil, Dirt; Other	2002	202	69	286	45	1	603
	2003	265	102	358	68	4	797
	2004	264	108	368	73	2	815
	2005	197	85	332	61	0	675
	2006	141	65	281	49	5	541
	2007	144	68	263	52	2	529
	2008	161	60	247	47	1	516
	2009	112	52	201	33	0	398
	2010	118	50	177	38	1	384
	2011	121	59	187	41	2	410
	2012	147	64	214	52	5	482

Table 1-2 Crashes by Weather Condition, Light Condition, and Crash Severity

Weather Condition	Light Condition					Total
	Daylight	Dark, But Lighted	Dark	Dawn or Dusk	Other	
Crashes in 2008						
Normal	3,429,000	746,000	534,000	161,000	**	4,869,000
Rain	346,000	121,000	77,000	29,000	**	573,000
Snow/Sleet	136,000	48,000	61,000	11,000	**	256,000
Other/Unknown	59,000	18,000	27,000	8,000	**	112,000
Total	3,970,000	932,000	699,000	209,000	**	5,811,000
Crashes in 2009						
Normal	3,242,000	692,000	481,000	164,000	**	4,579,000
Rain	324,000	108,000	71,000	23,000	**	526,000
Snow/Sleet	111,000	37,000	38,000	13,000	**	199,000
Other/Unknown	16,000	5,000	8,000	4,000	**	34,000
Total	3,693,000	842,000	598,000	204,000	1,000	5,338,000
Crashes in 2010						
Normal	3,343,000	714,000	454,000	169,000	1,000	4,680,000
Rain	291,000	85,000	48,000	25,000	**	450,000
Snow/Sleet	140,000	48,000	54,000	12,000	**	254,000
Other/Unknown	17,000	6,000	9,000	2,000	**	35,000
Total	3,792,000	852,000	566,000	208,000	1,000	5,419,000
Crashes in 2011						
Normal	3,242,000	692,000	481,000	164,000	**	4,579,000
Rain	324,000	108,000	71,000	23,000	**	526,000
Snow/Sleet	111,000	37,000	38,000	13,000	**	199,000
Other/Unknown	16,000	5,000	8,000	4,000	1000	34,000
Total	3,693,000	842,000	598,000	204,000	1000	5,338,000
Crashes in 2012						
Normal	3,460,000	796,000	471,000	167,000	**	4,895,000
Rain	317,000	127,000	58,000	28,000	**	529,000
Snow/Sleet	85,000	25,000	36,000	10,000	**	155,000
Other/Unknown	15,000	6,000	8,000	6,000	**	35,000
Total	3,876,000	955,000	574,000	210,000	**	5,615,000

1.2 Thesis Objectives

From previous literatures (Chapter 2) we can know that many research works have been done to investigate the impacts of weather on road safety problems, variable speed limits in fog areas, and the VISSIM simulation model building and application. As for fog-related traffic accidents, it is necessary to study the proper safety method to reduce the accident rates and enhance the road safety situation. Variable speed limits have been presented as an effective way to deal with some special road condition. Whether it is useful in applying in different visibility road sections or not is still an issue that needs to be discussed. Traffic simulation is also proved to be a useful method to conduct the roadway condition study, and it has been acknowledged that VISSIM is a valid tool for microscopic traffic simulation.

This study aims at investigating the influential factors to two main kinds of traffic conflicts on the fog-affected freeway, which are lane-change conflict and rear-end conflict. Based on the traffic flow's trajectory data, the accident locations can be mapped on a coordinate system, which is corresponding to the actual road of Interstate 4. The different road segments have different visibility, which indicate different weather conditions. From the accident locations on this coordinate system, it can be investigated that how the visibility and variable speed limits influence the traffic conflict distributions on the freeway under different traffic volume conditions.

1.3 Thesis Framework and Outline

1.3.1 Thesis Framework

The thesis framework is shown in Figure 1-1.

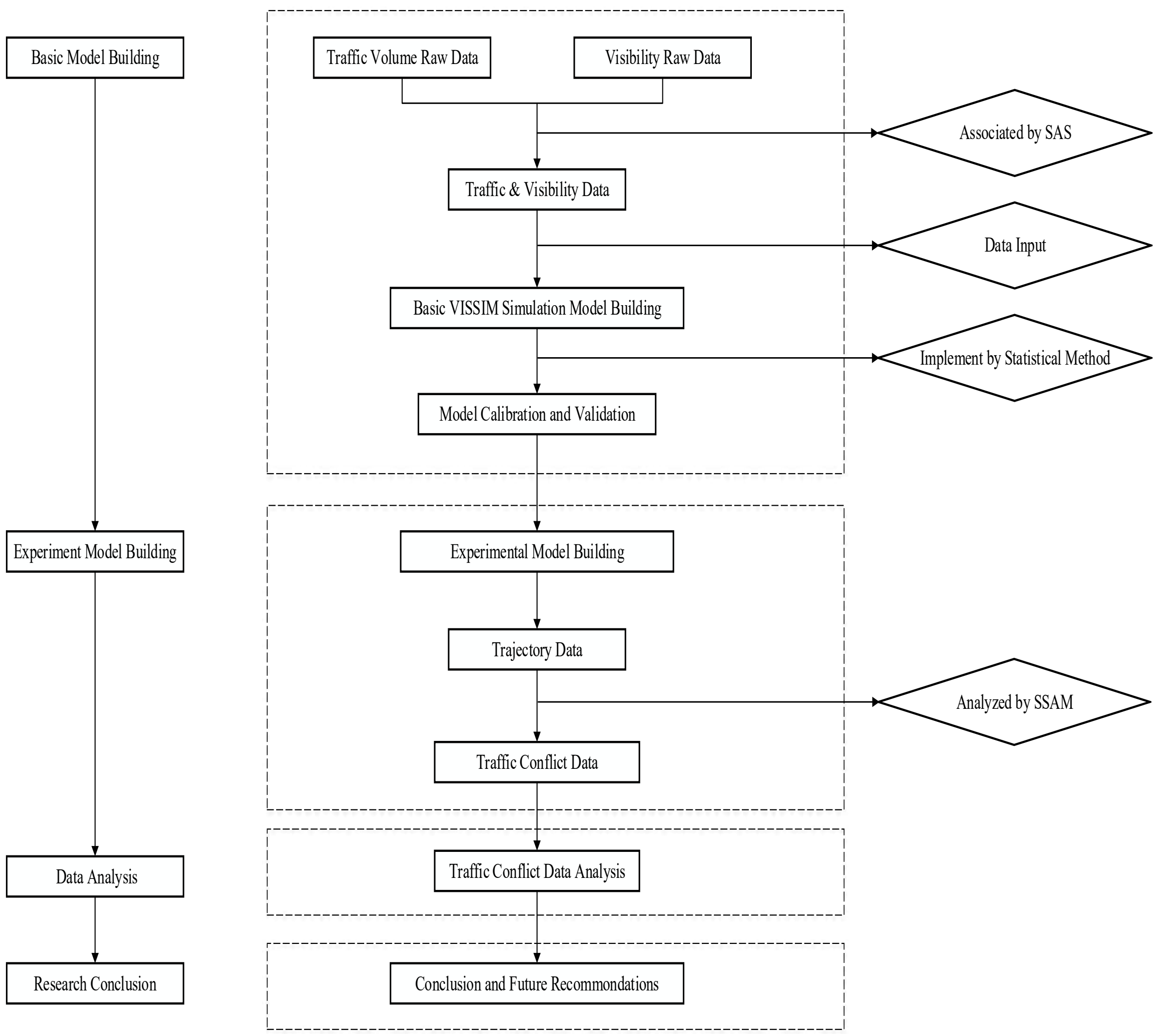

Figure 1-1 Thesis framework

1.3.2 Thesis Outline

The remainder of this thesis is organized in six chapters. Chapter two reviews the previous research about the relationship between fog and driving behaviors, the fog influence on visibility, the model building experiences in VISSIM, and the VISSIM model calibration and validation. The variable speed limit effects are also discussed in this part. Besides, the traffic conflict data analysis methods and the surrogate safety assessment model (SSAM) application in conflict analysis are mentioned in this chapter.

Chapter three presents a detailed explanation of the methodologies that are used in this research, which give an introduction to the research road segment selection, data collection, basic simulation model building, calibration and validation in VISSIM, and experiment design and conflict analysis in the surrogate safety assessment model.

In Chapter four, a basic simulation model was built based on VISSIM to simulate the scenario of driving in fog. This chapter also indicates the data source that was used for building the model. The experimental model is also introduced in this chapter. This experimental model gives the assumption of the three different road segments which contains two no-fog areas and a fog area. The third step that the different kinds of traffic conflicts analysis in SSAM is also applied in chapter four.

Chapter five analyzes the two main types of traffic conflicts occurring in the experimental base on their trajectory data. The two main conflict types are lane-change conflict and rear-end conflict. The accident location distribution is studied under different speed limit conditions in the fog area and different traffic volume levels to see which factor is the most influential one on vehicles' collisions on the freeway.

Chapter six concludes with the discussion of important results and points out some directions for the future research.

CHAPTER 2. LITERATURE REVIEW

A clear vision of a road is crucial for establishing traffic safety, and fog is an important factor affecting road visibility. Fog impact on traffic safety and driving behavior is mainly reflected in the visibility. The purpose of many previous studies was to find out significant parameters to describe the driving behavior characteristics. A review of the literatures for the study on the relationships between fog and visibility, VISSIM model calibrating, and driving behavior parameters is given in the following sections.

2.1 Relationship between Driving Behaviors and Fog

2.1.1 Fog Related Driving risks

Different factors may affect the occurrence of fog-related accidents directly or indirectly. The fog-related crashes effect factors in Florida were compared to clear-visibility crashes effect factors, and this study also indicated a significant difference between fog-related accidents and clear-visibility condition in crash severity and collision type (M. Abdel-Aty, et al., 2011).

Patterns in expressway Automatic Vehicle Identification (AVI) traffic data were also identified, which may be better than the patterns in compensation visibility related (VR) crashes data (M. Abdel-Aty, et al., 2012). The research of Ruth Bergel-Hayat et al indicated the relationship between weather and traffic crashes at an aggregate level by month (Bergel-Hayat, et al.,2013). Time series model was also applied to analyze the weather variables and road injury accidents to help us understand how the weather affects traffic accidents rate.

2.1.2 Fog Influence on Visibility

Panos Konstantopoulos et al used a driving simulator to study how driving experience and visibility condition affect drivers' driving behavior. They divide drivers into driving instructors and learner drivers. By checking two kinds of drivers' eye movements in three scenarios, which are day, night and rain routes, they found that driving instructors performed better than learner drivers in all study modules, including sampling rate, processing time and road scan wideness (Konstantopoulos, et al.,2010).

Two experiments were conducted to see whether the headway reduction under fog condition could be explained (Caro, et al. 2009). Their study shows that both visual cues, other than the visual angle of its lead car, and environment traffic flow may make the headway change.

2.1.3 Driving Behaviors under Different Weather Conditions

Fog may make drivers feel that they drive faster than their actual speed, and car following behavior in fog should differ from driving in fine weather(Boer, 2007). The drivers' speed choices and their driving performance were studied by simulating the fog scenario. He suggested that drivers often pretend to keep driving in a high speed even though the visibility condition has been reduced. In this situation, even the road hazards are within the stopping distances, drivers may not see them due to poor visibility. The looking forward distance in this kind of fog is almost the same as driving at night (Brooks et al., 2011).

Hassan, H. M. and Abdel-Aty, M. A. developed a crash likelihood prediction model, which can identify the traffic flow factors that gave rise to accidents related to visibility on expressways (Hassan & Abdel-Aty, 2013). This likelihood function uses real-time traffic flow variables as independent variables, and tests the hypothesis by comparing crash versus non-crash incidents at low visibility conditions.

Mark Brackstone focused on the car following behaviors in many conditions, such as motorway driver behavior (Mark Brackstone 2002). Hany Hassan proposed some measures to improve traffic safety and driving behavior in reduced visibility conditions (H. M. Hassan, 2011). In his paper, he presented two ways to ensure drivers' safety under poor visibility situations. The first depends on drivers' self-behavior, and the second is giving drivers information about the coming weather change by using technique methods.

2.2 VISSIM Model Building, Parameters Calibration and Validation

2.2.1 VISSIM Model Building

Car following behavior in fog is also studied in S. Mitra and K. Utsav's research by analyzing drivers' speed and headway maintenance in reduced visibility(S. Mitra, 2011). In general following headways increased with speed, however, the increase is not enough to avoid potential collision. Wim van Winsum studied the human factor in car following models (Winsum, 1999).

Considering the weather condition, Mohamed A Abdel-Aty et al developed a crash-likelihood prediction model (Pemmanaboina, 2006). In this model, they use real-time traffic flow data and rain data, which were obtained from the instruments on Interstate 4, to calibrate the traffic accident model. And from their study, a statistical significant association result has been proved.

Siddharth S M P and Gitakrishnan Ramaduraib presented a method of calibrating VISSIM model automatically using data from Chennai (Siddharth & Ramadurai, 2013). They used sensitivity analysis to find the parameters' impact on driving behavior in Indian heterogeneous condition. ANOVA and other statistic methods were also used in this test. In this paper, automated calibration process is recommended to do the analysis in VISSIM, especially when there are more parameters in the model. In the interchange traffic operational analysis, there are some guidelines in simulation model selecting (Elefteriadou2, 2005).

2.2.2 Model Calibration and Model Validation

Referring to the value choice for parameters, which are related to the road safety, it can be concluded from a study that choosing values which are realistic-but-unsafe is better than choosing values which are safe-but-unrealistic (Bonsall, Liu, & Young, 2005).

A method was proposed to calibrate the parameters in VISSIM to investigate the relationship between driving behavior and snow weather condition. The parameters calibration of traffic models is the way of finding parameters that can match historical data best. This procedure includes two steps: first, compare the model predictions to the target value; second, minimize the prediction deviation. Weather conditions are also considered in calibrating models' parameter. The driving behaviors on snowy weather conditions has been simulated to find the influence of the weather (Johannes Asamer, 2011).

During snowy road conditions, these following parameters of a car-following model can be impacted: desired speed, desired acceleration/deceleration, and minimum following distance. After applying a linear regression to the vehicle data, the saturation flow rate of this model can be calculated. The third step is sensitivity analysis. By using the above method, the model's parameters can be calibrated (Asamer. J, 2011).

The VISSIM model is also applied in simulating the medium-sized network model, and the method of medium network model calibration and validation is also proposed (Sayed, 2011). This study conducted a case study based in a British Columbia city, Vancouver, to investigate the calibration and validation measures. By operating the link charges, the route choice behavior can be calibrated. For model validation, the data of field travel time were collected for matching the travel time of the simulation outputs data.

Another case study was also carried on for a coordinated actuated signal system to calibrate and validate the macroscopic VISSIM simulation model (Schneeberger, 2003). During the procedure of this study, two crucial issues were confronted within the progress of putting the model calibration and validation into effect. The first issue referred to the statistical test when forming the hypothesis of the equation of the field data and the calibrated model. The second issue investigated the significance of the imagery and visualization in the course of calibration.

The calibration and validation to the simulation model of signalized intersection has also been conducted to study the vehicle safety performance (Cunto & Saccomanno, 2008).This paper presents a classified and objective procedure for doing the model calibration for traffic safety performance concern. For the purpose of describing the safety performance quantitatively, a crash potential index was used to reference the required deceleration rate at which a crash could be avoided. This VISSIM model calibration method contains four steps: (1) initial model input parameter selection, (2) statistical screening with a foldover factorial design, (3) developing the linear expression with the significant model inputs as independent variables and the safety performance as the dependent variable, (4) estimating the best-matched parameters by using a genetic algorithm. In order to test the model's transferability and reliability, the validation procedure was processed based on the vehicles' field traffic data.

A model that simulated the four-crossover diamond interchange in VISSIM was also calibrated and validated by the field data (Bastian J. Schroeder, 2014). This study proved that the model is able to replicate the simulation of a Double-Crossover Diamond (DCD) interchange and presented the matters that need attention about the speed setting and route selection in the network. Their study further showed that validating the model is easier in an extended route than a short one. A shorter road segment's validation comes along with more difficulties. How to define the differences between the field data and the model simulation result was also regarded as a challenging issue.

Based on the experimental design and the network optimization, a research result proposed a systematic method to deal with the model calibration and validation. And by building simulation model in VISSIM, this method was applied into an independent model (Park, B, 2006). This study developed a case of an arterial network, which consisted of twelve intersections with coordinated actuated signals in urban area. Travel time was selected as the calibration measurement, and the maximum queue length was chosen as the model validation measurement parameter. As a study result, these two parameters were found to be effective for model calibration and validation in arterial intersection network in VISSIM.

2.3 Speed Limit Adjustment Influence on Driving Behavior and Traffic Conflicts

Speed limits are implemented to enhance the road safety condition and many previous studies have been conducted to investigate the effects of speed limit settings. A research study was focused on the way that a link-specific speed limit rule equally distributes the road traffic flow in a network in a macroscopic view (Hai Yang, 2012). And this research found that this network of speed limits could decentralize the objective traffic flow mode. What's more, by controlling the speed limits of different road segments, this network speed limits can work as a toll network to form a target traffic flow mode.

As demonstrated in the study that assesses the variable speed limits' safety advantages, some safety benefits were stated by using a comprehensive real-time crash prediction model based on traffic simulation, and it found that variable speed limits can contribute to a total of 25% traffic conflicts within the dangerous road traffic situation (Lee, 2004). (1) Conservative measures are helpful in reducing the traffic crash potential. (2) There are more traffic crashes in the road, which contains frequent speed limit changes but without enough duration intervention. (3) Lower speed limits offer more traffic safety benefits, while they will lead to longer travel time. (4) The traffic crash potential reduces most at the large traffic weaving areas, and advanced warning that is taken before the vehicles coming into these turbulence locations can lead to less crash potentials.

Some researchers studied the factors that influence driving behaviors status in bad visibility conditions on freeways and two-lane roads. They also examined the extent that drivers rely on the advanced warnings shown on the Changeable Message Signs (CMS), which change according to the different traffic and visibility situations (H.M. Hassan, 2012). This research is based on a survey of several groups of people and it inspected the vehicle's reaction to different traffic and visibility scenarios. The study group is divided by ages and gender. Their conclusion indicated that males and younger drivers have a lower probability to reduce their speed when they see the CMS in variable speed areas than the female and older driver groups. These instructions worked better to those who have a good knowledge of signs than those who are not, while in heavy fog situation. The road types also have effects to the driving behavior in fog. Comparing to driving on a two-lane road, driving on a freeway has a lower likelihood of reducing their speed when the drivers see a CMS and the visibility is low.

A control strategy of variable speed limits was also developed in order to reduce the risk of rear-end crashes nearing the bottlenecks of freeways (Zhibin Li, 2014). The algorithm for the optimum control strategy development is shown in Figure 2-1.The simulation experiment showed that the variable speed limits control strategy had a better performance in the scenario of middle traffic volume demand than high traffic demand.

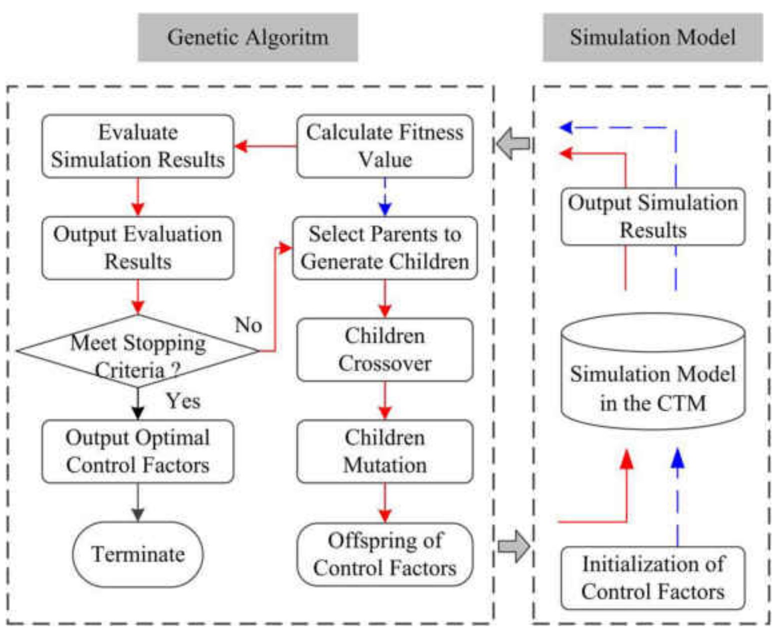

Figure 2-1 the optimum control strategy determination algorithm (Zhibin Li, 2014)

The real-time variable speed limit was also evaluated by simulation models which simulated the congested freeway scenario (Joyoung Lee, 2013). In this research, a microscopic model, which was built in VISSIM was used to simulate a section of an interstate highway with a 5-mile length, and the data of the field travel time was used to calibrate this model. The extent of the whole travel time reduction, which was influenced by the variable speed limit system depended on driver obedience rates and its maximum rate can be as high as 12%. Due to the experiment results, the study concluded that there were remarkable savings in travel time when the study area was in moderate or highly congested conditions.

