SIMULATION OF A CRASH PREVENTION TECHNOLOGY AT A NO-PASSING ZONE SITE

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Abstract

No-passing zone crashes constitute a sizable percentage of the total crashes on two-lane rural roads. A detection and warning system has been devised and implemented at a no-passing zone site on route 114 of Southwest Virginia to address this problem. The warning system aims at deterring drivers from illegally conducting a passing maneuver within the no-passing zone area. The violating driver is warned in real time to stop the illegal act. This system is currently operational and its main function is to warn the no-passing zone violator. The aim of this research is to extend the warning system to the opposing vehicle in the same lane of the persistent violator in order to avoid crashes caused by the illegal maneuver that is taking place at a crest vertical curve of the two-lane rural road.

In order to test the new system prior to its physical installation, a computer simulation has been developed to represent the real world violation conditions so that a better understanding of the problem and its varying scenarios would be achieved. The new simulation, which is the focus of this thesis, takes advantage of an existing simulation developed earlier to replicate only the illegal maneuver without giving any warnings to the opposing vehicle. The new program simulates the outcome of deploying a warning sign to the opposing driver for crash avoidance purposes assuming that all violators persist to pass the vehicle ahead.

More than 712,000 computer runs were conducted to simulate the various possible outcomes including the sensitivity analysis. A critical comparison was made between the previous system that warned only the violating vehicle and the current program that warns both the violator as well as the opposing vehicle. The results indicate that warning the opposing driver would reduce the rate of unavoidable crashes by approximately 11% in the east direction and 13.25% in the west direction.

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John El Khoury

To The Memory Of My Father, Said

To The Hard Work Of My Mother, Layla

To My Lovely Sister, Jacky

And Finally To My Dear Brothers, Jack & Joud

For Their Continuous Love And Support

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CHAPTER1. INTRODUCTION

1.1 Problem Description

Route 114 in Montgomery County, Virginia, also known as “Peppers Ferry Road”, is a two-lane rural road that connects the town of Christiansburg and the city of Radford. The busiest part of Route 114 is the 5-mile stretch that connects the New River Valley Mall and the Radford Army Ammunition plant. Its pavement has a uniform width of approximately 29 feet.

The geometry of the first few miles of Route114 consists of several consecutive vertical curves. One of these vertical curves, located between station points 110 and 140, has been the scene of several accidents, and is the subject of this research. The road profile of this vertical curve is shown in Figure 1.1. It is located at 0.6 mile west of the Christiansburg town limit. The average daily traffic volume on this section of Route 114 is about 12,000 vehicles, obtained from field surveys conducted in September 2000.

In approximately seven years, from January 1994 to November 2000, eleven fatal crashes occurred on the identified section of Route 114 resulting in a total of 12 deaths and 29 injuries. Five of these crashes occurred on the stretch described above. All these crashes were head-on collisions. These fatal accidents, except for one, all occurred between the half-mile and one-mile mileposts west of the Christiansburg limit. In addition, 167 other crashes occurred on that road resulting in 181 injuries (no fatalities). The statistics show that most of the fatal crashes were caused by violators who crossed the solid yellow line at high speeds to pass the vehicles in front of them and collided with an opposing vehicle that was traveling in the opposing lane.

Two main factors contributing to such severe crashes were found to be:

- The geometry of the study section of Route 114, where almost all accidents took place, has a grade of 4.2 % on the west and east sides of the curve. That may reduce the climbing speed and the performance of some vehicles, and thus degrades the following vehicle's climbing performance. In addition, the three consecutive vertical curves reduce the visibility and increase the sight distance required for safe passing.

- In spite of the two solid yellow line markings and the "No Passing" signs that prohibit passing maneuvers, it seems that many drivers attempt to make an overtake maneuver on these crests without having a clear visibility of the opposing traffic and sufficient passing sight distance.

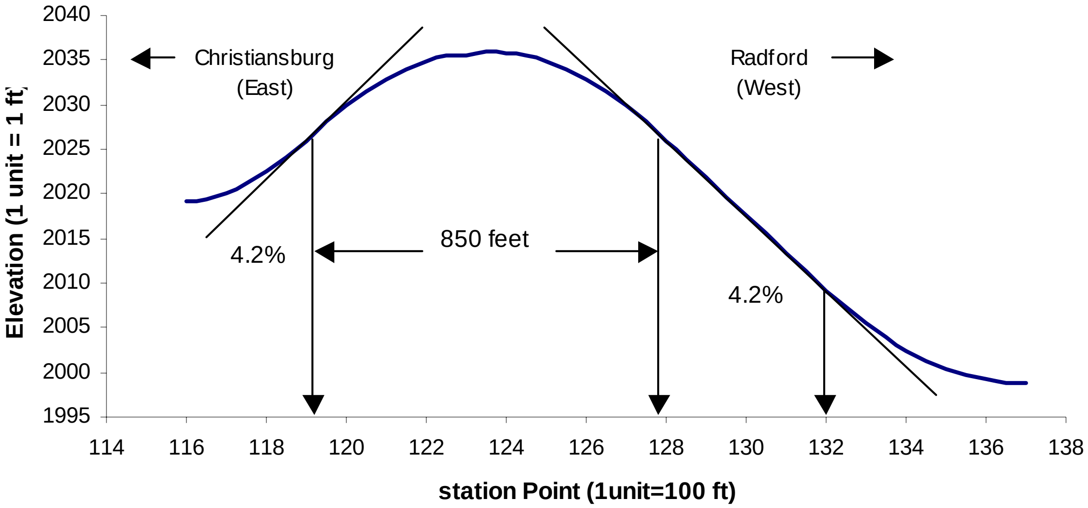


Figure1.1 - No Passing Zone Vertical Profile

1.2 Problem Statement

The low visibility and short passing sight distance due to successive crest vertical curves on route 114 has rendered passing maneuvers within the no-passing zone highly susceptible to severe head-on collisions.

1.3 Problem Solving Approach

The system under study utilizes elements of the ITS technologies such as detection and surveillance technologies, dynamic warning messages, and a communication infrastructure. In addition, the project falls under the crash prevention and safety track where vehicles are alerted to avoid collision and mitigate crash severity.

As a result, a detection and warning system was deployed through funding from Virginia Department of Transportation (VDOT) to mitigate the severity of the situation and to promote safety. The present system warns the violator in an attempt to discourage him/her from continuing the maneuver and to resume the proper lane. But, the system is helpless in case of a persisting violator who would not obey the warning message. Figure 1.2 shows the architecture of the current deployed system.

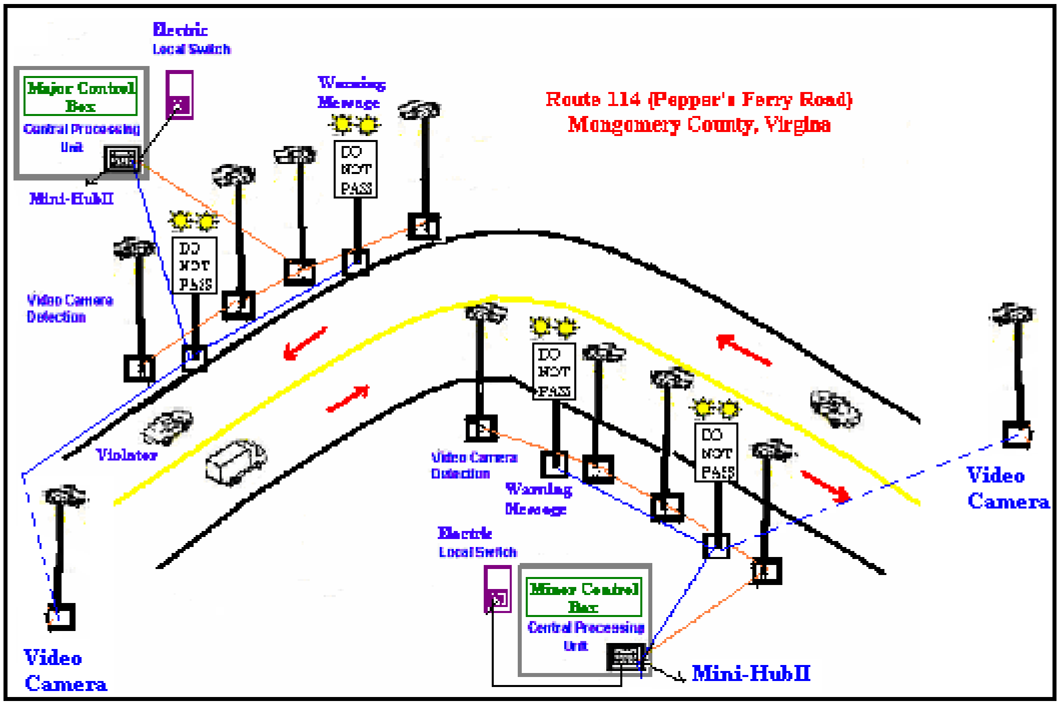


Figure 1.2 - An Overview of the System Architecture Deployed on Route114

In order to reduce and/or mitigate the severity of crashes caused by the persisting violators, a system that warns the opposing vehicle is being considered for deployment. Figure 1.3 shows the architecture of the system that includes the warning of the opposing vehicle.

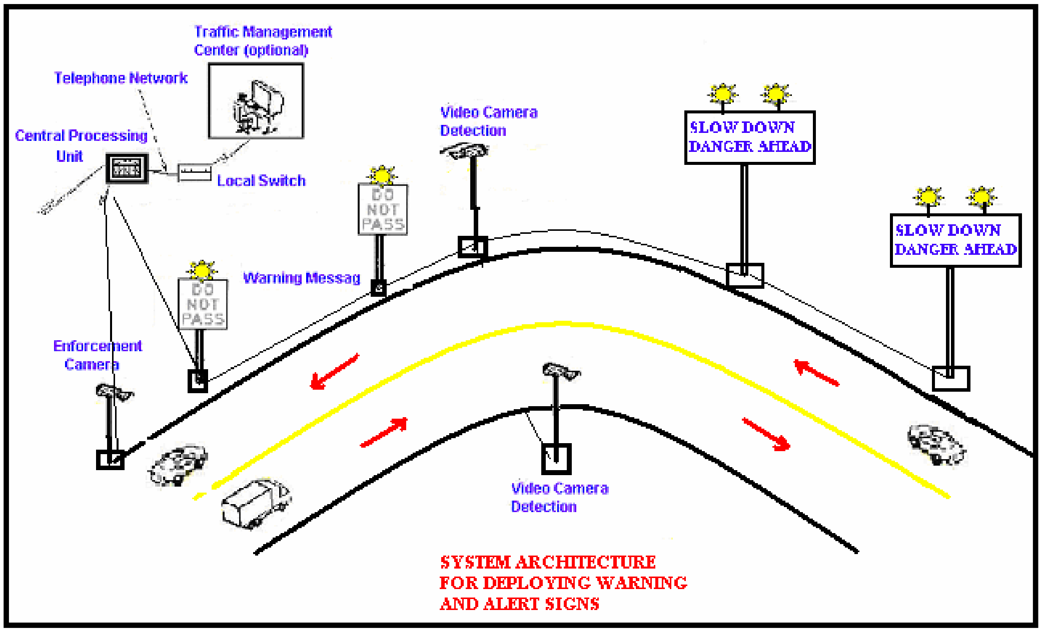


Figure 1.3 - An Overview of the Planned System Architecture (west direction)

1.3.1 Research Objectives

In order to test the new system prior to its physical installation, a computer simulation has been developed to represent the real world violation conditions so that a better understanding of the problem and its varying scenarios would be achieved. The new simulation, which is the focus of this thesis, takes advantage of an existing simulation developed earlier to replicate only the illegal maneuver without giving any warnings to the opposing vehicle. The new program simulates the outcome of deploying a warning sign to the opposing driver for crash avoidance purposes assuming that all violators persist to pass the vehicle ahead. Thus, the main objective of this research is to quantify the benefits of warning the opposing vehicle of the risky situation ahead using the extended simulation.

1.4 Other Discussed Approaches

Other alternatives to this ITS deployment have been considered by VDOT officials, such as widening the road to 4-lanes, installing concrete New Jersey barriers between the two lanes in the no-passing zone, and leveling off the crest vertical curve. In fact, the long-range plan for the District calls for widening the road to 4-lanes, but due to budgetary constraints, this alternative is not part of the upcoming 6-year Transportation Improvement Plan. The barrier alternative was deemed infeasible because of the available width of the road pavement, the need to access the abutting properties, and the legal requirement to install impact attenuators at the end points of the barrier system. The leveling alternative was also evaluated to be impractical because of the geometry of the road, the civil works involved, the costs, and the traffic interruptions and the safety considerations. Based on these considerations, the ITS alternative proved to be practical in the short term, and considered that it can play a role in preventing possible accidents at the site.

1.5 Thesis Layout

The remaining part of this thesis report is organized as follows: Chapter 2 presents the literature review of ITS crash prevention countermeasures, chapter 3 depicts the current deployed system on route 114 and its characteristics, chapter 4 discusses the architecture of the extended simulation, chapter 5 portrays the simulated results and sensitivity tests, and chapter 6 summarizes the research results and the conclusions.

CHAPTER 2. LITERATURE REVIEW

2.1 The Safety Issue

2.1.1 Introduction

The U. S. Department of Transportation's National Highway Traffic Safety Administration has lately announced that highway fatalities reached the highest level since 1990, while the injury level dropped down to an all time minimum. Alcohol-related fatalities remain at 41 percent of the total with 17, 419 deaths in 2002, up slightly from 17,400 in 2001. Historically, the majority of passenger vehicle occupants killed in crashes have not been wearing safety belts; that trend continues in 2002 with 59 percent unrestrained. As highway crashes continue to claim the lives of thousands of people, the grim statistics underscore the need for better state laws, stricter enforcement and safer driving behavior. The number of injured people has dropped from 3.03 million in 2001 to 2.92 million in 2002, a record low, with the largest decrease in injuries among occupants of passenger cars. This decline can be attributed to many factors including the improved vehicle design and technology and the deployment of tougher federal safety standards. U.S. Transportation Secretary, Norman Y. Mineta, says: "It is time to acknowledge that history is calling us to another important task. It is the battle to stop the deaths and injuries on our roads and highways." "The Bush Administration is committed to improving safety on our highways – safety is our highest transportation priority," continues Secretary Mineta,. "We have proposed a comprehensive series of initiatives to help make highways safer, and I personally urge states to pass tough laws prohibiting drunk driving and requiring the use of safety belts. Once and for all we must resolve the national epidemic on our highways" (23).

SAFETEA (Safe, Accountable, Flexible and Efficient Transportation Equity Act of 2003), the Bush Administration's surface transportation legislative proposal, will provide more than $15 billion over six years for highway safety programs. This is more than double the amount provided by the previous act, TEA-21 (Transportation Equity Act for the 21st Century). The majority of this funding would be through a new core highway safety infrastructure program instead of the existing Surface Transportation Program safety set-aside. In addition, SAFETEA will create a new safety belt incentive program to strongly encourage states to enact primary safety belt laws and achieve substantially higher safety belt use rates. SAFETEA will also combine the several safety programs administered by NHTSA into a consolidated grant program.

"It may cost you your life if you drink and drive or fail to wear your safety belt", said NHTSA Administrator Jeffrey Runge, MD. "On the other hand, driving sober and wearing a belt will significantly increase your chance of survival on the highway."

2.1.2 Accident Statistics

Though overall fatalities has increased to 42,815 in 2002 from 42,196 in 2001, the fatality rate per 100 million vehicle miles traveled (VMT) remains at 1.51, a historic low. According to Federal Highway Administration estimates, VMT has increased in 2002 to 2.83 trillion, up from 2.78 trillion in 2001. NHTSA estimates show that highway crashes, in general, cost society $230.6 billion a year, about $820 per person. A fatality in rollover crashes account for 82 percent of the total fatality increase in 2002. In 2002, 10,666 people have died in rollover crashes, up 5 percent from 10,157 in 2001. The number of persons killed in sport utility vehicles (SUVs) that rolled over has risen 14 percent. Sixty-one percent of all SUV fatalities involve rollovers. These crash statistics are relative to all areas in the United States. (20)(22)

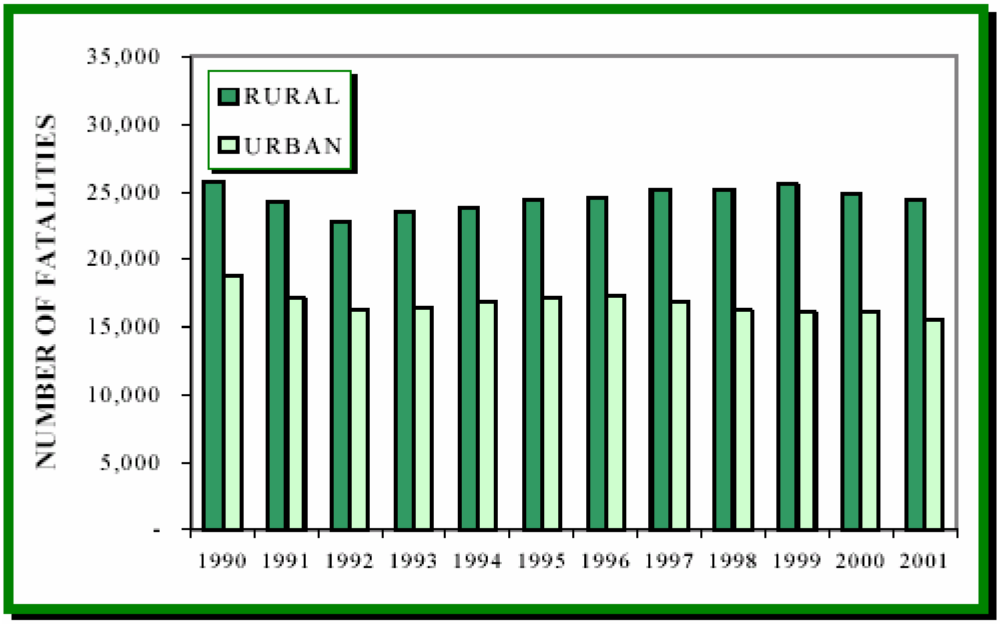
NHTSA's Fatality Analysis Reporting System (FARS) also shows that, in 2002:

- Motorcycle fatalities increased for the fifth year in a row following years of steady improvement. A total of 3,244 riders died, up slightly from 3,197 in 2001. It was the smallest increase in motorcycle fatalities in five years. However, deaths among riders 50 and over increased 26 percent.
- Alcohol-related fatalities have been rising steadily since 1999. However, deaths in low alcohol-involvement crashes (.01-.07 blood alcohol concentration (BAC)) dropped 5.5 percent from 2001 to 2,401 deaths.
- Fatalities from large truck crashes dropped from 5,111 in 2001 to 4,897 in 2002, a 4.2 percent decline.
- Fatalities among children seven and under dropped to historic low levels. In 2002, 968 children seven and under were killed, down from 1,059 in 2001.
- Pedestrian deaths also declined, to 4,808, a 1.9 percent drop from 2001.
- In fatal crashes between passenger cars and LTVs (light trucks and vans, a category that includes SUVs), the occupants of the car were more often fatally injured. When a car was struck in the side by an LTV, the fatality was 20.8 times more likely to have been in the passenger car. In a head-on collision between a car and an LTV, the fatality was 3.3 times more likely to be among car occupants.

2.1.3 Rural Crash Rates

This section discusses the crash rates of rural areas contrasting them with the urban values. From a general point of view, the United States is a highly urbanized society. Seventy-nine percent of the United States population lives in urban areas based on the 2000 census (U.S. Census Bureau, 2001a). Federal-aid legislation specifically defines an urban area as a census place with an urban population of 5,000 to 49,000, or a designated urban area with a population of 50,000 or more (FHWA, 2000). People in the U.S. consequently end up traveling more on urban roads than on rural roads. (24)

Consequently, it stands to reason that there are more motor vehicle crashes on urban than on rural roads. Surprisingly, in 2001, 60 percent of all U.S. motor vehicle fatal crashes occurred on rural roads (NHTSA, 2001). A fatal crash is a motor vehicle accident where one or more persons dies. The 2001 crash data show that there were 22,735 fatal crashes involving 34,165 vehicles and 59,359 individuals, resulting in 25,737 fatalities in rural areas, while urban areas accounted for 15,060 fatal crashes involving 22,290 and 41,609 individuals resulting in 16,379 fatalities. When adjusted for miles traveled, the rural fatality rate was 2.3 fatalities per hundred million vehicle miles traveled (VMT), while the urban rate was 1.0 fatality per hundred million VMT. In other words, for every mile driven, a motor vehicle fatality is more than two times as likely to occur on a rural road than on an urban road. Besides, head-on crashes, which is the bulk problem addressed in this project, are more prevalent in rural areas making up 17 percent of all rural fatal crashes. In urban areas, head-on crashes are responsible for less than 9 percent of all urban fatal crashes. Besides, the damage to vehicles involved in rural fatal crashes is more severe than the damage to vehicles involved in urban fatal crashes as measured by the percent of disabling deformation. Almost 80 percent of vehicles involved in rural fatal crashes are disabled, whereas 65 percent of vehicles involved in urban fatal crashes are disabled, which shows the higher severity of rural crashes.



Source: NCSA, NHTSA, FARS 1990-2001

Figure 2.1 - Number of Traffic Fatalities by Year and Location

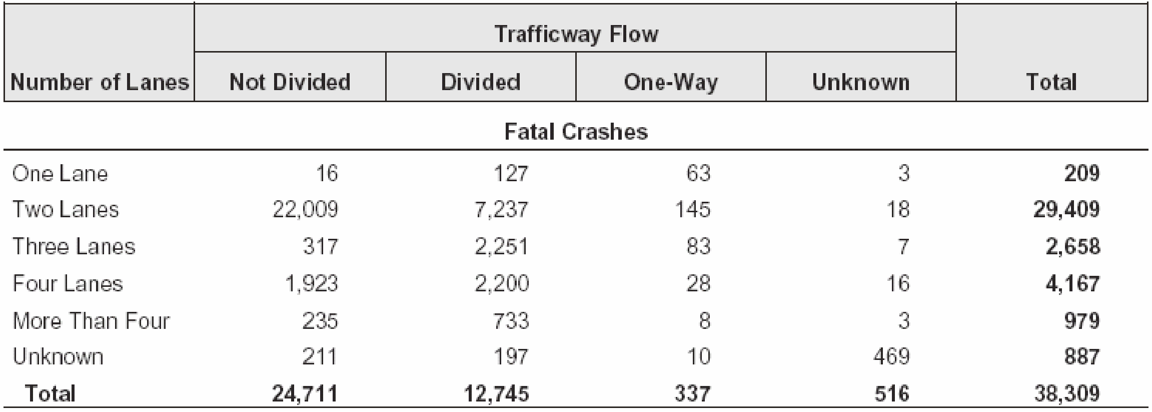
Table 2.1 - Fatal Crashes by Land Use and Speed Limit[♣]

Speed Limit	Land Use						Total	
	Rural		Urban		Unknown			
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
30 mph or less	932	24.6	2,830	74.8	22	0.6	**3,784**	**100.0**
35 or 40 mph	2,096	32.0	4,425	67.5	34	0.5	**6,555**	**100.0**
45 or 50 mph	3,653	52.4	3,287	47.1	35	0.5	**6,975**	**100.0**
55 mph	10,088	82.6	2,089	17.1	32	0.3	**12,209**	**100.0**
60 mph or higher	5,459	72.1	2,101	27.8	9	0.1	**7,569**	**100.0**
No Statutory Limit	82	82.8	17	17.2	0	0.0	**99**	**100.0**
Unknown	406	36.3	691	61.8	21	1.9	**1,118**	**100.0**
Total	**22,716**	**59.3**	**15,440**	**40.3**	**153**	**0.4**	**38,309**	**100.0**

Table 2.1 presents the fatal accidents statistics of the year 2002, which is consistent with the previous years statistics, showing that rural crashes are about 60% of the total nations fatal crashes. Table 2.2 divides the fatal crashes among the different highway layouts (number of lanes) and the corresponding traffic flow characteristics. As shown, two-lane two way undivided highways, that is the same layout of route 114 under study, are the most frequent scenes of fatal crashes. 22,009 fatal crashes occurred on such roads in 2002. Nevertheless, 60% of this number of crashes occurred on rural roads amounting to approximately 13,200 fatal crashes. That is, about 34.5% of the total fatal crashes of the United States occur on rural two-lane two-way highways, such as route 114 of southwest Virginia.

[♣] 2002 Motor Vehicle Crash Data from FARS and GES

Table 2.2 - Fatal Crashes by Number of Lanes and Traffic Flow[♣]



	Trafficway Flow				
Number of Lanes	Not Divided	Divided	One-Way	Unknown	Total
Fatal Crashes					
One Lane	16	127	63	3	**209**
Two Lanes	22,009	7,237	145	18	**29,409**
Three Lanes	317	2,251	83	7	**2,658**
Four Lanes	1,923	2,200	28	16	**4,167**
More Than Four	235	733	8	3	**979**
Unknown	211	197	10	469	**887**
Total	**24,711**	**12,745**	**337**	**516**	**38,309**

2.2 Crash Reduction Initiatives

New technologies are being developed to reduce the number of motor vehicle accidents, which are mainly caused by driver error. Because these technologies are not necessarily compatible, USDOT has instituted the Intelligent Vehicle Initiative (IVI) program. This initiative aims to ensure that the technologies will work together in a way that is not confusing or counterproductive to users. Its primary goal is to accelerate the development and deployment of driver assistance products that have the potential of reducing the number and severity of motor vehicle collisions. The IVI covers applications for light vehicles, commercial trucks, transit buses, and specialty vehicles such as highway maintenance vehicles. DOT is working with industry and others to help build critical knowledge bases, develop performance guidelines and objective test procedures, evaluate IVI systems using field operational tests, and assess their potential benefits. (29)

Under the same umbrella, the National Highway Traffic Safety Administration has initiated a program where such collision avoidance technologies can be tested and evaluated. Since the classes of vehicles that are being dealt with cover a wide range, an innovative idea to cut on the financial burdens is to use one car that can simulate the behavior of a number of other car types. Thus, to study the correlation between vehicle response characteristics and driver commands relative to crash avoidance, the NHTSA's Office of Crash Avoidance Research (OCAR) has at its disposal a comprehensive set of tools and facilities. These include the Vehicle Research and Test Center, and the National Advanced Driving Simulator (currently being developed). To augment these tools and facilities, OCAR has defined its concept of a Variable Dynamic Test-bed Vehicle (VDTV). This vehicle will be capable of emulating a broad range of automobile

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[♣] 2002 Motor Vehicle Crash Data from FARS and GES dynamic characteristics, allowing it to be used in development of collision avoidance systems, and conducting of driving-related human factors research, among other applications.