Joseph Perrin studied the effect of the variable speed limit signs on vehicles' driving behavior under the destructive weather conditions (Perrin. J, 2000). His study showed that the Adverse Visibility Information System Evaluation (ADVISE) could reduce the traffic volume's velocity by 22% and increase the average speed by 15%. What's more, this research results found that it is necessary to install the ADVISE system for further safety concern due to its effect in reducing traffic conflicts.

2.4 Traffic Conflict Data Analysis by Using SSAM

Discussions have been made to investigate that whether VISSIM simulation model and SSAM conflict analysis can offer rational conflict estimations of signalized intersections with field traffic accident data (Huang.L, et al., 2013). To test the validity of SSAM approach for road conflict assessment at signal intersection, Huang compared the simulated crash results, which generated from the simulation model built in VISSIM to the field collected traffic accident data. And the threshold values were also adjusted in SSAM. He found that between the two groups of data, there was a rational consistency. However, this research also found that SSAM and VISSIM didn't work well in assessing the unexpected driving behaviors (e.g. illegal lane-changes) in the reality road.

In order to do the assessment of the crash frequency rates on a large-scale network simulation model, it is necessary to take the road safety surrogate measurements as a predictor. Alexander Ariza did the validation of the predictor in his study by using the Surrogate Safety Assessment Model (SSAM) and the Paramics microsimulation suite (Ariza, 2011). Similar to the way that SSAM suggested with the models those were based on traffic conflicts, he explored a generalized linear model with a negative binomial error structure and a linear regression to associate the conflicts to accident rates. After comparing the model's simulation result to the historical conflict data in Toronto, Canada, the predictions based on traffic volume were computed from a negative binomial generalized linear regression model, which was fitted to the main crossing of the real world. What was found from this study is that its conflict-based simulation model's predictions worked well in comparing to the intersections, but not well for main roads.

The safety condition of freeway merging and diverging influence areas was also assessed by Markos Alito Atamo by using simulation traffic method (Atamo, 2012). This study used both Traffic Conflict Technique (TCT) and SSAM, which were developed by Federal Highway Administration (FHWA) as the surrogate measures to study the road facility safety problems. VISSIM was used to offer the simulation data for further conflict analysis. He recommended this technique to assess the safety conditions in roadway's merging and diverging areas based from his research.

SSAM can also be applied within the progress of estimating crash modification factors. Usama Shahdah pointed out that SSAM defined different parameters which corresponding to different kind of conflict event by using a special algorithm hence SSAM can estimate the amount of conflicts by using two different Time-To-Collision (TTC) thresholds (Shahdah, et al., 2014).

Referring to the research of TCT, TTC has been approved to be a valid measurement parameter in classifying the traffic crash severity and distinguish crucial driving behaviors from normal driving behaviors (Richard van der Horst, 2006). The research results of the driving behavior in bad visibility situation indicated that, the TTC level from 4.5s to 5s is better of the value of 4s. In addition, the distances that range from 0.02485 miles to 0.07456miles should be given more attention in fog condition.

CHAPTER 3. METHODOLOGY

3.1 Research Procedure

The main goal of this thesis is to study how the traffic conflicts are influenced by different speed limits under fog condition. Since crash occurrence under foggy conditions is a rare event and when it occurs it causes major pile up of vehicles, traffic conflicts was selected as a surrogate measure for crashes. Furthermore, the scope of this thesis is to include what kind of changes these traffic conflicts could have due to the different levels of traffic volume. According to the FHWA (Administration, MAY 2008), there are three main kinds of traffic conflicts: lane change, rear end, and crossing. Since I-4 is a freeway and the study area doesn't include an intersection, this thesis focuses only on the first two kinds of conflicts. In order to achieve the above research goal, the research process is divided into the following three tasks.

1) Basic model building

Generally, a VISSIM simulation model building consists of two parts of data. First, the basic model that comprises the I-4 scenario simulation, which uses the field road and traffic flow data to build and fine-tune the parameters for the model. Next, the field visibility data is used to calibrate the driving behavior parameters in this model. Both the two parts of data sets that were collected before need to be organized and formatted correctly into the proper format. The performance of the model is validated over a 4-mile part of I-4 freeway in the city of Orlando for which real traffic flow data and visibility data were provided by the traffic flow detector and the FMS system. After calibration and validation, this model could be used as the basic model for the experiment in the next task.

2) Experiment model building

It is generally understood that different weather events can affect the road and vehicle's driving behaviors. According to FHWA (Park.B.B, 2010), fog's primary roadway impact is reducing the visibility. The low visibility's primary impacts to the traffic operation and driving behavior are reduced speeds and increased delay, increased speed variability, and increased crash risk. To discern and quantify the low visibility's influence, it is necessary to divide the whole study road into 2 components: fog area, and no-fog area. The fog area is set in the middle of the no-fog area, and thus makes the no-fog area splits into two sections ---section 1 to the West of the fog area, and section 2 to the East of the fog area. In order to investigate the impact of speed change in the fog area, the speed limit that set in the fog area is different with the limit in the two no-fog areas. In no-fog areas, the speed limit is 70 mph corresponding to the I-4's situation. However, the limit in the fog area is set as three levels to investigate the extent of the different speed limits can have on traffic conflicts. The three levels are 40 mph, 50mph, and 60mph.

3) Traffic conflict data analysis

Traffic conflict condition is mainly analyzed by SSAM. Due to the three zones of the study area, this research's emphasis is the conflict locations. For the purpose of finding the distinctions of traffic crashes between the high-visibility zone and the low-visibility zone, it is necessary to recognize which conflicts are in the no-fog zone and which are in the fog zone. All the traffic conflict location points are given by the means of coordinates in the trajectory files. Based on these coordinates, the conflict points can be mapped on a two-dimensional coordinate system.

3.2 Combination of Traffic Flow Data and Visibility Data

The data that we need for supply parameters are traffic flow speed, volume, traffic composition, and look-ahead distance (which could be introduced from the visibility data set). A methodology to join the field traffic flow data and the visibility data by using SAS, the statistical software, is presented in this section. The SAS code is provided in the appendix. The quality assurance in the input data is required in conducting the data preparation, and the error checking procedure is needed to delete the out liners from the data.

3.3 Driving Behavior Model

In VISSIM, the traffic flow model is based on the time step, and it is a microscopic model with discrete and random driver-vehicle-units. For longitudinal vehicle movement, this traffic flow model provides a psycho-physical car following model; for lateral vehicle movement, it provides a rule-based algorithm. The model is based upon Wiedemann's car following model (AG PTV, 2011).

Wiedemann's car following model was first formulated in 1974, and it assumes that a driver's driving behavior is one of the four following modes: free driving, approaching, following, and braking. Once the driver is faced with a certain scenario that can be described as a combination of the speed difference and the space, the driver can change his/her driving behavior from one mode to another. How to change his/her driving behavior depends on the driver's perception and senses, and thus makes the model named as a psycho-physical car-following model. Its scheme is shown in Figure 3-1 (AG PTV, 2011). There are two main driving behavior models in VISSIM. One is Wiedemann 74, and the other one is Wiedemann 99. These two models share many similarities. But Wiedemann 99 is designed in a different way to simulate the freeway's scenario better. Since I-4 in the study area is a freeway, Wiedemann 99 is selected to model the field road condition.

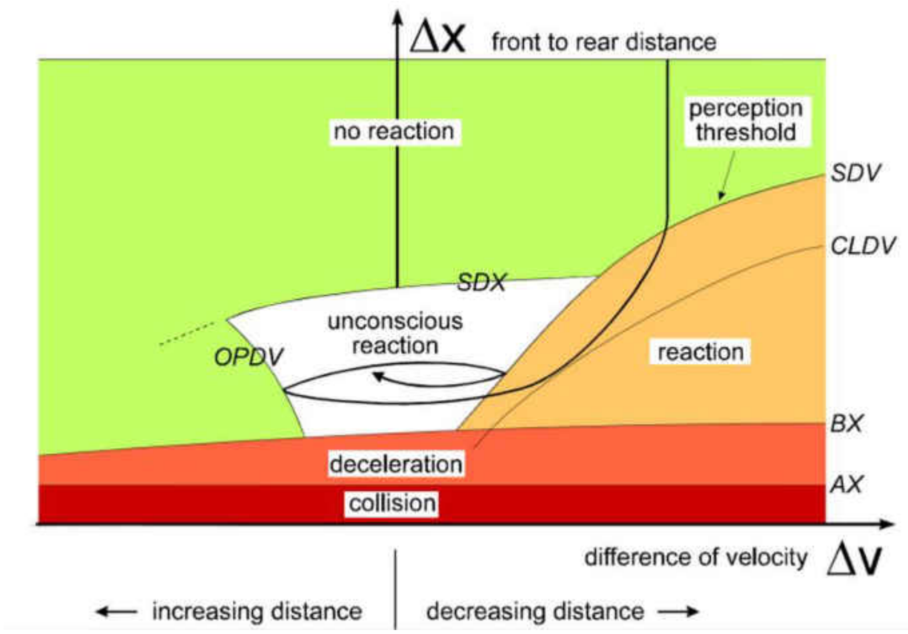

Figure 3-1 Wiedemann 1974 car following model

3.4 Model Calibration by Using T-test

T-test is conducted to do the model calibration and validation. It is applied to compare the speed of the simulation outputs and the speed in the field data to see whether the difference between the two groups of data is small enough. If the difference is small to a certain extent, this group of simulation results is accepted, which means the model from which the result is generated is also accepted.

The t-test compares one group of observations with a second group. It is often used to determine whether there is a significant difference between the two groups. As the first step, a null hypothesis, which means the lack of a difference, should be put forward. Its hypothesis test formula is shown as equation 3-1.

$$t = \frac{\bar{x} - \Delta}{s / \sqrt{n}} \tag{3-1}$$

Where: $\bar{x}$, the mean of the change values;

Δ, the hypothesized difference (If testing for equal means, take 0 as its default value.);

s, the sample standard deviation of the differences;

n, sample size;

The freedom degree, n-1.

This statistical progress generated two values as a probability of the data difference. One is t-value, and the other one is p-value. The p-value can't be produced from the t-test directly. It is figured up from the t-value. T-value is related to the size of the difference between the two groups of observations, and a larger t-value indicates a larger difference. For evaluating the test result, t-value is not as useful as p-value. P-value can measure the likelihood of the event happening in the sample data under the condition that the null hypothesis is true. A high p-value means that the data has a high possibility with a true null hypothesis, while a low p-value suggests there are enough evidences to reject the null hypothesis.

3.5 Conflict Data Analysis

3.5.1 Conflict Angle

The conflict location's data are processed by SSAM to obtain X, Y coordinate data of the simulation results, allowing them to be mapped as the conflict trajectory on the map of I-4. In SSAM, all the conflicts are summarized into the four following types: unclassified, crossing, rear-end, and lane-change (Pu, L., & Joshi, R., 2008). How to classify a crash in to the four types depends on its conflict angle. For each pair of vehicles that crashed into each other, their conflict angle is computed based on a theoretical conflict point, at which the two vehicles converge. A very small angle means that the vehicles' trajectories are close to each other and a potential rear-end collision could occur, while a large angle implies a potential right-angle or head-on collision of the two vehicles. The conflict angle is illustrated in Figure 3-2 (Pu, L., & Joshi, R., 2008).

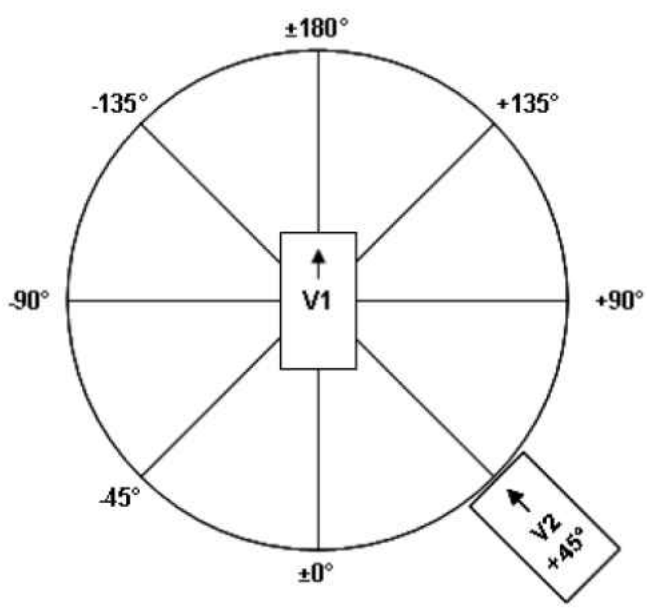

Figure 3-2 Conflict angle illustration

Corresponding the Figure 3-2, when the following vehicle coming near from left, a negative angle is recorded, whereas a positive angle is recorded when the second vehicle approaches from right. The conflict angles range from $-180°$ to $+180°$. The conflict types are assigned into the four following types as the above rules, which are shown in Table 3-1.

Table 3-1 Conflict angles of different conflict types

Conflict type	Conflict angle
Unclassified conflict	No conflict angle information provided.
Crossing conflict θ_c	$\boldsymbol{\|\|\theta_c\|\| > 85°}$
Rear end crash θ_r	$\boldsymbol{\|\|\theta_r\|\| < 30°}$
Lane change conflict θ_l	$\boldsymbol{30° < \|\|\theta_l\|\| < 85°}$

3.5.2 Conflict Measure Parameters

SSAM uses several parameters to measure the conflicts and describe the conflict locations, and characteristics. The main conflict measure parameters are Time-to collision (TTC), Post encroachment time (PET), Maximum speed (MaxS), Speed difference (DeltaS), the second vehicle's initial deceleration rate (DR), the second vehicle's maximum deceleration (MaxD), and the maximum speed difference value among the two-crashed vehicle (MaxDeltaV). Their definitions are explained in the following section.

TTC is the minimum value of the time-to-collision within the conflict. This parameter is estimated by the crash location, speed, and the two car's trajectory. PET indicates the minimum post encroachment time observed during the progress of conflict. It is the time gap between the two road users reaching a common potential collision point. As shown in Figure 3-3, PET could be calculated as $PET = t_2 - t_1$. Its unit is second (s).

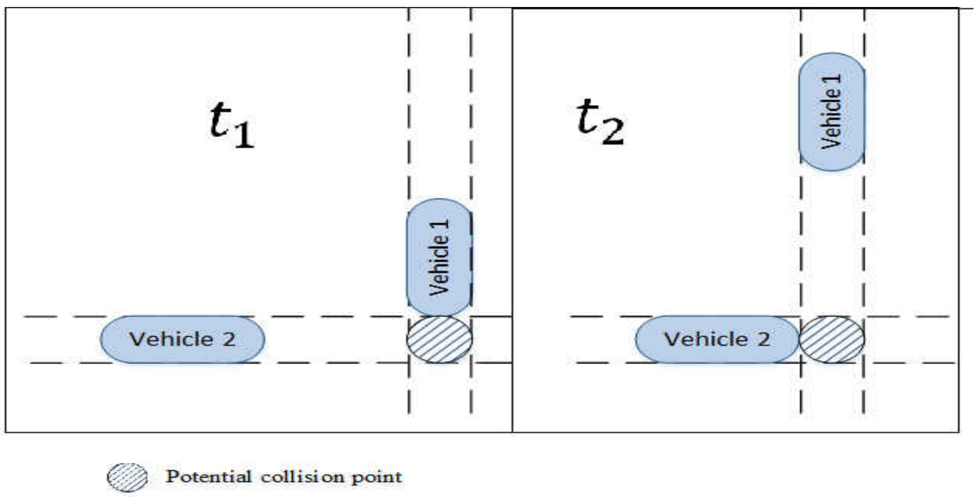

Figure 3-3 Post encroachment Time

MaxS is defined as the largest velocity of the two cars within the conflict. This parameter's unit in SSAM is meters per second. For research convenience, its unit is converted to the imperial unit in feet per second.

Delta is the speed difference at the time of the simulation time where the smallest TTC value occurs. To be expressed concisely, DeltaS can be calculated as the value of the two car's trajectories' difference.

DR is the original deceleration rate of the following vehicle. From the acceleration rate data set, DR can be recognized by the following rules: if the driver's reaction is braking, it is the first negative value during the accident; whereas it is the smallest positive value within this traffic accident. This parameter's unit in SSAM is meters per second. For research convenience, its unit is converted to the imperial unit in feet per second.

MaxD is the largest deceleration of the following car. If a car brakes during the accident, this parameter is logged in the data set as a negative number. Otherwise, it is recorded as a positive number to indicate no braking in this accident. This parameter's unit in SSAM is meters per second. For research convenience, its unit is converted to the imperial unit in feet per second.

MaxDeltaV represents the largest value of DeltaV in this accident.

3.5.3 Conflict Location

The trajectory files contain the coordinate information, which defines the location at where the conflicts happen. By noting the x-coordinate and the y-coordinate, conflict sites can be observed in a map. In SSAM, the x-coordinate is expressed as xMinPET, which means the conflict location's coordinate in the x-axis at the time when the PET reaches its minimum value. Similar to xMinPET, yminPET indicates the y-coordinate of the accident location when the smallest value of PET is observed.

CHAPTER 4. EXPERIMENTAL AND SIMULATION RESULTS

4.1 Basic Model Building in VISSIM

4.1.1 Data Source

4.1.1.1 Road segment selection

The study area is located on Interstate Road 4 (I-4) from milepost 19 to milepost 23 with a 4-mile length, situated between State road 559 and State road 557. For the purpose of this study, two sources of data were collected. One is the traffic data, which indicates the basic traffic condition of the selected road segment. The other one is the visibility data, which describes the relevance between weather condition and visibility level.

4.1.1.2 Visibility data

Since the fog concentration can't be used directly to describe the weather's effect on driving behaviors, visibility is taken as a surrogate parameter to measure the fog's influence. Visibility is defined as the looking-ahead distance in VISSIM, which contains the maximum and the minimum looking ahead distance of vehicles going in one scenario. To measure the value of visibility, the Fog Monitor System (FMS) was applied on the selected road segment. According to the second visibility quarterly report of Florida Department of Transportation (FDOT) (Abdel-Aty, et al., 2012), the FMS records several components in its output data. The output data series is shown in Table 4-1. All the units are converted to Imperial units for further calculation. The FMS generated a row visibility data every second.

Table 4-1 Field weather and visibility data and units

Name	Unit
Visibility	M
Air temperature	° F
Humidity	%
Barometric pressure	Kpa
Wind direction	/
Wind speed	Mph
Solar radiation	$\mathbf{W/m^2}$
Dew point	° F
Subsurface moisture	VWC
Rain fall	Inches

The fog monitor system was set on I-4 between milepost 19 and milepost 23 and roughly located on the road segment from State road 559 to State road 557. The length between the two next points is 0.25 mile. Their installation sites are shown in Figure 4-1 (Abdel-Aty, et al., 2012).

Figure 4-1 FMS installment locations

4.1.1.3 Traffic flow data

In order to investigate the basic characteristics of the traffic flow at this study area on I-4, a traffic flow data collection detector was installed on a data collection point on I-4. The yellow circle which is shown in Figure 4-2 points out its location. This equipment can record the accurate data of vehicle length, speed and lane allocation. About the vehicle speed, if the speed value in the database is 512, it means no reading and this data line should be deleted from the database. If speed is not read, the event length should also be ignored. The traffic flow detector records a line of traffic data into its data base every second.

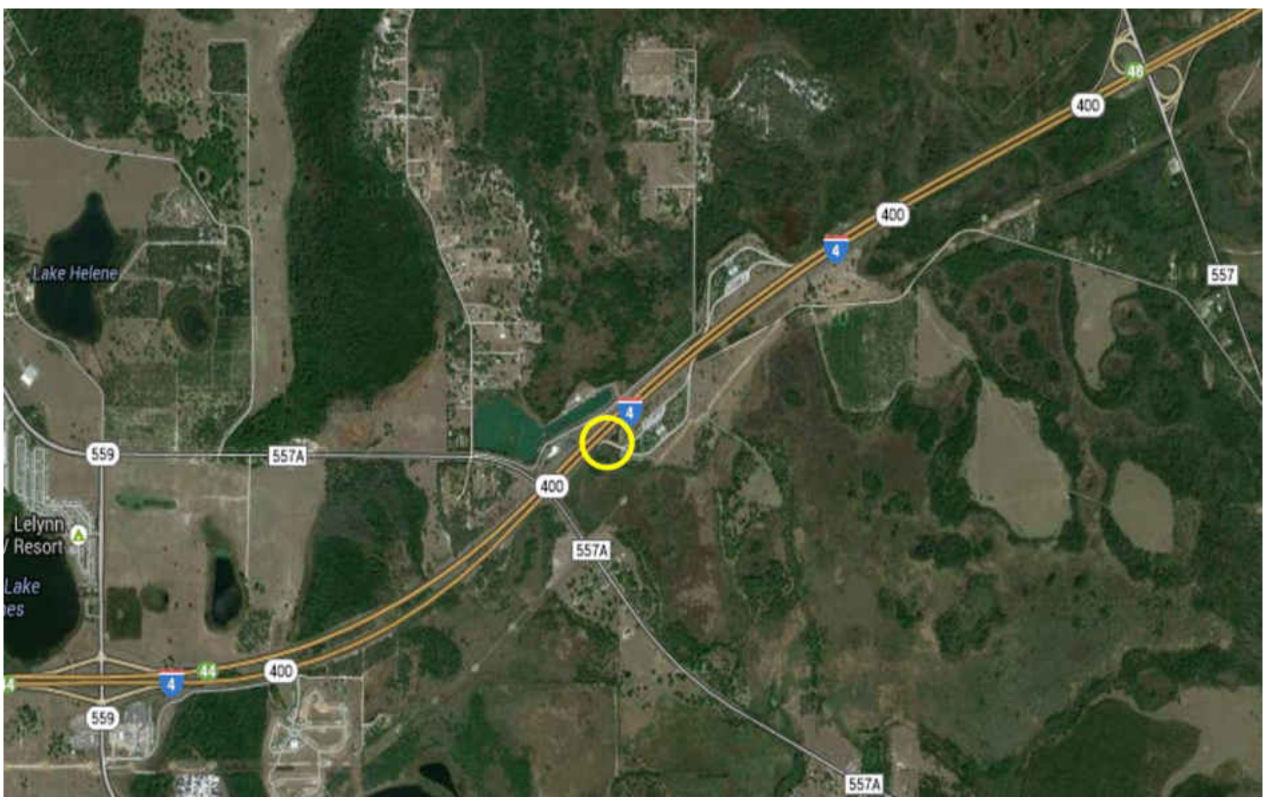

Figure 4-2 Traffic flow detector location

4.1.1.4 Data for Model Calibration

As the purpose of this research is to find the relationship between driving behaviors and fog-affected visibility, it's necessary to combine these two above sources of data into one to find the relevance of them. The statistical software, SAS, was used to do this data processing.

Because both of these two data sets were organized by time, time can work as a link between the traffic data set and visibility data set. The traffic data was organized by lane of each hour. The vehicles are classified as small vehicles and heavy vehicles. If the value in the vehicle length column is 1, define this vehicle as a small vehicle; otherwise, define it as a heavy vehicle. Those above steps generate the basic traffic volume data set with the speed of each vehicle on each lane of different hours. From this data set, the traffic volume of each hour on each lane can also be known by summarizing this data. Referring to the visibility data, the visibility column is also sorted by hour so that it can share a common link, the "hour" column, which makes the two data sets as a new data set. The new data set describes in what kind of a speed a car drives through different visibility conditions at different hours. The combination steps are summarized as following:

Step 1. Combine each hour's data rows into one group for both the two data sets, respectively. Generate a new column *hour* in each data set.

Step 2. Use the whole hours' average speed value, visibility value as that hour's speed value and visibility value.

Step 3. Combine the two data sets together by the common variable column *hour*. A new data set containing the data of each hour's traffic speed, vehicle length, and visibility can be built.

According to this field data, the value of visibility in fine weather and good vision condition is 1.24 miles (2000 meters). In 24 hours a day, fog and low-visibility situation mainly appear between 5:00 am and 10:00 am. After 12:00 pm at noon, the fog almost disappears, which result in good sight for drivers, and the visibility values are almost all 1.24 miles. So the length of 1.24 miles is chosen as the value of looking ahead distance in the no-fog road segments. As for the fog area, the look-ahead distance value is chosen by the worst visibility condition based on the field data. According to the field data, the visibility from 7:00 am to 8:00 am on February 4 is the lowest among all days of field data collection. And this hour's maximum and minimum looking ahead distance are 0.17 miles (276 meter) and 0.09 miles (149 meters) respectively. So these two values are used for the fog area in the simulation model.

Referring to the traffic flow data, the data of traffic volume and traffic speed in the same time period, 7:00 am to 8:00 am on February 4, are chosen for basic simulation model calibration.

4.1.2 Model Network Building

To duplicate the I-4's condition, a VISSIM model was built and composed on six-lane, two-way freeway setting. Its geometry shape is shown in Figure 4-3 marked in yellow. This model can be simplified as Table 4-3.

Figure 4-3 The fog area setting

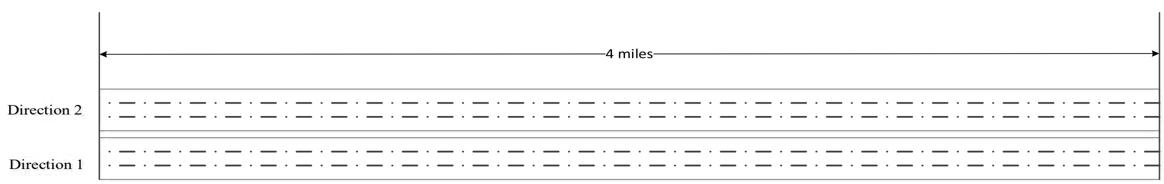

Figure 4-4 The basic simulation model in VISSIM

4.1.3 Model Calibration and Validation

4.1.3.1 Model Calibration

In order to simulate the road traffic condition, three driving behavior parameters are selected for model calibration based on Wiedemann's 1999 car following model as shown in Table 4-2.

Table 4-2 Parameters' meaning in the basic model

Symbol	Name	Meaning	Unit
CC1	Headway time	It is the time that a driver wants to keep.	s
CC2	'Following' variation	This parameter restricts the longitudinal oscillation or how much more distance than the desired safety distance a driver allows before he intentionally moves closer to the car in front.	mile
CC6	Speed dependency of oscillation	It indicates the distance's impact on speed oscillation when a vehicle is in a following process. A large value means a greater speed oscillation with an increasing space. If setting CC6's value as 0, it means that the distance won't affect the speed oscillation.	none

Each driving behavior parameters has 4 values as shown in Table 4-3.

Table 4-3 Values of the parameters for calibrating the basic model

Symbol	Name	Value			
CC1	Headway time	0.9	1.2	1.5	1.8
CC2	'Following' variation	0.0025	0.0050	0.0075	0.0099
CC6	Speed dependency of oscillation	0	8.00	11.44	14.00

The four values of each parameter generate $4^3 = 64$ groups of combination parameters. Running these combination groups comes up with 64 rows of output data. Each row contains the model's simulation results, which are traffic speed. Three runs with three different random seeds were conducted in VISSIM for each of the 64 groups, and thus come to a total of 192 runs. The average speed was recorded for all the 192 runs. The results from the groups were then averaged to represent each of the 64 different parameter groups.

4.1.3.2 Model Validation

The basic simulation model was tested and validated over the two directions of the freeway using speed as the calibration parameter. After identification, both the speed of the field data and the speed in the simulation result of two directions are normal distributed. The test results are shown in Figure 4-5 and Figure 4-6.

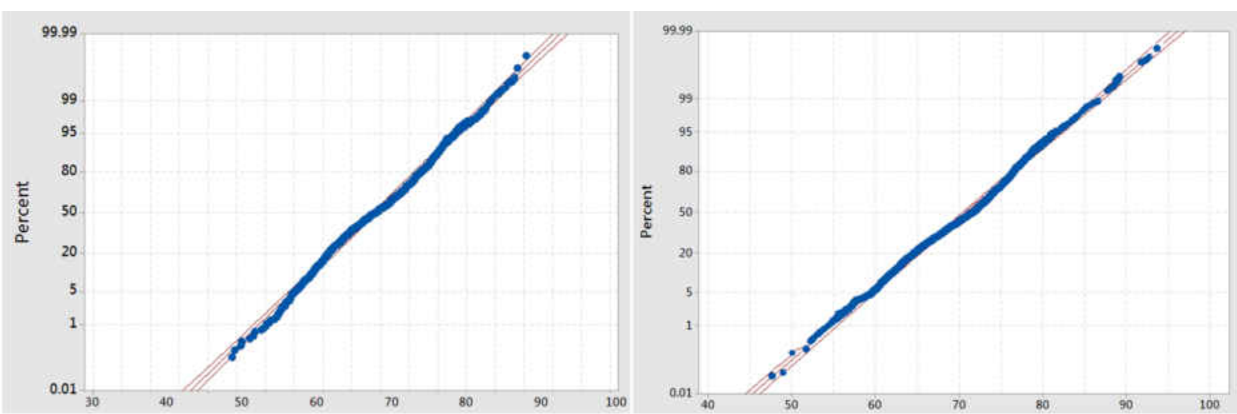

Figure 4-5 Probability plot of the speed of direction 1and 2 in the field data

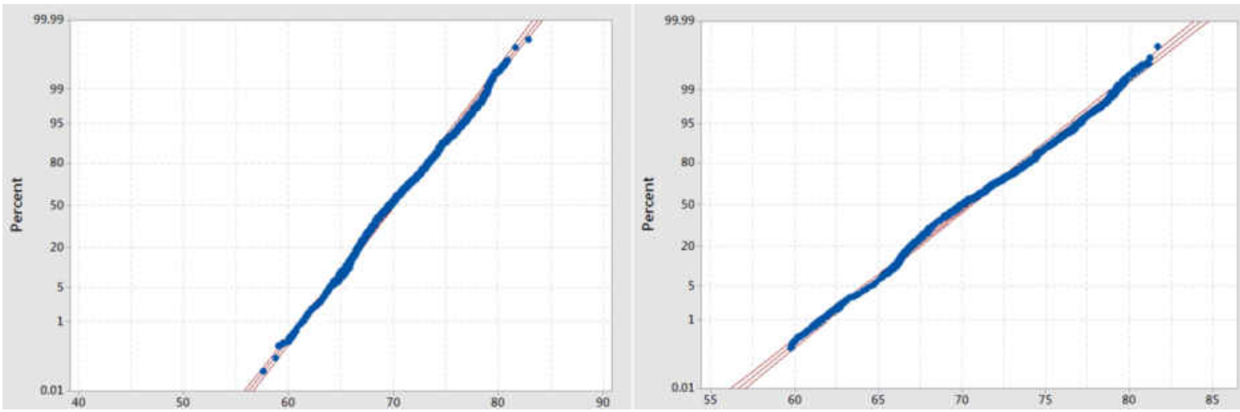

Figure 4-6 Probability plot of the speed of direction 1and 2 in the simulation data

The t-test was used to compare the speed of field traffic flow and the speed of the simulation result of this basic VISSIM model. The speed of field data was labeled as Group 1 and the speed of simulation was labeled as Group 2. The group that has the lowest difference level between Group 1 and Group 2 is the group that best describes the field road traffic flow condition. The results showed that the group of "headway time=0.9s, 'Following' variation=0.0025 miles, Speed dependency of oscillation=11.44" has the smallest p-value, and all the p-values are less than 0.05, which means this group is the best-match group. The details the t-test results of the two orientations are shown in Table 4-4 and Figure 4-7.

Direction 1:

95% confidence interval for mean difference: (-0.847, -0.065)

T-test of mean difference = 0 (vs ≠ 0): T-Value = -2.29, P-Value = 0.022

Table 4-4 T-test result of Direction 1

Name	N	Mean	StDev	SE Mean
Speed in the field data [mph]	1343	69.772	6.286	0.172
Speed in the calibration data [mph]	1343	70.229	3.569	0.097
Difference	1343	-0.456	7.304	0.199

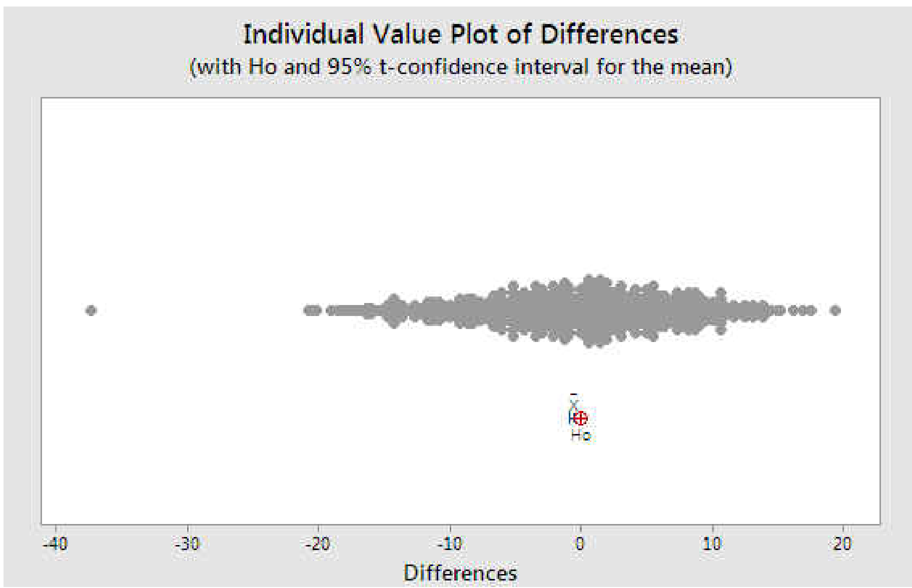

Figure 4-7 Individual value plot of differences of Direction 1

According to Figure 4-4, the differences between the two groups' speed concentrate around 0, which means low difference level between the field data and the simulation results.

Direction 2:

95% confidence interval for mean difference: (-1.429, -0.602)

T-Test of mean difference = 0 (vs ≠ 0): T-Value = -4.82, P-Value = 0.000

Table 4-5 T-test result of Direction 2

Name	N	Mean	StDev	SE Mean
Speed in the field data [mph]	1343	70.117	6.782	0.185
Speed in the calibration data [mph]	1343	71.132	3.733	0.102
Difference	1343	-1.015	7.724	0.211

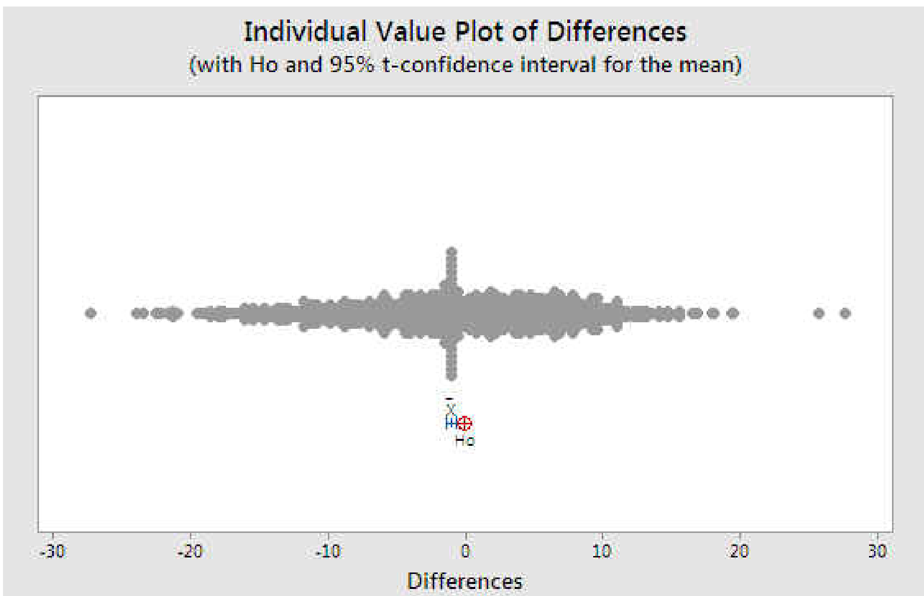

Figure 4-8 Individual value plot of differences of Direction 2

According to Table 4-5, the differences between the two groups' speed concentrate around 0, which means a low difference level between the field data and the simulation result.

4.2 Experimental Model Building and Simulation in VISSIM

4.2.1 Model Building

The road was divided into 3 sections: section 1, fog area, and section 2. Section 1 and 2 are normal weather areas, and fog area is a road section, which has the low visibility due to the fog. The length of section 1 and fog area are both 1.5-mile long. Section 2 is 1 mile long. Under the normal weather condition, the speed limit in section 1 and 2 are all 70 mph, whereas the fog area has a lower speed limit for driving safety concern. Three levels of speed limits in fog area are set, which are 40 mph, 50mph, and 60mph.

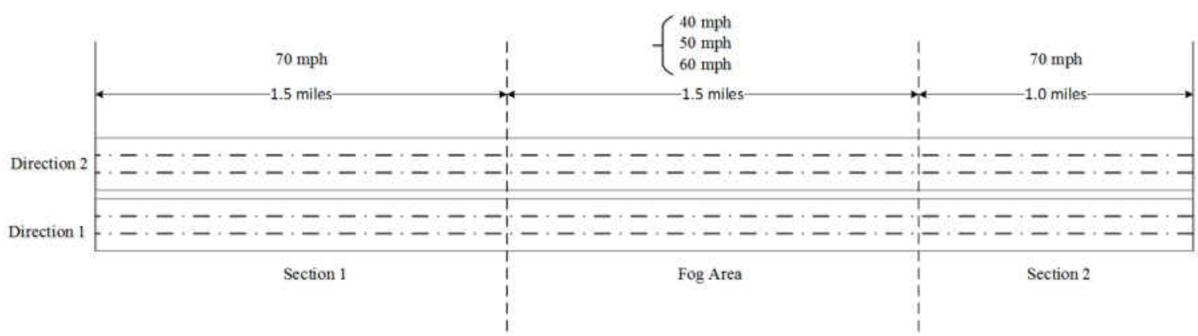

Figure 4-9 Experimental model setting

4.2.2 Parameters Setting

In order to study the traffic volume's influence on road safety condition and traffic conflicts, three different volume levels are set up in this model. The values and the levels that they stand for are shown in Table 4-6. Each value indicates the vehicle's number of one direction in an hour.

Table 4-6 Traffic volume setting

Traffic volume level	Traffic volume per direction (veh/hour)
Low	4000
Middle	8000
High	12000

Traffic composition of the experiment model is shown in Table 4-7. This setting is based on the field traffic data.

Table 4-7 Traffic composition setting

Direction	Car	HGV
1	0.448	0.552
2	0.484	0.516

4.2.3 Experiment Results

This experiment simulation model generates the trajectory data of the traffic flow. Due to the three levels of the traffic volume and three different speed limits in the fog area, the model produces nine trajectory data sets. The scenario with speed limit of 70 mph in the fog area is also conducted to investigate the condition of no speed limit change in low visibility area. Their combination is shown in Table 4-8.

Table 4-8 Trajectory data groups

Traffic volume level	**Traffic volume (veh/hour)**	**Speed limit in the fog area (mph)**
Low	4000	40
		50
		60
		70
Middle	8000	40
		50
		60
		70
High	12000	40
		50
		60
		70

4.3 Trajectory Data Analysis in SSAM

The SSAM model was run for the nine trajectory data groups and conflicts were observed from the software output. The conflict information is shown in Table 4-9.