2.3 Collision Situations

This section discusses the current deployed technologies that aim at minimizing the number of crashes and mitigating their severity in an attempt to contrast or evaluate their possible usage in our project that deploys an ITS system as a crash prevention tool. Prior to discussing the planned techniques to be installed or implemented, a brief overview of the most common problems leading to collisions is presented. There are seven major crash situations that can be listed as follows: the Rear-End collision, Lane change/Merge collision, Road Departure collision, Intersection collision, collision due to degraded Visibility, collision due to Driver's Condition, and finally collision due to Vehicle Stability. The following section presents general information and statistics about each type of collision condition as provided by the USDOT and the NHTSA estimates. (29)

2.3.1 Rear-End Collision Case

Approximately, 25% of the total number of crashes is related to rear end collision types, which sums up to about 1.5 million crashes a year. The techniques that are planned to be deployed to avoid such kind of collisions encompass sensors that detect the presence and speed of vehicles ahead and then provide warning messages. Early versions will use extensions of adaptive cruise control capabilities to detect and classify stationary objects and to determine the level of threat from vehicles in front. This will complement the limited speed control of adaptive cruise control systems. NHTSA estimates predict that the success of these technologies will reduce the rear-end collisions by 49 percent (759,000 crashes each year). Several projects have been completed and others are in progress, including a major operational test of a rear-end crash warning system for passenger vehicles. Rear-end crashes are also a significant problem for transit buses. The same technology developed for passenger cars will help reduce the number and severity of transit bus crashes. Performance of these systems may be enhanced in the future by combining them with route guidance and cooperative communications with highway infrastructure systems.

2.3.2 Lane Change/Merge Collision Situations

Collisions during lane changes and merges also represent a major problem area, accounting for 1 in 25 of all crashes, with 90 percent caused by lane changes and 10 percent by merges. Primarily, accidents in this case occur at an angle or a sideswipe position. This problem requires in-vehicle technology to help detect and warn drivers of vehicles in adjacent lanes. These systems monitor the lane position and relative speed of other vehicles beside and behind the equipped car, and advise drivers of the potential for collision. It is estimated that these systems could apply to 192,000 of the approximately 200,000 lane change/merge crashes each year. A project currently underway is studying the special needs of transit buses in these situations.

2.3.3 Road Departure Collision Case

This type of accidents mainly encompasses the single vehicle crash where the vehicle leaves the road before being involved in any collision. In fact, one in five crashes are reported as a single-vehicle roadway departure. NHTSA estimates that intelligent vehicle systems can apply to about 458,000 of the 1.2 million crashes each year. Systems to avoid road departure collisions will warn the driver when his or her vehicle is likely to deviate from the lane of travel. These systems track the lane or road edge and suggest safe speeds for the road ahead. Future capabilities may integrate an adaptive cruise control function to adjust vehicle speed for the shape of the road, based on input from a map database and navigation system (GIS/GPS). Eventual cooperative communication with the highway infrastructure or use of in-vehicle sensors to assess road surface conditions (e.g., wet, icy, etc.) could improve the performance of the system. Drowsy driver advisory systems may be incorporated as another enhancement.

2.3.4 Intersection Collision Case

The problem of intersection collisions requires systems that monitor a vehicle's speed and position relative to the intersection, along with the speed and position of other vehicles in the vicinity, advising the driver of appropriate actions to avoid a right-of-way violation or impending collision. It is a complex situation to fully develop collision avoidance systems at intersections since this requires full coordination among all the involved vehicles and the intersection infrastructure. The US Department of Transportation through the NHTSA developed a plan of study to resolve this problem. The plan focuses on implementing in-vehicle systems first, then augmenting those with information from map databases and cooperative communication with the highway (intersection) infrastructure. Technologies would sense the position and motion of other vehicles at intersections and determine whether they are slowing, turning, or violating right-of-way laws or traffic control devices. An analysis of crash data concludes that 30 percent of all crashes, or 1.8 million, were intersection/crossing path in nature. This problem area affects each of the IVI vehicle platforms. A separate section of this report will discuss the intersection problem with more details related to the technologies used in one of the projects and the planned enhancements as well as the accrued results.

2.3.5 Collision Due to Degraded Visibility

Reduced visibility is a major factor of crashes especially when a maneuver requires a fast and accurate visual response. It is responsible for more than 42 percent of all vehicle crashes. Reduced visibility can be caused by lighting and weather conditions such as glare, dawn, dusk, dark, artificial light, rain, sleet, snow, and fog. Analyses suggest that of incidents having reduced visibility as a cause, one-third involve single-vehicle roadway departure crashes and one-fifth pertain to rear-end collisions. Further, more than one-half of pedestrian incidents occur at night and include reduced visibility as a significant factor. Vision enhancement services will likely be introduced through in-vehicle systems that use infrared radiation from pedestrians, animals, and roadside features to give drivers an enhanced view of what's ahead. Future versions may include information from highway infrastructure improvements such as infrared reflective lane-edge markings. Manufacturers are already introducing night vision enhancement products.

2.3.6 Collision due to Vehicle Stability

This case is being handled by deploying in-vehicle systems that enhance stability especially in commercial vehicle that have higher centers of gravity and coupling points which make them more prone to jackknife or roll over. Most incidents of heavy vehicle instability are triggered either by braking or rapid steering movements. Because heavy vehicle instability often results in rollover, this problem is particularly serious in terms of its potential to cause loss of life, injuries, property damage, and traffic tie-ups. Two technologies look promising. The first is an in-cab device that shows the rig's rollover threshold and the driver's margin to it at any particular time. The second is a system for multiple-trailer combinations that will stabilize the rig by selectively applying braking at individual wheels. This system is intended to reduce a phenomenon called rearward amplification, where each successive trailer has a more severe reaction to an initial steering move by the driver. For this system to work, the entire combination must be equipped with electronically controlled braking systems (ECBS). Currently, ECBS is a production option from one tractor manufacturer.

2.3.7 Collision Due to driver’s Condition

Truck driver fatigue is a factor in 3 to 6 percent of fatal crashes involving large trucks. Fatigue is also a factor in 18 percent of single-vehicle, large-truck fatal crashes, which tend to occur more frequently in the late-night, pre-dawn hours. Commercial drivers themselves recognize fatigue and inattention as significant risk factors, having identified these conditions as priority safety issues at a 1995 Truck and Bus Safety Summit. Driver condition warning systems alert drivers of conditions such as drowsiness, a problem area for which DOT is currently developing a real-time, on-board monitor which measures the degree eyelids are covering the pupils, the best known predictor for the onset of sleep. Technologies are also being used to provide overall drowsiness status through feedback mechanisms, allowing the driver to formulate better sleep habits. This service will probably be introduced first on commercial vehicles.

2.4 ITS Crash Prevention Countermeasures

In this part of the thesis, I will be delving into the details of most ITS crash prevention countermeasures. The order of presenting these countermeasures is dictated by how much the countermeasure is related to the problem on route 114 and the possibilities of applying it to the route 114 problem area.

2.4.1 Intersection Problem

2.4.1.1 Introduction

Intersections are areas of highways and streets that naturally produce vehicle conflicts among vehicles and pedestrians because of entering and crossing movements. Reducing fatalities and injuries can only be accomplished by careful use of good road design, traffic engineering choices, comprehensive traffic safety laws and regulations, consistent enforcement efforts, sustained education of drivers and pedestrians, and the drivers' and pedestrians' willingness to obey and sustain the traffic safety laws and regulations.

2.4.1.2 General Information and Statistics

Intersection safety is a national priority for numerous highway safety organizations. Driving near and within intersections is one of the most complex conditions drivers encounter. In 2000, there were more than 2.8 million intersection-related crashes representing 44 percent of all reported crashes. Approximately 8,500 fatalities (23 percent of the total fatalities) and almost one million injury crashes occurred at or within an intersection environment. The cost to society for intersection-related crashes is approximately $40 billion every year. (15)

Despite improved intersection designs and more sophisticated applications of traffic engineering measures, the annual toll of human loss due to motor vehicle crashes has not substantially changed in more than 25 years. Two subgroups are involved in intersection/intersection-related crashes at high levels: senior drivers and pedestrians. Senior drivers do not deal with complex traffic situations as well as younger drivers do, and that is particularly evident in multiple-vehicle crashes at intersections. People 65 years and older have a higher probability of causing a fatal crash at an intersection, and approximately half of these fatal crashes involved drivers that were 80 years and older. Older drivers are more likely to receive traffic citations for failing to yield, turning improperly, and running stop signs and red lights. Intersections are disproportionately responsible for pedestrian deaths and injuries. Almost 50 percent of combined fatal and non-fatal injuries to pedestrians occur at or near intersections. Pedestrian casualties from vehicle impacts are strongly concentrated in densely populated urban areas where more than two-thirds of pedestrian injuries occur.

Table 2.3 - General Intersection Collision Statistics (16)

	TOTAL NUMBER	**PERCENT**
Total Fatality Crashes	37,409	
Total Intersection-related fatality crashes	8,474	22.6%
Total Injury Crashes	2,070,000	
Total Intersection-related injury crashes	995,000	48.1%
Total Property-Damage-Only (PDO) Crashes	4,286,000	
Total PDO Intersection-related crashes	1,804,000	42.1%
All Crashes	6,394,000	
Total Intersection-related crashes	2,807,000	43.9%
Total Fatalities	41,821	
Total Intersection-related injured persons	1,596,128	

The varying nature of intersection geometries and the number of vehicles approaching and negotiating through these sites result in a broad range of crash configurations. Preliminary estimates by the National Highway Traffic Safety Administration (NHTSA) indicate that crossing path crashes occurring at intersections represent approximately 26 percent of all police reported crashes each year. This proportion translates into 1.7 million crashes. For the aforementioned reasons, the USDOT through the NHTSA funded the Intersection Collision Avoidance System (ICAS) program that has been developed to address the intersection crash problem and apply ITS technology to prevent or reduce the severity of intersection crashes.

2.4.1.3 Definition of Crash Scenarios

This section of the thesis documents analyses performed in support of the Intersection Collision Avoidance using ITS Countermeasures program under NHTSA Contract No. DTNH22-93-C-07024. This work was performed by the Intelligent Transportation Group of Veridian Engineering and the Battelle Memorial Institute during the time frame of March 1, 1998 to August 1, 1999. This program is formed of three phases. Phase I has illustrated that collisions occurring within the boundaries of an intersection are the second most frequently occurring type of crash, (i.e., second only to single vehicle roadway departure crashes). Phase II of this program has investigated the technology and research available to construct the countermeasures described in Phase I. Technology requirements have been assessed in key areas, such as processors, sensors, actuators, and driver-vehicle interface (DVI) characteristics, to determine the equipment that will facilitate construction of a prototype intersection collision avoidance system. Phase III has developed the Test-bed systems, implemented the systems on a vehicle, and performed testing to determine the potential effectiveness of this system in preventing intersection crashes. Through this study, the intersection crash scenarios are divided into three primary and one secondary crash scenario that will be listed and discussed later on in this report. The section of this report about intersection is based on the study presented in phase III mentioned above. The vehicle test-bed can be seen in figure 2.2 below. (15)

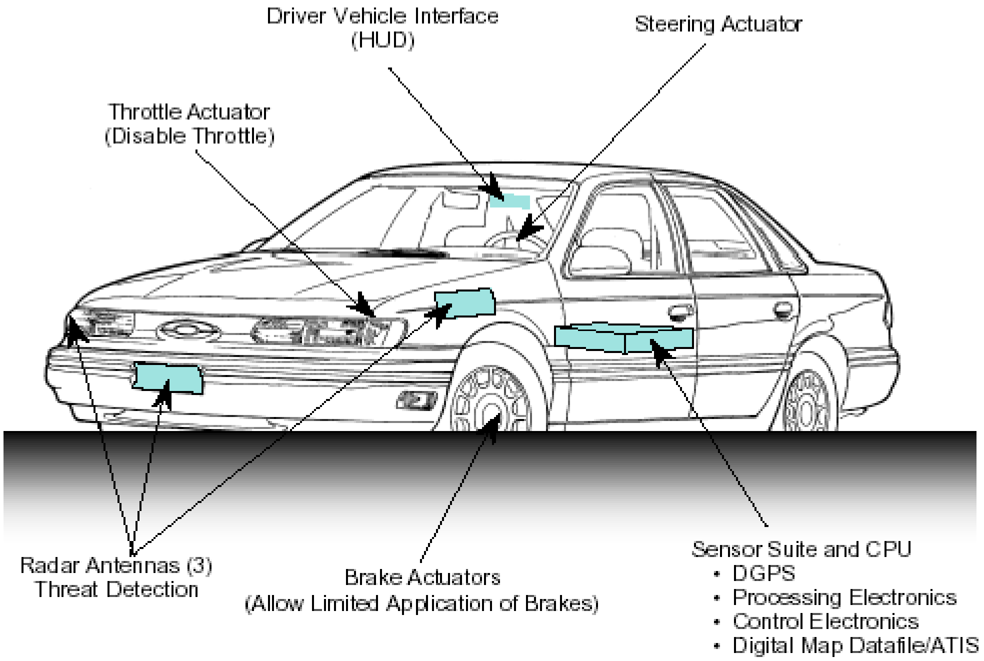


Figure 2.2 - Driver Advisory System Concept

2.4.1.3.1 Intersection Crash Scenario No. 1

The Subject Vehicle (SV) is required to yield, but not stop for the traffic control; therefore, no violation of the control device occurs. A large proportion of these cases consist of the SV approaching a traffic signal with a displayed green phase. All other cases in this scenario are cases where the SV is uncontrolled, where no traffic control device is present on the roadway segment being traveled by the SV. The SV attempts a left turn across the path of the Principal Other Vehicle (POV). The SV is either slowing, or at a stop in the traffic lane. This crash scenario is illustrated in Figure 2.3.

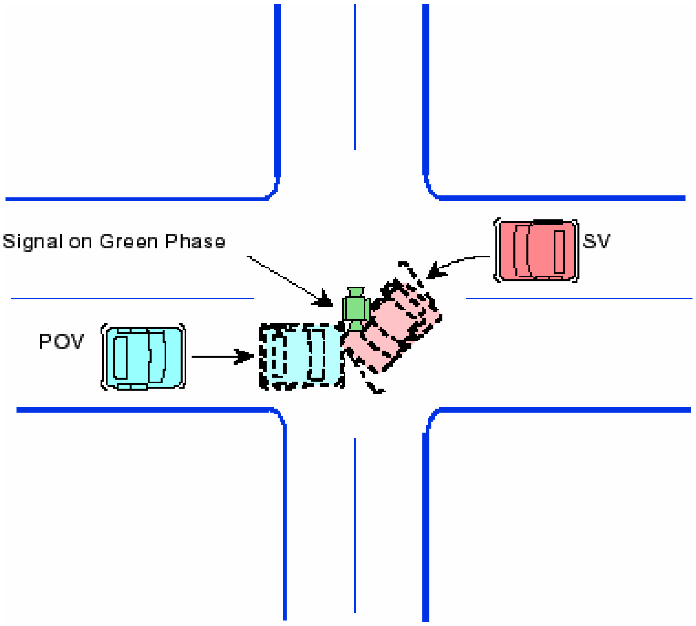


Figure 2.3 - Intersection Collision Scenario No.1

(Left Turn Across Path)

2.4.1.3.2 Intersection Crash Scenario No. 2

The SV is stopped, as required, prior to entering the intersection. Almost all the cases in this category are intersections controlled by stop signs along the roadway being traveled by the SV. No traffic control is present on the roadway being traveled by the POV. The SV attempts to traverse the intersection, or attempts to perform a left turn onto the roadway being traveled by the POV. This intersection crash scenario is illustrated in Figure 2.4.

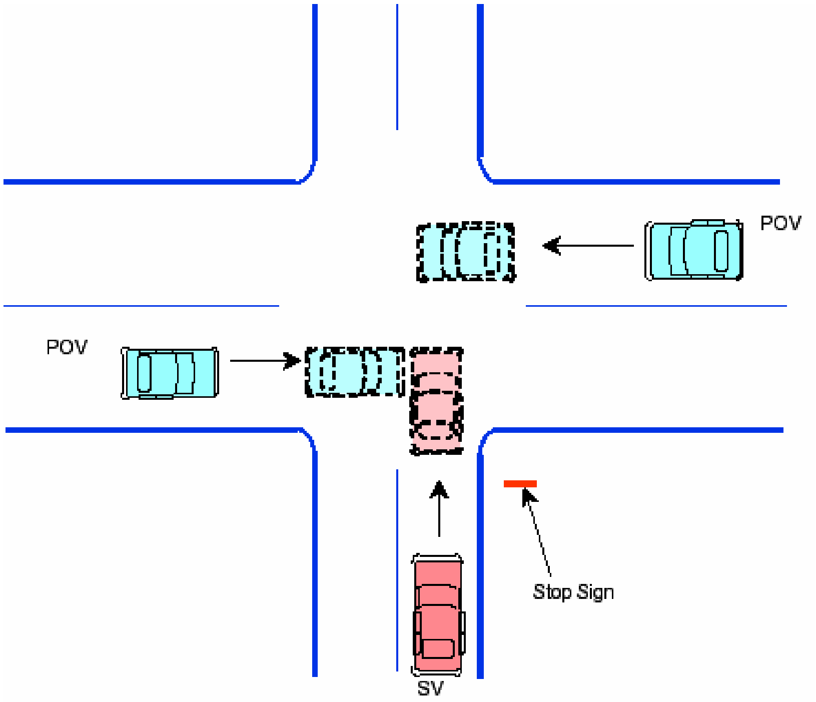


Figure 2.4 - Intersection Collision Scenario No.2

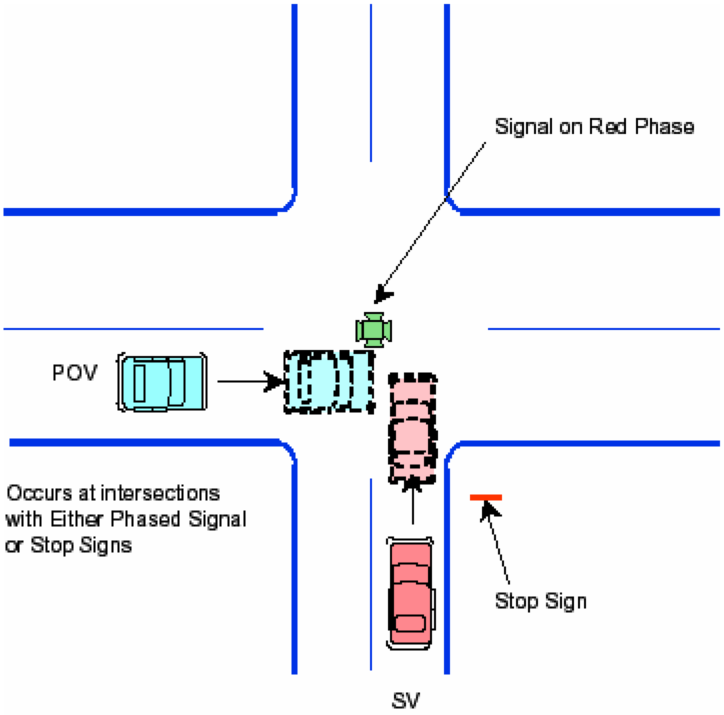
Perpendicular Paths (No Violation of Traffic Control)

2.4.1.3.3 Intersection Crash Scenario No. 3

The SV does not stop prior to entering intersection. All of these cases involve violations of the traffic control device. The POV has the right of way and enters the intersection. In a very high proportion of these crashes, the vehicles are performing an intersection traversal on straight paths. This intersection crash scenario is illustrated in Figure 2.5.

2.4.1.3.4 Intersection Crash Scenario No. 4

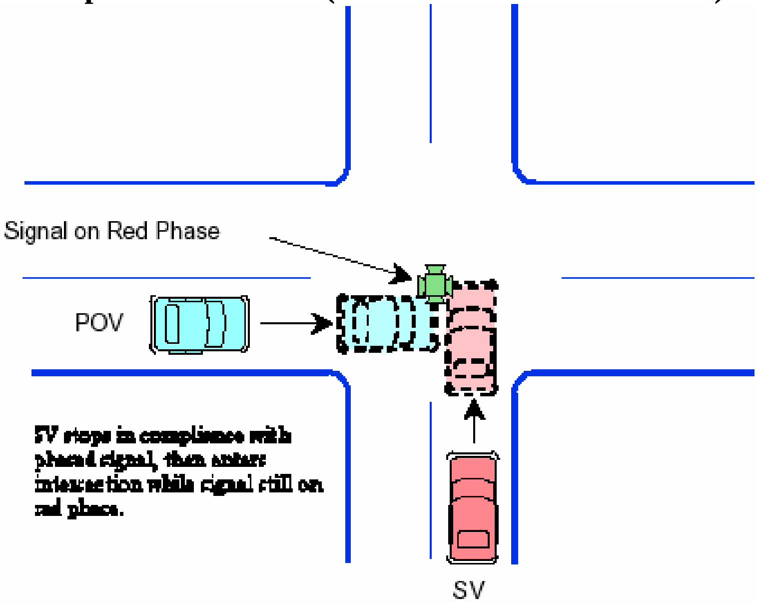
This is a distinct, although less frequently observed crash scenario than the first three described above. This scenario occurs when the subject vehicle approaches an intersection controlled by a signal with a displayed red phase. The SV stops, and then proceeds into the intersection prior to the signal phasing to green. This intersection crash scenario is illustrated in Figure 2.6.



Occurs at intersections with Either Phased Signal or Stop Signs

Figure 2.5 - Intersection Collision Scenario No.3

Perpendicular Paths (Violation of Traffic Control)



SV stops in compliance with phased signal, then enters intersection while signal still on red phase.

Figure 2.6 - Intersection Collision Scenario No.4

Premature Intersection Entry

Table 2.4 - Distribution of Intersection Crash Scenarios

No.	Crash Scenario	Percentage
1	Left Turn Across Path	**23.8**
2	Perpendicular Path - Entry with Inadequate gap	**30.2**
3	Perpendicular Path - Violation of Traffic control	**43.9**
4	Premature Intersection Entry - Violation of Traffic Control-Signal	**2.1**
	Total	**100**

2.4.1.4 ITS Countermeasure Architecture (16)

The Intersection Collision Avoidance System (ICAS) described in this section is designed to provide a driver with warnings of an impending crash or potential hazards at intersections. Thus, this system follows the same objectives of this thesis plan. The original design has been altered due to financial limitations. Primary changes include the elimination of the Signal-to-Vehicle Communication system, and the re-design of the Threat Detection System which will be discussed later. The elimination of the Communication system prevents the ICAS from being effective against collisions caused by drivers violating signals on red phase since no more information on the current signal phase is acquired from the signal. The Intersection Countermeasure is comprised of four sub-systems; the threat detection system, the GIS/GPS system, the driver vehicle interface, and the vehicle support system. The countermeasure has been designed as an “add-on” to the vehicle platform, where all components are integrated into the vehicle system and structure to the greatest extent possible in this type of application. Side-looking radars are placed on the vehicle roof in order to acquire data on vehicles approaching the intersection on perpendicular paths. This resulted in the placement of radars in obvious view on the roof of the vehicle.

2.4.1.4.1 Threat Detection System

The threat detection system utilizes millimeter wave radars to acquire data on vehicles approaching the intersection. The ICAS utilizes three VORAD EVT-200 radar systems. These radars operate at 24 GHz frequencies and provide range and range rate data. The radar antennas are mounted to a scan platform, which are motorized, and gear-driven to allow the radars to be pointed to specific areas of the intersection as the vehicle approaches the intersection. An optical encoder, mounted along the rotational axis of the antenna, provides angular position data. The scan platform is designed to allow the antenna to be positioned, through computer control, to the adjacent roadways of the intersection the vehicle is approaching. Three scan platforms are utilized; two on the vehicle roof to monitor the perpendicular roadways and one forward-looking unit to monitor the parallel roadway. A photograph of the three radars installed on the ICAS Test-bed is shown in Figure 2.7.

Figure 2.7 - The ICAS Test-Bed

The standard VORAD electronics is used to process the data coming out of the antennas. The tracker utilizes radar data, in conjunction with information on the intersection provided by an on-board map data-file, to determine if the ICAS Test-bed will occupy the intersection at the same time as vehicles on perpendicular, or parallel, but opposite direction paths.

2.4.1.4.2 GIS/GPS System

The Geographical Information System/Global Positioning System (GIS/GPS) is a system that includes a Global Positioning System (GPS), a differential correction receiver, and an on-board map database to prevent collisions at un-signalized intersections. The system uses differentially corrected position information provided by the GPS to place the ICAS Test-bed on a specific roadway identified in the map database. The map database contains information about the location of intersections, along with roadways. The map data-file used in this program is a modification of the standard NavTech product. The map data-file for the test area was modified by use of higher precision of intersection location, and the inclusion of a data field for traffic controls at intersections. This information is used by the countermeasure to locate the ICAS vehicle on a roadway, and to determine vehicle distance to intersection. With the distance to intersection known the speed of the vehicle can be acquired from vehicle sensors, such as the speedometer, and used to calculate the braking effort required to prevent intersection entry, or

"a_p". This metric is used to monitor driver reaction to the intersection prior to entry. The warning value (0.35g) is a compromise between assuring that the driver has not responded to the stop sign at the intersection they are approaching, and the desire to limit false alarms. The algorithm deactivates the warning if vehicle speed is less than 5 mph. In the ICAS application, the calculation of a_p is limited to those intersections controlled by stop signs. This feature could be expanded to phased signals through the use of a signal to vehicle communication system. If the system detects that the driver is not responding to the intersection, through exceeding the a_p threshold, a warning is provided to the driver through the Driver-Vehicle Interface.

With some alteration to it, such a system could perform effectively in warning drivers of dangerous violators ahead by the fact that the GIS/GPS system in the vehicle can identify the position of the vehicle itself as well as the violating vehicle and calculate, based on the imbedded map, whether there is a possibility of crash or not had the driver seen the violator or did not. Then, it displays the warning to the driver. But, a condition for this to work is that all vehicles are to be equipped with the appropriate devices.

2.4.1.4.3 Driver Vehicle Interface

The Driver-Vehicle-Interface (DVI) is used to transmit warnings to the vehicle driver. The DVI utilizes multiple sensory modes to transmit the warnings. Included within the DVI is a Head-Up Display (HUD), auditory system, and haptic warning system. The HUD and auditory systems are commercially available components that were utilized to support this program. This system utilizes a secondary, computer controlled brake system on the ICAS testbed. The system is triggered when the a_p threshold is exceeded. The haptic system provides three deceleration pulses to warn the driver of the intersection they are approaching and to react to it.

2.4.1.4.4 Vehicle Systems

The vehicle systems are systems that have been integrated into the chosen passenger car (Ford Crown Victoria) in order for the ICAS to function properly. Other features considered when selecting the vehicle are room to install the ICAS equipment and a heavy-duty charging system. The ICAS equipment has been successfully integrated into the Vehicle with a minimal amount of modifications. The two areas where changes were made are the vehicle braking system, and installation of a roof mount for the various equipments. The changes made to the vehicle could have been made at the factory if this system were accepted by a vehicle manufacturer.

This system comprises a cluster of homogeneously functioning subsystems that aim at minimizing crashes at intersections, as previously stated. Such a system, although extremely expensive for our deployment purposes, has the ability to address the route 114 problem. To be able to do that, vehicles as well as the road infrastructure should be equipped with the aforementioned devices. Similar to the concept of warning vehicles approaching an intersection, this system, with the proper devices and road map, can also warn both the violator and the opposing vehicle of a clear and present danger situation. First, through the installed infrastructure devices, such as lane sensors, the system detects the violation action, and then warns the opposite vehicle, as well as the violator, by sending signals to the vehicle devices just mentioned in the driver vehicle interface section above. Thus, such an application can be slightly adjusted to fit our purposes.