Table 4-9 Conflict information

Traffic volume [veh/hour]	Speed limit in the fog area [mph]	Conflict type		Total
		Lane-change	Rear-end	
4000	40	689	452	1141
	50	384	166	550
	60	253	103	356
	70	690	403	1093
8000	40	1712	5611	7323
	50	1484	4416	5900
	60	1519	3784	5303
	70	1811	4456	6267
12000	40	1806	4819	6625
	50	1502	4069	5571
	60	1419	4399	5818
	70	1713	4480	6193

CHAPTER 5. SIMULATION RESULTS ANALYSIS

5.1 Geometry Analysis of the Conflict Locations

All the conflict locations are recorded as coordinates (x_i, y_j) in the SSAM analysis result. Based on the coordinates, a reference frame can be built to describe the trajectory of conflicts by putting conflict points (x_i, y_j) into the frame. These points generate a curve, which almost coincide with the shape of I-4, with the length of 4 mile.

Corresponding to the experimental model, the curve can also be divided into three parts: section1, fog area, and section 2. The length of the curve in section 1 is 1.5 miles, in fog area is 1.5miles, and in section 2 is 1 mile. Their geometry description is shown in Figure 5-1. The units of the numbers on the number lines are miles.

Section 1 starts from point P and ends at point M. Fog area is located between the other two sections with a start point M and an end point N. Section 2 starts from point N and ends at point Q.

From the database of conflict location coordinates, the two endpoints' coordinates of the trajectory curve can be described as following.

$$P(x_p, y_p)$$

$$Q(x_q, y_q)$$

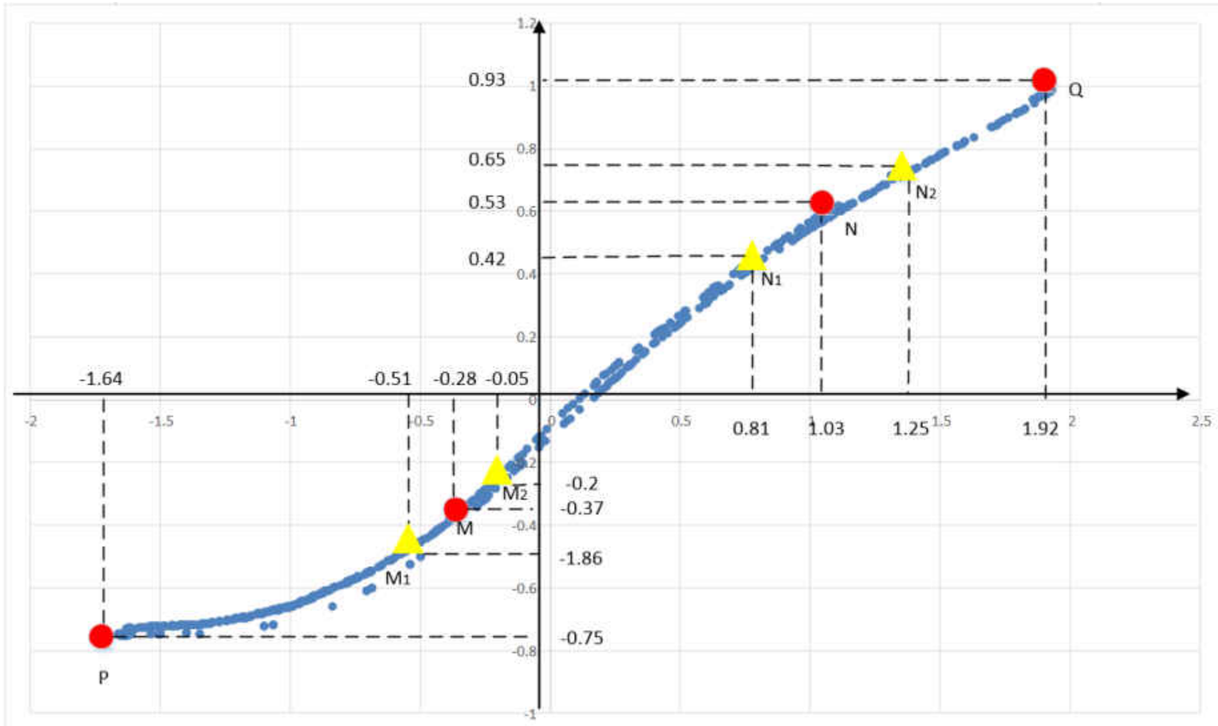

Figure 5-1 Geometry description of the conflict coordinate system

From the reference frame and the geometry relationship between the curve and each road segment, the coordinates of point M and point N, which are the split points that divide the whole curve into three segments, can be calculated. Their coordinates are shown as following.

$$M(x_m, y_m)$$

$$N(x_n, y_n)$$

Since the study segment of I-4 is from southwest to northeast, the curve of conflict location points is increasing along the positive direction of the coordinate system monotonically. This results in that the values of the coordinates in section 1 are always smaller than the coordinate values in fog area. And the coordinate values in fog area are also smaller than the coordinate values in section 2. Their relationships can be shown as the following formula 5-1.

$$\begin{cases} x_p < x_j < x_m , & y_p < y_j < y_m & \text{Section 1} \quad [1] \\ x_m < x_j < x_n , & y_m < y_j < y_n & \text{Fog area} \quad [2] \\ x_n < x_j < x_q , & y_n < y_j < y_q & \text{Section 1} \quad [3] \end{cases} \tag{5-1}$$

Separated by road sections, the number of conflicts of each speed level and traffic volume level can be counted and summarized into Table 5-1.

Table 5-1 Summary of the conflict number by road segment and traffic volume

Traffic Volume (veh/h)	**Speed Limit (mph)**	**Conflict Number**			**Total**
		Section 1	**Fog Area**	**Section 2**	
4000	40	563	321	257	1141
	50	314	77	159	550
	60	219	25	112	356
	70	513	323	257	1093
8000	40	3533	1432	2358	7323
	50	3159	554	2187	5900
	60	2625	629	2049	5303
	70	2895	1302	2070	6267
12000	40	2434	1540	2652	6625
	50	2584	970	2017	5571
	60	2981	498	2338	5818
	70	2598	1209	2386	6193

To study the conflict characteristics of the areas around the joint points of two road segments, the overlap areas were marked. An overlap area is a road segment that next to the joint point of two road segments, and has a length of 0.25 mile. As shown in Figure 5-1, M_1 is the split point which is 0.25 miles away from the joint point M of the section 1 and the fog area. M_2 is another split point which also has 0.25 miles length away from M in the opposite direction of M_1. N_1 is the split point which is 0.25 miles away from the joint point N of the fog area and the section 2. N_2 is another split point which also has 0.25 miles length away from N in the opposite direction of M_1. The conflict number in each small road segment is shown in Table 5-2.

Table 5-2 Conflict number summary of all road segments

Traffic volume [veh/hour]	Speed limit in the fog area [mph]	Conflict number summary of all road segments							Total
		Section 1		Fog area			Section 2		
		P-M_1	M_1-M	M-M_2	M_2-N_1	N_1-N	N-N_2	N_2-Q	
4000	40	466	97	93	180	48	65	192	1141
	50	256	58	40	28	9	16	143	550
	60	206	13	12	9	4	7	105	356
	70	415	98	93	182	48	65	192	1093
8000	40	2810	723	644	610	178	521	1837	7323
	50	2673	486	346	160	48	363	1824	5900
	60	2164	461	342	155	132	432	1617	5303
	70	2221	674	579	563	160	380	1690	6267
12000	40	2005	429	536	719	285	683	1968	6625
	50	2202	382	526	329	115	436	1581	5571
	60	2534	447	318	96	84	459	1880	5818
	70	2026	572	511	579	119	230	2156	6193

5.2 Lane-change Conflict

Lane changing is a common driving behavior on the road. It was defined as a substantial lateral position change of a vehicle. In this traffic trajectory-based simulation model, different conflict types are defined by conflict angle of the vehicle trajectory. The angle of lane changing conflict θ_l is set as $30° \leq \theta_l \leq 85°$. The threshold diagram is shown as Figure 5-2.

On freeway, lane-changing behaviors are easy to cause traffic conflicts due to the high speed, even more so in the fog, which leads to the low visibility. The following sections discuss the effect of the different speed limits at the fog area on the lane change conflict numbers.

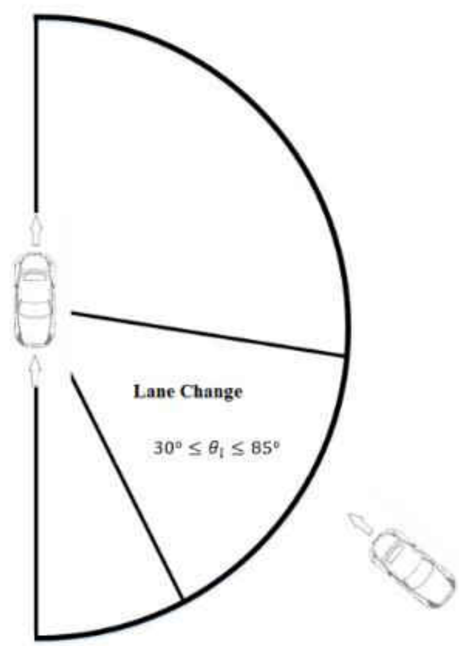

Figure 5-2 Threshold diagram of lane-change conflicts

5.2.1 Low Traffic Volume Level Case

5.2.1.1 The speed limit at fog area is 40 mph

The conflict numbers of the three areas are summarized in Table 5-3. The conflict locations are plotted in Figure 5-3. Point A and Point B are the projected points of Point M and point N respectively. They are used to label the division points of three road sections to make it easier to see which road segment a conflict point belongs to.

Table 5-3 Lane-change conflict summary of low traffic volume at the speed of 40 mph in the fog area

Volume (veh/h)	Speed Limit (mph)	Section 1	Fog Area	Section 2	Total
4000	40	299(43%)	226(33%)	164(24%)	689

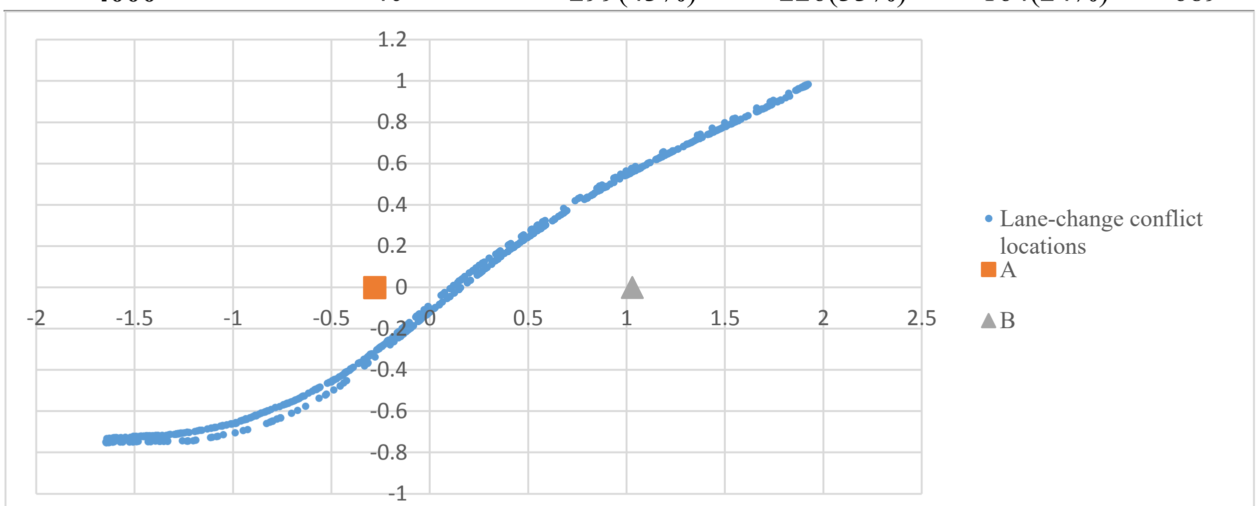

Figure 5-3 Lane change conflicts of low traffic volume at the speed of 40 mph in the fog area

According to Figure 5-3 and Table 5-3, the lane change conflicts mainly distributed in section 1. The conflict number in section 1 is 299, accounting for 43% of the total number of 689. In the fog area, the proportion of conflict number is 33%. And these conflicts mainly concentrated in the two outgoing road sections. That means that there is a high possibility of crashes when drivers driving out from the fog area.

5.2.1.2 The speed limit at the fog area is 50 mph

The conflict numbers of the three areas are summarized in Table 5-4. The conflict locations are plotted in Figure 5-4. Point A and Point B are the projected points of Point M and point N respectively.

Table 5-4 Lane-change conflict summary of low traffic volume at the speed of 50 mph in the fog area

Volume (veh/h)	**Speed Limit (mph)**	**Section 1**	**Fog Area**	**Section 2**	**Total**
4000	50	215(56%)	57(15%)	112(29%)	384

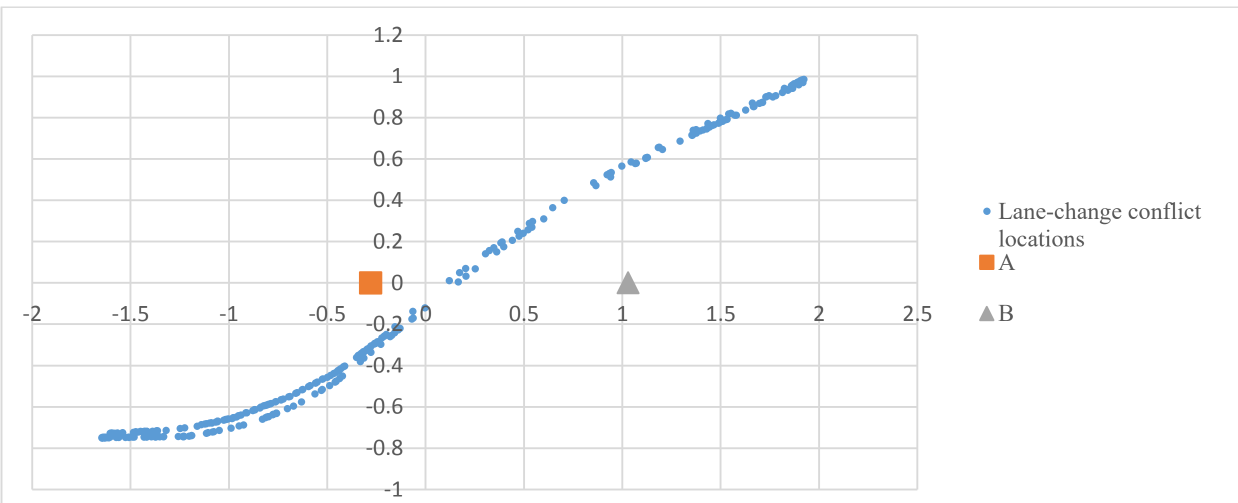

Figure 5-4 Lane-change conflicts of low traffic volume at the speed of 50 mph in the fog area

According to Figure 5-4 and Table 5-4, the number of crashes distributed in road section 1 is 215 and in section 2 is 112, accounting for 56% and 29% of the total number of 384 respectively. However, there are only 15% conflicts in the fog area, at this speed limit of low traffic volume level.

5.2.1.3 The speed limit at fog area is 60 mph

The conflict numbers of the three areas are summarized in Table 5-5. The conflict locations are plotted in Figure 5-5. Point A and Point B are the projected points of Point M and point N respectively.

Table 5-5 Lane-change conflict summary of low traffic volume at the speed of 60 mph in the fog area

Volume (veh/h)	Speed Limit	Section 1	Fog Area	Section 2	Total
4000	60 mph	150(59%)	19(8%)	84(33%)	253

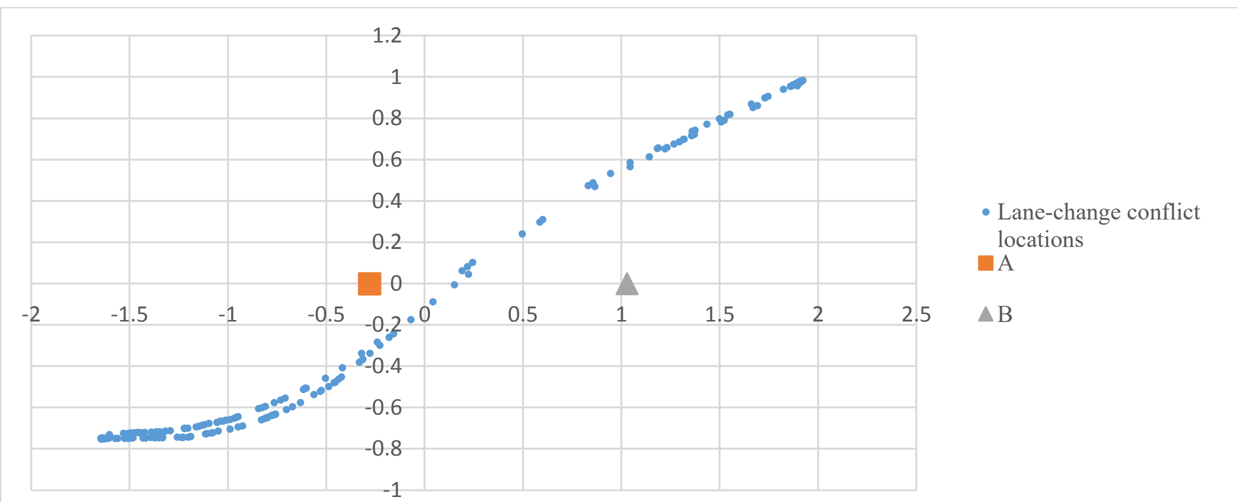

Figure 5-5 Lane-change conflicts of low traffic volume at the speed of 60 mph in the fog area

According to Table 5-5 and Figure 5-5, the lane change conflicts almost all distributed in section 1 and section 2. There are 150 conflicts happened in section 1 and 84 happened in section 2. Only eight percent of the lane change conflicts occurred in fog area. What is noteworthy is that all these conflict locations are close to the two end points of the conflict curve. This phenomenon indicates a low possibility of lane change crashes at the two roads' junction and fog area at this speed level and traffic volume level.

5.2.1.4 Conclusion

Generally, when the traffic volume is low, the total number of all conflicts stays at a relative low level, as shown in Figure 5-6. Due to the low volume, the following vehicle can keep enough space from the one in front. This car following distance contributes to reducing the lane change conflict number and enhancing the level of road safety.

However, there are still some differences of the three speed limits in the fog area. There are more conflicts occurring when the speed limit in fog area is 40 mph than the other two. And the conflict numbers goes down as the speed limit in fog area increases. This results from the difference between the speed limits in the other two sections and in the fog area. The speed limit in fog area is higher, the speed difference between two neighboring areas is smaller, and this leads to slighter external influence to drivers. Drivers don't need to make too many changes on their driving behaviors, which reduces the risk of crashes.

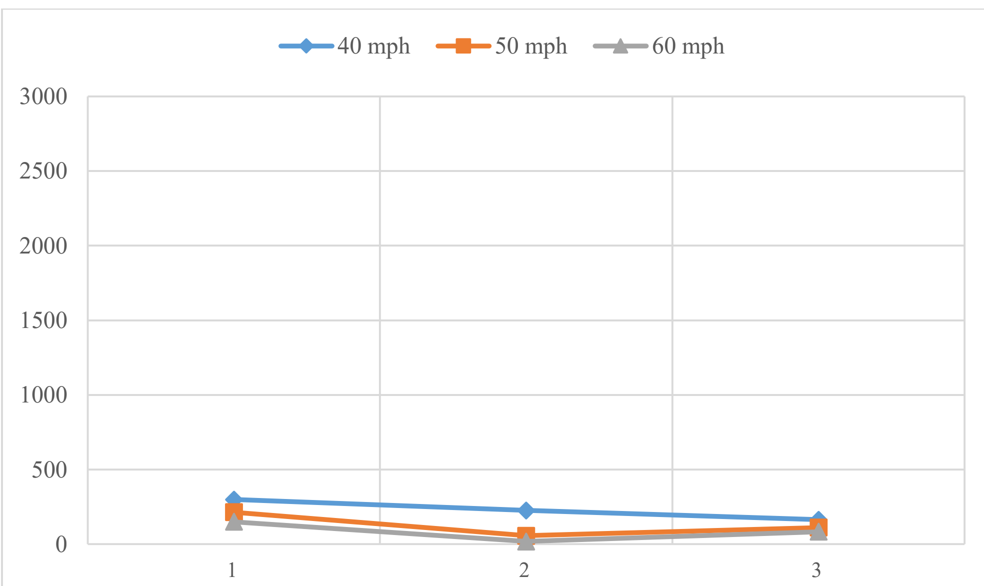

Figure 5-6 Lane-change conflict summarize of low volume traffic

5.2.2 Middle Traffic Volume Level Case

5.2.2.1 The speed limit at the fog area is 40 mph

The conflict numbers of the three areas are summarized in Table 5-6. The conflict locations are plotted in Figure 5-7. Point A and Point B are the projected points of Point M and point N respectively. They are used to label the division points of three road sections to make it easier to see which road segment a conflict point belongs to.

Table 5-6 Lane-change conflict summary of middle traffic volume at the speed of 40 mph in the fog area

Volume (veh/h)	Speed Limit (mph)	Section 1	Fog Area	Section 2	Total
8000	40	813(47%)	473(28%)	426(25%)	1712

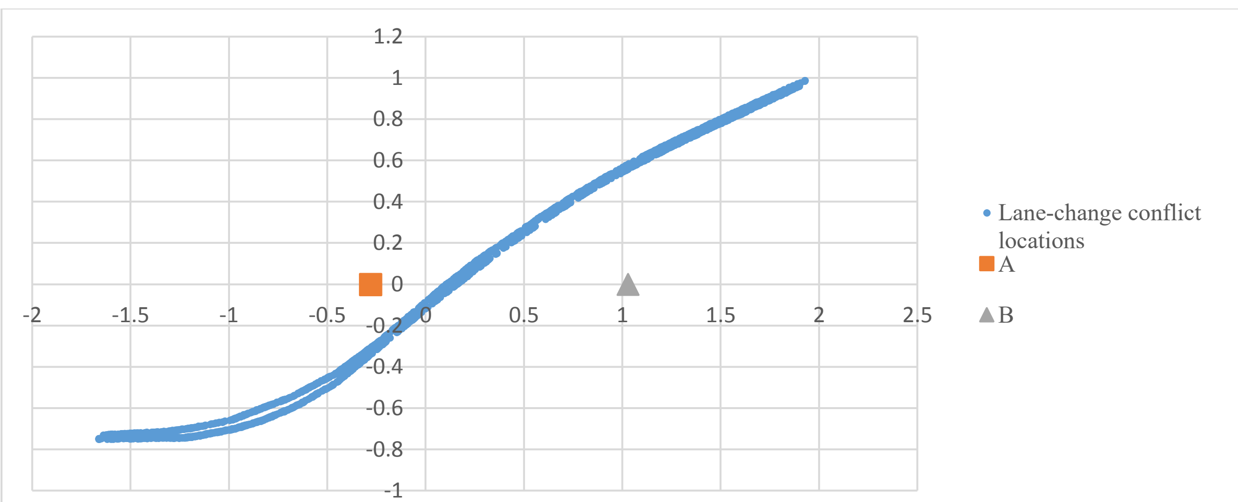

Figure 5-7 Lane-change conflicts of middle traffic volume at the speed of 40 mph in the fog area

According to Figure 5-7 and Table 5-6, the lane change conflicts distributed in all road sections, which is different with the low volume level. The conflict number in section 1 is 813, accounting for 47% of the total number of 1712. The fog area and section 2 share a similar proportion, which is 28% and 35% separately. Section 1 has the highest possibility of lane change crashes at the speed level of 40 mph.

5.2.2.2 The speed limit at the fog area is 50 mph

Table 5-7 summarized the number of crashes of 50 mph speed limit in fog area at the middle traffic volume level. The conflict locations are plotted in Figure 5-8. Point A and Point B are the projected points of Point M and point N respectively. They are used to label the division points of three road sections to make it easier to see which road segment a conflict point belongs to.

Table 5-7 Lane-change conflict summary of middle traffic volume at the speed of 50 mph in the fog area

Volume (veh/h)	Speed Limit (mph)	Section 1	Fog Area	Section 2	Total
8000	50	700(47%)	217(15%)	567(38%)	1484

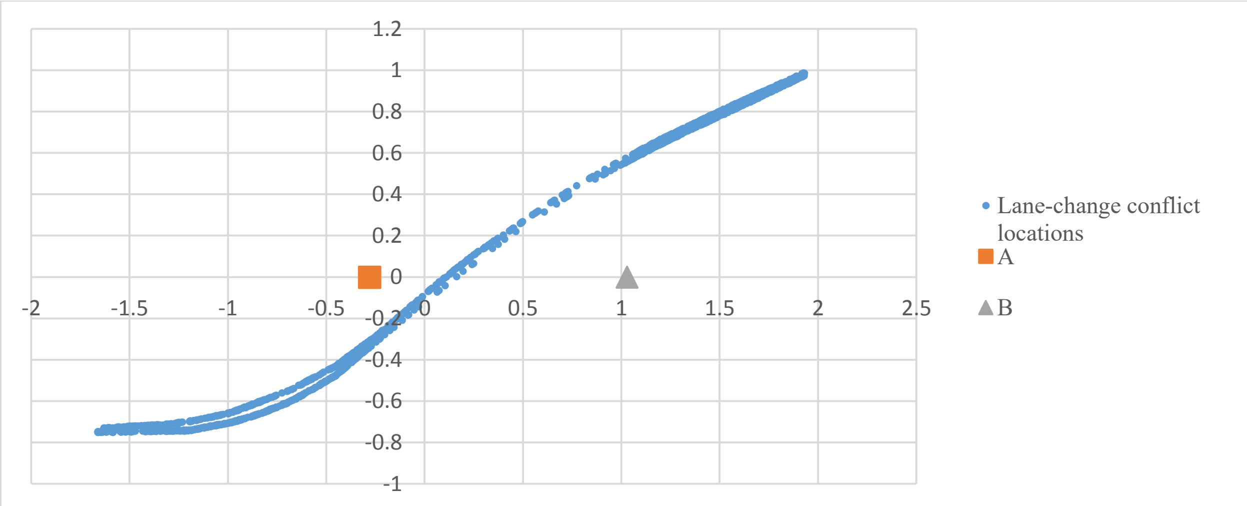

Figure 5-8 Lane-change conflicts of middle traffic volume at the speed of 50 mph in the fog area

According to Figure 5-8 and Table 5-7, the lane change conflicts mainly distributed in section 1 and 2. The conflict number in section 1 is 700, accounting for 47% of the total number of 1484. Section 2 contains 567 conflicts. In the fog area, the proportion of conflict number is 15%. The total percent in no-fog area is 85%, which means high probability of lane change crashes when the visibility is in good condition. As soon as people drive to the fog area, they can't see as clear as normal weather. This situation makes them reduce their speeds and drive more carefully. Lane change behavior occurs less than the normal visibility condition.

5.2.2.3 The speed limit at the fog area is 60 mph

The conflict numbers of the three areas are summarized in Table 5-8. The conflict locations are plotted in Figure 5-9. Point A and Point B are the projected points of Point M and point N respectively. They are used to label the division points of three road sections to make it easier to see which road segment a conflict point belongs to.

Table 5-8 Lane-change conflict summary of middle traffic volume at the speed of 60 mph in the fog area

Volume (veh/h)	Speed Limit (mph)	Section 1	Fog Area	Section 2	Total
8000	60	772(51%)	209(14%)	538(35%)	1519

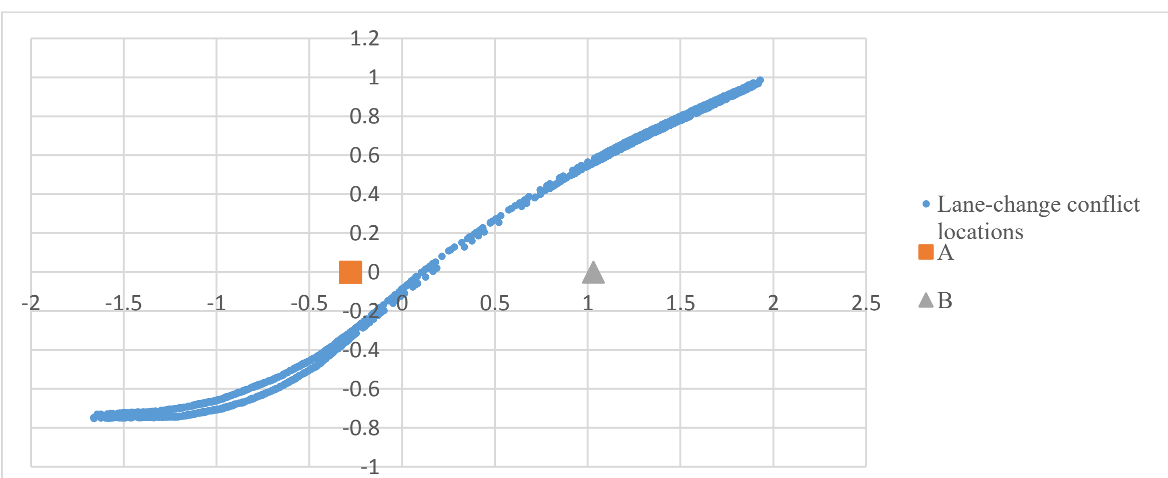

Figure 5-9 Lane-change conflicts of middle traffic volume at the speed of 60 mph in the fog area

According to Figure 5-9 and Table 5-8, the lane change conflicts also mainly distributed in section 1 and 2. The conflict number in section 1 is 772 and in section 2 is 538, accounting for 51% and 35% of the total number of 1519. In the fog area, the proportion of conflict number is only 14%. This condition is similar to the 50 mph-speed-limit condition in fog area. This phenomenon also contributes to the careful driving behavior and the less lane-changing behavior.

5.2.2.4 Conclusion

When the traffic volume is at a middle level, drivers tend to drive more carefully in the fog area. In all the three conditions with different speed limits in the fog, there are more lane change conflicts in the no-fog areas than in the fog area. Considering the fog area's different speed limits, shown in Figure 5-10, the conflict number increases when the difference of the speed limits between the fog area and the other sections getting bigger. A large velocity difference leads to more lane-change conflicts in freeways.

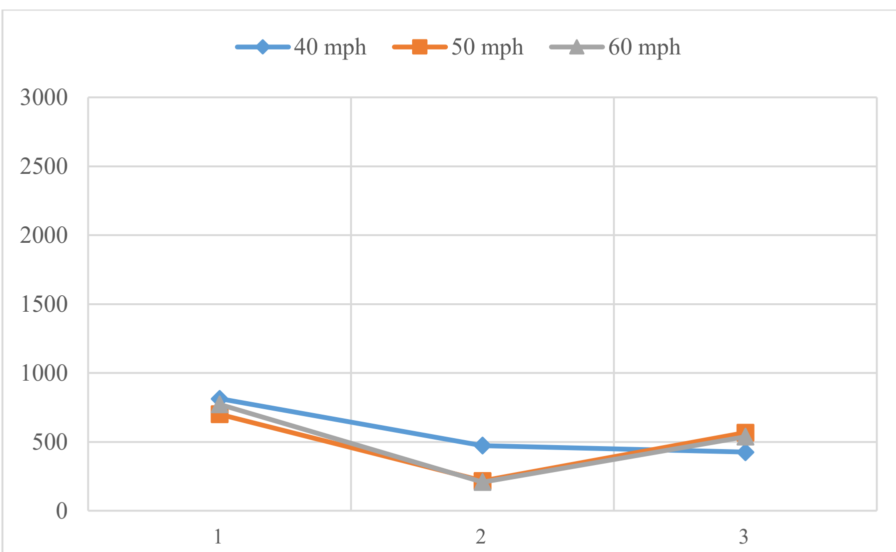

Figure 5-10 Lane-change conflict summarize of middle volume traffic

5.2.3 High Traffic Volume Level Case

5.2.3.1 The speed limit at the fog area is 40 mph

The conflict numbers of the three areas are summarized in Table 5-9. The conflict locations are plotted in Figure 5-11. Point A and Point B are the projected points of Point M and point N respectively. They are used to label the division points of three road sections to make it easier to see which road segment a conflict point belongs to.

Table 5-9 Lane-change conflict summary of high traffic volume at the speed of 40 mph in the fog area

Volume (veh/h)	Speed Limit (mph)	Section 1	Fog Area	Section 2	Total
12000	40	702(39%)	537(30%)	567(31%)	1806

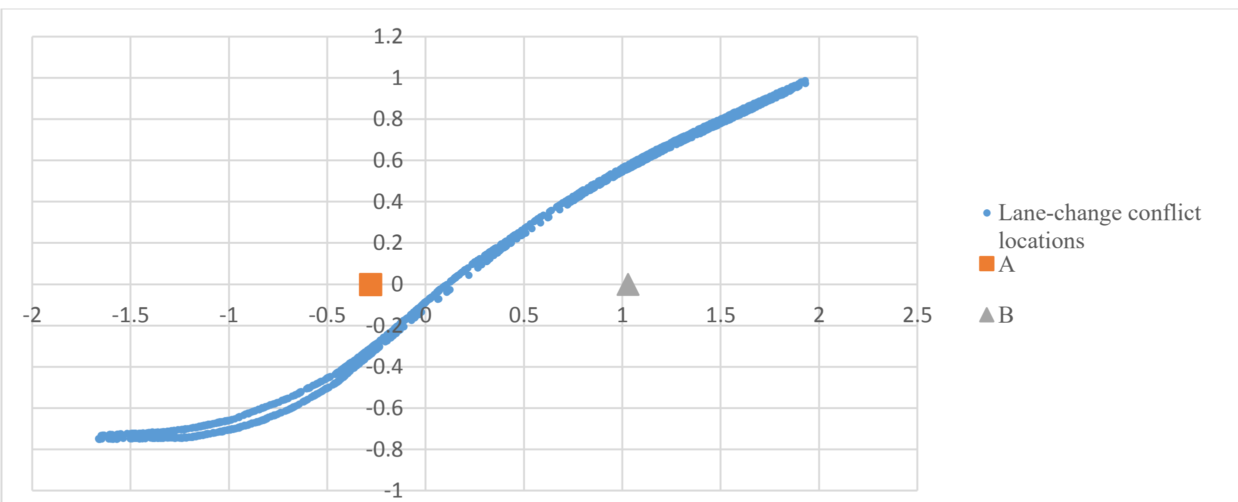

Figure 5-11 Lane-change conflicts of high traffic volume at the speed of 40 mph in the fog area

According to Table 5-9 and Figure 5-11, the lane change conflicts distributed in section 1 mostly. The conflict number in section 1 is 702, accounting for 39% of the total number of 1806, which is the highest of the three parts of the road sections. In the fog area, the proportion of conflict number is 30%. The probability of the lane change crashes occurs in fog area is higher than it occurs in section 2 at this speed limit and traffic volume level.

5.2.3.2 The speed limit at the fog area is 50 mph

The conflict numbers of the three areas are summarized in Table 5-10. The conflict locations are plotted in Figure 5-12. Point A and Point B are the projected points of Point M and point N respectively. They are used to label the division points of three road sections to make it easier to see which road segment a conflict point belongs to.

Table 5-10 Lane-change conflict summary of high traffic volume at the speed of 50 mph in the fog area

Volume (veh/h)	Speed Limit (mph)	Section 1	Fog Area	Section 2	Total
12000	50	654(44%)	359(24%)	489(33%)	1502

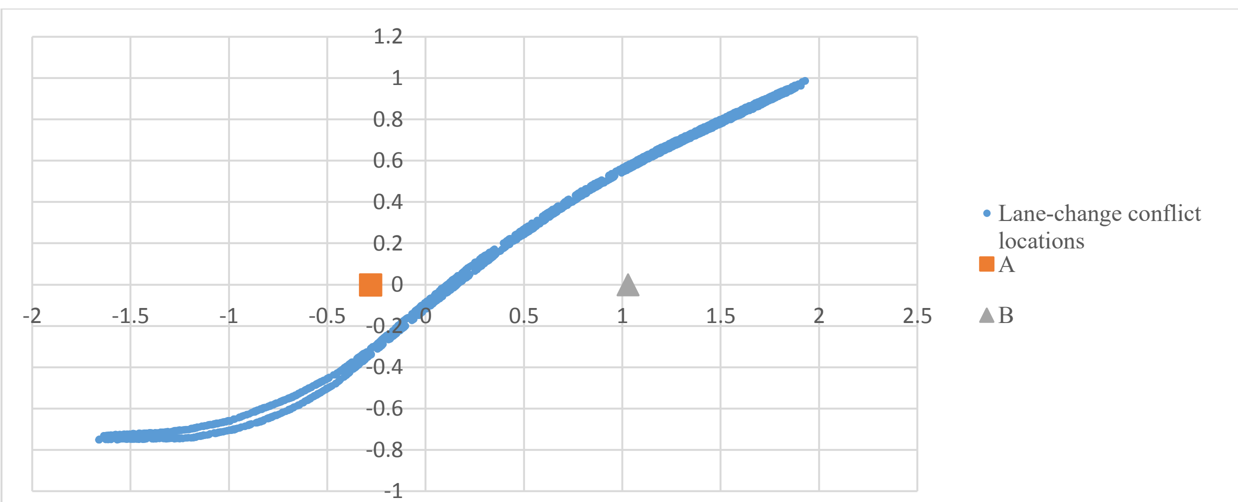

Figure 5-12 Lane-change conflicts of high traffic volume at the speed of 50 mph in the fog area

According to Figure 5-12 and Table 5-10, the total number of accidents is 1502. Section 1 and section 2 contains the majority of all the crashes happened on this road segment with a sum of

77% of the total. In fog area, only 24% lane change conflicts happened. The lane change conflicts are also more frequency occurring in no-fog areas.

5.2.3.3 The speed limit at the fog area is 60 mph

The conflict numbers of the three areas are summarized in Table 5-11. The conflict locations are plotted in Figure 5-13. Point A and Point B are the projected points of Point M and point N respectively. They are used to label the division points of three road sections to make it easier to see which road segment a conflict point belongs to.

Table 5-11 Lane-change conflict summary of high traffic volume at the speed of 60 mph in the fog area

Volume (veh/h)	Speed Limit (mph)	Section 1	Fog area	Section 2	Total
12000	60	700(49%)	170(12%)	549(39%)	1419

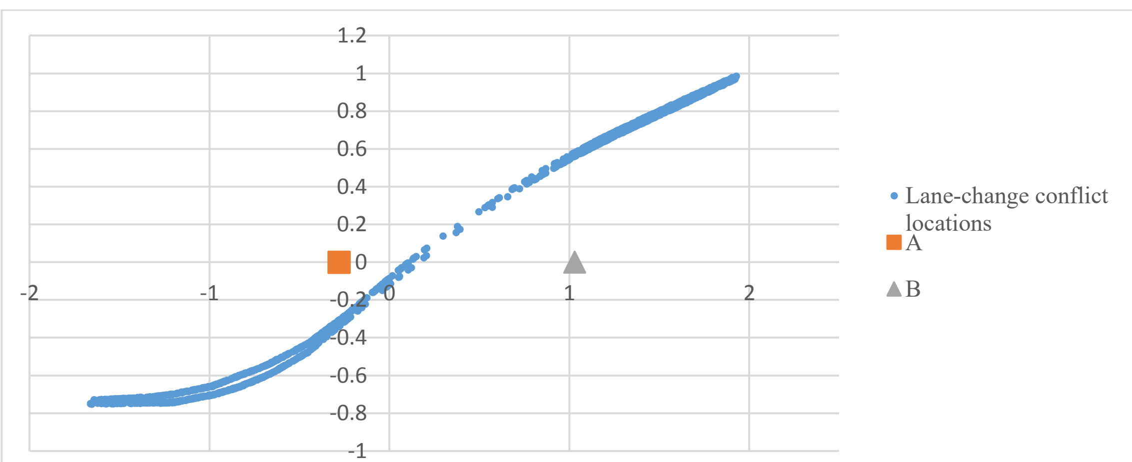

Figure 5-13 Lane-change conflicts of high traffic volume at the speed of 60 mph in the fog area

According to Figure 5-13 and Table 5-11, the lane change conflicts are mainly distributed in section 1 and 2. Section 1 and section 2 contains the majority of all the conflicts happened on this road segment with a sum of 88% of the total, much higher than fog area. In fog area, only 12% lane change conflicts happened. The lane change conflicts are also more frequency occurring in no-fog areas. That means that there is a high possibility of lane change accidents at the no-fog areas.

5.2.3.4 Conclusion

When the traffic volume is at a high level, drivers tend to drive more carefully in the fog area. And it is not easy to have a chance to drive to another lane when the road density is high. In all the three conditions with different speed limits in the fog area, there are more lane change conflicts in no-fog areas than that in the fog area. Considering the different speed limits, which are shown in Figure 5-14, the conflict number increases as the speed limit varies more from the speed limits of other sections. Large velocity difference leads to more lane change conflicts in freeway. The possible reason of section 1 containing more crashes than section 2 is due to the longer distance that section 1 has.