2.4.2 Reduced Visibility Problem

2.4.2.1 Introduction

This section of the report provides a preliminary analysis of reduced visibility crashes to support the development of crash avoidance system (CAS) concepts as part of the Intelligent Vehicle Highway System (IVHS). A reduced visibility crash is defined and background on driver perception is presented in order to identify candidate sources of visibility limitations and enhancements. Some indications as to the size of the reduced visibility problem are presented. Candidate functional crash avoidance concepts are presented in terms of in-vehicle warning systems, roadway information systems, direct vision enhancement systems, and imaging vision enhancement systems. Reduced visibility is related to route 114 problem in the sense that the violator, as well as the opposing vehicle at the no-passing zone on route 114, has no visibility of the oncoming traffic due to the crest vertical curve alignment of the road. For this reason and because it includes ITS crash countermeasures, the reduced visibility issue is being discussed in this thesis report.

2.4.2.2 Definition

Reduced visibility influences on driver performance can assume a variety of forms. The driver may briefly deviate from the road after losing sight of the roadway edge or pileups may occur that involve dozens of cars colliding in the fog, with the resulting loss of life, serious injury, and financial costs. Like many complex factors, reduced visibility can be defined in a variety of ways. Reduced visibility is defined here as: "*Interference, caused by low light or obscurants, with the capability of the road, other vehicles, or potential obstacles to stand out in relation to their backgrounds so as to be readily detected by a driver.*" With respect to viewing conditions, reduced visibility is assumed to occur under both daylight and nighttime conditions.

In simplest terms, the driver's visual requirements involve target detection, recognition, and identification. Object visibility is fundamentally proportional to object angular size and apparent object-background luminance contrast. Angular size is a function of distance and orientation between object and viewer. Apparent contrast is a function of ambient lighting (such as nighttime driving) and the presence of obscurants in the air (such as driving in fog, dust, or rain). (25)

Generally speaking, it is clear that fog and rain reduce the ability of an observer to perceive contrast and visual angle attributes of an object or visual scene. Hence, the ability to detect lane edge markings, roadway alignment, and curves based on purely fovea1 cues is degraded.

2.4.2.3 ITS Countermeasure Architecture

After discussing the problem in general, it is time to present the Intelligent Vehicle highway system (IVHS) crash avoidance techniques related to the reduced visibility case. These countermeasures include many categories of which few are listed hereunder. (25)

2.4.2.3.1 Direct Vision Enhancement Systems

Direct vision enhancement increases the type or amount of information normally available to the driver from sources outside of the vehicle. Examples of direct vision enhancement are taillight redesigns and ultraviolet high-beam headlights. Rockwell's team at Ohio State University constructed a taillight consisting of a red light with three boxes. At long distances, the red light appeared as a single box. When the distance to the vehicle decreased, two boxes could be seen. If the distance was very tight, three boxes were seen. In effect, the following driver could gauge the distance between the two vehicles on the basis of the appearance of the taillight. However, a disadvantage of this system can be that "Smart" taillights might change in brightness in response to reduced visibility conditions. Another form of direct vision enhancement that is intended to reduce glare and increase seeing distance is polarized head-lighting (Johansson and Rumar, 1968; Perel, 1994). The system consists of a polarized filter over each headlight and a polarized filter (the analyzer) through which the driver views the oncoming traffic. Since the 19 polarization axis of the opposing traffic headlights is 90 degrees from the analyzer, the headlight intensity is greatly reduced when viewed through the analyzer. An analyzer may also be placed on rear view mirrors to reduce glare from following vehicles. Ultraviolet high-beam headlights, used in addition to normal low-beam headlights, can increase the visibility range at night up to 200 meters (656 feet), yet do not cause blinding glare to oncoming traffic (Najm, 1994; Fast & Ricksand, 1994). To be effective, however, fluorescent pigments must be embedded in those objects (clothing, road signs, lane markings, vehicles, etc.)

to be made visible to the driver. In spite of this limitation, UV headlights are a potentially valuable approach since they are not disrupted by fog, mist, and small amounts of snow. Direct vision enhancement as a countermeasure category, is of special interest as a reduced visibility support because such systems enhance the natural functioning of the human visual system. No special displays are required that can serve to distract the driver from the main task of monitoring the movement of the vehicle along the road. Nor must the driver learn how to interpret the information provided by a display. For these reasons, direct vision enhancement should be considered an important potential aid for reduced visibility driving.

2.4.2.3.2 Imaging Vision Enhancement Systems (VES)

Imaging vision enhancement systems (IVES) use sensors that can penetrate the darkness or atmospheric obscurants to present the driver with an image of the road scene superior to that available to the naked eye. The driver would be presented with a visual representation of the road scenario with sufficient range ahead that crash avoidance is feasible, perhaps with a recommended travel speed (Fancher et al., 1994). As Najm (1994a, 1994b) points out, such a system requires sensors (e.g., infrared, active or passive millimeter-wave radar imaging, charge-coupled device (CCD sensors), illuminator (for active systems), processor, and driver display. Imaging VES do not provide overt warning of obstacles (though there may be an excessive speed warning). Instead, these systems provide (in principle) optical information that the driver needs for vehicle control and object detection. Imaging is frequently presented as a concept for reduced visibility crash avoidance (Fancher et al., 1994; Kippola and Stando, 1994; McCosh, 1993).

Passive far infrared sensing is commonly referred to for automotive applications. It operates by sensing the thermal signature of objects that are warmer than their backgrounds (e.g., cars, pedestrians, animals); although that is less useful in rain or snow, since the infrared spectral range faces difficulties to contrast between wet object surfaces. Thus, it is best functional in dark situations. Active millimeter-wave radar imaging is currently under investigation by Ford Motor Company (Hughes, 1993; Kippola and Stando, 1994).

While the image presented in a simulated head-up display (HUD) shows highlighted lane markings and icons of vehicles in the fog ahead, there are problems to be overcome. For example, such a system will not work without treating the pavement markings and, presumably, other signs with a reflective material. Charge-coupled devices (CCD) are undergoing a variety of research and development efforts. CCD cameras are sensitive from the ultraviolet, visible, and near infrared spectral range. Under low light conditions, an image intensifier is used which, unfortunately, makes the cameras prone to streaking and blooming from bright sources (e.g., headlights from oncoming cars or trucks). VES image presentation may be provided to the driver either as an in-vehicle cathode ray tube (CRT) display or as a head-up display (McCosh, 1993). However, there are few concerns about the latter technology. Concerns include increased visual allocation to the CRT rather than the road scene and disruption of driver-vehicle performance while looking at the CRT. That is why many researchers are looking at the second display alternative, the head-up display (HUD). What is clear is that drivers will have difficulty in getting accustomed to the unnatural HUD imagery that is likely to be feasible (at least with infrared sensors) in the near term. HUDs are supposed to enhance safety because the driver does not have to take eyes off the road. Thus, the ability of the driver to learn to apprehend such imagery, and the training required to develop this ability, are also key research questions. The limited field of view of sensors compared to the driver's visual field (as well as the eye box) suggests that the HUD may provide a tunnel-vision view of the road scene. The impact of such technology to affect driver behaviors (e.g., visual allocation) and driver-vehicle performance (e.g., driving speed, lane-keeping performance) must also be assessed.

The vision enhancement devices mentioned in the two sections above are not applicable to route 114 problem since the line of sight is interrupted by the crest curve that these systems cannot overcome.

2.4.2.3.3 Roadway Information Systems

Reduced visibility crashes might be alleviated by roadway information systems. Traditionally, road signs, traffic signals, and pavement markings have been used to provide the driver with information about appropriate travel velocity, the need to brake, potential obstacles to watch for, and changes in roadway alignment. Within the IVHS umbrella, Variable Message Signs (VMS) might alert the driver of poor visibility conditions ahead and suggest appropriate reduced travel speeds or alternate routes. Rumble strips may be another example of a roadway information system that is particularly useful for avoiding roadway departures in reduced visibility conditions. Indeed, the system currently deployed at route 114 utilizes dynamic message warning signs to deter violators from committing an illegal action. The proposed extension to the system, which is being simulated at the meantime, makes use of a VMS that displays danger warning to the opposing vehicle.

2.4.2.3.4 In-Vehicle Crash Warning Systems

Reduced visibility is a crash circumstance that may be associated with a variety of crash types such as rear-end, roadway departure, head-on, and intersection crashes, among others. This suggests that in-vehicle crash warning systems directed toward alleviating these various crashes could be of benefit for reduced visibility conditions as well. For rear-end crash avoidance, candidate systems include forward-looking radar or laser systems that present an in-vehicle warning if the driver is approaching a lead vehicle too closely. For roadway departure/drift-out-of-lane crash avoidance, laser-based lane sensors and machine vision systems could present a warning to the driver when the vehicle is leaving the lane. For intersection crash avoidance, vehicle-to-roadway communication or vehicle-to-vehicle communication systems may be appropriate. The driver interface to such crash warning systems may be auditory, visual, or tactile in nature. Visual displays typically consist of alphanumerics, symbols, colored lights, or icons (e.g., outline of a vehicle). Auditory displays are typically beeps that may be coded by pitch, intensity, duration, or wave form to convey information to the driver. Speech warnings are also a possibility (COMSIS, 1993). Tactile displays may provide warnings or cautions to the driver by forces provided from the system to the driver via the steering wheel or pedals.

2.4.3 Road Departure Problem

2.4.3.1 Introduction

A statistical review of the 1992 General Estimation System (GES) and Fatal Accident Reporting System (FARS) databases indicate that run-off-road crashes are the most serious of crash types within the US crash population. The crashes account for over 20% of all police reported crashes (1.6 million / year), and over 41% of all in- vehicle fatalities (15,000 / year). Some of the most important characteristics of road departure crashes are the following: (19)

- They occur most often on straight roads (76%)
- They occur most often on dry roads (62%) in good weather (73%)
- They occur most often on rural or suburban roads (75%)
- They occur almost evenly split between day and night

2.4.3.2 Definition and Main Causes

Road departure can be defined as any single vehicle crash where the first harmful event occurs off the roadway, except for backing and pedestrian related crashes. Road departure crashes are also referred to as “run-off-road crashes”, or “lane departure crashes”. Studies indicate that run-off-road crashes are primarily caused by the following six factors (in decreasing order of frequency): (19)

- Excessive speed (32.0%) - traveling too fast to maintain control
- Driver incapacitation (20.1%) - typically drowsiness or intoxication
- Lost directional control (16.0%) - typically due to wet or icy pavement

- Evasive maneuvers (15.7%) - driver steers off road to avoid obstacle
- Driver inattention (12.7%) - typically due to internal or external distraction
- Vehicle failure (3.6%) - typically due to tire blowout or steering system failure

2.4.3.3 Types of Road Departure Warning Systems

This report mentions two primary functions for the road departure warning systems, which are termed "lateral" and "longitudinal" road departure warning. A lateral warning system (also called a Lane Drift Warning System or LDWS) is designed to detect when the vehicle begins to drift from the road. The goal for a longitudinal warning system (also called a Curve Speed Warning System or CSWS) is to detect when the vehicle is traveling too fast for the upcoming road segment. (19)

2.4.3.3.1 LDWS

The LDWS uses sensors to determine the vehicle’s state (position/velocity) relative to the road. A collision warning algorithm interprets this state to determine if the vehicle is in danger of unintentionally drifting out of the travel lane. If so, the system provides a warning to the driver. A LDWS is designed to prevent those run-off-road crashes caused primarily by driver inattention and driver incapacitation. It utilizes data about the dynamic state of the vehicle, in combination with information about the geometry of the road ahead to determine if the vehicle's current position and orientation will likely lead to a road departure. There are many conceivable ways (depends on the designer) of estimating the lateral position of the vehicle relative to the lane, including:

- A forward-looking video-based sensor to track visible road features
- A downward looking video-based sensor to track visible lane markings
- Sensors to detect continuous or intermittent magnetic markers placed down the center or edge(s) of the lane
- A laser or millimeter wave radar transmitter/receiver pairs to actively illuminate and measure the position of special targets/markers placed in or on the roadway infrastructure
- A high accuracy DGPS receiver with an accurate digital map of the road network.

2.4.3.3.2 CSWS

The CSWS uses sensors to determine the vehicle’s state (position/velocity) relative to the upcoming curve, and the safe speed for traversing the upcoming curve. A collision-warning algorithm interprets this information to determine if the vehicle is traveling too fast for the upcoming curve. If the vehicle's current velocity exceeds the safe speed, a sequence of driver interface functions is triggered to alert the driver of the danger and avoid a crash. A CSWS is designed to prevent those run-off-road crashes caused by excessive speed and lost directional control. The sensing functions that need to be performed by a CSWS include: (19)

- Determine vehicle position and orientation relative to the upcoming curve
- Determine vehicle stability characteristics
- Determine vehicle dynamic state relative to the road
- Determine geometric characteristics of upcoming road segment
- Determine pavement conditions of upcoming road segment
- Determine driver intentions

In order to determine accurately and reliably the vehicle's position and orientation relative to the upcoming curve, both the LDWS and the CSWS use one of the following technologies:

- A GPS receiver and a digital map of the road network
- Beacons located at curves broadcasting the curve's position to approaching vehicles
- Upcoming road geometry information encoded in the roadway infrastructure (e.g. magnetic markers) and sensed by short-range sensors on the vehicle.

Obviously, both systems, as are, are not applicable to route 114 project. However, a GPS receiver and a digital map of the road can be used for our purposes as discussed in an earlier section of the report.

2.4.4 Lane Change/Merge Problem

2.4.4.1 Introduction and Definition

The lane change family of crashes typically consists of a crash in which a vehicle attempts to change lanes, merge, pass, leave/enter a parking position, drifts and strikes, or is struck by another vehicle in the adjacent lane, both traveling in the same direction. The condition of initial travel in the same direction is the key distinguishing feature of lane change crashes from crossing paths and opposite direction crashes. In 2000, there were 565,000 lane change crashes involving light vehicles (9.2 percent of all light vehicle crashes). Of these, 545,000 crashes (96.5 percent) involved 2 vehicles. The general principles behind the definition of lane change crashes in this report are: (17)

- The vehicles involved must initially be traveling on *parallel paths* in the *same direction*. If they are on intersecting paths, or traveling in opposite directions, then the collisions are not classified as lane change crashes.

- The encroachment, whether intentional (as in a typical lane change) or unintended (as in drifting), is the first in a sequence of events leading to the crash. This means that lane encroachment that occurs as a consequence of loss of control due to catastrophic vehicle failure, or lane encroachment that occurs as an avoidance maneuver in response to another crash-imminent situation, are excluded.

2.4.4.2 Possible Crash Scenarios and Statistics

There are many possible combinations of vehicle movements and critical events that could lead to a lane change crash, as shown in Table 2.5. This table shows the distribution of lane change crashes by different combinations of light vehicle movements, and different critical events that are defined just above the table. (18)

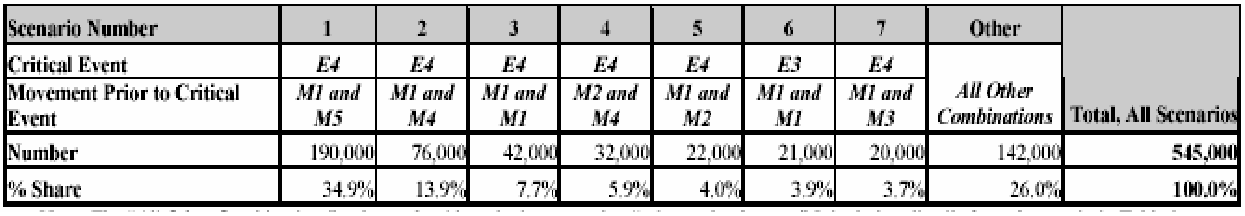
Key for Critical Event: The Respective Columns Include Crashes in Which At Least One of the Vehicles Had The Code Specified.

E1: Vehicle Failure
E2: Other Loss of Control
E3: Another Vehicle in Same Lane; Traveling Faster, Slower, Accelerating, Decelerating, Stopped, etc.
E4: One Vehicle Encroaching Into Another Lane; Another Vehicle Has Critical Event of Other Vehicle Encroaching Into Its Lane
E5: Pedestrian or Pedalcyclist
E6: Animal or Object
E7: Other Codes

Key for Movement Prior to Critical Event: In Each Row, The Two Vehicles Involved Have the Two Respective Codes Specified.

M1: Going Straight
M2: Passing
M3: Entering/Leaving Parked Position
M4: Turning
M5: Simple Lane Change
M6: Merging
M7: Other Movement

Table 2.5 - Distribution of Major Pre-Crash Scenarios for Lane Change Crashes
of Light vehicles (Two-vehicle crashes only; based on GES 2000)



Scenario Number	1	2	3	4	5	6	7	Other	Total, All Scenarios
Critical Event	*E4*	*E4*	*E4*	*E4*	*E4*	*E3*	*E4*	*All Other Combinations*	
Movement Prior to Critical Event	*M1 and M5*	*M1 and M4*	*M1 and M1*	*M2 and M4*	*M1 and M2*	*M1 and M1*	*M1 and M3*		
Number	190,000	76,000	42,000	32,000	22,000	21,000	20,000	142,000	**545,000**
% Share	34.9%	13.9%	7.7%	5.9%	4.0%	3.9%	3.7%	26.0%	**100.0%**

Six of the seven largest scenarios are characterized by the critical event of one vehicle encroaching into the lane of another vehicle. The encroaching vehicle is performing a simple lane change maneuver in the most common scenario, accounting for almost 35 percent of lane change crashes. In the next highest scenario, the encroaching vehicle is making a turning maneuver at a relative frequency of 14 percent. The third largest scenario involves no planned maneuver on the part of the driver of the encroaching vehicle; rather, it appears that the driver failed to stay within the lane and drifted into the adjacent lane. The circumstances could include drugs and alcohol, fatigue/drowsiness, inattention, or failure to keep one's lane (especially at high speeds, on a curve, or both). The three other encroachment scenarios, in order of size, are passing combined with turning maneuvers (5.9 percent), passing maneuvers (4.0 percent), and parking maneuvers (3.7 percent). (17)

2.4.4.3 ITS Countermeasures

In response to the high number of crashes associated with lane change and merging maneuvers, the automotive electronics industry has initiated a number of efforts to develop in-vehicle countermeasures capable of detecting objects to the side of a vehicle and providing a warning to the driver, i.e., Side Collision Avoidance Systems or SCAS. SCAS are designed to warn of impending collisions and can detect not only adjacent vehicles but vehicles approaching at such a speed that a collision would occur if a lane change were made. For example, Autosense Ltd. is developing an infrared-based collision-warning device for blind-spot obstacle detection (19). With this system, drivers are alerted to the presence of an object in the blind spot by an icon that flashes in the side view mirror. Similar devices are being developed by a host of electronics and automobile manufacturers. Side sensing systems (or "blind spot" sensors) are intended primarily to be used as supplements to outside side/rear mirror systems, and to aid drivers during lane change, merging, and turning maneuvers (NHTSA, 1993).

Side object detection systems (SODS) represent a subset of SCAS; they warn of the presence of adjacent vehicles only, whether or not there is a lane change. SODS devices encompass a wide range of sensor technologies. Both active and passive sensor technologies are being used as the core hardware technology of collision avoidance systems. Active technologies include radar (millimeter wave, or microwave), ultrasonic, and laser devices. Although the physics are very different across these devices, the basic principles of operation are similar. Active obstacle detection sensors in production or under development consist of one or more transmitter and receiver units mounted on the side of the vehicle. These units send data to a central processor that determines if an obstacle of interest has been detected and, if so, display a visual and/or auditory warning to the driver. Passive sensors, which include infrared and video devices, send the infrared or video signal directly to a display mounted inside the vehicle, where the external scene to the side of the vehicle can be viewed in real-time by the driver. Although collision avoidance devices that would automatically take control of a vehicle (e.g., steering, braking, or acceleration) in the event of an impending collision are technologically feasible and being considered (19), informing the driver and warning the driver of an obstacle or a potential collision is still the method of choice.

Clearly, such systems are not applicable in the route 114 project since there is no lateral change of vehicle location involved in the accident causes. Rather, the project addresses the issues of head-on collision scenario.

2.4.5 Rear-End Crash Problem

2.4.5.1 Introduction

Although it accounts for more than one quarter of the total number of crashes on our highways, the rear-end crash problem is selected to be discussed last. That is because the previously discussed technologies aid in the understanding and appreciation of the relative simplicity of avoiding this kind of problems rendering the ITS countermeasures deployed in this field the most successful. Unlike the complicated systems required for intersection collision avoidance for example, the rear-end collision prevention techniques are much straightforward and make use of technologies previously mentioned such as the radar sensing equipments. Although the rear-end collision problem is not related to the route 114 project definition, it will be discussed in this thesis as part of the ITS deployed countermeasures.

2.4.5.2 Background

By far, the most promising light vehicle crash avoidance research is in the area of rear-end collisions. During the years 1992-1996, rear-end collisions accounted for roughly 1.6 million police-reported crashes annually, constituting roughly one-quarter of all such crashes. Perhaps up to 2 million minor rear-end collisions occur annually but are not reported to police. The prevalence of these collisions may be attributed to many factors, such as poor road conditions, excessive speed, and poor road alignment. However, driver inattention, following too closely, external distraction, and poor judgment are the primary causes of more than 80% of all rear-end collisions. Furthermore, approximately 94% of police-reported rear-end crashes occur on straight roads, suggesting that visibility problems or curves are not to blame. Incidents attributable to these errors could be prevented by a system that would alert drivers when they are in a potentially dangerous situation before it is too late to make avoidance maneuvers. (27)

2.4.5.3 General Statistics

Approximately 37% of all rear-end collisions occur when two vehicles are traveling at a constant speed and the lead vehicle decelerates. Only slightly less common (33%) is the scenario in which one vehicle encounters another vehicle stopped in a travel lane ahead. In 14% of rear-end collisions, both vehicles were in the same lane but the leading vehicle was traveling slower. Roughly 5% of these collisions occur when two vehicles are both decelerating and the lead vehicle decelerates at a higher rate.

2.4.5.4 ITS Countermeasures

The rear-end Crash Avoidance Systems currently under development operate by using radar, lasers, or other remote sensors to determine the distance to and relative speed of the leading vehicle. A computer within the car performs calculations to determine if sufficient stopping distance and time are available. The system can alert the driver through visual, tactile, and auditory warnings, such as a voice that says "Look ahead" or "Brake." Warnings may become increasingly more urgent as the risk of collision increases. Future generations of Crash Avoidance Systems may also incorporate the ability to initiate evasive actions, such as braking that may prevent an accident even if the driver does not respond to warnings. It is important to note that the systems under development work autonomously; i.e., without any special equipment in other cars or on the road.

The Crash Avoidance Research Team studying these new systems is part of the Volpe Center's Accident Prevention Division. Team members Wassim Najm, Marco DaSilva, Andy Lam, and Joseph Koziol are engineers who now focus on the development of Crash Avoidance Systems; John Smith, an operations research analyst, provides support to their research. In order to study the factors that contribute to rear-end collisions, Wassim Najm turned to the NHTSA General Estimates System (GES) database, a nationally representative sample of police collision reports. These files contain data about, respectively, road conditions and time of accident, vehicle speed and driver characteristics, and age and injury. An analysis of 60,000 collisions described in the GES identified the twenty most common pre-crash scenarios, of which the top five comprise almost 90% of all rear-end crashes. The GES database suggests that the majority of the drivers who were involved in rear-end collisions performed no action to avoid the crash. Those who did attempt to steer or brake to avoid the collision constitute only a fraction of those involved. These data suggest that the causes for many rear end collisions lie not outside the car on wet roadways or around blind curves, but inside the car with drivers increasingly distracted by cellular phones, shaving, radios, and a multitude of comfort devices. Those drivers who are attentive may be able to initiate evasive maneuvers in time to avoid the crash. (27)

The USDOT in cooperation with General Motors will sponsor an "operational field test" of state-of-the-art rear-end Crash Avoidance Systems. The University of Michigan Transportation Research Institute will conduct the field test and collect data. As the Independent Evaluator of the test, the Volpe Center will review this data, evaluate the effectiveness, and provide an estimation of its safety benefits. One prototype Crash Avoidance System has already been subject to both controlled on-road studies and driving simulator tests in the laboratory. Wassim Najm compared the results of these tests to the GES database to determine how many rear-end collisions the system could have prevented. His findings indicate that, if 100% of all cars were equipped with the system, and if all drivers used the system properly, almost half (47.7%) of the rear end crashes could have been prevented, potentially saving 10.7 billion dollars annually. Furthermore, one related system has also been tested in real-life driving conditions. Field tests were conducted on an Intelligent Cruise Control system that uses remote sensors to measure the gap to the leading vehicle and adjusts the throttle of the car accordingly. The Volpe Center's evaluation of the field test determined that the system has the potential to prevent approximately 12,000 rear-end collisions on interstate highways; based on 1996 GES crash statistics.

2.4.5.4.1 Radar-Based Anti-Collision System

The purpose of this section is to provide a deeper insight on the ITS Technologies that were discussed as solutions to the rear-end crash problem. The system that is being presented is the radar-based anti-collision system developed by Radar Control Systems, Inc. (RCS). In its configuration, the system is intended to provide a warning to the driver when the equipped vehicle is in danger of being involved in a collision with another vehicle or object as already mentioned. This is achieved by reflecting a radar signal from vehicles or objects ahead and using this information to calculate range. Changes in range over time (closing rate), range to the object, and vehicle speed are then used to activate the alarms. The system has been tested earlier to evaluate its ability to activate the alarm at various closing rates on several types of vehicles, its sensitivity to pedestrians, bicycles and motorcycles, its interference resistance, and its capability under degraded atmospheric conditions. Brief descriptions of the system’s architectural components are listed hereunder. The system was provided by RCS in April 1990, and was mounted in a 1989 Ford LTD. The system is installed so that it is active whenever the vehicle is running. It has a detection range of approximately 500 feet. The normal system includes the following apparatus: (27)

- A pivoting ***microwave radar head,*** mounted in the front grill of the vehicle. The radar head moves as the vehicle’s steering wheel is turned, following the direction of the front tires. The head emits a microwave radar signal which is reflected from vehicles and objects in the beam’s path. The reflected beam is received by the head and the resulting data is sent to the signal processing unit.

- A ***signal processing unit*** receives the data from the radar head. The data are processed using the system's algorithms, and when required, the processing unit activates the auditory alarms.
- A dashboard mounted ***driver*** *interface* which allows the driver to change system parameters by moving various slide switches. The driver may indicate the roadway type (e.g., highway, normal), the atmospheric condition (e.g., rain, normal), and the alarm onset mode (e.g., normal, early). For these tests the system was left in the "normal" setting except for the freeway testing where the range switch was set at "highway."
- A ***speaker*** which provides the driver with the auditory alarm.

2.4.6 Driver Condition Problem

2.4.6.1 Introduction and Definition

Several researchers have attempted to define drowsiness over the years. Torsvall and Akerstedt (1988) defined drowsiness as the "state during which sleep is perceived as difficult to resist, the individual struggles against sleep, performance lapses occur, and sleep eventually ensues." (22) Much research has been conducted to operationally define drowsiness to aid in the detection of drowsy drivers. Several physiological measures, performance measures, and subjective ratings have been shown to be good predictors of drowsiness. Much research about this subject has been conducted at Virginia Tech and details of these studies can be found in previous technical reports. For the purpose of this report, the literature will focus on existing drowsiness detection systems, drowsiness countermeasures, and appropriate warning and alarming stimuli.