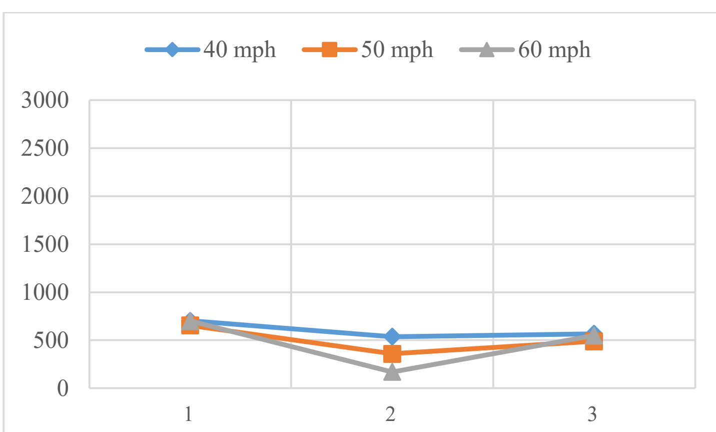

Figure 5-14 Lane-change conflict summarize of high volume traffic

5.2.4 Lane-change Conflict Analysis in the Overlap Areas

The data of lane-change conflict number is concluded in Table 5-12, and the one-mile's conflict number was shown in Table 5-13. The speed limit of 70 mph was set in the fog area to stand for the condition of no speed limit difference between the different road segments.

Table 5-12 Lane-change conflict number of each segment

Traffic volume [veh/hour]	Speed limit in the fog area [mph]	Lane-change conflict number							Total
		Section 1		Fog area			Section 2		
		$P\text{-}M_1$	$M_1\text{-}M$	$M\text{-}M_2$	$M_2\text{-}N_1$	$N_1\text{-}N$	$N\text{-}N_2$	$N_2\text{-}Q$	
4000	40	253	46	56	134	36	36	128	689
	50	178	37	25	25	7	11	101	384
	60	138	12	6	9	4	7	77	253
	70	254	46	56	134	36	36	128	690
8000	40	663	150	104	297	72	127	299	1712
	50	554	146	88	104	25	154	413	1484
	60	608	164	71	91	47	147	391	1519
	70	700	138	113	292	85	126	357	1811
12000	40	594	108	109	344	84	157	410	1806
	50	539	115	107	198	54	126	363	1502
	60	564	136	68	67	35	151	398	1419
	70	629	164	104	309	74	98	335	1713

Table 5-13 Lane-change conflict number of one mile in each segment

Traffic volume [veh/hour]	Speed limit in the fog area [mph]	Lane-change conflict number per mile						
		Section 1		Fog area			Section 2	
		$P\text{-}M_1$	$M_1\text{-}M$	$M\text{-}M_2$	$M_2\text{-}N_1$	$N_1\text{-}N$	$N\text{-}N_2$	$N_2\text{-}Q$
4000	40	202	184	224	134	144	144	171
	50	142	148	100	25	28	44	135
	60	110	48	24	9	16	28	103
	70	203	184	224	9	144	144	171
8000	40	530	600	416	297	288	508	399
	50	443	584	352	104	100	616	551
	60	486	656	284	91	188	588	521
	70	560	552	452	91	340	504	476
12000	40	475	432	436	344	336	628	547
	50	431	460	428	198	216	504	484
	60	451	544	272	67	140	604	531
	70	503	656	416	67	296	392	447

As shown in Figure 5-15, Figure 5-16, and Figure 5-17, the conflict number has different characteristics in different road segments. In all the segments, there are more lane-change conflicts per mile when the traffic volume increases. It can be noticed that, during the period of driving into the fog zone, the numbers of lane-change conflict decrease in general, and the middle of the fog area has the least conflicts, which indicates that this road segment has the smallest possibility of lane-change crashes. What's more, when the speed limit is set as 70 mph in the fog area, there are more conflicts than the other three speed limits. Except the 70 mph speed limits, the conflict numbers of the other limit groups increase with the difference of the limits between two next areas. So the 40 mph limits has the most conflicts. Apparently, the conflict number of 70 mph limit has a different characteristic with the others, which means that the reduced speed limit is useful in reducing lane-change conflict number under the fog condition.

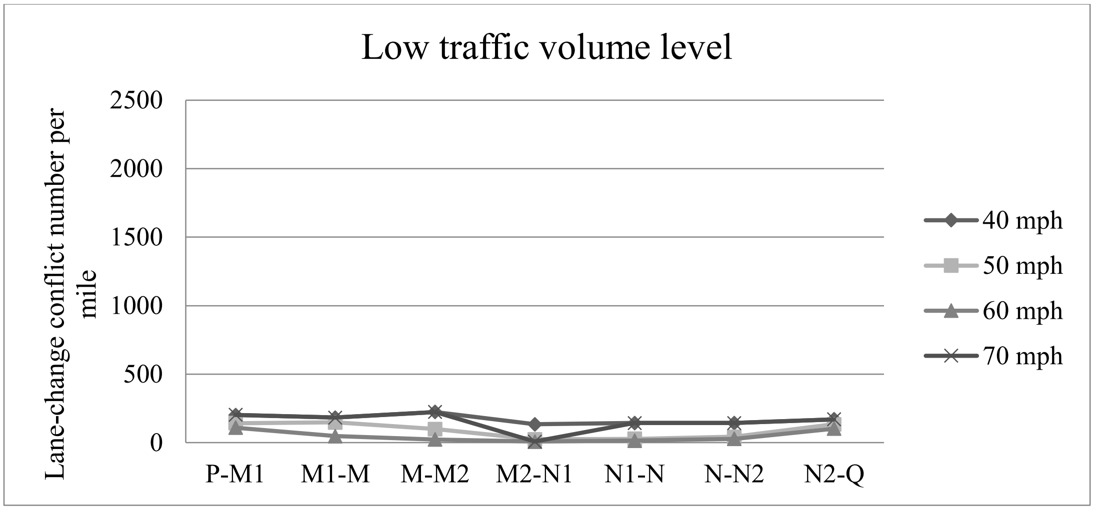

Figure 5-15 Lane-change conflict number in one mile at the low traffic volume level

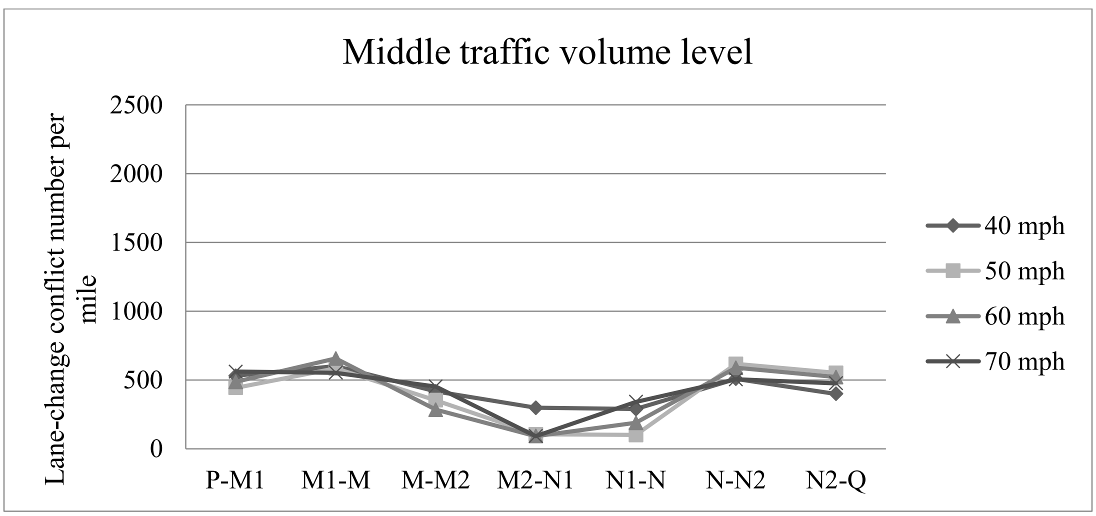

Figure 5-16 Lane-change conflict number in one mile at the middle traffic volume level

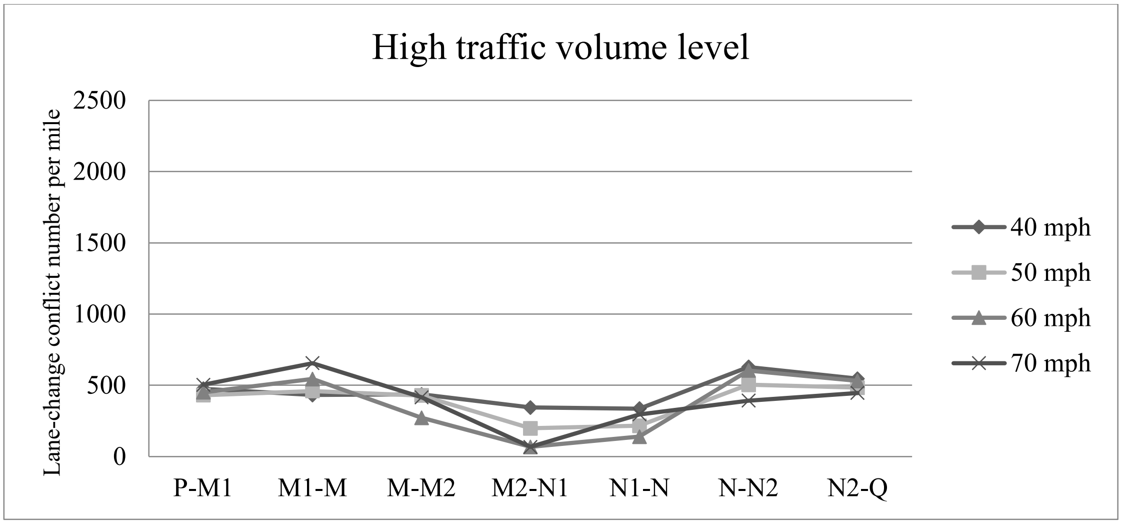

Figure 5-17 Lane-change conflict number in one mile at the high traffic volume level

5.3 Rear-end conflict

Car following is one of the uppermost driving behaviors. This kind of driving behavior could lead to rear-end crash under lower visibility. Rear end crash is a traffic accident in where a vehicle crashes into the one in front of it. In this traffic trajectory-based simulation model, different conflict types are defined by conflict angle of the vehicle trajectory. The angle of rear end conflict θ_r is set as $0^\circ \leq \theta_r \leq 30°$. The threshold diagram is shown as Figure 5-18. On freeway, due to the high speed, it is not easy to see the front road condition clearly with the low visibility in fog days. This condition usually causes a rear end crash accident. The following sections discussed the affections of the different speed limits at the fog area to the rear end conflict numbers.

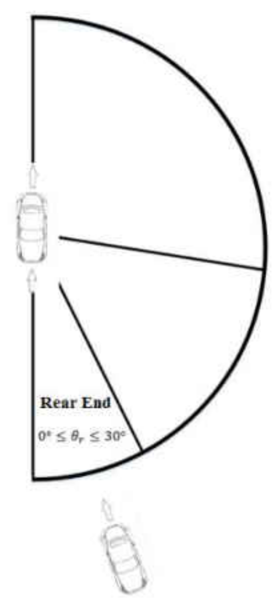

Figure 5-18 Threshold diagram of rear-end conflicts

5.3.1 Low Traffic Volume Level Case

5.3.1.1 The speed limit at the fog area is 40 mph

The conflict numbers of the three areas are summarized in Table 5-14. The conflict locations are plotted in Figure 5-19. Point A and Point B are the projected points of Point M and point N respectively. They are used to label the division points of three road sections to make it easier to see which road segment a conflict point belongs to.

Table 5-14 Rear-end conflict summary of low traffic volume at the speed of 40 mph in the fog area

Volume (veh/h)	Speed Limit (mph)	Section 1	Fog Area	Section 2	Total
4000	40	264(58%)	95(21%)	93(21%)	452

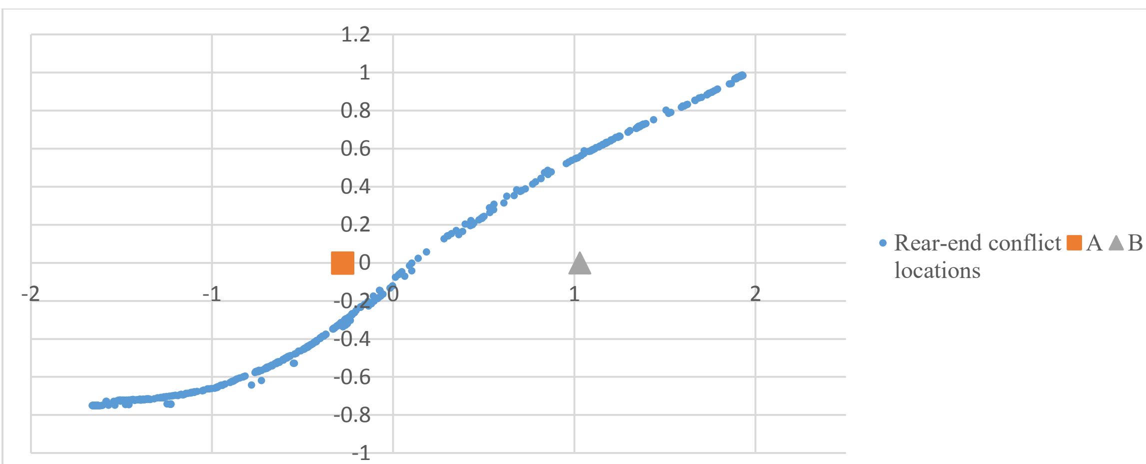

Figure 5-19 Rear-end conflicts of low traffic volume at the speed of 40 mph in the fog area

According to Figure 5-19 and Table 5-14, all rear end conflicts are in the fog area. The conflict proportion in section 2 and the fog area are all 21%. That means that there is a high possibility of rear end crashes in section 1 when the traffic volume is low and the speed limit difference between the two adjacent road segments is large.

5.3.1.2 The speed limit at the fog area is 50 mph

The conflict numbers of the three areas are summarized in Table 5-15. The conflict locations are plotted in Figure 5-20. Point A and Point B are the projected points of Point M and point N respectively.

Table 5-15 Rear-end conflict summary of low traffic volume at the speed of 50 mph in the fog area

Volume (veh/h)	Speed Limit (mph)	Section 1	Fog Area	Section 2	Total
4000	50	99(60%)	20(12%)	47(28%)	166

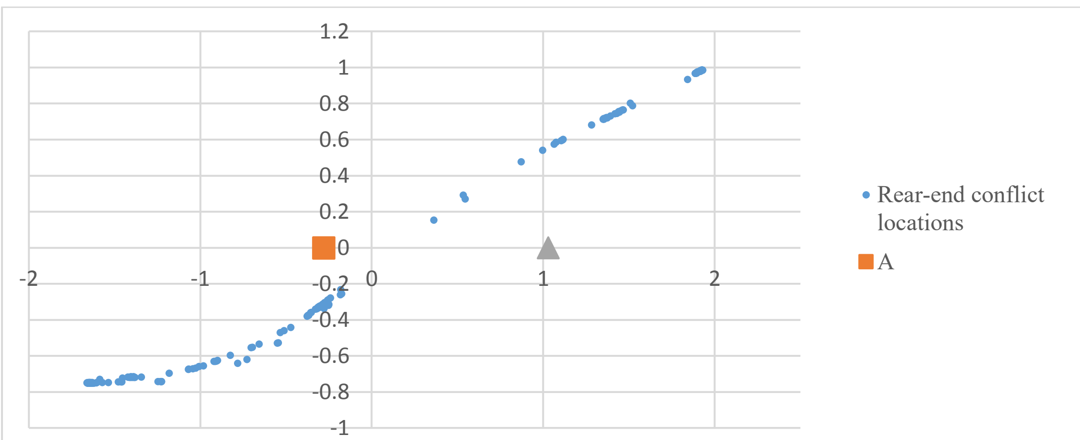

Figure 5-20 Rear-end conflicts of low traffic volume at the speed of 50 mph in the fog area

According to Figure 5-20 and Table 5-15, the number of rear-end conflicts distributed in the fog area is only twenty, accounting for 12% of the total number of 166. The majority of the other rear end conflicts took place in section 1. And 28% conflicts come up in section 2. Section 1 is the most dangerous road section for rear-end crashes at this traffic volume and the speed limit in the fog area.

5.3.1.3 The speed limit at the fog area is 60 mph

The conflict numbers of the three areas are summarized in Table 5-16. The conflict locations are plotted in Figure 5-21. Point A and Point B are the projected points of Point M and point N respectively.

Table 5-16 Rear-end conflict summary of low traffic volume at the speed of 60 mph in fog area

Volume (veh/h)	Speed Limit (mph)	Section 1	Fog Area	Section 2	Total
4000	60 mph	69(67%)	6(6%)	28(27%)	103

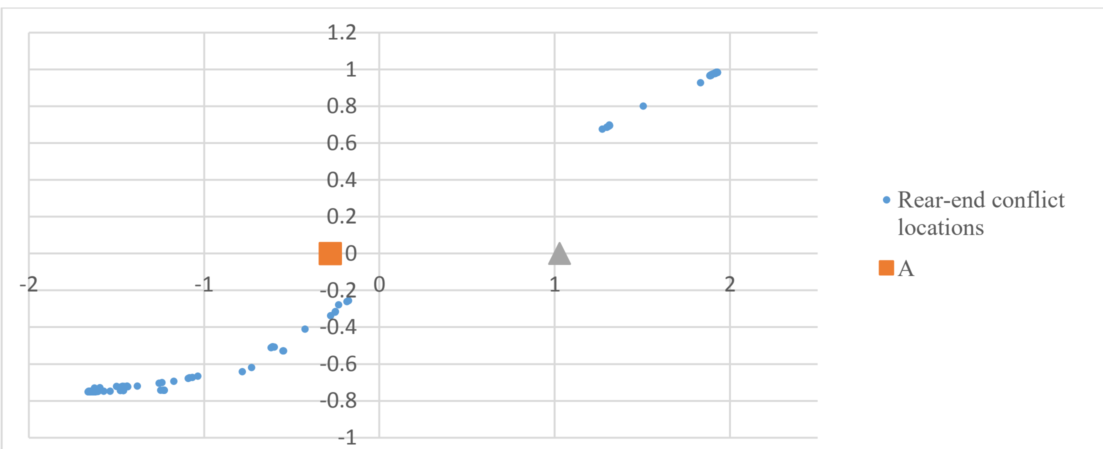

Figure 5-21 Rear-end conflicts of low traffic volume at the speed of 60 mph in the fog area

According to Figure 5-21 and Table 5-16, almost all the rear-end conflicts happened in section 1. Considering the low traffic volume, the low amount of accident number 103 is reasonable. It is remarkable that the majority conflicts occurred in the no-fog area with a proportion of 94%. The accident locations are near the southwest and the northeast end point of the curve.

5.3.1.4 Conclusion

Generally, when the traffic volume is low, the total number of all conflicts stays at a relative low level, as shown in Figure 5-22. Due to the low volume, the following vehicle can keep enough space from the one in front. This adequate car-following distance and low traffic volume make it possible for drivers to avoid the potential rear end accidents. Even in the fog area, vehicles can have enough space and time to retrain from crashing into the front car.

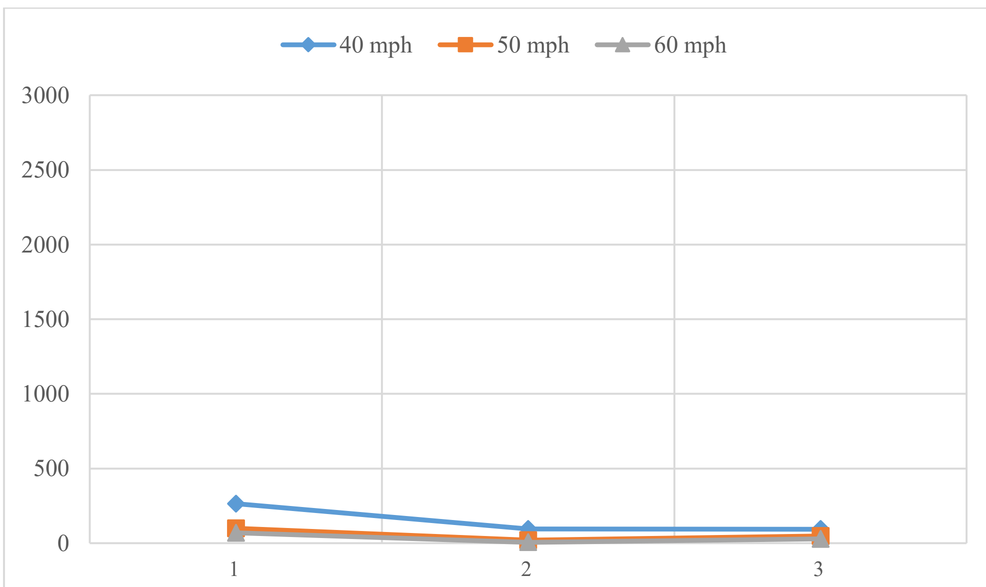

Figure 5-22 Rear-end conflict summarize of low volume traffic

5.3.2 Middle Traffic Volume Level Case

5.3.2.1 The speed limit at the fog area is 40 mph

The conflict numbers of the three areas are summarized in Table 5-17. The conflict locations are plotted in Figure 5-23. Point A and Point B are the projected points of Point M and point N respectively. They are used to label the division points of three road sections to make it easier to see which road segment a conflict point belongs to.

Table 5-17 Rear-end conflict summary of middle traffic volume at the speed of 40 mph in the fog area

Volume (veh/h)	Speed Limit (mph)	Section 1	Fog Area	Section 2	Total
8000	40	2720(48%)	959(17%)	1932(34%)	5611

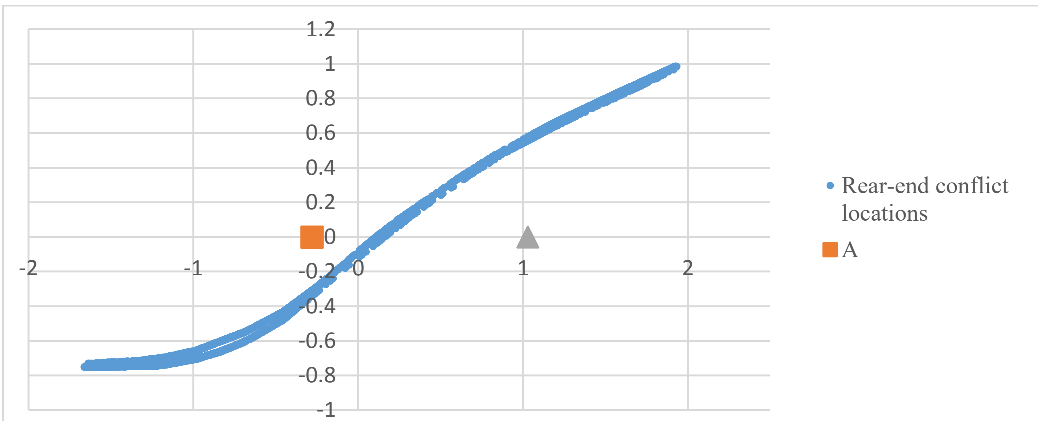

Figure 5-23 Rear-end conflicts of middle traffic volume at the speed of 40 mph in the fog area

According to Figure 5-23 and Table 5-17, the rear end conflicts distributed in section 1 most, which is similar to the scenario of the low volume level. The conflict number in section 1 is 2720, accounting for 48% of the total number of 5611. There are 959 rear-end conflicts in the fog area, which is of 17% of all conflicts at this traffic volume level and this speed level. From the conflict location distribution diagram, the density of conflict points in the two no-fog areas is higher, which indicates that it is more likely to crash into the front car at the two road segments for vehicles at the middle level of traffic volume.

5.3.2.2 The speed limit at the fog area is 50 mph

Table 5-18 summarized the conflicts' number of the scenario of 50 mph speed limit in the fog area at the middle level of traffic volume. The conflict locations are plotted in Figure 5-24. Point A and Point B are the projected points of Point M and point N respectively. They are used to label the division points of three road sections to make it easier to see which road segment a conflict point belongs to.

Table 5-18 Rear-end conflict summary of middle traffic volume at the speed of 50 mph in the fog area

Volume (veh/h)	Speed Limit (mph)	Section 1	Fog Area	Section 2	Total
8000	50	2459(56%)	337(8%)	1620(37%)	4416

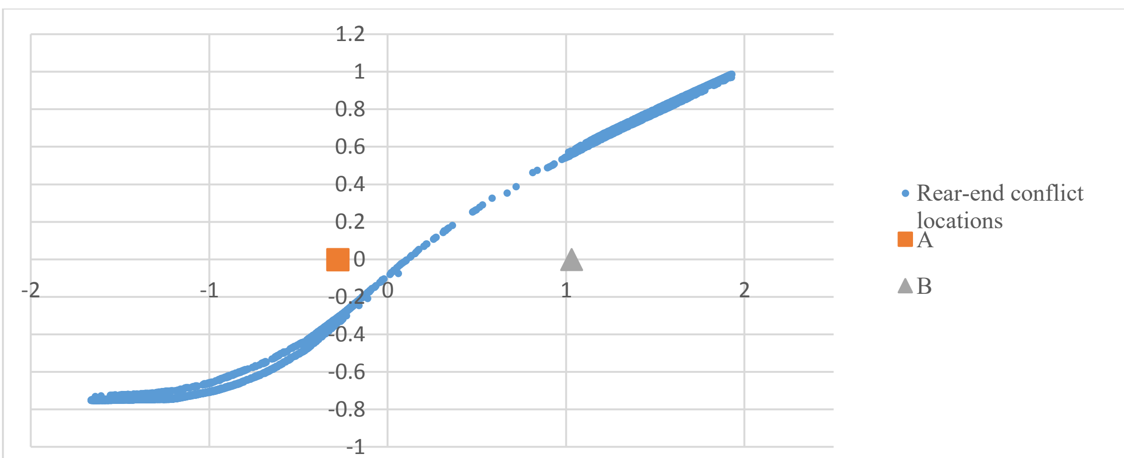

Figure 5-24 Rear-end conflicts of middle traffic volume at the speed of 50 mph in the fog area

According to Figure 5-24 and Table 5-18, the rear end conflicts distributed in section 1 is 56% of the total. The conflict number in section 2 is 1620, which is less than it in section 1. In the fog area, the proportion of conflict number is only 8%. The total percent in no-fog area is 92%, which means a high probability of rear-end accidents when the visibility is good at this traffic volume level. As soon as people drive to the fog area, they can't see as clearly as normal weather. Their looking-ahead distance reduces, and this makes them reduce their speeds and drive more carefully. The careful-kept car following distances can be contributed to the lower accident rate in the fog area.

5.3.2.3 The speed limit at the fog area is 60 mph

The conflict numbers of the three areas are summarized in Table 5-19. The conflict locations are plotted in Figure 5-25. Point A and Point B are the projected points of Point M and point N respectively. They are used to label the division points of three road sections to make it easier to see which road segment a conflict point belongs to.

Table 5-19 Rear-end conflict summary of middle traffic volume at the speed of 60 mph in the fog area

Volume (veh/h)	Speed Limit (mph)	Section 1	Fog Area	Section 2	Total
8000	60	1853(49%)	420(11%)	1511(40%)	3784

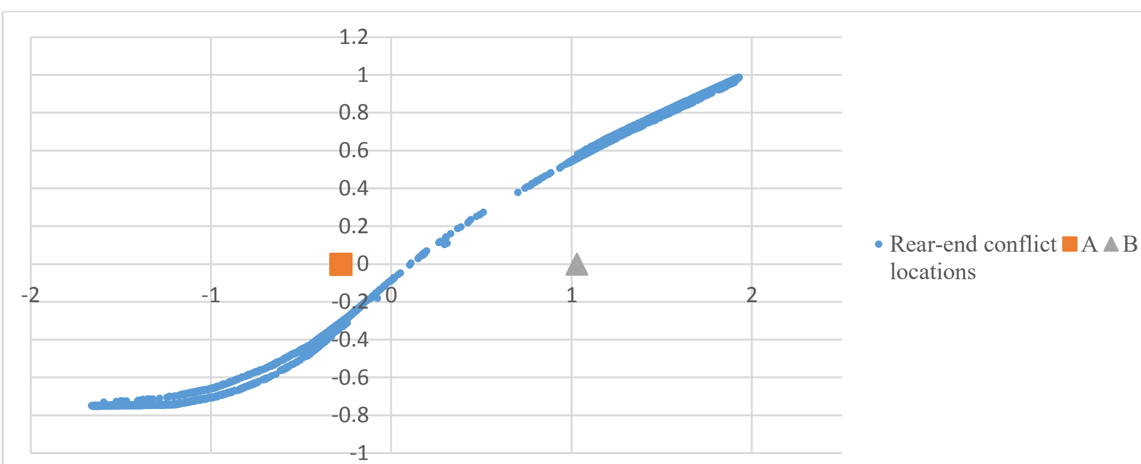

Figure 5-25 Rear-end conflicts of middle traffic volume at the speed of 60 mph in the fog area

According to Figure 5-25 and Table 5-19, the rear-end conflicts also mainly distributed in section 1 and 2. The conflict numbers in section 1 is 1853 and in section 2 is 1511, accounting for 89% of the total number of 3784. In the fog area, there are only 420 rear-end conflict shows up. This condition is similar to the 50 mph-speed-limit conditions in fog area. This phenomenon also contributes to the careful driving behavior and the enough car-following distance.

5.3.2.4 Conclusion

When the traffic volume is at a middle level, drivers tend to drive more carefully in the fog area. In all the three fog area speed limit conditions, there are more rear-end conflicts in the no-fog area that the in fog area. Considering the different speed limits, as shown in Figure 5-26, the conflict number increases as the speed limit varies more from the other parts' limit. Large velocity difference leads to more chances of rear ends in freeways.

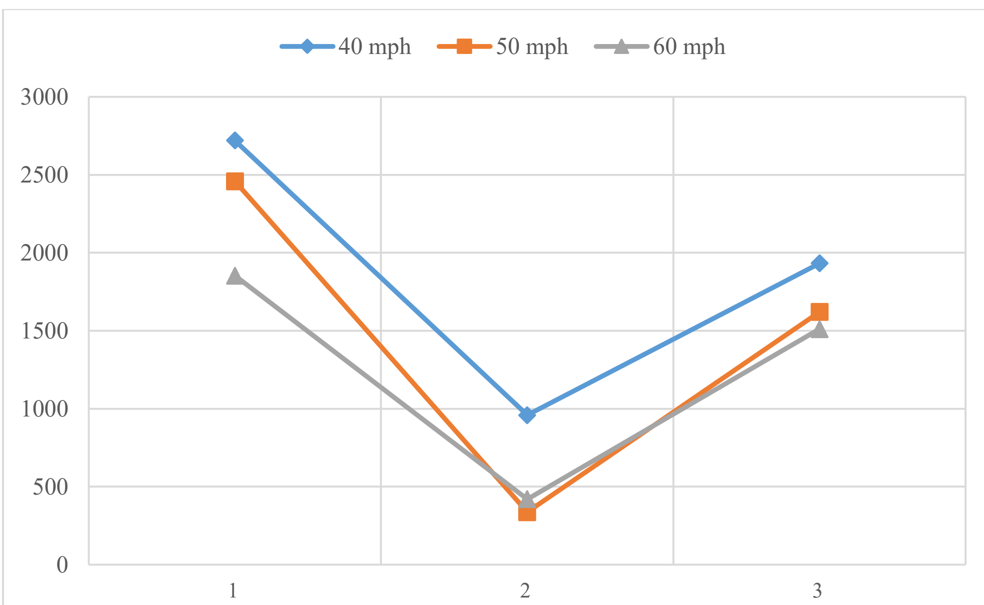

Figure 5-26 Rear-end conflict summarize of middle volume traffic

5.3.3 High Traffic Volume Level Case

5.3.3.1 The speed limit at the fog area is 40 mph

The conflict numbers of the three areas are summarized in Table 5-20. The conflict locations are plotted in Figure 5-27. Point A and Point B are the projected points of Point M and point N respectively. They are used to label the division points of three road sections to make it easier to see which road segment a conflict point belongs to.

Table 5-20 Rear-end conflict summary of high traffic volume at the speed of 40 mph in the fog area

Volume (veh/h)	Speed Limit (mph)	Section 1	Fog Area	Section 2	Total
12000	40	1732(36%)	1003(21%)	2085(43%)	4820

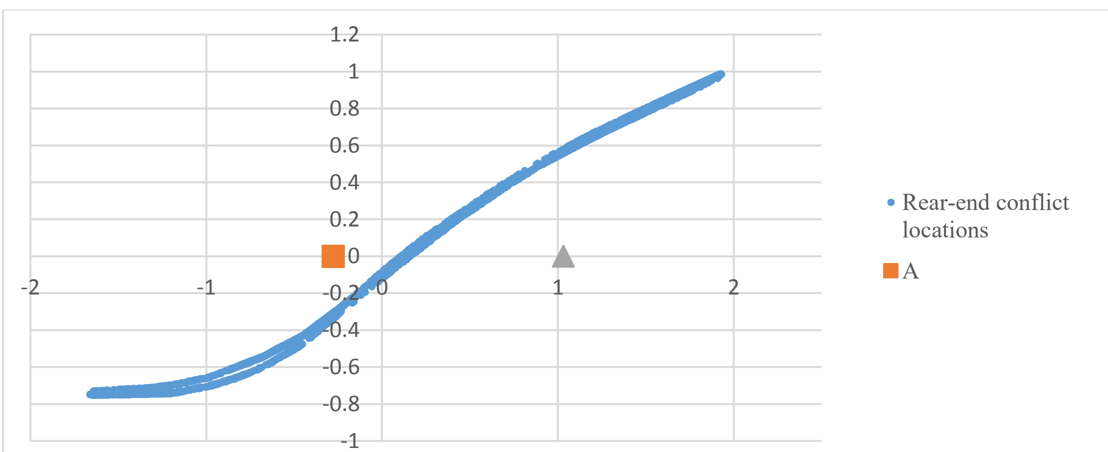

Figure 5-27 Rear-end conflicts of high traffic volume at the speed of 40 mph in the fog area

According to Figure 5-27 and Table 5-20, more than half percent rear-end conflicts occurred in section 1. The conflict number in section 1 is 1732, accounting for 36% of the total number of

4820. In the fog area, the proportion of conflict number is 21%. The probability of a car crashes into its front one in fog area is lower than it occurs in section 1and 2 at this speed limit level and this traffic volume level.

5.3.3.2 The speed limit at the fog area is 50 mph

The conflict numbers of the three areas are summarized in Table 5-21. The conflict locations are plotted in Figure 5-28. Point A and Point B are the projected points of Point M and point N respectively. They are used to label the division points of three road sections to make it easier to see which road segment a conflict point belongs to.

Table 5-21 Rear-end conflict summary of high traffic volume at the speed of 50 mph in the fog area

Volume (veh/h)	Speed Limit (mph)	Section 1	Fog Area	Section 2	Total
12000	50	1930(47%)	611(15%)	1528(38%)	4069

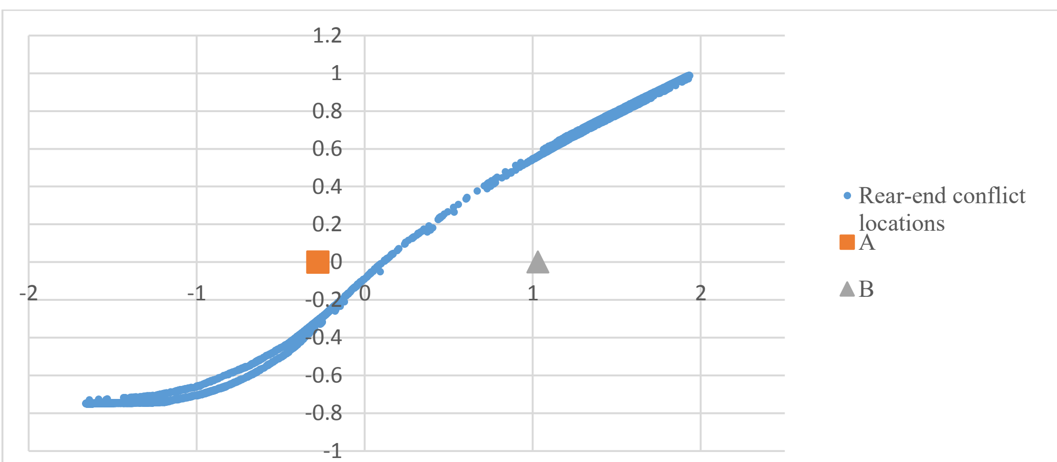

Figure 5-28 Rear-end conflicts of high traffic volume at the speed of 50 mph in the fog area

According to Figure 5-28 and Table 5-21, the total number of rear-end conflicts in this scenario is 4069. Section 1 and section 2 contains the majority of all the rear-end conflicts happened on this study road segment with a sum of 85% in total. In the fog area, only 15% rear-end conflicts happened. The rear-end conflicts are also more frequency in the no-fog areas, which can be seen from the high density of the plots.

5.3.3.3 The speed limit at the fog area is 60 mph

The conflict numbers of the three areas are summarized in Table 5-22. The conflict locations are plotted in Figure 5-29. Point A and Point B are the projected points of Point M and point N respectively. They are used to label the division points of three road sections to make it easier to see which road segment conflict point belongs to.

Table 5-22 Rear-end conflict summary of high traffic volume at the speed of 60 mph in the fog area

Volume (veh/h)	Speed Limit (mph)	Section 1	Fog Area	Section 2	Total
12000	60	2281(52%)	328(7%)	1789(41%)	4398

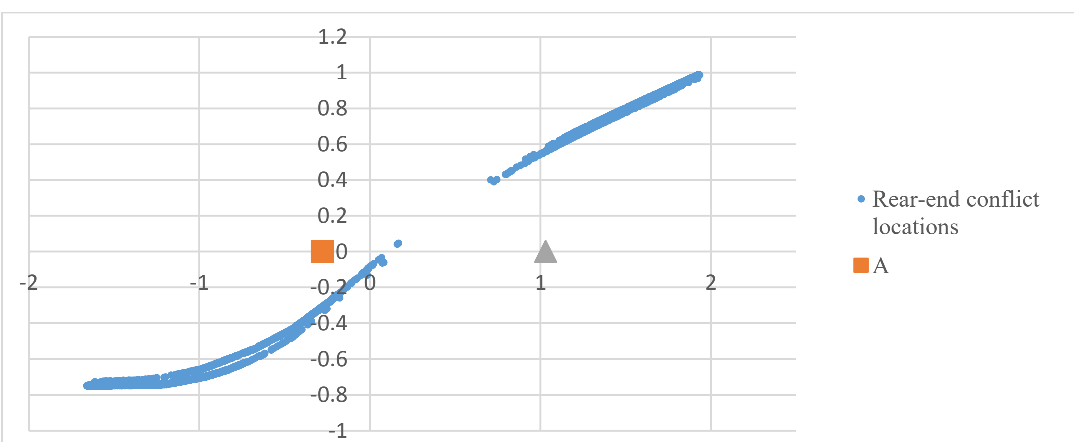

Figure 5-29 Rear-end conflicts of high traffic volume at the speed of 60 mph in the fog area

According to Figure 5-29 and Table 5-22, the rear-end conflicts mainly distributed in section 1 and 2. Section 1 and section 2 contains the majority of all the conflicts happened on this road segment with a sum of 93% of the total, much higher than the fog area. In the fog area, only 7% rear-end conflicts happened. It is also more frequency for a vehicle crashing into its front car's rear part in non-fog areas. That means that there is a high possibility of experiencing a rear end crash for a vehicle at the no-fog areas.

5.3.3.4 Conclusion

When the traffic volume is high, drivers tend to drive more carefully in the fog area. In all the three fog area speed limit conditions, there are more rear-end conflicts in no-fog areas than in the fog area. Considering the different speed limits, as shown in Figure 5-30, the larger the speed limit difference between the fog area and the other two sections, the more the rear-end conflicts occur. Large velocity difference leads to inadequate time to adjust their car following distance, which causes a higher possibility for a vehicle to crash into the front one.