2.4.6.2 Background and General Statistics

Driver drowsiness concerns to a great extent the transportation researchers today since it is a major cause of motor vehicle accidents. Luxury, comfort, reduced outside road noise and minimal vehicle vibration are the main criteria of today's automobile designs, which rank cars' quality and favorability. However, these qualities in a vehicle can add to the problem of driver drowsiness for the driver is in a much relaxing state than ever before. Operating a motor vehicle requires constant monitoring of the surrounding environment. When a driver becomes drowsy it becomes increasingly difficult to be attentive to the driving task.

Based on the research conducted at Virginia Tech, these statistics have been found helpful in presenting the problem significance. Over the course of one year 50% of all fatalities on the Ohio Turnpike were attributed to accidents involving drowsiness (Kearney, 1966). In a 1980 survey reported by Seko (1984), 75% of all drivers surveyed reported having experienced drowsiness while driving. Planque, Chaput, Petit, Tarriere, and Chabanon (1991) reported 26% of fatal accidents on the motorways in France were caused by drowsy drivers. Data taken over the five year period of 1989-93 was recently summarized in a NHTSA Research Note (Knipling and Wang, 1994). These national statistics were taken from the NHTSA General Estimates System (GES) and the Fatal Accident Reporting System (FARS) data sources. A summary of the findings is as follows: (21)

- There were 56,000 crashes annually in which driver fatigue/drowsiness involvement was cited in the police report (0.9 % of all crashes).
- There was an annual average of 40,000 non-fatal injuries due to drowsy drivers.
- There was an annual average of 1,357 fatal accidents involving a drowsy driver (3.6% of ail fatalities during the five year period),
- Actual involvement of driver fatigue/drowsiness is most likely much greater due to under reporting.

Few things are worth mentioning before discussing the drowsiness measures. First, people often do not recognize they are drowsy until after they begin to exhibit symptoms. Second, some individuals may not exhibit any strong symptoms or indicators of sleep onset. Third, people's ability to predict the likelihood of sleep varies widely. Finally, the process of becoming drowsy is felt to be reversible suggesting that countermeasures could be quite effective. Recent studies conducted at Virginia Polytechnic Institute and State University, funded by The National Highway Traffic and Safety Administration, has investigated both physiological and performance measures but focused on the latter. The goal of this research was to develop an appropriate warning system to produce a fast acting drowsy driver detection and alerting system for use with the detection algorithms described in Wierwille et al. (1994). The purpose of the warning signals is three-fold: first, to advise the driver that a drowsiness condition has been detected; second, to re-alert the drowsy driver; and third, to maintain his or her alertness for a period of time, making it possible to find a safe place to pull off the road and refresh.

2.4.6.3 Countermeasures to Drowsiness

2.4.6.3.1 Simple Countermeasures

These countermeasures include simple things like avoiding prolonged hours of driving, attaining adequate amount of sleep and rest, and shunning certain kinds of food and drugs, etc. In general, three kinds of countermeasures are mentioned in the literature; and these are: driver-oriented, vehicle based, and environmental countermeasures. The driver-oriented countermeasures consist of educating drivers to recognize the signs and dangers of drowsiness while driving through driver training courses and mass media campaigns. Vehicle-based countermeasures consist of listening to the radio and providing ventilation, possibly by opening the window. Environmental countermeasures include rest breaks and pavement treatment like the rumble strips that showed to be extremely effective.

Other types of simple countermeasures may include chewing gum, singing along with the radio, sitting on something hard, and taking off the right shoe. But no research has proven the effectiveness of these types of countermeasures on a range of audience.

2.4.6.3.2 Chemical Countermeasures

Caffeine is considered by many as a favorable way to keep them awake while driving for extended periods of time. Based on many researches by Childs, Haworth, and Warburton, it was found that a large dose of caffeine may disrupt visual attention in those who do not normally consume much caffeine, while enhancing visual attention in those who normally consume a large amount of caffeine. Haworth et al. (1990) cites many studies that have shown stimulants, such as amphetamines, to improve tracking, concentration, and attention. The effect of these drugs is shown to be greater when the subject is sleep deprived. This suggests that they could be used to counteract fatigue. However, stimulants have also been found to increase risk-taking behaviors. Because of this, they would probably not prove to be good countermeasures to use while performing a vigilance task such as driving (Haworth et al.,1990). Nicotine has been supported in the literature as having a positive effect on the performance of vigilance tasks (Wesnes and Warburton, 1978). However, when considering any of the mentioned stimulants one must realize that they are drugs and might have serious health effects. For this reason, and because of individual differences in peoples' reactions to these drugs, they probably should not be considered viable sources of drowsiness countermeasures. A recently identified approach to combating drowsiness is the use of stimulating scents (Kaneda, Iizuka, Ueno, Hiramatsu, Taguchi, Tsukino, 1994).

2.4.6.3.3 Mechanical Countermeasures

There have been many mechanical devices that can measures the human drowsiness while driving such as the eyelid closure monitors, head nodding monitors, and reaction time monitors. One device, which monitors eyelid closures, is the Onguard developed by an Israeli company, Xanadu Ltd. This battery-operated device, which consists of a small infrared sensor and an electronic processor, can be fitted to a standard pair of eyeglasses. The device directs a beam of infrared light at the eye and measures the light reflected back. When the eye is closed the amount of light reflected back is reduced. When the eye is closed for longer than 0.5 second an alarm is activated. Head nod detectors have also been marketed to detect drowsiness in drivers. The Electronic Transistor Safety Alarm and Dozer's Alarm are two examples of this type of detection device. These units, each of which consists of an angular rotational detector, are placed over the top of the ear and buzz loudly when the head nods forward past a certain angle. Finally, there are reaction time monitors. Roadguard is one such device. Once installed, the device is activated when a car is put into high gear. A timer stops at random periods of 4-14 seconds and a small red light is illuminated on the dash board. This light must be deactivated by the driver within three seconds or an alarm will sound. The ALERTMASTER and Button Steering Wheel Alarm are similar devices. The ALERTMASTER requires the driver to apply constant pressure on a pedal located to the left of the clutch. When constant pressure is not maintained the horn sounds. The effectiveness of this device relies on the assumption that when a driver becomes drowsy the left foot will relax and not maintain the pressure needed (Hulbert, 1972). The Button Steering Wheel Alarm operates on the same principle. In this device the button is located on the steering wheel. As with the ALERTMASTER, an alarm is activated when constant pressure is not maintained on the button.

2.4.6.3.4 Vehicle-Based Countermeasures

Many researchers - Kaned, Artaud, Planque, Lavergne, Cara, Lepine, Tarriere, and Gueguen (1994) - have focused on a detection system which uses image processing of the driver's face to detect diminished alertness. The image of the driver's face is processed to locate the eyes and then determine the degree to which they are open. Nevertheless, many studies involving drowsiness detection have been conducted in the Vehicle Analysis and Simulation Laboratory at Virginia Tech. There are several physiological measures that have been proven to be good predictors of driver drowsiness. However, there are problems with recording these measures because the necessary instrumentation is either intrusive upon the driving task or annoying to the driver. For these reasons, performance measures as predictors have been the topic of numerous research projects at Virginia Tech.

2.4.6.4 ITS Alert Systems

The goal of a warning is to change a person's behavior. To be effective, warnings must be sensed, received, understood, and heeded (Sanders and McCormick, 1993). Besides, when designing crash avoidance warnings for vehicles, the time available to react must be considered, and the alarm must be designed so that it conveys the appropriate level of urgency. Other aspects that should to be considered include variations in vehicles and drivers. On the other hand, an effective warning signal must be intrusive and convey a sense of urgency. However, warning systems in vehicles must not be so intrusive and urgent that they startle the driver, and possibly put him or her in more danger, or annoy the driver to the point that he or she will deactivate the system. At the same time, the warning must not be so conservative that it fails to result in the desired effect of alerting a driver of an approaching danger. That is why multiple levels of warnings should be used to alleviate the activation of urgent false alarms. Multiple settings should be available on warning alarms.

2.4.6.4.1 Driver alertness warnings

There are many possible ways to alert a driver in a drowsy condition. These include auditory displays such as tones, buzzers, rumble sound, and speech. Other possibilities include vibrations of the steering column or driver's seat. Possible methods of maintaining a driver's alertness level are seat vibration, supply of fresh air, driver involvement in a secondary task, and the use of a stimulating scent, such as peppermint (Kaneda et al., 1994). Another possible method of maintaining a driver's alertness is the use of a lane-minder. This is a concept developed by Wierwille in 1989 which consists of sensors located in the vehicle which are able to sense the boundaries of the lane. If the vehicle exceeds those boundaries an alarm is activated.

2.4.6.4.2 Auditory displays

Auditory displays are generally preferred for their effectiveness in alerting (Horowitz and Dingus, 1992). However, special precautions must be taken to avoid startling or distracting the driver. Also, it is suggested that sounds coming from a single area be avoided unless they are consistent with the direction of the hazard (Lerner et al., 1993). The fundamental frequencies used in acoustic warnings should be in the range of 500-3000 Hz.

2.4.6.4.3 Tactile displays

Studies done inside simulators suggest that vibration may have an alerting effect and for this reason, should be considered a viable warning signal for driver drowsiness. It is suggested that tactile displays, such as vibration, be located in the driver's seat or the steering column (Lemer et al.1993).

2.4.6.4.4 Visual displays

A visual display is suggested to be used as an initial signal in a warning system. However, in a drowsy driver alerting system the use of visual displays is problematic. If a driver is drowsy and inattentive he or she may be less likely to perceive a visual warning in time to react appropriately. If a visual signal is used as part of a warning, it should be presented within 15 degrees of the driver's normal line of sight of the roadway (Lemer et al., 1993).

2.4.6.4.5 Termination of warnings

Warnings which are automatically triggered by a specific condition should be presented for at least one second and until the triggering condition no longer exists (Lemer et al., 1993). Immediately following the termination of the alarm the system should be reactivated in order to detect any quickly reoccurring decrease in alertness. Besides, the mode of termination in these cases should not be too easily accessed. For this reason, the termination control should require some physical motion on the part of the driver.

In general, ITS drowsiness countermeasures do not relate directly to the route 114 project. However, they can indirectly aid in the mitigation of crashes on route 114. Since the police reports of the accidents that occurred on route 114 showed that 20% of drivers were driving under alcohol influence, then we can assume that reducing alcohol impairment effect on drivers can decrease the probability of an accident. The hypothesis is that such drowsiness countermeasures might have positive effects in reducing driver impairment relative to BAC levels. We know that alcohol degrade the perception reaction time of a person, including drivers; thus, some of the chemical countermeasures, taken as a single example, mentioned in this section can still add to the alertness of some drivers despite their alcohol impairment (better than having no alert at all).

2.4.7 Other ITS Systems

2.4.7.1 Introduction

This section of the thesis lists different ITS crash countermeasures. There are many available systems that are already deployed in real projects such as the ice/friction detection and warning system that detects the pavement condition and activates an advisory speed based on that, systems that warn drivers on minor roads of the presence of vehicles on major road and vise versa, warning systems for drivers making left turn of vehicles making left turn ahead, weather condition warning systems, systems that warn drivers of animal presence on the highway, and the horizontal curve warning system.(1) One example will be discussed in the following section that is related to the horizontal curve warning system.

2.4.7.2 Guidelight

A collision countermeasure system of this type is currently in operation in Japan. It has undergone extensive testing on a test track and has now been installed in actual portions of the highway. The name of the system is Guidelight. One of the Guidelight systems consists of a series of lights around the curve and an ultrasonic detector on each end of the curve. When a vehicle is detected, the lights are activated ahead of the vehicle at a rate dependent on the speed of the vehicle. The lights warn the driver of another vehicle entering the curve from the opposite direction that there is an oncoming vehicle. The ISO standard being developed for "cooperative warning of the presence of oncoming vehicles on curves" is based upon the Guidelight system, so Guidelight may become the standard collision countermeasure system for this type of warning. Figure 2-6 shows an example of the Guidelight system. (25)

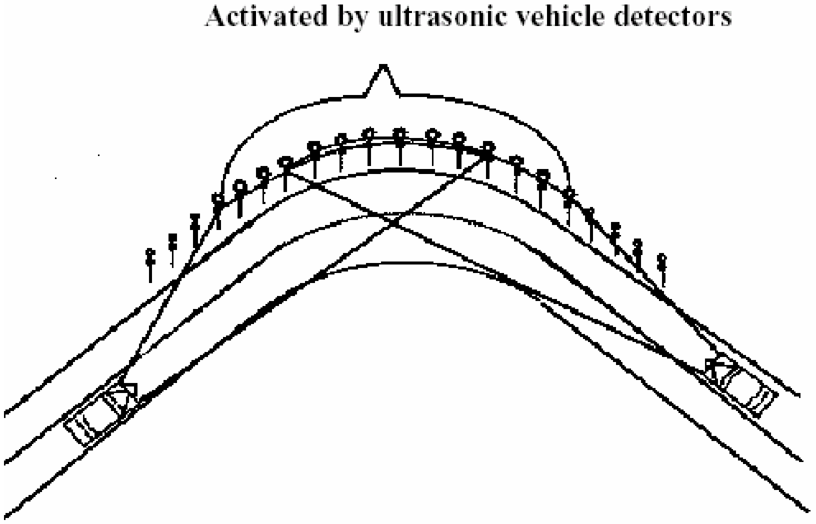


Figure 2.8 – Guidelight Design for Horizontal Curves

Another possible collision countermeasure system proposed would consist of a pair of warning signs which would be activated as soon as a vehicle enters the curve in order to warn vehicles traveling in the opposite direction. A possible active warning sign would have two flashing lights on top and depict a two-way traffic road (assuming there are only two lanes) with a car in the oncoming lane. Both the flashing lights and the representation of the car will flash when the sign is activated. (25)

Such a system is comparable to the system deployed on route 114 since it addresses traffic problems on curves and uses sensors to detect the presence of the opposing vehicle. In other words, a similar system can be altered to address our problem, vertical curves, instead of its present objective of warning vehicles on horizontal curves.

2.5 Human Factors

2.5.1 Introduction

The Human Factors Research Program addresses human performance-related issues that affect highway system design. Current human factors research focuses on highway Safety and Intelligent Transportation Systems (ITS). FHWA is placing special emphasis on the trend of the United States to increase numbers of older drivers and implications of this trend on highway safety and ITS design. Human factors research products include highway system design guidelines and handbooks based upon empirical human performance data collected in the laboratory and in controlled, on-the-road tests.

The purpose behind this section is to address some questions about human factors in such situations and the circumstances surrounding the process of violations. Mainly, we are interested in the human behavior under emergency and danger situation and how do drivers make their decisions when directly exposed to a crash. In addition, we wish to understand the prevailing conditions that might lead violators to accelerate or decelerate when they see the oncoming vehicle or get a warning, as well as, the role of the psychological and aggressive history of the offender. Nonetheless, human factors include the study and analysis that might describe our assumption that vehicle B is neutral all the way during the violation process, and the corresponding behavior of driver B once he/she perceives such situation. Unfortunately, most of our inquiries in the human factor section were not answered due to the lack of ongoing research in such fields. Thus, the following portion of the human factor section describes the general human factor research fields done up to this day even if they were not directly related to the project scheme.

2.5.2 Current Human Factors Research

At the moment, “human factor” issues are one of the least researched areas in transportation engineering and it is the concern of recent projects and efforts. Considering the project presented in this report, an inherent data requirement is to know to what level the systm is serving its need. In other words, for a system that displays a warning message to no-passing zone violators, it is quite crucial to acquire some kind of statisitics on how many violators are obeying the message signs and how many are not. This number or percentage will be logically related to how efficient the system is in dispalying the message at the right time, or how credible and accurate the system is in response to its intended purpose.

Of the main objectives of ITS deployment projects is to provide reliable traffic information to motorists. However, the highway system has few operating situations that make it difficult to achieve this goal. Congestion, delays, and accidents can sometimes make information provided to motorists unreliable when it is received. Natural conditions form an obstacle, at times, to supplying accurate traffic information especially relative to projects where the weather has a role. For example, weather plays an important role in the accuracy of the Autoscope detection and surveillance machine vision data, which will be discussed in a later chapter of this report. Such unreliability may cause drivers to discount, or even ignore, traffic messages displayed on programmable road signs or other information-delivery systems. Thus, the key objectives of studying "Human Factors" issues relative to the discussed project would be to:

1. Assess the impact of false alarm rates on system use;
2. Quantify the effects of false alarms on subsequent driver behavior.

2.5.2.1 Information Reliability vs. Trust Levels

Currently, there are few results based on empirical studies to guide the highway engineer concerning what level of accuracy is needed to gain driver acceptance and trust. In some domains, a single bad experience is enough to prevent people from using a service or machine again. Traffic information systems must be sufficiently reliable so that motorists continue to accept and use the systems. For example, Batelle Human Factors Transportation Center has develpod a Route Guidance Simulator that aims at acquiring data that the highway engineer can use to select a level of information reliability that will maintain the driver's acceptance and use of route guidance information. Such data has an effect on ITS project objectives and minimum standards, in general. The Route Guidance Simulator has been operated by drivers of various ages and data about their acceptance and trust levels to the route guidance information provided has been recorded. A sample output of the mean trust levels of drivers based on the provided information accuracy can be seen in figure 2.9 below.

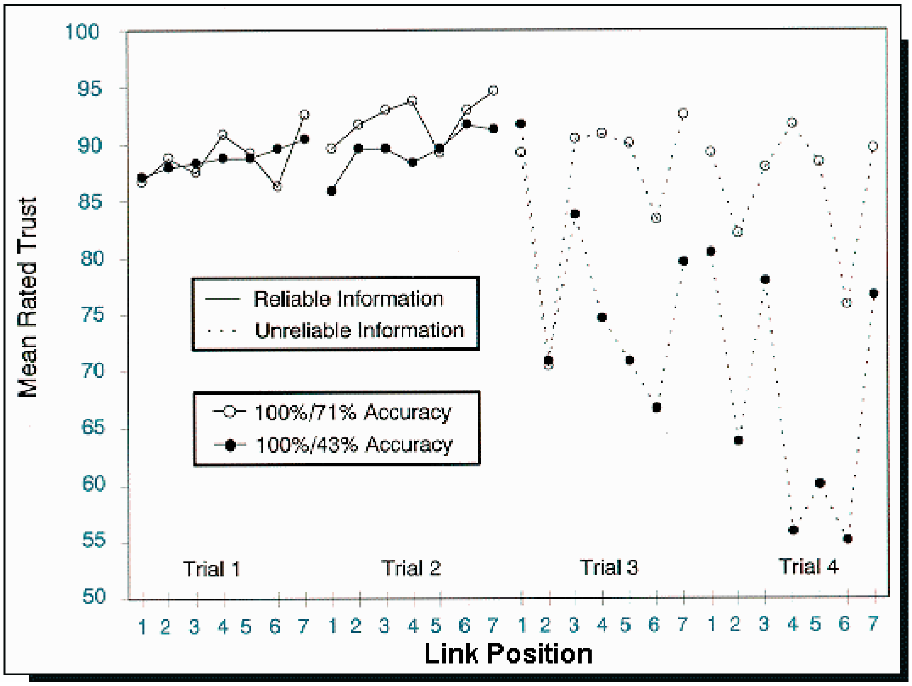


Figure 2.9 - Mean Trust Levels Relative to Information Accuracy

Based on this research, M. Joseph Moyer, engineering research psychologist, came up with the following conclusions:

- Drivers use and benefit from accurate traffic information.
- Information that is less than 100 percent accurate can be useful.
- Driver trust in an unreliable system recovers when accurate information is presented, but the recovery is not always complete.
- Traffic information reliability above 70 percent is recommended.

2.5.2.2 Other Human Factors Research

Most of the human factors research is directed towards identifying the impact of introducing intelligent vehicle information systems (IVIS) on driver performance. The main goal of intelligent information systems, in the first place, is to improve mobility and decrease travel time, besides other goals. Thus, researching human factors in this field is basically to provide standard guidelines to producing IVIS designs. To accomplish this, a behavioral model that predicts driving task performance decrements due to interaction with IVIS has been developed. The behavioral prototype software was named IVIS DEMAnD after Intelligent Vehicle Information Systems Design Evaluation and Model of Attention Demand. In other words, the model measures the degree of attention or inattention of the driver when aided by IVIS during his driving task, where few of these IVIS not only require extracting information from the auditory display but also further processing by the driver.

Under the sponsorship of the Federal Highway Administration, the Georgia Institute of Technology is conducting a series of experiments that will provide human factors design guidelines for future traffic management centers (TMC). The experiments are being conducted in a high-fidelity simulator of an advanced TMC. The simulator can duplicate the functions and operator workstations of real-world centers, including user-computer interfaces, automated support systems, and remote television cameras.

A series of experiments has been conducted on the Iowa Driving Simulator (IDS) to investigate the following issues.

- Driver capabilities and limitations must be considered to ensure successful implementation of the Automated Highway System (AHS).
- Human factors investigations of driver performance characteristics provide the basis for determining system design configurations and features.
- Driver and system attributes are being assessed during the initial design and conceptual phases of the AHS;

thereby ensuring the system will be usable and acceptable to the entire driving population.

From what preceded in this thesis report, it is clear that any new system deployment related to human lives and safety is preceded by excessive research and simulation experiments that asses the functionality of the system and its performance in order to replicate real life situations. For these reasons, the next section of this report will discuss the available simulations that address rural roads which might have some correlation to our problem.

2.6 Simulation

2.6.1 Introduction

The purpose behind any simulation is an attempt to predict aspects of the behavior of some complex system by creating an approximate mathematical model of it. This can be done by physical modeling, by writing a special purpose computer program, or by using a more general simulation package, probably still aimed at a particular kind of simulation. In our case, there have been many simulation packages written for the sole purpose of understanding and testing the operations and functionality of rural roads. Before discussing the degree to which the available packages can relate to route 114 problem description, the following section will discuss the general aspects of the available simulation softwares of rural highways.

2.6.2 Other Simulation Packages For Two-Lane Highways

This part of the report includes identification of two computer simulation models for two-lane highway operations available in the market. The two candidate models are the TWOPAS model, developed by Midwest Research Institute and others for the Federal Highway Administration, and the TRARR model, developed by the Australian Road Research Board (now ARRB Transport Research, Ltd.). These two models are solely dedicated to two-lane highway configuration operations.

2.6.2.1 TWOPASS

The TWOPAS model is a microscopic computer simulation model of traffic on two-lane highways. The predecessor of the TWOPAS model was originally developed by Midwest Research Institute (MRI) in NCHRP Project 3-19, "Grade Effects on Traffic Flow Stability and Capacity," which resulted in the publication of *NCHRP Report 185* in 1978. The model was originally known as TWOWAF (for TWO Way Flow). MRI improved TWOWAF in 1981 in an FHWA study entitled, "Implications of Light-Weight, and Low-Powered Vehicles in the Traffic Stream." Then, in 1983, Texas Transportation Institute (TTI) and KLD and Associates made further updates to TWOWAF, which resulted in the version of the model that was used in the development of Chapter 8 for the 1985 HCM. (14) TWOWAF had the capability to simulate traffic operations on normal two-lane highways, including both passing and no-passing zones, as well as the effects of horizontal curves, grades, vertical curves and sight distance. Subsequent to the publication of the 1985 HCM, MRI developed the TWOPAS model by adding to TWOWAF the capability to simulate passing lanes, climbing lanes, and short four-lane sections on two-lane highways. A modified version of TWOWAF known as ROADSIM was also developed and included in FHWA's TRAF model facility at about this time. As a microscopic model, TWOPAS simulates the operation of each individual vehicle on the roadway. The operation of each vehicle as it advances along the road is influenced by the characteristics of the vehicle and its driver, by the geometrics of the roadway, and by the surrounding traffic situation. The following features are found in TWOPAS: (14)

- Three general vehicle types—passenger cars, recreational vehicles, and trucks.
- Roadway geometrics specified by the user in input data, including horizontal curves, grades, vertical curves, sight distance, passing lanes, climbing lanes, and short four-lane sections.

- Traffic controls specified by the user, particularly passing and no-passing zones marked on the roadway.
- Entering traffic streams at each end of the simulated roadway generated in response to user-specified flow rate, traffic mix, and percent of traffic in platoon.
- Variations in driver performance and preferences based on field data.
- Driver speed choices in unimpeded traffic based on user-specified distribution of driver desired speeds.
- Driver speed choices in impeded traffic based on a car-following model that simulates driver preferences for following distances (headways), based on relative leader/follower speeds, driver desired speeds, and desire to pass the leader.
- Driver decisions concerning initiating passing maneuvers in the opposing lane, continuing/aborting passing maneuvers, and returning to normal lane, based on field data.
- Driver decision concerning behavior in passing/climbing/four-lane sections, including lane choice at beginning of added lane, lane changing/passing within added lanes and at lane drops, based on field data.
- Processing of traffic and updating of vehicle speeds, accelerations, and positions at intervals of 1 second of simulated time.

2.6.2.2 TRARR

TRARR ("**TRA**ffic on **R**ural **R**oads") was developed in the 1970s and 1980s by the Australian Road Research Board. Originally run on mainframe computer systems, the program was ported to a PC version (3.0) in 1986. A recent version (4.0) was produced in 1994 and included a (DOS) graphical interface (albeit with reduced functionality) and the ability to import road geometry data for the creation of road sections. The latter greatly simplified the data creation requirements.(13)

TRARR is a micro-simulation model; i.e. it models each vehicle individually. Each vehicle is randomly generated, placed at one end of the road and monitored as it travels to the other end. Various driver behavior and vehicle performance factors determine how the vehicle reacts to changes in alignment and other traffic. TRARR uses traffic flow, vehicle performance, and highway alignment data to establish, in detail, the speeds of vehicles along rural roads. This determines the driver demand for passing and whether or not passing maneuvers may be executed.

TRARR is designed for two-lane rural highways, with occasional passing lane sections. TRARR can be used to obtain a more precise calculation of travel time, frustration (via time spent following), and VOC benefits resulting from passing lanes or road realignments. For strategic assessment of road links, TRARR can also be used to evaluate the relative benefits of passing lanes at various spacing. TRARR uses four main input files to describe the situation to be simulated: (13)

- **ROAD**: the section of highway to be studied, in 100m increments. It includes horizontal curvature, gradient, auxiliary (passing) lanes, and no-overtaking lines.
- **TRAF**: the traffic volume and vehicle mix to be simulated. Other information regarding the simulation time and vehicle speeds is also contained here.
- **VEHS**: the operating characteristics of the vehicle fleet. The relevant details relating to engine power, mass, fuel consumption, and so on are entered into this file.
- **OBS**: the points along the highway at which to record data on vehicle movements. TRARR can provide a range of values including mean speed, travel times, and fuel consumption.

As a modeling tool for evaluation of rural passing lanes and realignments, TRARR has proved to be an adequate package. However a number of potential drawbacks have been identified through practical experience that can be listed as follows:

- Inability to handle varying traffic flows down the highway, particularly due to major side roads.
- Inability to properly model the effects of restricted speed zones (such as in small towns).
- Inability to model congested situations e.g. temporary lane closures or single-lane bridges.
- Difficulty in using field data for calibration, with no automatic calibration assistance built in.
- Difficulties creating and editing road data, particularly for planned new alignments.
- Limited ability to use the same tool to check for speed environment consistency and safety risks.

In recent work for the California Department of Transportation (Caltrans), the Institute of Transportation Studies (ITS) at the University of California-Berkeley (UCB) has developed a user interface, known as UCBRURAL, for use with the TRARR and TWOPAS models. The interface provides a convenient tool for users:

- To enter input data on traffic volumes, traffic characteristics, and geometric features of two-lane roads
- To run either the TRARR or TWOPAS model
- To display the output in a convenient graphical format

The UCBRURAL interface has not involved any substantive changes to either model; however, it provides a more convenient means for users to run either model.

Based on the above description of the aforementioned software packages, it has been found that none of the existing models is applicable to route 114 problem. The two packages perform quite well in simulating normal conditions of traffic, as to regular passing maneuvers, congestion assessment, traffic variations, etc, but neither one can deal with abnormal conditions of traffic flow such as the case we are simulating. These softwares cannot apprehend drivers' violations of the traffic rules, such as the passing maneuvers that are conducted within no-passing zone stretches of the two-lane rural road (Route 114 problem). Thus, a unique simulation had to be written to address the situation under study. In this sense, the latter simulation is innovative and pioneer in mimicking the actual violation patterns recorded on route 114 of southwest Virginia.

CHAPTER 3. SYSTEM DEPLOYMENT

3.1 Introduction

This section of the thesis will discuss the current deployed system on route 114 (Pepper's Ferry Road) and will focus on the system deployment and monitoring, data collection and monitoring, and some further recommended enhancements.

The deployed system at the No-passing zone area on route 114, of southwest Virginia, encompasses surveillance and detection technology, warning signs, and a communication network. The overall system performance and workability has been tested at the Smart Road Center of Virginia Tech on December 2000 prior to deployment in the actual no-passing zone area. After the system selection process was complete, the real life deployment was initiated. The actual system deployment has been completed by the end of June 2003.

3.2 The Deployed System

The architecture of the fully installed detection and warning system is shown in Figure 3.1. Eight video detection cameras are installed on 40 ft poles to monitor the desired detection area. The actual deployed system is shown in figure 3.2 that presents the four cameras mounted on poles along with the two flashing message signs for detecting and warning the violator going east towards Christiansburg. Exactly the same configuration is utilized for the other direction going west towards Radford. The deployed warning and safety system can be subdivided into 4 subsystems, which briefly are the Detection subsystem, the Control Processor, the Warning subsystem, and the Communication subsystem. These subsystems would harmoniously work together to convey the right and required warning message and collect the sought after data.

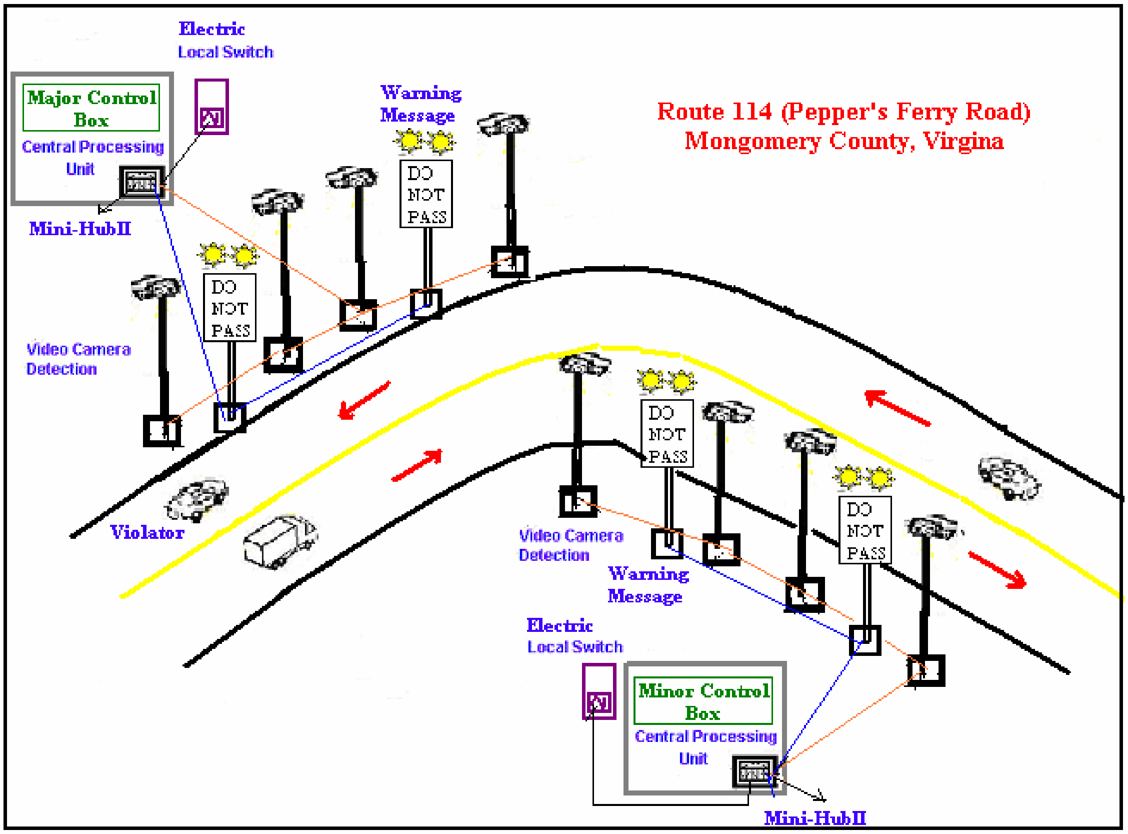


Figure 3.1 - System Architecture for Deploying Warning Signs

Figure 3.2 - Actual System Architecture on Route 114 (Going East)

3.2.1 Detection Subsystem (Surveillance)

The deployed surveillance system was selected based on the results of testing several market-available technologies that could have provided similar desired outputs. Interim reports I and II that were submitted to VDOT described in details these systems and the experiments conducted at the “Smart Road” at Virginia to select the best system. The selection set finally on the AUTOSCOPE Solo software that uses the machine vision technology for detecting the violator and supporting the warning provision of the system.

The AUTOSCOPE detection system uses virtual detectors drawn on a video image to collect traffic data. The detectors are drawn on a live video image or a bitmap snapshot of the video image. The user can easily size or move detectors for changing traffic patterns or optimizing performance. This feature proves to be very beneficial and cost effective when additional lanes are added. The Personnel can adjust the detector layout from a PC. The PC also stores a backup copy of the detector file. Detector performance is visually verifiable by watching the detectors change color on the live video image on the PC screen. The AUTOSCOPE Video Detection Systems (VDS) provides real-time images of road conditions and serves as an incident verification tool. Figure 3.3 shows the AUTOSCOPE system configuration.

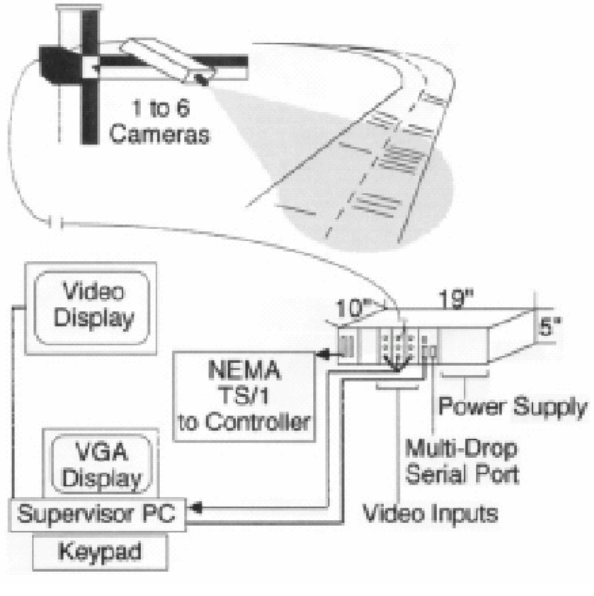


Figure 3.3 - AUTOSCOPE System Configuration

3.2.1.1 Integrated Sensor Hardware

Machine vision technology has emerged as an excellent alternative to inductive loops for traffic sensing. Recently, there has been further advancement of this technology that helps improve the reliability and maintainability of the video sensors. A new sensor system design has been introduced which takes advantage of the advancement in the miniaturization of digital electronics to integrate the opto-electrical transducer and the computing electronics into an integrated vision sensor. The integrated vision sensor is supported by a new communication architecture that offers optimal routing of the machine vision detection results, full motion video as well as digital imagery. The integrated sensor system consists of two hardware subsystems: the Machine Vision Processor (MVP) and the communication network. Figure 3.4 shows the integrated sensor which was used at the route 114 project site.

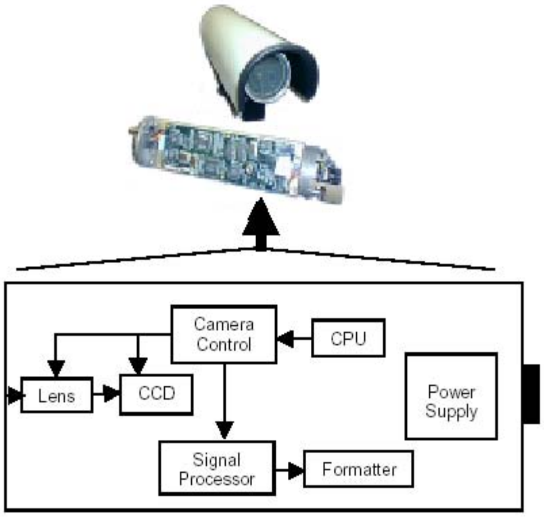


Figure 3.4 - Integrated Video Sensor

To improve reliability under varying illumination conditions the CCD camera control has been integrated with the processor. This allows the processor to perform closed-loop gain and bias control of the images. The sensor hardware has the following input/output: Vehicle detection decision, Traffic data, Supervisory control, System status, Analog imagery, and Digital imagery. The system consists of a special communication hub to facilitate low cost management of the sensors from the two installed control panels (one for each direction). The hub has three major communication functions: Data Multiplexing, Video Multiplexing, and Hub-to-Hub Interconnection. Data and video from multiple sensors are multiplexed at a hub for the long haul transmission to the control panel. At each node in the network, a hub multiplexes data and imagery from several sensors. In the deployed system, each hub located in a control panel collects and processes data from four MVPs. A desktop PC functions as a communication server (Comserver). The users perform sensor management functions from this Comserver PC. These functions include detector layout modifications to fit the seasonal change and data downloading and storing.

3.2.2 Control Processor

As mentioned earlier, through the new integrated system the AUTOSCOPE Solo Machine Vision Processor (MVP) is now embedded into the CCD to achieve maximum reliability against illumination, which is one of the major triggers for false alarm calls, and routing capability of the collected data. Data collection capabilities and applications of the deployed system include Directional Detection, Stopped Vehicle detection, Support for variable message signs (provide warning message triggering), Traffic Volume Count, and Occupancy. The system features that stand out are the camera coverage, which is wide and can be verified on a monitor. Also, they are proven to be accurate even for varying lighting conditions and weather conditions. Their flexible detector layout is also an added advantage, where the zone is variable from 1.5-30 meters, depending on the height. Nevertheless, each camera can manage up to 32 zones of detection summing the number in 114 project case with 8 cameras to 256 zones. Besides, a single camera can also cover a range of up to 6 lanes.

3.3 Warning Message Design

Two warning message signs are installed on each side of the road relative to each direction. The sign installation has been completed in May of 2003 (see figure 3.5). Mainly, the purpose of these signs is to warn violators hoping to deter them from continuing their risky maneuver at an early stage before even the opposing car is yet perceived. That is to provide a longer reaction time period for the violator to abort passing and return to the right lane before it is too late to do so. In addition, the signs ought to inflict a certain psychological influence on violators who when violating will have a yellow flashing light in their face. In other words, when seeing the flashing light the violator will realize that his/her illegal act has been uncovered and his/her tendency would probably be to return to the right lane. That is why the message is designed to be dynamic rather than static like other information signs. Since they address violators, the signs are placed on the other bank of the road in each direction to better convey the required message. The AUTOSCOPE processor controls these signs. When the processor detects and verifies a violation, a digital signal turns the flashing signs on for a user specified time, which is 5 seconds in 114 project. This time interval is a variable key that can be changed within the AUTOSCOPE communication system by entering it through a laptop depending on the type of warning sign and the corresponding requisite flashing time.

Figure 3.5 - Dynamically Flashing Message Signs

3.3.1 Wording

The aim of the displayed message sign is to give early warning to a violator so that he/she would abort the illegal maneuver at an early stage to gain precious time to be able to go back to the right lane or stop if another opposing vehicle is seen. That is why the wording of such a message has to be as short as possible to provide the violator with more time reacting to the sign information rather than reading it. Besides, clarity is an important element for this kind of warning. As a result, the chosen sign design that has been installed already is the standard static “DO NOT PASS” regulatory sign. However, to fit this project study and objective, the signs were equipped with flashing lights that, as explained earlier, are dynamically activated upon detecting a violator.

3.3.2 Design

The design of the four installed signs follows the set standards of the MUTCD as for shape, color, lettering, dimensions, position, and erection. Since the signs ought to convey a regulatory message, they have rectangular shape with white background and black lettering just like the speed limit signs. Based on the road speed, the letters were chosen to be 10 inches all in upper case. A 1 inch black border is set next to the ¾ inch white edge. Referring to the discussion earlier, the signs are positioned to the left side of the flow to closely fall within the violator vision.

3.4 Communication Subsystem

The communication subsystem is mainly made up of the two control panels that are responsible for coordinating the system actions that vary from detection to warning. This part of the system has been modified relative to its original design in order to conform to the new site obligations. The modifications will be discussed in the control panel section that follows.

3.4.1 Control Panels

Two control panels are provided, a major control panel (see figure 3.6), which is the central unit relative to the east direction detection cameras, and a minor control panel (see figure 3.8) that collects the data from the four west cameras. The Mini-Hub II that is responsible for the message signs activation is shown in figure 3.7. The deployed system is completed with each control panel functioning separately. Each control panel has its own electric supply and Mini-hub II processor to activate the corresponding signs.

The problem is that to be able to run the system through the major panel, the 2 signs for the eastbound direction and the other 2 signs for the westbound direction are to be hooked to the main panel from which they will be activated. That would make a coherent centralized system. That meant that VDOT had to do one of two things: either to dig through the road pavement for the cable extension or to pass the cable over the road and let it hang on high poles. Neither of the two alternatives has been approved by VDOT and thus, a new system configuration has been implemented.

The latest system design is completed with each control panel acting separately. Thus, the system is now divided into two parts, each independent from the other. Each has its own electric supply and Mini-hub II processor to activate the corresponding signs. Relative to this issue, the equipment ordered to activate the signs on both directions is based on the previously planned system architecture, and by the recent alteration, additional equipment has been ordered to satisfy the new system design. Such a modification consumed more time than we expected since we had to redesign the system, reorder and install the new equipment

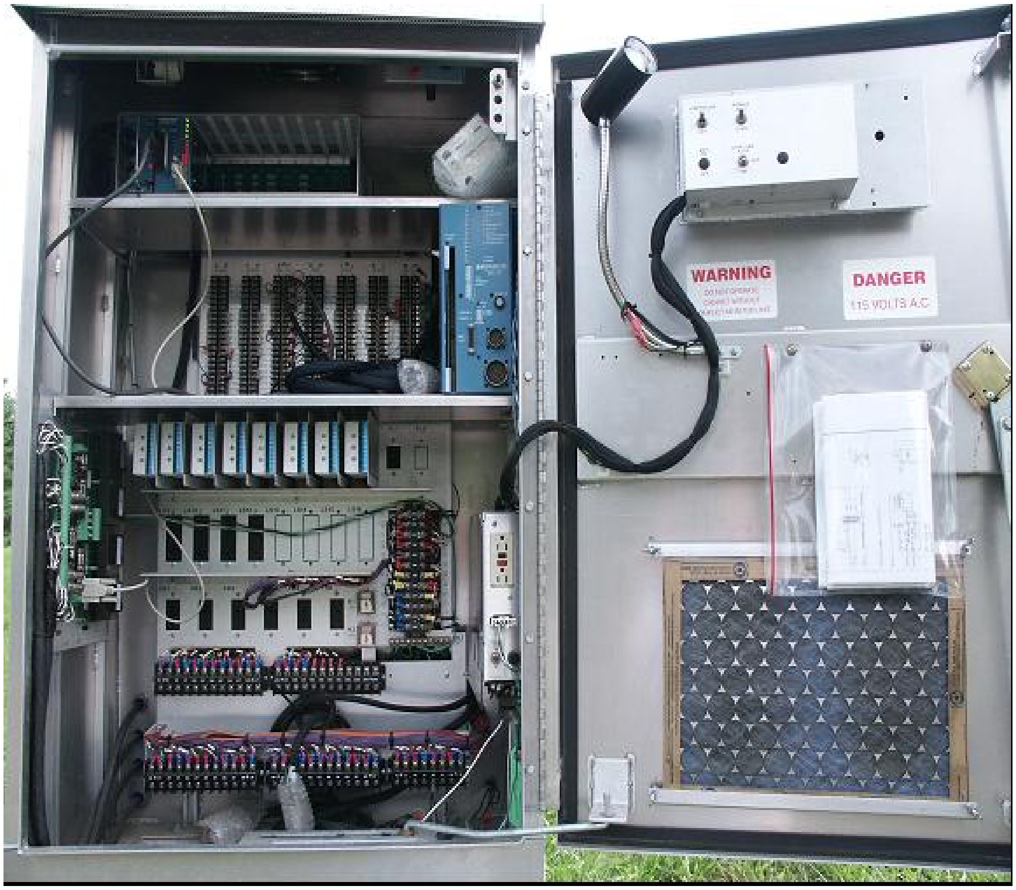


Figure 3.6 - Major Control Panel

Notice the Mini-Hub II that is placed at the top left of the panel to activate the signs. A closer look at it can be viewed in Figure 3.7, where the four lights representing the state of the corresponding four MVPs can be distinguished.

Figure 3.7 - Mini-Hub II in Major Control Panel

Figure 3.8 - Minor Control Panel

3.4.2 Software Calibration

The software part of the system has been modified few times regarding the AUTOSCOPE calibration and detection sensitivity. Although the system in general has been declared active towards the end of July, the AUTOSCOPE system has been separately collecting data since the end of February. Data since that date has been gathered and studied and statistics have been stored for research purposes and for VDOT information updates. The bigger part of the work done towards the system calibration has lately addressed the AUTOSCOPE detection sensitivity to better fit the site conditions.

One thing noticeable in this technology is the concept of background signature that might lead to false alarms due to the continually varying scene conditions and illumination alterations. After attuning the system and performing many field tests, the system operation is now complete and fit to the site weather conditions. The system is precise and accurate once tuned and calibrated using the various embedded AUTOSCOPE utilities. The effect of fixed objects' shadows has been managed by background suppression. While as for dynamic reflections and shadows, the software uses biasing criteria for the background signature. The software is coping with the illumination transition period by continuous update and adaptation to a new background reference to which the current image data is compared. Nevertheless, the feature detection measures are dynamically updated relative to the change in signature strengths. Briefly, it is through continuous adaptation process that the software surmounts difficult weather conditions such as rainy weather, snow and fog.

The deployed system exploits the embryonic AUTOSCOPE technology and makes use of its ability to:

- Operate in presence of shadows, illumination variations, and light reflections through the previously mentioned adapting signature detection, thus minimizing the false alarm rate experienced by other systems.
- Adapt to a variety of scene backgrounds without fixed marks endowing this system with higher reliability over different installation situations.
- Locate a detector on the screen in any desired configuration associated with the roadway conditions versus the limited capability of other systems to certain number of detectors and configurations.
- Function properly in congested traffic conditions even when vehicles are stopped through the background-updating feature that prevents vehicle fusion with the background.

3.5 System Operations

There are two consecutive steps that the system goes through when it detects a violator. The first step is to verify the violation, which is achieved through the AUTOSCOPE machine vision technology (MVP). The second complementary step is the triggering of the warning message to deter violators from completing their illegal action within the no-passing zone area. The AUTOSCOPE functionality is not restricted to detection and warning actions only, but also it collects data and statistics about the count, speed, and density of the regular traffic and as well as the violating vehicles.

3.5.1 AUTOSCOPE Surveillance Operations

This part of the system is responsible for detecting and verifying the violation event prior to activating the warning message signs. The discussion, in this report and the previous two, has mentioned till now the AUTOSCOPE features as to its advantages and its adequate capability to perform at route 114 environment. A detailed description of the detection technology used in the AUTOSCOPE software is briefly discussed next. The detector layout of a sample camera scene is presented in figure 3.9 below. In the figure, different kinds of detector types can be selected. Each detector type is intended to calculate and collect specific traffic data, such as the number of cars that pass a certain point in a user specified time interval. In general, a detector layout may encompass the following types of detectors: Count, Presence, Boolean Detector Function, Speed, Label, Detector Station, Incident, Scheduler, Contrast, and Speed Alarm. Out of these 10 possible kinds of detectors, the shown detector layout in figures 3-11 utilizes only six that are Count, Presence, Boolean Detector Function, Speed, Layout, and Detector Station. Brief elaboration on each used detector type will be discussed next.

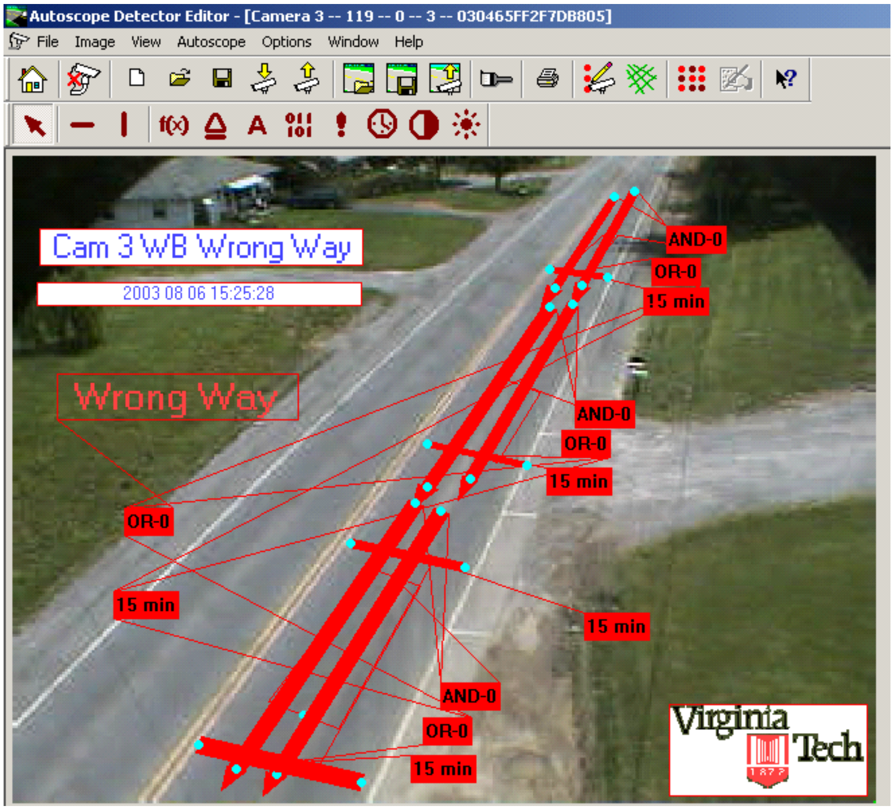
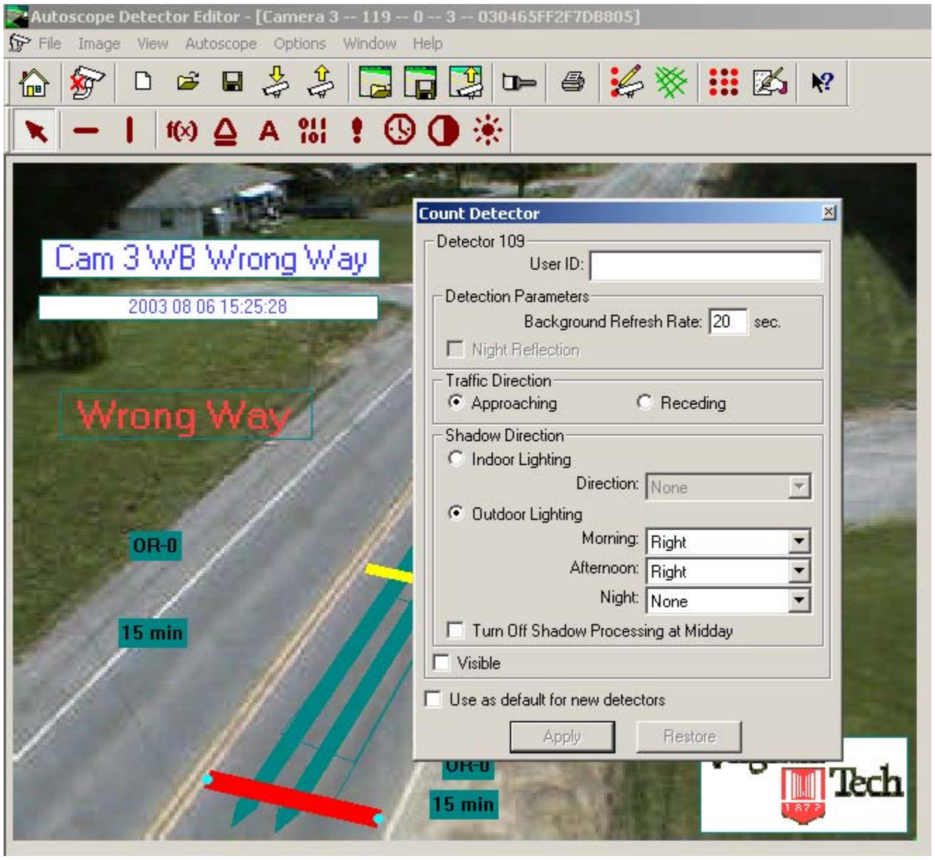


Figure 3.9 - Sample Detector Layout

Count Detector: Count Detectors perform the vehicle detection processing, that is, the detectors show whether or not there is a vehicle over the vision sensor. In addition, count detectors compile traffic volume statistics where the volume is the sum of vehicles detected during a user specified time interval, which is set in the Set Preferences or the File Configuration. Besides, there are no restrictions on how to orient count detectors in the field of view; however, these are usually straight lines drawn perpendicular to the lane of traffic using the computer mouse. It is drawn on the image where the vehicles pass and by positioning the mouse pointer on the start node and then holding and dragging to the required length. The detectors that are used in a typical detection file are about 0.6 to 1.2 meters thick and 1.5 to 2 car widths long. The individual count detector parameters menu is shown in figure 3.10 (notice that the menu is displayed while the detector itself is highlighted in red, similarly for the other detectors). As can be seen from the figure, each detector has a unique ID in every detector file. In the detection parameters section, there is a background refresh rate key that specifies the guaranteed minimum time (for safety) an object may remain stationary before the Machine Vision Processor (MVP) considers it as part of the signature background as it has been explained earlier. In this project's case, this is specified to 90 seconds. Nevertheless, the night reflection box is checked to allow the MVP to compensate for roadway reflections caused by dense headlights that might trigger false alarms. Besides, the traffic direction is specified based on whether the traffic is approaching the MVP camera or away from it. The final utility is the shadow direction box that prevents false vehicle detection caused by shadows cast by vehicles in adjacent lanes. There are many options to specify where the shadows are supposed to come from based on the time of day and detector orientation relative to the sun position at that time.



Count Detector

Detector 109

User ID:

Detection Parameters

Background Refresh Rate: 20 sec.