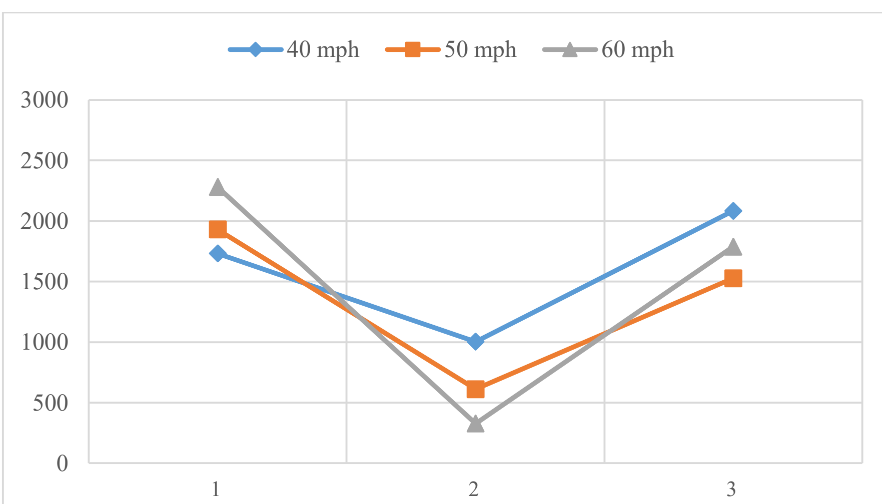

Figure 5-30 Rear-end conflict summarize of high volume traffic

5.3.4 Rear-end Conflict Analysis in the Overlap Areas

The data of rear-end conflict number is concluded in Table 5-23, and the one-mile's conflict number was shown in Table 5-24. The speed limit of 70 mph was set in the fog area to stand for the condition of no speed limit difference between the different road segments.

Table 5-23 Rear-end conflict number of each segment

Traffic volume [veh/hour]	**Speed limit in the fog area [mph]**	**Rear-end conflict number summary**							**Total**
		Section 1		Fog area			Section 2		
		P-M_1	M_1-M	M-M_2	M_2-N_1	N_1-N	N-N_2	N_2-Q	
4000	40	213	51	37	46	12	29	64	452
	50	78	21	15	3	2	5	42	166
	60	68	1	6	0	0	0	28	103
	70	161	52	37	48	12	29	64	403
8000	40	2147	573	540	313	106	394	1538	5611
	50	2119	340	258	56	23	209	1411	4416
	60	1556	297	271	64	85	285	1226	3784
	70	1521	536	466	271	75	254	1333	4456
12000	40	1411	321	427	375	201	526	1558	4819
	50	1663	267	419	131	61	310	1218	4069
	60	1970	311	250	29	49	308	1482	4399
	70	1397	408	407	270	45	132	1821	4480

Table 5-24 Rear-end conflict number of one mile in each segment

Traffic volume [veh/hour]	**Speed limit in the fog area [mph]**	**Rear-end conflict number per mile**						
		Section 1		Fog area			Section 2	
		$P\text{-}M_1$	$M_1\text{-}M$	$M\text{-}M_2$	$M_2\text{-}N_1$	$N_1\text{-}N$	$N\text{-}N_2$	$N_2\text{-}Q$
4000	40	170	204	148	46	48	116	85
	50	62	84	60	3	8	20	56
	60	54	4	24	0	0	0	37
	70	129	208	148	48	48	116	85
8000	40	1718	2292	2160	313	424	1576	2051
	50	1695	1360	1032	56	92	836	1881
	60	1245	1188	1084	64	340	1140	1635
	70	1217	2144	1864	271	300	1016	1777
12000	40	1129	1284	1708	375	804	2104	2077
	50	1330	1068	1676	131	244	1240	1624
	60	1576	1244	1000	29	196	1232	1976
	70	1118	1632	1628	270	180	528	2428

As shown in Figure 5-31, Figure 5-32, and Figure 5-33, the conflict number has different characteristics in different road segments. In all the segments, there are more rear-end conflicts per mile when the traffic volume increases. It can be noticed that, during the period of driving into the fog zone, the numbers of rear-end conflict decrease in general, and the middle of the fog area has the least conflicts, which indicates that this road segment has the smallest possibility of rear-end crashes. What's more, when the speed limit is set as 70 mph in the fog area, there are more conflicts than the other three speed limits. Except the 70 mph speed limits, the conflict numbers of the other limit groups increase with the difference of the limits between two next areas. So the 40 mph limit has the most conflicts. Apparently, the conflict number of 70 mph limit has a different characteristic with the others, which means that the reduced speed limit is useful in reducing rear-end conflict number under low visibility conditions.

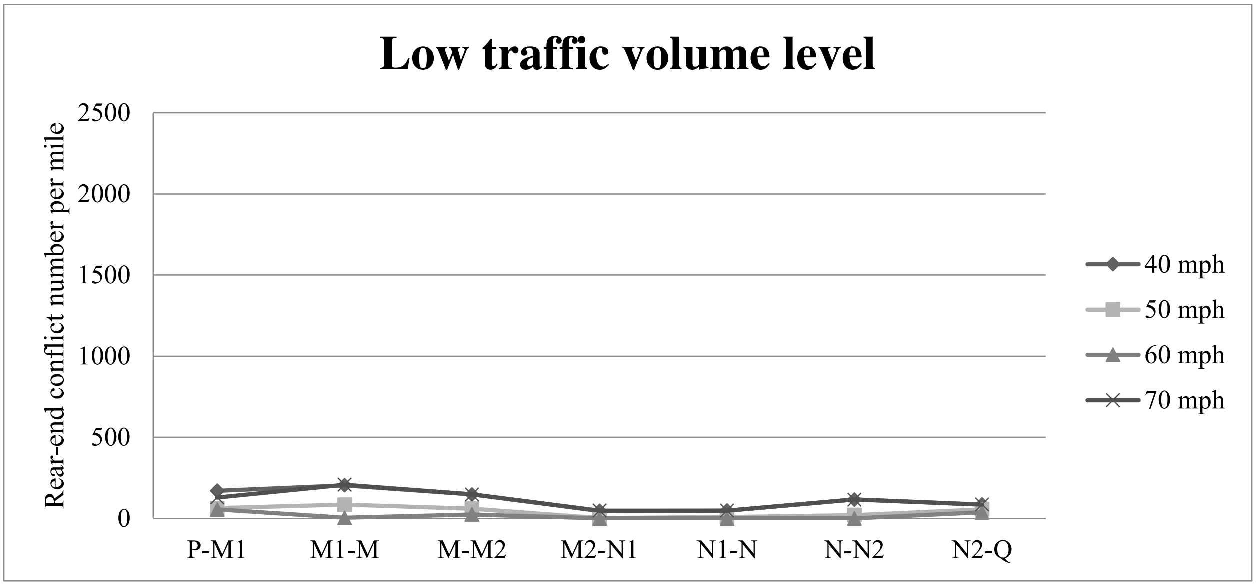

Figure 5-31 Rear-end conflict number in one mile at the low traffic volume level

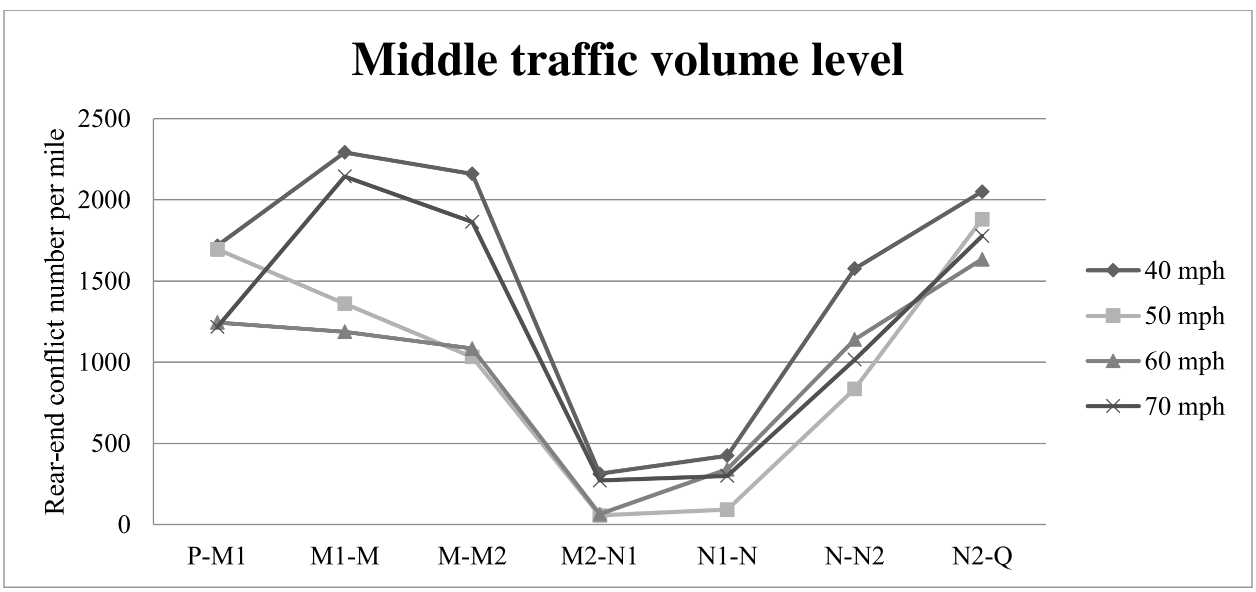

Figure 5-32 Rear-end conflict number in one mile at the middle traffic volume level

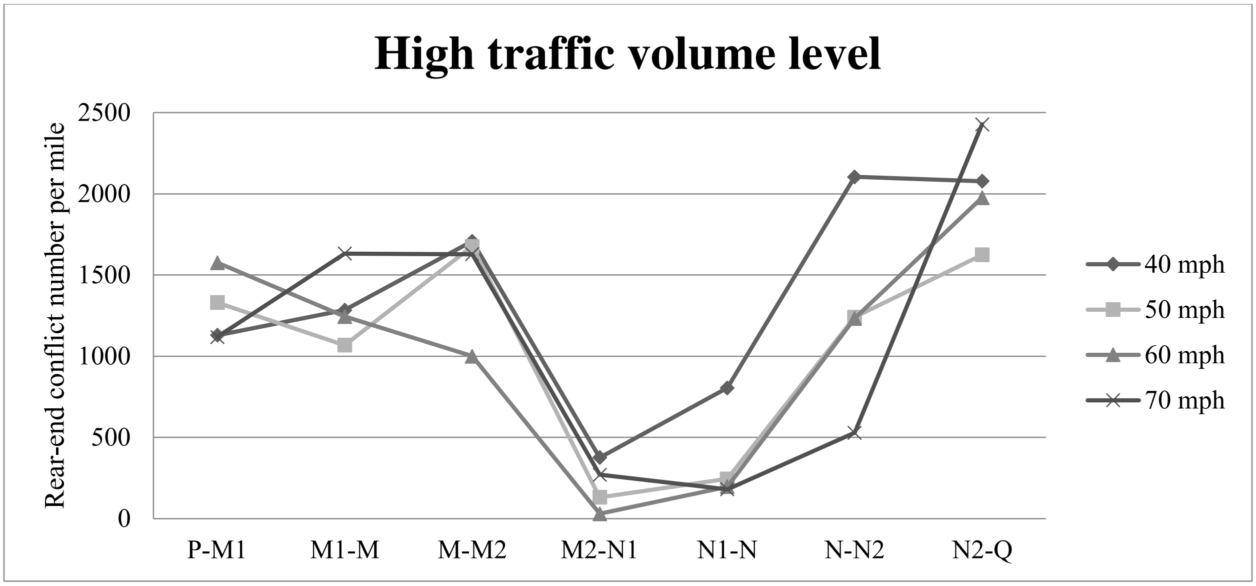

Figure 5-33 Rear-end conflict number in one mile at the high traffic volume level

5.4 Conflict Analysis of the Basic Model

The basic model with the traffic composition data from the field data set. In order to investigate the influence of different visibility conditions, seven levels of looking ahead distances were set to simulate the different visibility road conditions. With a total length of 4 miles, all the study area of the road was set as one looking ahead distance without any change of visibility. The speed limit of the whole road segment is 70 mph. The conflict numbers per mile of two main conflict types are shown in Table 5-25.

Table 5-25 Number per mile of two types' conflict in different looking ahead distance

Looking ahead distance (mile)	Lane-change	Rear-end
0.1243	3	8.5
0.3107	3.5	16.5
0.4971	2.5	15
0.6835	5.5	10
0.8699	5	16
1.0563	2.5	8
1.2427	5.5	18.5

Another finding about the influence of the visibility is that although the input traffic volume values are the same, the outputs of the traffic volume under different looking ahead distances are different. When the looking ahead distance increases, there are more vehicles driving through the study road segment, which is shown in Table 5-26.

Table 5-26 The output traffic volumes under different looking ahead distances

Looking ahead distance (mile)	**Output traffic volume (veh/hour)**
0.124274	9887
1.24274	10050

*The input traffic volume for the both looking ahead distances is 12000 veh/hour.

This result shows that when the looking ahead distance increases, which means that the visibility is good, there are more vehicles can drive through the same road segment in a same time period. And this indicates that a better visibility allows more vehicles use the road at the same time. Due to the reason above, the car following distances for most of the vehicles on the road become smaller. And thus results more lane-change and rear-end conflicts.

5.5 Conclusion

5.5.1 The Effect of Traffic Volume

According to the data analysis results, the level of traffic volume has a strong influence on the conflict number. As the traffic volume increases, the conflict numbers go up. The reason for this phenomenon is that when there are more vehicles on the road, the car-following distance is smaller. This leads to shorter responding time for drivers to make effective measure when they are faced with dangerous situations.

For lane changing behavior, drivers couldn't find enough interspace on their next lane, which raise the risk of lane change conflicts. When in fog area, it is even harder for drivers estimating their adjacent lane's situation due to the low visibility. However, this situation makes drivers drive more carefully and less lane change behaviors than in the normal weather to keep them safe.

Referring to car following behavior, there is no adequate distance for the following car to keep the safety distance when the road density is high. And thus may result in the rear-end crashes. Known from the simulation results, the number of rear-end conflicts is smaller in the fog area than in the other two sections. This should be contributed to the more careful driving behaviors and less acceleration and deceleration behaviors.

5.5.2 The Effect of Different Speed Limits

The different speed limits in the fog area are also crucial factors for lane-change conflicts and rear-end conflicts. Actually, what makes influence on the safety condition is the speed limit difference between the normal area and the fog area. The conflicts occurred more when the difference is bigger. That is because when a vehicle driving into a fog area, which has a different speed limit, the driver has to change his/her driving behavior to adapt the rule in the new area. But due to the low visibility, they may not judge the speed and distance of the vehicles on the neighboring lane, and don't have enough time and space to reduce their speed immediately. And this condition may result in a lane change conflict. About the rear end conflicts, drivers may not estimate their front traffic condition accurately, including estimating their safety distance to their front vehicle. Thus leads to a higher probability of rear-end crashes. It is noticeable that comparing to the three levels of reduced speed limit, the limit of 70 mph has a bigger conflict number in most scenarios. This phenomenon indicates that a lower speed limit in the fog area is helpful in reducing the risk of these two types of conflicts.

5.5.3 The Conflicts in the Overlap Areas

Different road segments contain different conflict characteristics. The trends of rear-end conflict and lane-change conflict are similar. In all the segments, there are more conflicts in one mile as the traffic volume goes up. The overlap areas which are out of the fog areas have more conflicts than those inside of the fog area. The conflict numbers decrease the fog area and reach its smallest point in the segment of "$\mathrm{M_2 - N_1}$". In the middle of the fog area, there are least conflicts among all road segments, which indicate that this road segment has the smallest possibility of crashes.

CHAPTER 6. CONCLUSION

6.1 Research Findings

Fog is a common weather condition in nature, and it has a great influence on the visibility status. What's more, visibility has a strong relationship with the road safety issue and the traffic conflict problem. In this research, fog area was denoted by lower visibility level to be distinguished from the clear weather condition, which was described by higher visibility level. Concerning the road traffic safety issue, different speed limits were set among the areas with different visibility conditions. A lower speed limit was set up in poor visibility areas, whereas a higher speed limit was applied in clear visibility road segments; thus making it possible to investigate the impact of different speed limits on road traffic safety problems.

According to the study area's road type on I-4, this thesis focused on the analysis of two main types of conflicts: lane-change conflict and rear-end conflict. In each conflict type, three groups were set depending on the different traffic volume levels, which are low volume level, middle volume level, and high volume level. By conducting the above experiments and study, the research results can be concluded. The major findings and research contributions are summarized as following.

Generally, the numbers of lane change conflicts and rear-end conflicts increased along with the traffic volume. The more vehicles on the road, the higher the probability of crashes it is. Among these three road sections, the fog area had the lowest lane-change conflict number. This phenomenon can be contributed to the more careful driving behaviors of the road users in the fog area, which means that drivers tend to reduce their lane change frequency to adapt to low visibility environment in the fog area.

Another finding is that there were more conflicts observed in simulation in all three-road sections when the speed limits in the no-fog areas and in the fog area were different. That is because of the lack of enough time for drivers to reduce their speed to meet the low speed limit requirement of the fog area as soon as they drive into the low visibility zone. For lane-change behaviors, drivers didn't have enough time to observe the adjacent lane's condition and make accurate decisions, and thus resulted in lane-change conflicts. Referring to rear-end conflicts, large difference between the speed limits in two nearing road sections also led to less reaction time for vehicle drivers to brake in time, and this generated more rear-end conflicts on all the three sections of the road.

Since the weather condition and the visibility status are uncontrollable factors, and the traffic volume is also a rigid demand which can't be reduced easily after a road is built up, a speed limit that is lower than the normal weather areas' speed limits is preferred as a recommendation for safety concern.

6.2 Future Recommendations

In this thesis, three road segments were set at a preliminary condition to study the variable speed limits' impact and different visibility's influence on traffic conflict problems. In the future, the speed limits' accurate settlement location can be studied to decide the best location for changeable message signs in order for the driver to have enough time to react to the new speed limit and reduce or resume their speed to meet the new requirement.

Besides the conflict location's information, the results of the road traffic conflict analysis of SSAM also contain the data of TTC and PET. Due to these two parameters functions in road traffic conflict analysis, it is effective to use TTC and PET as an entry point to study the road safety issues and analyze the crash problems. Furthermore, if traffic conflicts are somehow correlated with traffic crashes due to fog conditions, one can predict the probability of crash occurrence using conflict frequencies.

APPENDIX SAS CODE FOR FIELD DATA ANALYSIS

```
libname project "D:\visibitily project\Feb 4.xlsx";

data Feb_4;

set project.'sheet1$'n;

drop time;

if Lane=0 or Lane=1 or Lane=2 then Lane_group=1;

else Lane_group=2;

if Classfication=1 then Classfication_G=1;

else classfication_G=2;

run;


*By hour, lane, Classification_G;

proc sort data=Feb_4;

by Hour Lane classfication_G;

run;


proc summary data=Feb_4;

by Hour Lane classfication_G;
```

```
var classfication_G;

output out=Feb_4_group1 n=count;

run;

data Feb_4_group1;

set Feb_4_group1;

drop _TYPE_ _FREQ_;

run;



*By Hour, Lane_Group, Classification_G;

proc sort data=Feb_4;

by Hour Lane_Group classfication_G;

run;



proc summary data=Feb_4;

by Hour Lane_Group classfication_G;

var classfication_G;

output out=Feb_4_group2 n=count;
```

```
run;

data Feb_4_group2;

set Feb_4_group2;

drop _TYPE_ _FREQ_;

run;

*By Hour Lane_Group;

proc sort data=Feb_4;

by Hour Lane_Group;

run;



proc summary data=Feb_4;

by Hour Lane_Group;

var Lane_Group;

output out=Feb_4_group3 n=count;

run;



data Feb_4_group3;
```

```
set Feb_4_group3;

drop _TYPE_ _FREQ_;

run;



*Export output to excel;

proc export data=Feb_4_group1

outfile='D:\visibility project\hour_Lane_Class_Volume'

  DBMS=EXCEL REPLACE;

    SHEET="Volume";

RUN;

proc export data=Feb_4_group2

outfile='D:\visibility project\hour_3Lanes_Class_Volume'

  DBMS=EXCEL REPLACE;

    SHEET="Volume";

RUN;

proc export data=Feb_4_group3

outfile='D:\visibility project\hour_3Lanes_Volume'
```

```
   DBMS=EXCEL REPLACE;
    SHEET="Volume";
RUN;


PROC EXPORT DATA= work.scores
    OUTFILE= 'C:\excel files\class.xls'
    DBMS=EXCEL REPLACE;
     SHEET="class";
RUN;
```

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