☐ Night Reflection

Traffic Direction

● Approaching ○ Receding

Shadow Direction

○ Indoor Lighting

Direction: None

● Outdoor Lighting

Morning: Right

Afternoon: Right

Night: None

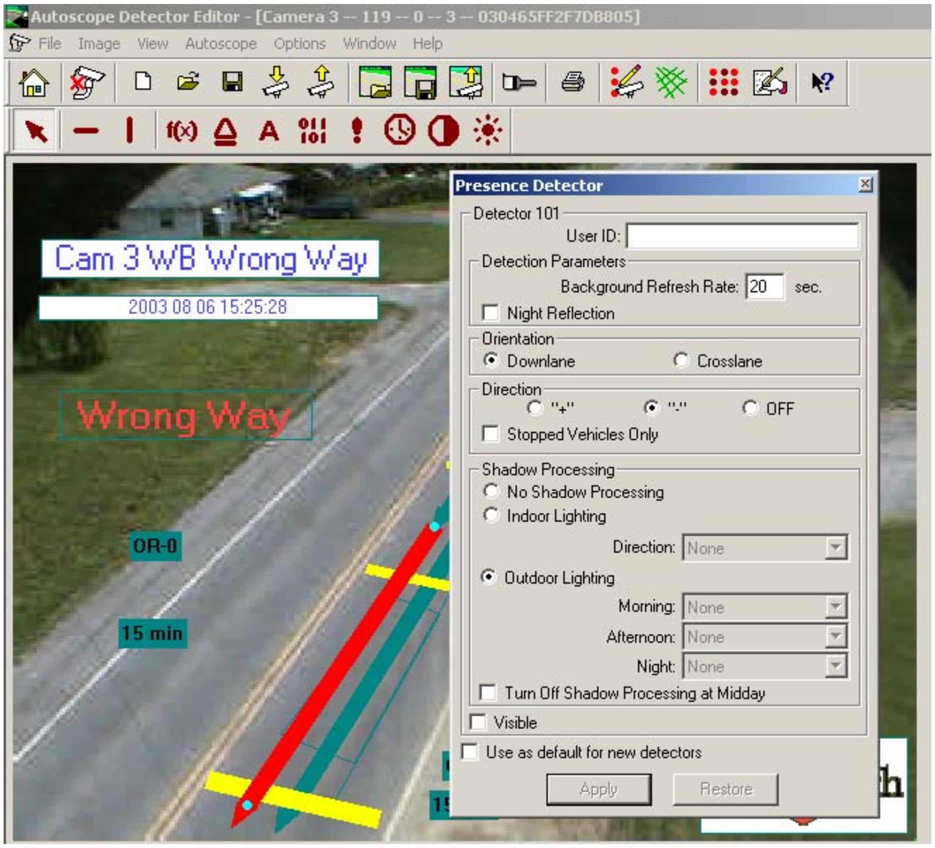
☐ Turn Off Shadow Processing at Midday

☐ Visible

☐ Use as default for new detectors

Figure 3.10 - Individual Count Detector Parameters Menu

Presence Detector: Presence Detectors identify the presence of a vehicle in the field of view. The detector will turn on while a vehicle passes and remains under the detector. It is suitable for directional detection purposes. For further accuracy in the detection process, two or more presence detectors are combined to ensure that a vehicle has been detected. Doing so, more than 99% accuracy is achieved. The combining process utilizes the Detector Functions (Boolean) such as AND, OR, NOR, NAND, and M of N, which allow the user to include, exclude, or otherwise qualify what constitutes a 'presence'. Presence detectors are also straight lines like count detectors but drawn parallel to the flow of traffic and can be drawn with no restrictions in a similar manner. Figure 3.11 depicts the individual presence detector parameters menu that shows on top the unique ID of that detector in a detector file. The detection parameter utility as well as the shadow processing for this type of detector is similar to the aforementioned count detector's. Two other utilities are shown in the figure, the 'orientation' and the 'direction'. The 'orientation' defines whether the presence detector is a Cross-lane (perpendicular to the lane) or a Down-lane (parallel to the lane); while the 'direction' defines in which direction to detect traffic and this is done only after the field of view is calibrated. Great attention is given to the calibration process since this process influences many traffic data.



Presence Detector

Detector 101

User ID:

Detection Parameters

Background Refresh Rate: 20 sec.

☐ Night Reflection

Orientation

● Downlane ○ Crosslane

Direction

○ "+" ● "-" ○ OFF

☐ Stopped Vehicles Only

Shadow Processing

○ No Shadow Processing

○ Indoor Lighting

Direction: None

● Outdoor Lighting

Morning: None

Afternoon: None

Night: None

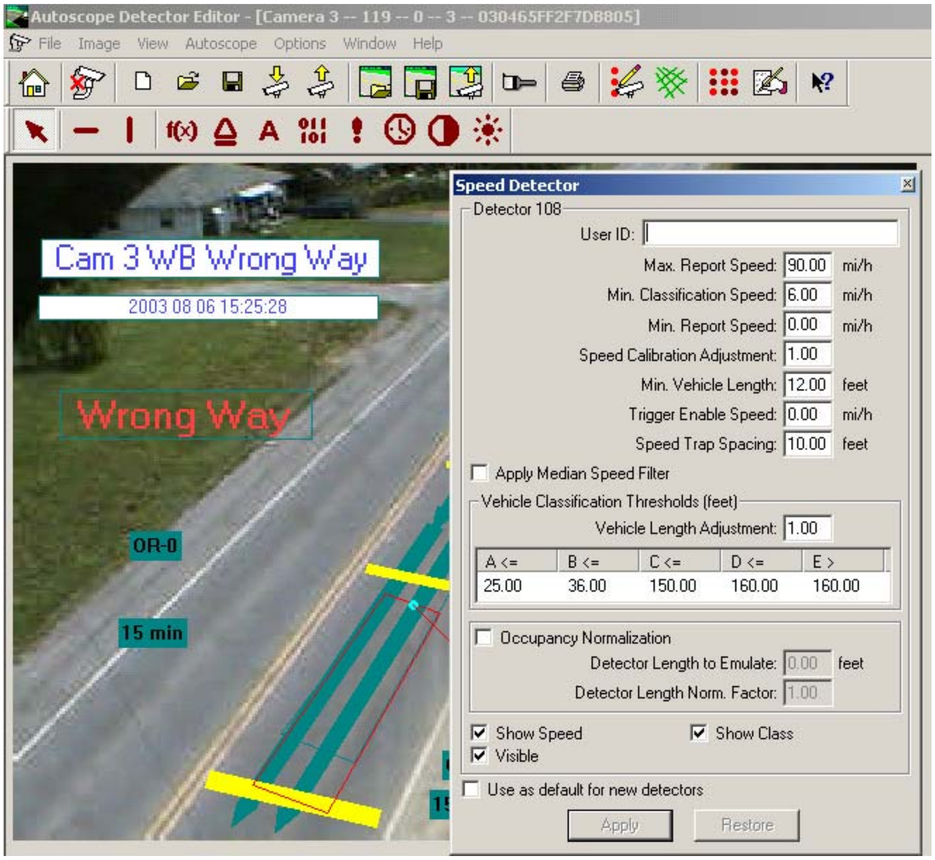
☐ Turn Off Shadow Processing at Midday

☐ Visible

☐ Use as default for new detectors

Figure 3.11 - Individual Presence Detector Parameters Menu

Speed Detector: Speed Detectors generate traffic information such as the vehicle speeds (in mph or km/h), vehicle lengths, and vehicle classification into five different categories based on the measured lengths. In order for the speed detector to function properly it must be paired with a count detector. The speed detector is to be placed on the upstream side of the associated count detector. The speed detector processes data only when the count detector changes state from on to off. It appears as a trapezoid on the detector layout file. The function of the speed detector is greatly dependant on the calibration of the field of view. After that is done, the speed detector records the speed of a vehicle when the count detector is turned on only. The same process used for the previous two detectors, is used to create a speed detector using the mouse. The speed detector parameters can be changed from the toolbox portrayed in figure 3.12. The available utilities are quite obvious to understand and are specified to fit the site characteristics.



Detector 108
User ID:
Max. Report Speed: 90.00 mi/h
Min. Classification Speed: 6.00 mi/h
Min. Report Speed: 0.00 mi/h
Speed Calibration Adjustment: 1.00
Min. Vehicle Length: 12.00 feet
Trigger Enable Speed: 0.00 mi/h
Speed Trap Spacing: 10.00 feet
☐ Apply Median Speed Filter

Vehicle Classification Thresholds (feet)
Vehicle Length Adjustment: 1.00

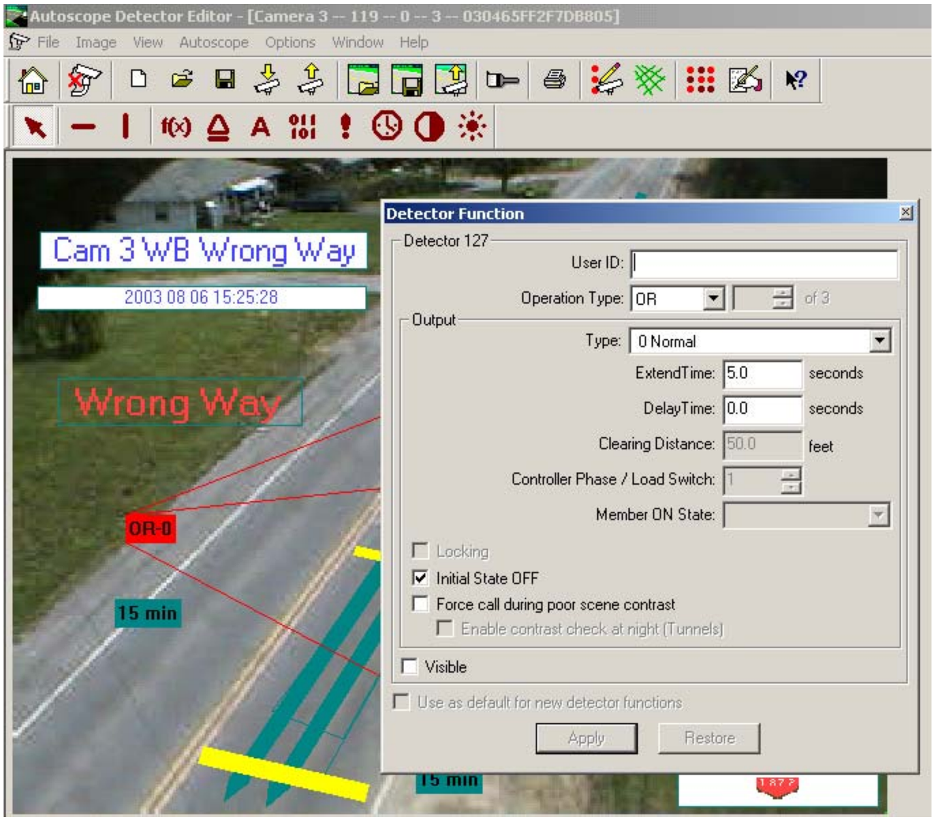
A <=	B <=	C <=	D <=	E >
25.00	36.00	150.00	160.00	160.00

☐ Occupancy Normalization
Detector Length to Emulate: 0.00 feet
Detector Length Norm. Factor: 1.00
☑ Show Speed
☑ Show Class
☑ Visible
☐ Use as default for new detectors

Figure 3.12 - Individual Speed Detector Parameters Menu

Detector Functions: The Boolean Detector Function combines the normal outputs of two or more detectors into one customized output. Typically, a single detector performs its function, such as counting, when a vehicle enters its zone. The detector registers a simple on or off output to the MVP. However, when two or more detectors are combined into a detector function, Boolean logic relays the conditions that must be present before the grouping generates an output. The detector function is created by clicking on the utility represented on the detector file as a function sign, and then specifying the sought logic function. The detector function parameters menu can be viewed in figure 3.13. This kind of detector has also an ID and a place to specify the type of logic to be used when combining detectors. The extended time defines how long the Detector function stays on. For the route 114 project, it is the time the flashing light will stay on after a violation is detected and that is 5 seconds. The delay time is set to zero since it is needed that the function turns on at the instant of detection and verification with no additional delay.

Clearing distance is not used in this project since it usually applies to intersection surveillance where there is a dilemma zone. Finally, the initial function state is set to off at first, which will change after detection. Figure 3.9 shows one of the refinements added to the detection logic utilized by the MVPs at the site which is a detector function that uses the AND logic to declare a violation. This means that the violation will not be acknowledged until both parallel presence detectors are activated, along with the count detector, by an object that occupies the detectors more than certain duration (0.3 sec). In this way, a violation will not be recorded, or at least not considered, unless it is linked with a minimum reasonable speed through which it can cover the detector length. This test has been named the ‘Wrong Alarm’ test.



Detector 127

User ID:

Operation Type: OR ▾ of 3

Output

Type: 0 Normal

ExtendTime: 5.0 seconds

DelayTime: 0.0 seconds

Clearing Distance: 50.0 feet

Controller Phase / Load Switch: 1

Member ON State:

☐ Locking

☑ Initial State OFF

☐ Force call during poor scene contrast

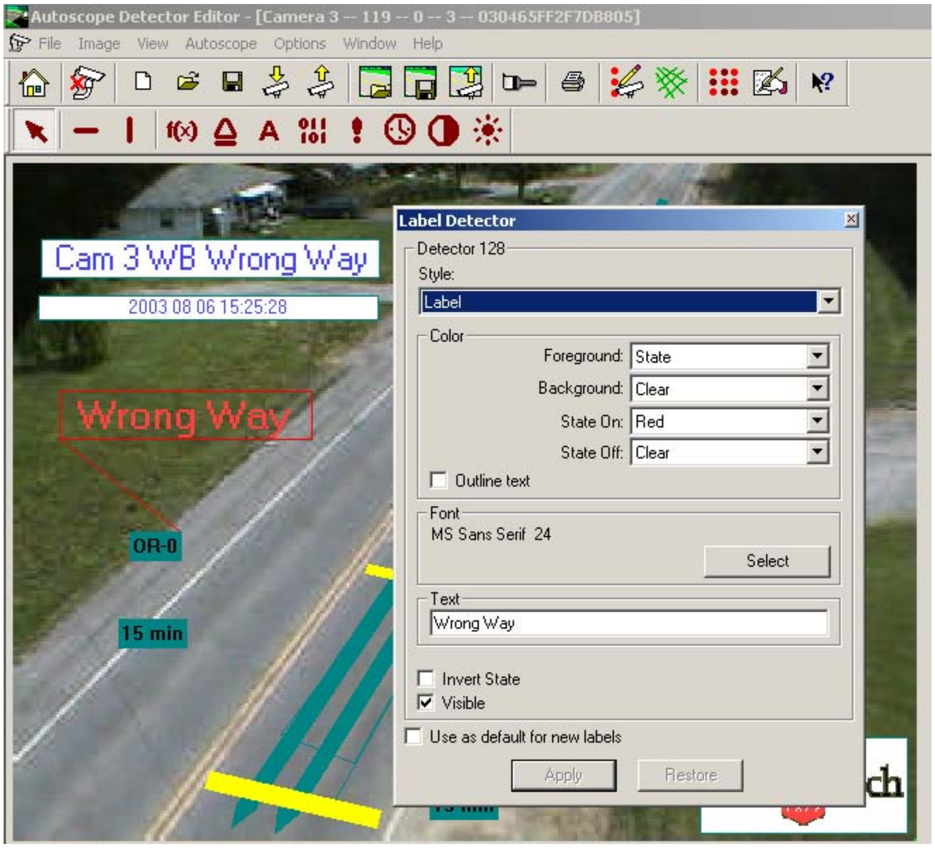
☐ Enable contrast check at night (Tunnels)

☐ Visible

☐ Use as default for new detector functions

Figure 3.13 - Detector Function Parameters Menu

Label Detector: Label Detectors are used to display information on the MVP video output and to pass input information to other detectors. They cannot have inputs that are outputs from other MVP’s but only from the same MVP where the detector is. Basically it is used to identify the different functions and also add some signatures to the video output of the MVP that is only aesthetic. Three label detectors are used for the output of the Route 114 project as can be seen in the figure 3.9 presented earlier. The first label detector is a box that flashes upon violation verification displaying ‘Wrong Way’. The second one is used for the clock display while the last one is only for signature showing the camera number in the upper left of the screen and the Virginia Tech Logo in the lower right of the image. The most important one is the ‘Wrong Way’ label detector which, when it turns on, conveys the signal to the Mini-Hub II to activate the flashing signs. The label detector is linked to the Presence and Count detectors by a Boolean logic function. Figure 3.14 below shows the first kind of label detector that is the ‘Wrong Way’ alarm.



Label Detector

Detector 128

Style: Label

Color

Foreground: State

Background: Clear

State On: Red

State Off: Clear

☐ Outline text

Font

MS Sans Serif 24

Select

Text

Wrong Way

☐ Invert State

☑ Visible

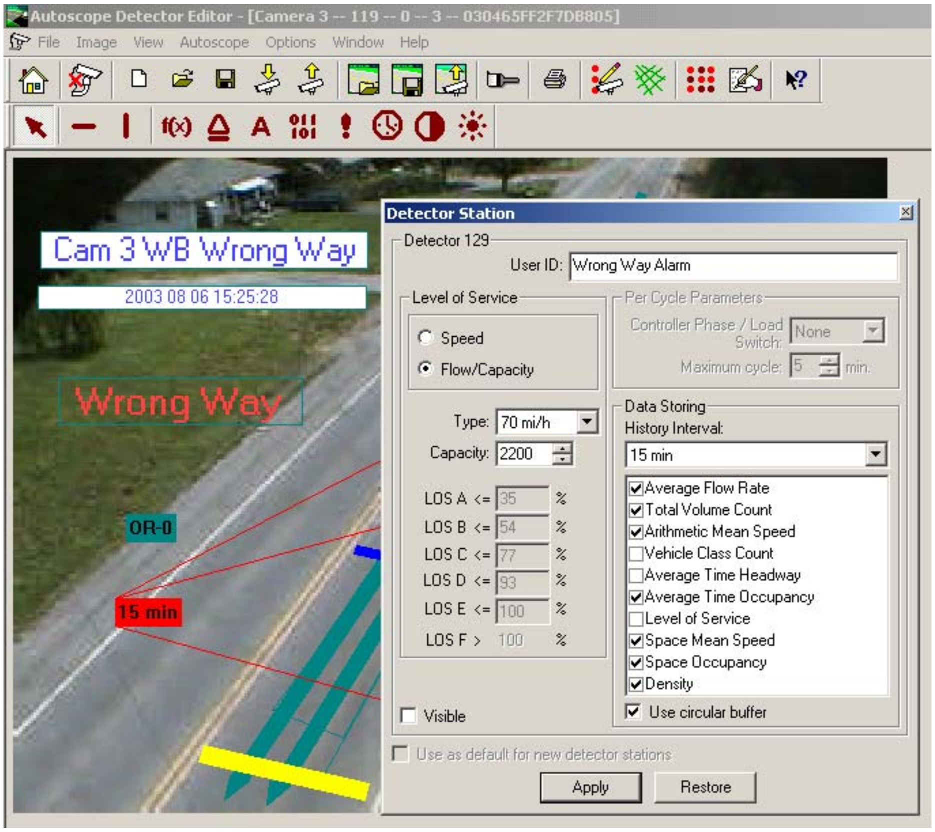
☐ Use as default for new labels

Apply

Restore

Figure 3.14 - Individual Label Detector Parameters Menu

Detector Station: Detector Stations collect and report traffic data gathered over user specified time intervals. Data can be accumulated over 1minute, 5 minutes, 10 minutes, 15 minutes, 30 minutes, or one hour. Each MVP detector output file utilizes one detector station that is linked to all the other detectors of that MVP so that to have one output file from each camera. That is 8 output files are generated corresponding to the 8 cameras installed at the site for both directions. Figure 3.15 presents the detector station parameters menu from which the requisite data arrays are selected and thus will show in the output file. A sample output file from a typical MVP data is presented in a following section in this report.



Autoscope Detector Editor - [Camera 3 -- 119 -- 0 -- 3 -- 030465FF2F7DB805]

Detector Station

Detector 129

User ID: Wrong Way Alarm

Level of Service

○ Speed
● Flow/Capacity

Type: 70 mi/h
Capacity: 2200

LOS A <= 35 %
LOS B <= 54 %
LOS C <= 77 %
LOS D <= 93 %
LOS E <= 100 %
LOS F > 100 %

☐ Visible

Per Cycle Parameters

Controller Phase / Load Switch: None
Maximum cycle: 5 min.

Data Storing

History Interval: 15 min

- ☑ Average Flow Rate
- ☑ Total Volume Count
- ☑ Arithmetic Mean Speed
- ☐ Vehicle Class Count
- ☐ Average Time Headway
- ☑ Average Time Occupancy
- ☐ Level of Service
- ☑ Space Mean Speed
- ☑ Space Occupancy
- ☑ Density

☑ Use circular buffer

☐ Use as default for new detector stations

Figure 3.15 - Detector Station Parameters Menu

The Econolite Control Products Inc. personnel have aided in the calibration process of the system more than once after viewing the collected data, studying it, and implementing new ideas to the system configuration in an attempt to customize the system performance to fit the study area conditions. Besides, it is agreed on that the system performance is subject to the varying conditions of the site especially concerning the weather state. That is why continuous adjustment to the system configuration is to be done to accommodate the varying conditions through out the year.

3.5.2 Sign Activation

The last part that has been completed in the overall system structure is the message sign installation and activation process. As mentioned earlier, the signs on each side of the road now function independently each connected to a control box and having its own Mini-Hub II activation kit. Following the violation detection and verification, the detector files send a triggering signal to the Mini-Hub II that is connected to the AUTOSCOPE system through the detector file input/output configuration key. Each Mini-Hub has four lights representing the condition of the four MVPs installed on the site per direction of flow. When this signal reaches the Mini-Hub, the light of the corresponding MVP from which the signal originated changes from its stable state to a blinking state which, in turn, will send a ‘1’ digital signal to the message making it flash for a user specified duration that was mentioned previously.

Many violation trials have been performed after the system full activation was declared. The system performance is greatly reliable in the case of violation.

3.6 Sample Data Output

A sample data output is presented hereunder in table 3.1. This output is for camera 1. Notice that there are two detectors 113, and 115 to cover the required detection zone assigned to this MVP. Nevertheless, detector 117 and 118 are the count detectors that are connected to their corresponding detector stations that provide the required traffic data for each direction. In addition, detector 126 is the label detector (‘Wrong Way Alarm’) that is connected to two presence and speed detectors (113 and 115). It gathers the output from the two detectors and analyses it through the Boolean logic set within its parameters that is already discussed earlier. This data table presents the following information in the columns from left to right: detector ID, Date, Time, Volume Count, Mean Speed (time mean speed), Average Time Headway, Average Flow, Average Time Occupancy, Level of Service, Space Mean Speed, Space Occupancy, and Density respectively.

After the AUTOSCOPE system installation at Route 114, the data has been collected since the end of February 2003. However, the data collection process has gone through consecutive calibration and filtering processes to obtain the best possible results. Table 3.2 presents the statistics averaged for the four cameras per direction during the month of October 2003. The collection period is from 10/24/2003 till 10/29/2003 spanning over a little more than five days (7429 minutes of data). The table shows the count of regular traffic and the average space-mean speed of the flow during that collection period. At this point, the data is highly comparable to the data collected in the filed in September 2000. The Average daily traffic is 12110 (12000 from filed survey in the year 2000). Nevertheless, the violations count that was obtained from the September 2000 survey indicated an average of 0.75 violations per day going West, and about 2 violations per day going East. These values are comparable to the data presented in table 3-2 which shows that there is about 0.82 violations per day going West and 5 violations per day going East.

Table 3.1 - Sample Output from Camera 1

113 - Camera 1 WW Speed Detector # 1
115 - Camera 1 WW Speed Detector # 2
117 - Cam1 WB Traffic Speed Detector
118 - Cam1 EB Traffic Speed Detector
126 - Wrong Way Alarm

Det ID	Date	Time	Volume Cc	Mean Spee	Average Ti	Average Fl	Average Ti	Level of Se	Space Mea	Space Occ	Density
113	2003,09,11	16:03:00	0	0	0						
115	2003,09,11	16:03:00	0	0	0						
117	2003,09,11	16:03:00	10	43.19922	5.449219	600	6	65	43.03906	4.238281	13.9375
118	2003,09,11	16:03:00	8	49.625	5.5625	480	7.5	65	49.16797	3.589844	9.761719
126	2003,09,11	16:03:00	0	0	0						
113	2003,09,11	16:04:00	0	0	0						
115	2003,09,11	16:04:00	0	0	0						
117	2003,09,11	16:04:00	9	43.44141	6.289063	540	6.664063	65	43.125	4.503906	12.51953
118	2003,09,11	16:04:00	8	48	6.0625	480	7.5	65	47.92188	3.84375	10.01563
126	2003,09,11	16:04:00	0	0	0						
113	2003,09,11	16:05:00	0	0	0						
115	2003,09,11	16:05:00	0	0	0						
117	2003,09,11	16:05:00	2	41.5	0.777344	120	30	65	41.21484	0.664063	2.910156
118	2003,09,11	16:05:00	11	44.08984	11.18359	660	5.453125	65	41.03906	6.824219	16.08203
126	2003,09,11	16:05:00	0	0	0						
113	2003,09,11	16:06:00	0	0	0						
115	2003,09,11	16:06:00	0	0	0						
117	2003,09,11	16:06:00	0	0	0	0	60	65	0	100	0
118	2003,09,11	16:06:00	8	43.5	7	480	7.5	65	40.16797	4.386719	11.94922
126	2003,09,11	16:06:00	0	0	0						
113	2003,09,11	16:07:00	0	0	0						
115	2003,09,11	16:07:00	0	0	0						
117	2003,09,11	16:07:00	11	34.45313	6.003906	660	5.453125	65	33.97266	4.953125	19.42578
118	2003,09,11	16:07:00	11	37.45313	11.45703	660	5.453125	65	30.97656	6.230469	21.30469
126	2003,09,11	16:07:00	0	0	0						

Table 3.2 - Data Statistics for Five Days (10/24/2003→10/29/2003)

	West Direction	**East Direction**
	Towards Radford	**Towards Christiansburg**
Regular Traffic Count	30506	30044
Average Traffic Speed (mph)	48.75	50.73
Violation Counts	4.25	26.25
Average Violation Speeds (mph)	68.67	53.45
Average Daily Traffic	6101	6009
Total Daily Traffic (Both Directions)	**12110**	

3.7 Overall System Assessment

This report presents the assessment of the AUTOSCPE detection reliability as well as the physical system architecture. The assessment is based on the presented data analysis and the planned system upgrading.

3.7.1 AUTOSCOPE Detection Assessment

Based on the presented data in tables 3.1 and 3.2, it is clear that the AUTOSCOPE system calibration and adaptation to the site conditions have proven to be beneficial as to improving the system reliability and accuracy and decreasing the system false alarms although not totally eliminating them. All the cameras show improvement in their output.

Nevertheless, another issue ought to be mentioned as part of this discussion. This issue can be comprehended just by looking at figure 3.17 below. This is the scope of vision of camera 1. The braches from the tree on the right side of the picture infringe into the camera's vision to a great extent. For such reasons, the detection zone has been shortened to avoid these branches. Thus, sometimes the system detection and warning time might be delayed due to the reduced surveillance zone. For this reason, one of the sensitivity tests that was conducted using the simulation dealt with increasing the detection time of the system to account for such cases. Cutting these branches can offer to extend the detection zone and thus advance the detection instant as well as the sign activation giving more time to violators to respond. In the same sense, the slightly higher rate of false detection that camera 8 is also showing can be attributed to the position of the violation speed detectors for that camera right on one of the house exits on that road. Probably, every time a car from that household heads somewhere from that exit a violation is triggered. Figure 3.18 shows the speed detectors right on the house exit where the cars are parked. This issue has been lately addressed by internally filtering the recorded violations to a minimum speed of 30 mph, thus eliminating all those caused by the exits on the detected stretch of route 114, and by leaving some space in detection in front of the house exit. For this reason, the sensitivity tests conducted in chapter five of this thesis dealt with increasing the detection time of the system, as mentioned earlier, but in this case to account for those violators who might start their maneuver in the space between the detection zones of that camera. So, the sensitivity of the detection time is checked in chapter five.

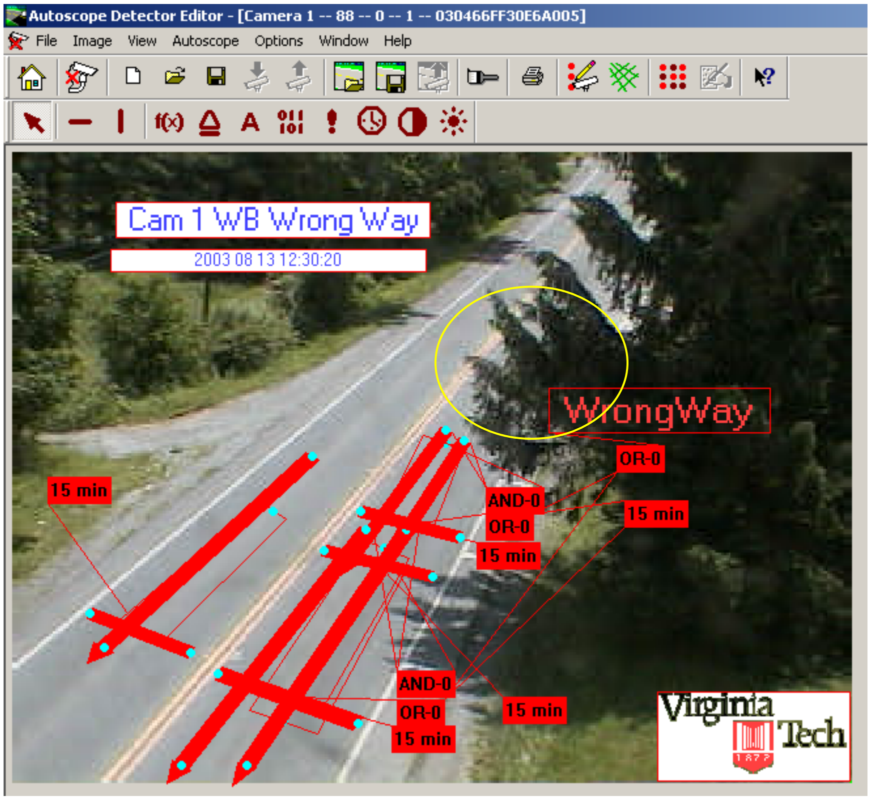


Figure 3.17 - Tree Branches Infringe Into Camera 1 Scope

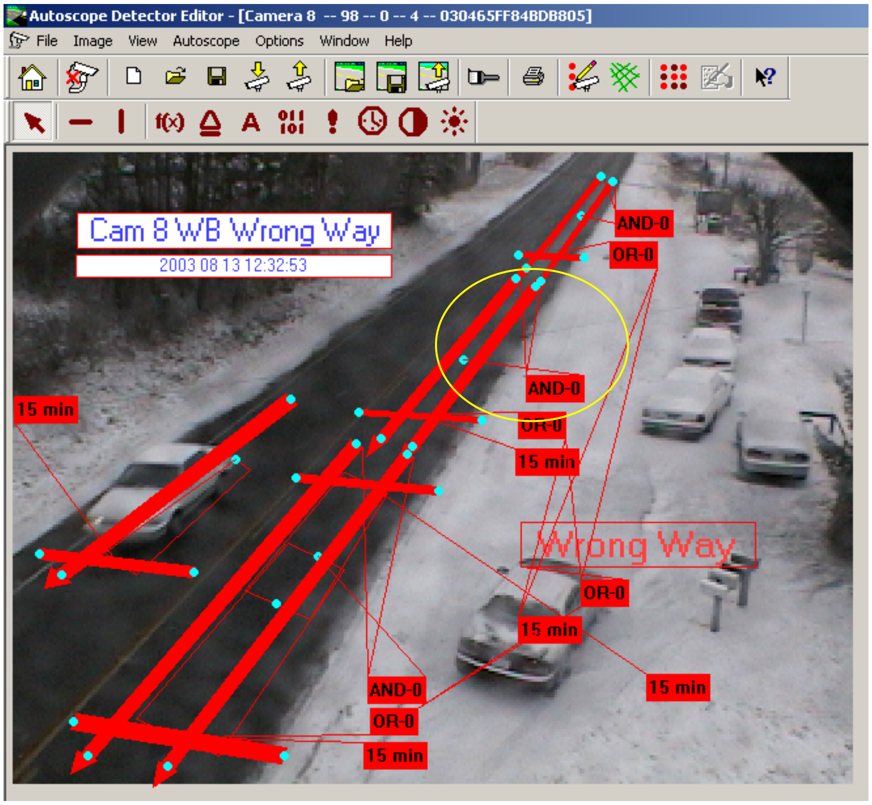


Figure 3.18 - Detectors Right on House Exit

3.7.2 Physical System Assessment

The physical system assessment will deal with equipment currently installed on the site. The system's main aim is to convey a warning message to those who are illegally passing in a no-passing zone stretch so that these violators are deterred from continuing the risky maneuver. The simulation shows that if all violators obey the warning message, the accident occurrences will be virtually eliminated. Thus, great attention is to be given to the role of the warning message by itself and more to the design of these signs to a greater extent. However, the current installed signs are not that enforcing. The signs are only regular No-passing zone enforcement signs that have two yellow lights mounted on top. A better sign would be a Variable Message Sign that is fully illuminated when a violator is detected to better fulfill its sought role. Variable Message Signs, in this case, are capable of providing a stronger psychological influence on violators through their full lighting board that captures the vision.

3.8 Recommendations

Referring to what has been discussed in this report; four major recommendations are to be stated. The first is related to the AUTOSCOPE detection system tuning. More resources are to be put into this field to better calibrate the surveillance system and find the optimal setup that suits the site's conditions, knowing that some seasonal changes are to be implemented during the year to accommodate the varying weather conditions. The second concerns the clearing of the MVP's scope of vision that has been pointed out earlier in the discussion. The few tree branches are supposedly a source of false alarm triggering. The third addresses the VMS that ought to replace the existing ordinary regulatory signs to enhance the enforcement side of the project. The last issue is the video recording system that ought to be implemented. Further discussion about the benefits of this system is presented in the Video Recording Subsystem section of the report. These recommendations aim at enhancing the system performance as much as possible to better resemble the simulated system performance so that the simulation output and the real life output match to some acceptable level.

3.8.1 Video Recording Subsystem

Two EH 2500 series camera systems, each placed at one end of the detection zone, serve to confirm the validity of the recorded violations of the AUTOSCOPE surveillance system. These two cameras are triggered to start recording when the AUTOSCOPE system is in the detection state. So, at the same time the central processor sends a signal to the warning message signs to flash, the video recording cameras get a similar signal to switch to the violation recording phase. This is the method utilized to assure that the violation has really took place since the AUTOSCOPE system, as discussed earlier, can detect a violation but can not verify that the violator has abided by the message sign and went back to the correct lane. Once the lower camera is activated, the recording starts for the required time of the violation. Videotapes are obtained from the recorder and then contrasted against the collected MVP one-minute data. Another purpose of providing the recoding cameras is to study the false alarm frequency of the AUTOSCOPE system in an attempt to tune the system to better fit the conditions of the site.

3.9 System Verification

Following the system installation and tuning, the verification process has proved the adequate functionality of the discussed detection and warning system through field tests and violation experimentation. Many intentional violations have been conducted on that section of the road and the results proved 100 percent reliability of the deployed system as to detection and warning signs activation. Figure 3.19 shows one planned violation that was recorded by the west video recording camera. The figure presents a car in its early violation stage when it was detected, followed by two shots after the warning signs have been activated. The last photo in figure 3.19 is a zoomed image presented to better show the flashing signs. As to the collected data, the tuning process of the AUTOSCOPE system proved to be productive. The data shows adequate resemblance to the site violation frequencies that have been manually recorded prior to the system installation as part of the research done based on VDOT's request.

Figure 3.19 - System Operation Verification

CHAPTER 4. THE SIMULATION

4.1 Introduction

A computer simulation, by definition, is the use of a mathematical model to recreate a situation, often repeatedly through the computer help, so that the likelihood of various outcomes can be more accurately estimated. As defined, the purpose behind the simulation is to estimate or predict the performance of the planned system if it were to be implemented. In addition, sensitivity tests could be made to encompass most probable outcomes of various cases, once the simulation showed enough resemblance to the real life situation.

As it has been mentioned in the literature review chapter, no simulation packages in the current market have the capabilities to simulate centerline violations with limited passing sight distance on vertical curves. Therefore, a special code is written to perform such task through creating a microscopic, stochastic and period scanning simulation tool. This software was written by a previous PhD graduate of Virginia Tech, Jamal El Zarif. Thus, this chapter focuses on the extensions added to the previous code and the benefits that accrued from that in addressing the problem of persisting violators.

Following the simulation development is the validation process that takes place through field data collection. Now that the surveillance system is already deployed, data collection is made much easier than the earlier manual count methods. Data is stored and downloaded on a monthly basis from which traffic information is derived. The data is recorded and analyzed by the surveillance system processor that uses the machine vision technology to detect and extract traffic information, like traffic counts, violation counts, space and time mean speeds, density, and percent time occupancy, etc. This data is accumulated over 1minute period.

4.2 Existing Code Configuration(system before extension)

An existing simulation that was mentioned earlier (1) is being extended in this thesis to also warn the opposing vehicle in the path of the violator. The previous microscopic simulation uses the MATLAB language and is mainly based on stochastic processes. The code configuration consists of seven collaborative modules. The architecture of the code can be seen in figure 4.1. A brief listing of the modules is as follows:

- **Input Module:** containing all the input parameters used by other programs in the simulation.
- **Violation Generator:** generating violations based on certain criteria.
- **Road Profile Module:** providing the road coordinates per 50 ft.

- **Main Analysis programs:** calling all other subroutines to simulate the maneuver for every 0.1 second interval.
- **Support Analysis Modules:** computing different parts of the maneuver that are being repeatedly done.
- **Crash Outcome analysis:** compiling the results in terms of possible crashes per action per direction.
- **Report Module:** saving the output into text files.

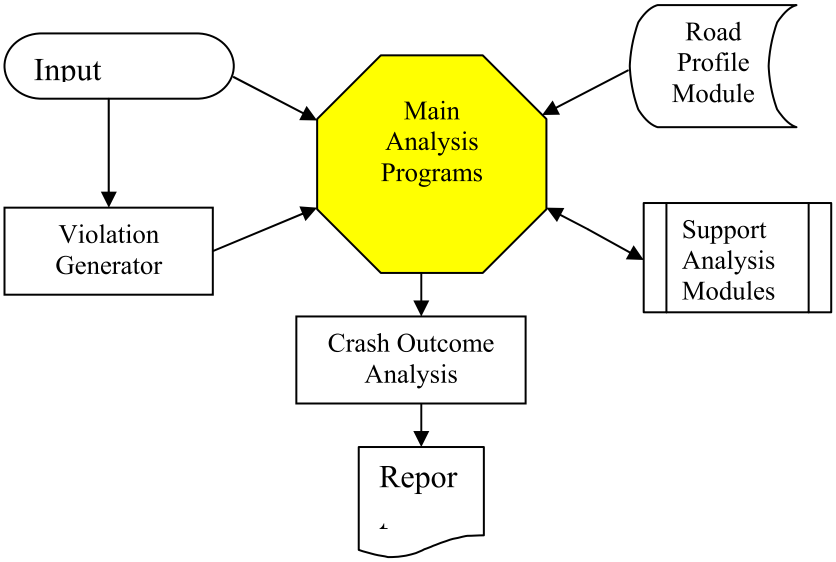


Figure 4.1 - Simulation Code Structure (1)

4.3 Defining the Input Parameters Used in the Base System

In most transportation systems the Driver, the Road, and the Vehicle interact to dictate the system progress and outcome. A listing of each of these components' parameters is presented here. These parameters were all kept the same as those used by the system before the extension is implemented in a way to contrast the results of the system before and after the modification. These are the same parameters that were used by Jamal El Zarif in conducting his simulation.

1. *Roadway-related parameters*: horizontal layout, vertical profile, and lane configuration.
2. *Vehicle-related parameters*: vehicles classes, location, speed, acceleration and deceleration.
3. *Driver-related parameters*: reflecting driver behavior and psychological conditions such as violation rate, perception / reaction time, reading time, and driving under influence (DUI) rate and its effect.

4.3.1 Roadway Related Parameters

4.3.1.1 Road Profile

VDOT provided the coordinates of the road in both directions for every 50 ft as previously mentioned. Based on each direction, and the position of the vehicles, a line of sight is checked to see whether the violator and the opposing vehicle have seen each other after which a reaction is initiated accordingly. The road stretch under consideration is 2100 ft. and is shown in figures 4.2(a) and 4.2(b).

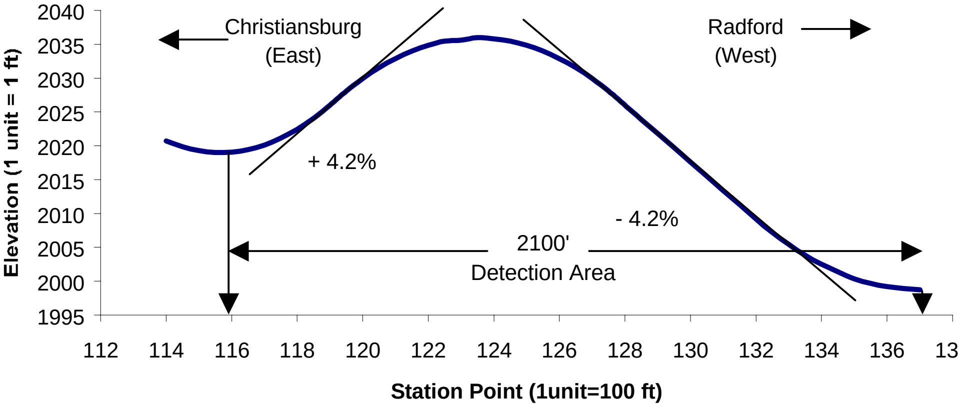


Figure 4.2(a) - Road profile

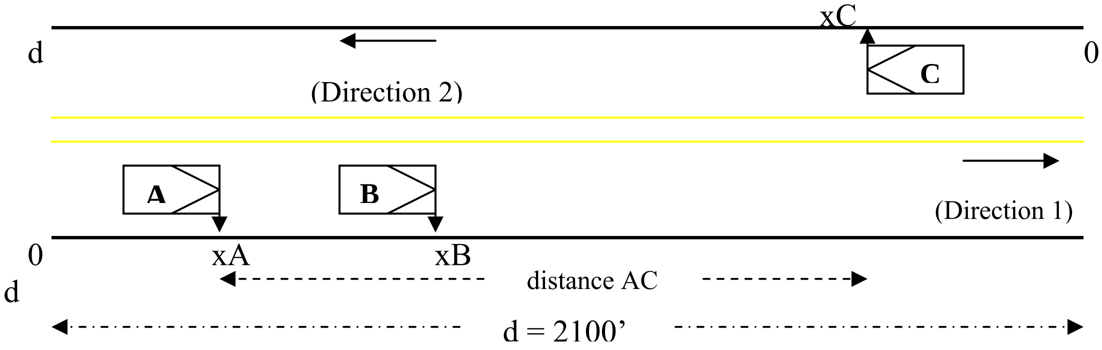


Figure 4.2(b) - Road plan

Figure 4.2 - Road plan and profile (1)

4.3.2 Vehicle-Related Parameters

4.3.2.1 Vehicle Composition

The vehicle composition used for this study was based on manual data collected at the field site. The data shows the following vehicle composition: Light vehicles (83%), Medium vehicles (14%), and Heavy vehicles (3%). A simple representation of an identical violation maneuver is portrayed in Figure 4.2(b), above, where vehicle A will try to pass vehicle B ahead while an opposing vehicle C is present. Three vehicles are defined for each maneuver. Vehicle A is the illegal passing vehicle, vehicle B is the passed vehicle, and vehicle C is the opposing vehicle. Based on the collected data and car dynamics, vehicle A can be either a light or medium vehicle type, while the other two vehicles can be of any class.

4.3.2.2 Vehicle Length

The standard vehicle lengths are used in this study (2). A Light Vehicle (LV) is 19 ft., a medium vehicle (MV) is 24 ft., and a heavy vehicle (HV) is 30 ft.

4.3.2.3 Vehicle Height

A study conducted by Fitzpatrick et al. (3) recommended the following vehicle and driver's eye height for use in geometric design. Driver's eye heights are 3.6 ft for LV, 4.3 ft for MV, and 7.6 ft for HV. While, vehicle heights are 4.3 ft for LV, 5.1 ft for MV, and 8.9 ft for HV, which are also shown in table 4.1.

Table 4.1 - Driver's Eye and Vehicle Heights

	Eye Height		**Vehicle Height**	
	Millimeters	Feet	Millimeters	Feet
Passenger Car (LV)	1082	3.6	1315	4.3
Multipurpose Vehicles (MV)	1306	4.3	1564	5.1
Heavy Vehicles (HV)	2329	7.6	2719	8.9

4.3.2.4 Vehicle Location

After generating the input parameters, initial conditions for each vehicle such as speed, location, and vehicle class need to be specified for the simulation to begin. Thus, the locations of vehicle A and C were to be generated at time =0 when vehicle B enters the detection area as shown in Figure 4.3.

4.3.2.4.1 Location of vehicle A:

The violating vehicle A was randomly located at time = 0 between the mean desired spacing d_d and the minimum headway $d_{AB\min}$, as shown in Figure 4.3. The mean desired spacing is calculated based on the following formula: $q = ku \rightarrow d_d = 1/k = u/q$ where

- d_d = Mean desired spacing;
- u = randomly selected speed;
- q = randomly selected traffic flow;
- k = space headway.

While the minimum headway $d_{AB\ min}$ is calculated based on the formula used in the Pitts car following model (by Halati 1996): $d_{AB}= L + 10+ k\, u_A + bk(u_B - u_A)^2$ (In feet) where

- $d_{AB\ min}$ = space between the lead vehicle and the following vehicle from front bumber to front bumber;
- L = Lead vehicle length (vehicle B).

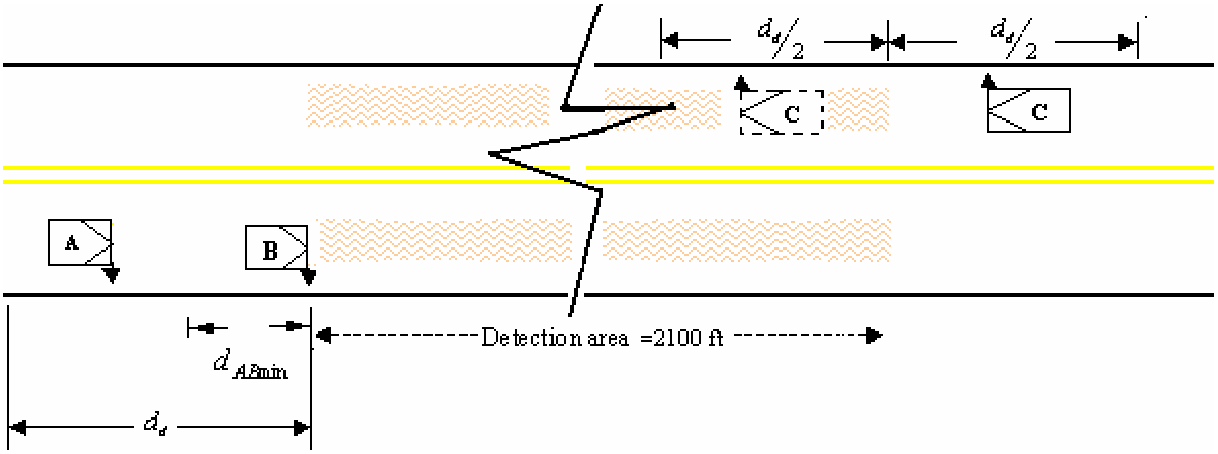


Figure 4.3 - Determination of Initial Locations of Vehicles A, B, &C

4.3.2.4.2 Location of vehicle C:

Similarly, vehicle C was randomly located within a mean desired spacing with equal probability inside or outside the detection area, as shown in Figure 4.3. The random traffic flow volume is selected, then using the traffic flow relationship, a random headway is calculated and then the desired spacing.

4.3.2.5 Vehicle Speed

A normal probability density function for each vehicle speed was formulated based on the data collected from the site. The initial speed of each vehicle was randomly selected from those curves to replicate real conditions. Table 4.2 presents the speeds for the east and west direction.

Table 4.2 - Normal PDF of Initial Speeds

Vehicle Class	**Light Vehicles**		**Medium Vehicles**		**Heavy Vehicles**	
Direction	East	West	East	West	East	West
Mean -μ	54	52	54	51	53	50
St. Dev.-σ	5	5	5	5	5	5

Once vehicles are generated, vehicle's B speed remains constant since it is considered not to interact with the passing action and is less by 5 mph than that of vehicle A, which is the mean speed difference threshold that activates the passing maneuver in the simulation that is shown in figure 4.4. Speed of Vehicle A varies based on the stage it is in and the action it takes when being detected or when it has seen opposing vehicle C. As to vehicle C, the previous code assumed C to have constant speed till it sees the violator because it is not warned by any means, after which it will decelerate to a complete stop. The new code endows vehicle C with more choice actions since vehicle C is now warned at the same time vehicle A is warned unless both cars see each other first where vehicle C then is forced to decelerate to come to a complete stop. A complete discussion of this improvement is presented at a later section of this chapter.

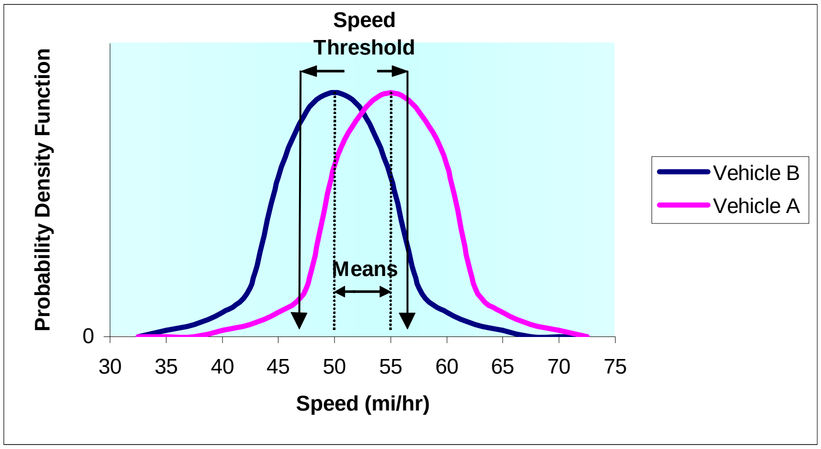


Figure 4.4 - Speed Distribution and Threshold of Vehicles A & B (1)

4.3.2.6 Acceleration Rate

Vehicle A is the only vehicle accelerating in the no-passing zone maneuver. Its maximum acceleration, which is updated at 0.1 sec. interval is the simulation, is based on vehicle class, current position in the zone, and roadway grade. The acceleration rates are computed based on the model – that is used to generate acceleration curves - presented in Rakha, Lucic, Van Aerde, and Setti's publication which is shown in figure 4.5 (6). Then the obtained acceleration for zero grades is converted to equivalent grade acceleration depending on the corresponding grade of the vehicle at every location.

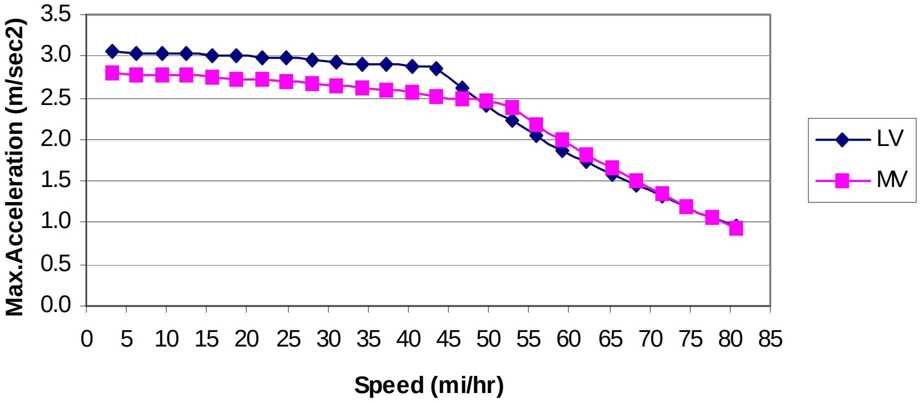


Figure 4.5 - Maximum Acceleration-Speed Relation at Level Grade (1)

4.3.2.7 Deceleration Rate

Deceleration rate is considered constant and is based on the fact whether the vehicle is surprised by the coming action or it is expecting it. Following Fambro's et al. (7) research on controlled braking performance, the means and standard deviations of –0.45g and 0.09g, respectively, were considered in simulating the braking deceleration for Vehicle A (expected case) and –0.55g and 0.07g, respectively, for Vehicle C (unexpected braking) as shown in table 4.3.

Table 4.3 - Percentile Estimates of Steady State Deceleration

	Unexpected	**Expected**
Mean	-0.55	-0.45
Standard Deviation	0.07	0.09
75th percentile	-0.43	-0.36
90th percentile	-0.37	-0.31
95th percentile	-0.32	-0.27
99th percentile	-0.24	-0.21

4.3.3 Driver-Related Parameters

4.3.3.1 No-Passing Zone Violation Rate

The number of simulated violations per year was 890, based on the data collected from the field. The Westbound direction experienced 170 violations, while the eastbound direction had 720 violations because more sight distance is available in latter direction.

4.3.3.2 Visibility Between Vehicles A and C

The visibility check between vehicle A and vehicle C is achieved through a subroutine that is executed every 0.1 seconds. At each time interval, the subroutine checks the location of vehicle A and vehicle C, and their corresponding grades on the curve. Then, it basically compares the line-of-sight elevation between the two vehicles to the curve elevation, and if there were an intersection between them; the two vehicles cannot see each other, else visibility is declared. Figure 4.6 represents the two cases of line-of-sight: interrupted in case 1 and clear in case 2.

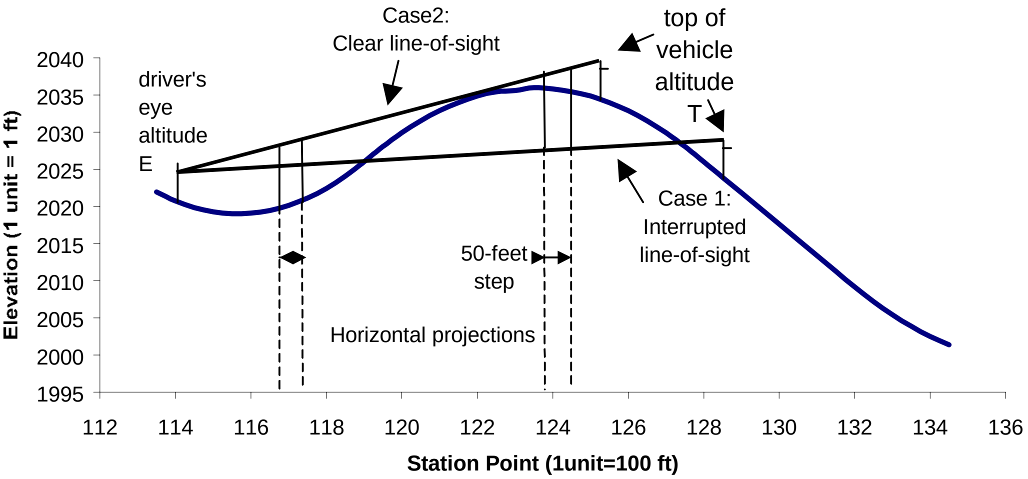


Figure 4.6 - Line-of-Sight Verification (1)

4.3.3.3 Human Factor Parameters

Driver characteristics are considered in this simulation, particularly those affecting perception and reaction times, time lags for reading and comprehension, and the effect of driving under the influence of alcohol. Few of the factors affecting driver behavior are discussed hereunder:

4.3.3.4 Perception-Reaction Time (PRT)

Two categories of PRT values were assumed based on the study conducted by Lerner et al. (9): The "expected" versus the "surprised". The PRT of the violating vehicle A is considered "expected" as the violator committing the illegal pass is aware of the risky consequences; thus, a mean and standard deviation of 0.54 s and 0.1 s, respectively, were assigned to vehicle A. In contrast, vehicle C traveling in the opposing direction is considered as "surprised" because the driver is unaware of the violating vehicle. Hence, a mean and standard deviation of 1.31 s and 0.61 s, respectively, were assigned to vehicle C.

Table 4.4 - Brake PRT Comparison (in Seconds)

	"Surprised"	**"Expected"**
Mean	1.31	0.54
Standard Deviation	0.61	0.1

50th Percentile	1.18	0.53
85th Percentile	1.87	0.64
95th Percentile	2.45	0.72
99th Percentile	3.31	0.82

4.3.3.5 Reading Time Allowance

In his study of the use of changeable Message Signs, Dudek (10) indicated that 85% of drivers familiar with the road and signs need about 0.5 sec. per word or 1.1 sec. per message unit. Thus, the reading time for a warning message to warn the violator is assumed to be 1 second, since the drivers on this road are mainly familiar commuters.

4.3.3.6 Time Lag Components

Two cases for time lag were previously considered for the base case scenario. The first one was when the violator was detected before seeing the opposing vehicle, thus the time lag was the sum of the displaying time, the reading time, and the PRT. The other case describes the situation where the violator sees the oncoming vehicle C before he/she is detected. For such a case, only PRT is included in the simulation. More cases of time lag were added to the new program structure to cover all simulated cases as is described in a later section of this chapter.

4.3.3.7 Driver's Conditions

Driver impairment is known to increase with the increase in blood alcohol content (BAC). This was proved by the study conducted by Moskowitz et al. (11) that showed that alcohol impairs one's reaction time and cognitive processing. Based on this study, an additional 0.5 seconds were added to the time lag of those drivers to account for alcohol impairment. The simulation considers 20 percent of the drivers to be driving under the influence (DUI). The assumption was based on the fact that 20% of the police reported crashes on route 114 during that period involved DUI conditions. A recent study by US Department of Health and Human services also shows that 11 millions Americans, including one in five 21 years old have driven under the influence of illegal drugs. Since this road connects two university campuses, it would be prudent to consider a large percentage of DUI drivers.

Table 4.5 - Performance Under Alcohol Influence

		Blood Alcohol Content (BAC) %					
Test	Pre-test	**0.10**	**0.08**	**0.06**	**0.04**	**0.02**	**0.00**
Reaction Time (sec)	3.5	4.1	4.1	4.1	3.8	3.6	3.4
Correct Responses (no.)	47	41	42	44	45	46	46
# Of Collisions (no.)	4		9	9	8	6	4

Times Over Speed (no.)	4		12	11	11	9	8

4.4 New Code Configuration (system after extension)

Basically, the new program maintained the same previous code structure as to the core program calling the input, the generator, the subroutines, and the output collection programs. As mentioned earlier, the main alteration was related to vehicle C action, which was restricted in the previous program to decelerating upon seeing the violating vehicle. From the results presented in the previous study, it is clear that the system is helpless in cases where the violator refused to obey the warning message sign (action3) and maintained the passing maneuver.

The solution to this case is to alert vehicle C of a danger zone ahead while vehicle A is violating hoping that by doing so, vehicle C will decelerate giving more space and time to vehicle A to complete the risky maneuver before a collision occurs. Consequently, extra warning signs are to be installed facing the opposing traffic flow in both directions of the road to prepare vehicle C to slow down in case of a persistent violator on the other side of the hill in spite of a no-passing zone warning message. As a result, a new code section is added to the simulation to account for the possible actions of vehicle C now that it is being warned. Nevertheless, new parameters pertaining to vehicle C are introduced to cover the various action requirements. The changed parameters and conditions are listed below relative to the aforementioned previous code parameters.

4.5 Modified parameters After System Extension

4.5.1 Vehicle-Related Parameters

4.5.1.1 Vehicle C Speed

The initial speed selection for vehicles A, B, and C remains unchanged. Nevertheless, the updated speeds of vehicles A and B through simulation are also maintained as before. However, the speed profile of vehicle C has been changed through the new code. Vehicle C action is no more restrained to decelerate upon seeing the violator only but also to react to the warning sign in a way to increase the chances of collision avoidance. As vehicle C sees the warning message flashing “SLOW DOWN DANGER AHEAD”, it automatically enters into its own time lag separately from vehicle’s A time lag, after which it starts decelerating to a certain minimum speed “vehC_Min_sp” specified by the user. Afterwards, vehicle C maintains this minimum speed till it sees vehicle A and then decelerates to a complete stop. If vehicle C sees the violator while it is decelerating to the minimum speed, then it starts the complete stop action. Since there is no research on the possible minimum speed of vehicle C, the simulation assumes a certain minimum speed defined by the user. Several minimum speeds have been varied in the sensitivity analysis carried for this parameter and their impacts are discussed in the results section.

4.5.1.2 Vehicle C Deceleration

Two categories for deceleration are considered, the “expected” and the “surprised”. In the previous code, vehicle C is considered to fall into the surprised category since it is actually being surprised by vehicle’s A violation upon seeing it. Now, that warning signs for vehicle C are to be implemented, the condition of C could be one of two cases. The first case is that vehicle C sees the violator before the detection system is activated, and hence it is considered to be in the “surprised” class. On the other hand, if the system detected the violation prior to sight attainment, then vehicle C is now warned of possible violator ahead and is no more surprised and thus falls into the “expected” class.

4.5.2 Driver-Related Parameters

4.5.2.1 Vehicle C Perception-Reaction Time

Two normal distributions of perception reaction times (PRT) relative to two categories, “expected” and “surprised” are considered. Knowing that vehicle A, the violator, is aware of his/her action; then he/she falls into the expected category of PRT. As for vehicle C, the new program differentiates between the two conditions vehicle C faces. The first condition occurs when it sees vehicle A before being warned, then the surprised category of PRT is adopted which has a mean value of 1.31 sec. and a standard deviation value of 0.61 sec. Otherwise, if the violation is detected first and vehicle C is warned then it follows the expected PRT values, which has a mean and standard deviation values of 0.54 sec. and 0.1sec., respectively.

4.5.2.2 Vehicle C Reading Time Allowance

The reading time allowance associated to the driver of vehicle C is 1 second, who is also considered to be a familiar commuter.

4.5.2.3 Vehicle C Time Lag Components

The simulation estimates three time-lag components as follows:

1- Verification process and message display time of 0.2 seconds.
2- Time lag for reading the message by the driver assumed to be 1 second.
3- Perception/ Reaction time lag

Two cases for time lag components are also considered. The first one is when the violator is detected before seeing the opposing vehicle. Thus, the time lag is the sum of the three time lags presented above. This case is also attributed to vehicle C, which has its own reading and reaction time when it is warned. The second case describes the situation where the violator sees the oncoming vehicle C before he/she is detected. In this case, the simulation adopts only the PRT time lag.

4.6 "Warning Vehicle A Only" Case (System Before Extension)

This scenario represents the current deployed system where the violator is being warned not to pass while traveling in the no-passing zone. The functionality of the program in this scenario limits vehicle C to only one response, while giving vehicle A three possible actions to choose from. Vehicle A can choose to decelerate to a complete stop (action 1), brake and go back behind vehicle B (action 2), or accelerate and pass vehicle B before colliding with vehicle C if avoidable (action 3). On the other hand, vehicle C is kept unwarned until it sees the violator, then it is eligible to decelerate to a complete stop. But this configuration as is shown in the previous study (1) revealed that the system is ineffective when vehicle A is taking action 3. The simulation results showed that head-on collisions are virtually eliminated if the violating vehicle A abides by the warning sign and adopt either action 1 or action 2 (1). However, for persisting violators who follow action 3 and continue their passing attempt in spite of the warning message, the simulation runs showed that this action would result in 41.9% head-on crashes in the East direction and 40.0% crashes in the West direction. The simulation has been validated for the base case by comparing the simulation results to the real world data. The results indicate a close match to the actual real-world condition (1.41 versus 0.71 average head-on crashes per year) (1).

4.7 "Warning vehicles A&C" Case (System After Extension)

The improvement to the previous version of the code is embedded in this scenario. The same previous simulation rules and steps apply for the case where the two vehicles A and C see each other before detection is accomplished. But, in the second case where vehicle A is detected before seeing vehicle C, vehicle A maintains its three possible actions, while vehicle C has new options to go through.

It is logical to assume that vehicle C, upon seeing a yellow flashing message sign saying "SLOW DOWN DANGER AHEAD", would commit to decelerate to a minimum speed waiting to achieve a complete sight of the opposite side of the road behind the crest. Thus, when the system detection is activated, vehicle A as well as vehicle C are warned and each go into their different time lag responses after which vehicle A chooses between the same three possible actions as before, while vehicle C starts decelerating to a minimum speed. While in its deceleration stage, visibility is checked to see if the two vehicles see each other. If it is true, vehicle C attempts to decelerate to reach a complete stop. Otherwise, it reaches the minimum speed and maintains it till it sees vehicle A after which it brakes further to stop. The flowchart explaining these actions is shown in Figure 4.8.

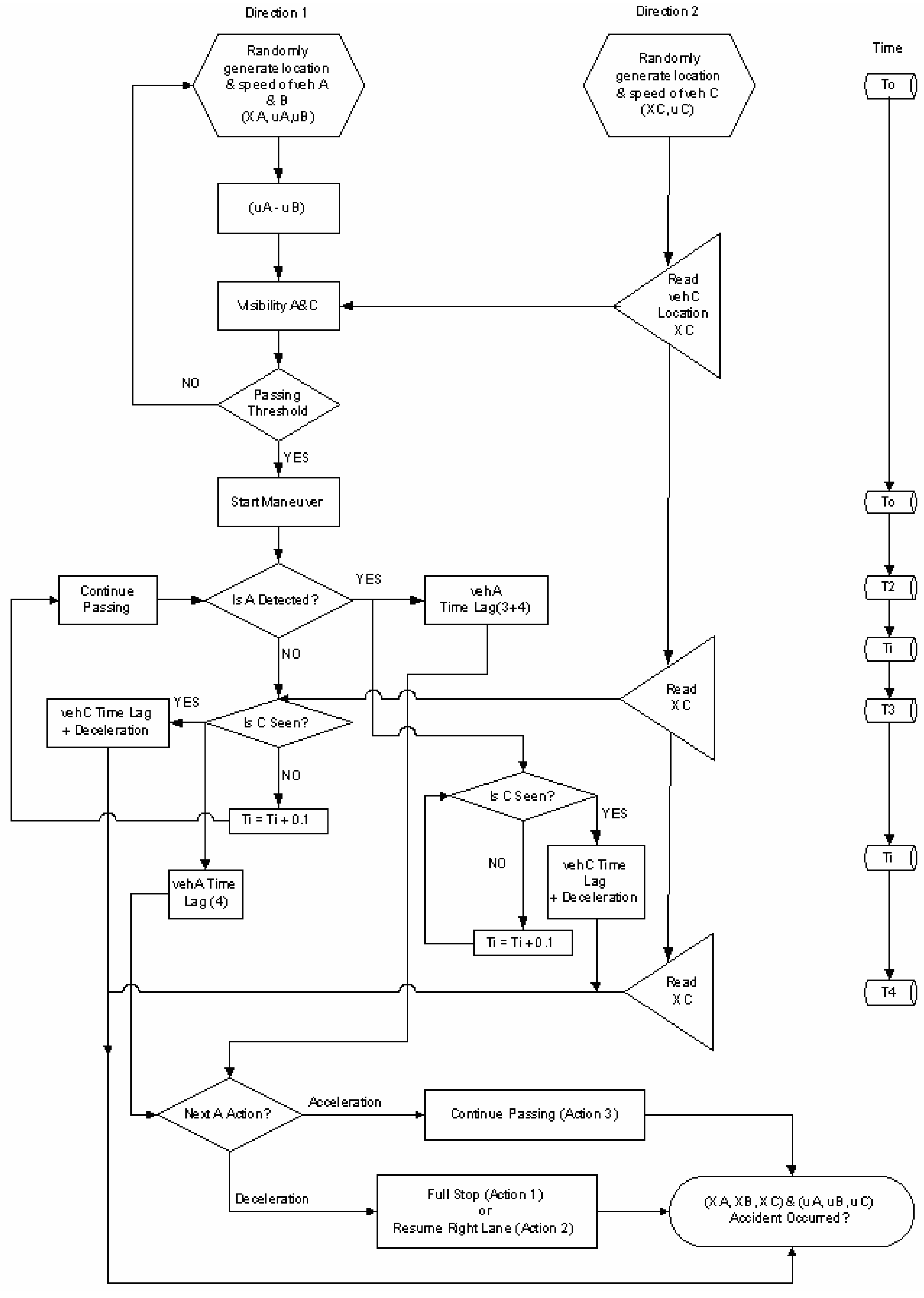


Figure 4.7 - Passing Violation With System Warning Vehicle A Only

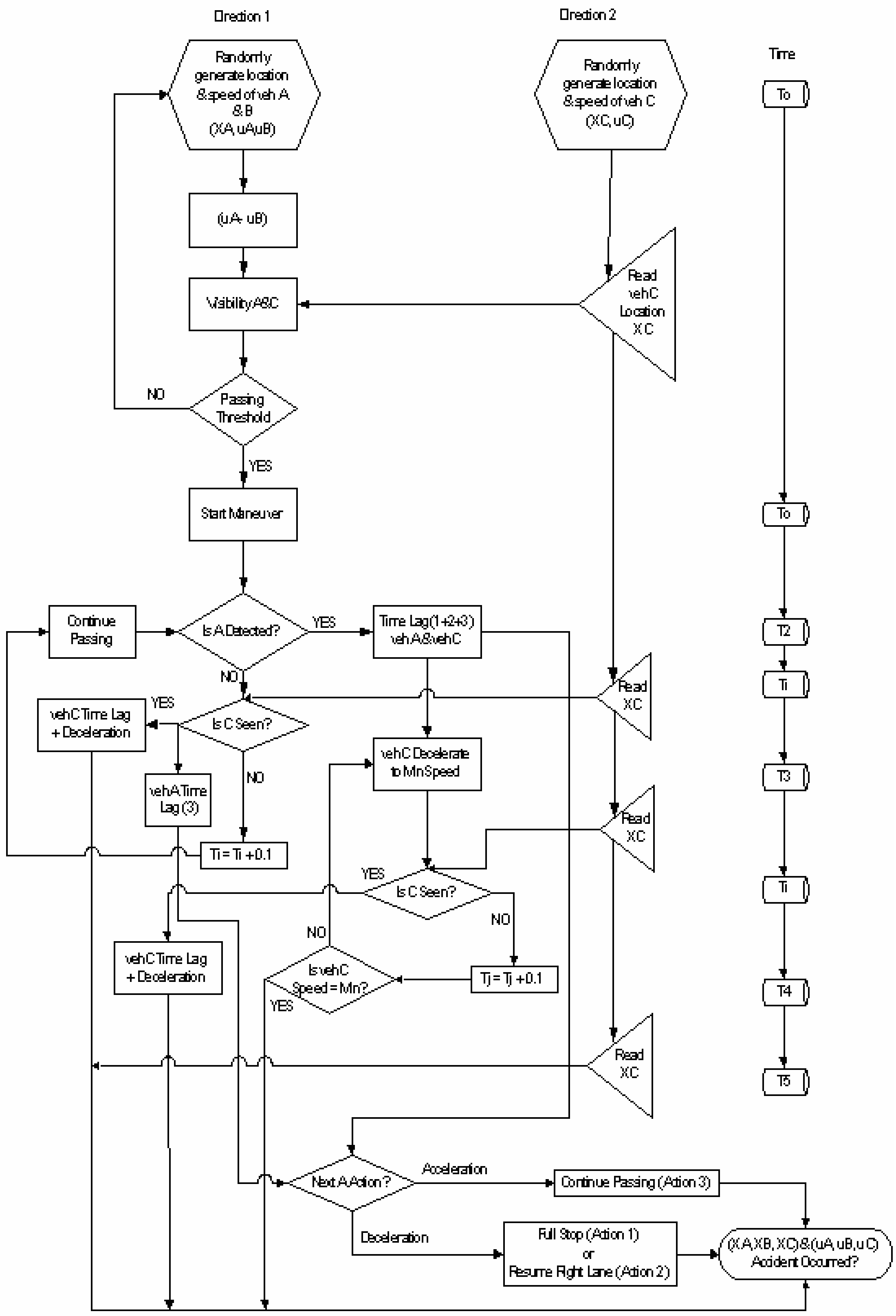


Figure 4.8 - Passing Violation With System Warning Vehicle A and C

4.8 Post Perception Actions

The position of vehicle B is unaffected by the violation action of Vehicle A (1). Regardless of A's action, vehicle B will stay neutral following its path and not responding to the violator maneuver. This assumption is not perfectly true in real life situations since driver of vehicle B may respond to the maneuver of vehicle A in his/her way. Such a response involves complex human issues that produce different reactions for driver of vehicle B which may render the possible outcomes intractable. Thus, for the sake of the simulation, the worst-case scenario was considered for simulating the passing maneuver where vehicle B is kept inactive. Vehicle C, on the other hand, is assumed to be active even before seeing vehicle A, since it perceives the warning sign at the same time vehicle A is warned and thus starts decelerating. The case that C will not respond to the warning sign and continue its way at the same speed is reflected in the same base case scenario to which the improvement scenario is being contrasted to. The minimum speed levels to which vehicle C decelerate to are user defined. They are considered in the sensitivity analysis part of the simulation to take the values of 10, 20 and 30 mph.

Vehicle A can take any of the three actions described earlier. However, we will suppose that drivers of vehicle A when perceiving the warning message, will mostly react accordingly and decelerate either to stop in action 1 or to go back behind vehicle B in action 2. However, we noticed from the previous study (1) that no collisions take place if these two actions are adopted by vehicle A. So, we do not intend to simulate these actions again in this chapter. As for action 3, which is the main focus of the simulation in this chapter, vehicle A is assumed to accelerate fully trying to pass vehicle B while vehicle C in the opposite direction is decelerating to avoid collision. The same governing criteria for declaring a collision in any simulation run are adopted from the previous study for all actions, which is when d- (XA+ XC)=0, where XA and XC are the positions of vehicles A and C, respectively, from both ends of passing zone distance d (1).

4.9 Simulation Results

The computer runs include simulating the case of warning vehicles A and C under action 3 for eastbound and westbound directions, for base case conditions, and for three different minimum speeds of vehicle C for a total of 8 runs for each violation. The total number of yearly violations obtained from the field data amount to 170 in the westbound direction and 720 in the eastbound direction. The simulation runs were conducted for 20 years making the total runs equal to 712,000 individual runs.

The simulation of every violation provides the speeds, locations, accelerations and decelerations, etc. of every vehicle at 0.1-second time increments. Table 4.6 presents the simulation results that show the critical comparison between the previous system results and the upgraded system benefits. Table 4.6 shows the comparison of the number of crashes resulting from the simulation of the violations per direction taking action 3. For each direction, the base case scenario is contrasted to three other situations where vehicle C minimum speed has been varied accordingly. Taking the west direction as an example, and where vehicle C decelerates to a minimum speed of 10 mph, the total crashes out of 170 simulated violations are 43. It used to be 68 before the system improvement. This means that 25 crashes are reduced corresponding to approximately 37% crash reduction out of the base case. Similarly, the same observations can be concluded for the other cases. A noticeable trend can also be viewed from the results in Table 4.6. They show that as the minimum speed for vehicle C increases the number of crashes increases too, which is intuitively logical. The results indicate that warning the opposing driver would reduce the possible crashes by a mean of 26.3% in the eastbound direction and 33.3% in the westbound direction. But this is not totally true since not all drivers persist to violate and the presented reduction rates are obtained based on the assumption that all violators take action three.

In addition, Table 4.7 portrays the speed statistics of vehicle A and C at the time of collision. Vehicle's A crash speed of 65 mph is common among all simulation runs and cases, which is expected since A accelerates to its maximum speed while trying to complete the risky maneuver. Another thing worth mentioning upon analyzing Table 4.7 is that the crash severity after upgrading the system is reduced by virtue of vehicle's C reduced crash speed. For the East direction, the average speed of vehicle C at crashes is zero while for the West direction the mean is 3 mph and that is also prevailing among all speed cases with some standard deviation differences. The authors consider that vehicle C is involved in an accident even if it veered off and used the shoulder to avoid the head-on collision. In fact, the site on route 114 has only 3-feet shoulder width, which is practically non-existent.

Table 4.6 - System Comparison

	East Bound Direction				West Bound Direction			
Simulated Violations	720				170			
Vehicle C minimum Speed (mph)	Base Case	10	20	30	Base Case	10	20	30
Number of Crashes	302	212	222	236	68	43	44	49
Standard Deviation	8.7	11	8.6	10	7.2	6	6.2	7
Percent Crashes of	41.9%	29.4%	30.8%	32.8%	40.0%	25.3%	25.9%	28.8%

Total Violations								
Reduction from Base Case	–	29.8%	26.5%	21.9%	_	36.8%	35.3%	27.9%

Table 4.7 - Speed Comparison of Vehicles A and C at Crashes

		Warning A Only		Warning Both A and C					
Action3 Crashes									
VehC_min_sp		**Random**		**10 mph**		**20 mph**		**30 mph**	
		E	**W**	**E**	**W**	**E**	**W**	**E**	**W**
Vehicle A	**Av. Min**	65	65	65	65	65	65	65	65
	Av. Max	65	65	65	65	65	65	65	65
	Av. Mean	65	65	65	65	65	65	65	65
	Av. St. Dev.	0	0	0	0	0	0	0	0
Vehicle C	**Av. Min**	0	0	0	0	0	0	0	0
	Av. Max	45	52	15	28	14	30	17	29
	Av. Mean	6	25	0	3	0	3	0	3
	Av. St. Dev.	10	13	1	7	1	7	1	7

* Note that vehicle A has reached its maximum speed of 65 mph. during all cases.

Now that the results of the system after extension were presented, it is necessary to contrast those to the previous system results as to the effective crash reduction rates. Table 4.8 and 4.9 below presents the results of the simulation done by Jamal el Zarif. Table 4.8 presents the results of the base simulation before the system extension, without deploying the system that warns the violator only, while table 4.9 shows the results of deploying the system to warn he violator but not the opposing vehicle as it is the case in the extended simulation discussed just earlier in this section. These two tables are presented to manifest the fact that the extended system dealt with drivers that persisted to violate and that the crash reduction rates accrued from the system extension apply only to those with crash risk 3 that are taking action three. So, for the east direction, the previous results show that 0.1 % of the violations are inevitable crashes as shown in table 4.8 and that 41.9 % of these crashes resulted from taking action three, which is the concern of the extended simulation. Thus, the 26.3% reduction rate applies only to the resulting percentage of (41.9 % * 0.1 %) = 0.042 %. That is, the actual reduction of crashes in the east bound direction is (26.3 % * 0.042 %) = 0.011%. So, the percentage of crashes with unavoidable collision risk before the system extension was 0.1%, but with the system enhancement the percentage decreased by 0.011% to become 0.089 %, which is equivalent to an eleven percent crash reduction. Similarly, for the west bound direction, the effective overall crash reduction rate is calculated to be (0.4%*40.1%*33.3%) = 0.053%. Thus, the resulting crash rate is decreased from its base value, which is shown in table 4.8, from 0.4% to 0.347%, which is equivalent to a 13.25% reduction in the overall inevitable collision rate in the west bound direction.

TABLE 4.8 - Crash Risk Indicator in Term of Possible Crashes by Direction (1)

	Violations With Crash Risk Indicator 0			Violations With Crash Risk Indicator 1			Violations With Crash Risk Indicator 2			Unavoidable Crash Violations (Crash Risk Indicator 3)		
Direction Run #	E	W	E+W	E	W	E+W	E	W	E+W	E	W	E+W
Average	250	35	286	275	16	291	194	118	312	0.68	0.73	1.41
Percent	34.8%	20.8%	32.1%	38.2%	9.4%	32.7%	27.0%	69.3%	35.1%	0.1%	0.4%	0.2%
St. Dev.	13.9	4.7	15.4	9.5	4.6	9.6	11.0	5.6	12.8	0.9	1.0	1.5

TABLE 4.9 - Crash Risk Indicator in Term of Possible Crashes by Direction (1)

	Violations With Crash Risk Indicator 0			Violations With Crash Risk Indicator 1			Violations With Crash Risk Indicator 2			Unavoidable Crash Violations (Crash Risk Indicator 3)		
Direction Run #	E	W	E+W	E	W	E+W	E	W	E+W	E	W	E+W
Average	419	102	520	302	68	370	0	0	0	0	0	0
Percent	58.1%	59.9%	58.5%	41.9%	40.1%	41.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
St. Dev.	8.7	7.2	10.0	8.7	7.2	10.0						

A brief comparison of two violation runs showing the benefits of the new system can be inferred from Figure 4.9 and 4.10 as follows (vehicle A variables are plotted in dotted lines, vehicle C in solid lines). Figure 4.9 shows the acceleration, speed, location and detection curves of vehicles A, B and C before the program improvement is implemented. At the 5th second of the run, the violator is detected and warned, but vehicle C has not been alerted yet and thus keeps the same speed as shown in the two corresponding plots. Then, at approximately the 8th second, the two opposing cars see each other, after which vehicle C starts decelerating. But shortly after that time the collision occurs due to the late response of vehicle C (notice the location curve is fixed on zero thereafter).

On the other hand, Figure 4.10 shows the same decision variables of the three vehicles for a similar run after the system is upgraded. Now, at the 3rd second the violation is detected but both vehicles A & C are now warned. So directly after reading and PRT time lags, vehicle C starts decelerating to a minimum speed trying to avoid the crash with the opposing car. Vehicle C maintains this minimum speed till it sees the violator at the 13th second and then decelerates to a complete stop where vehicle A successfully completes the passing maneuver and the collision is avoided.

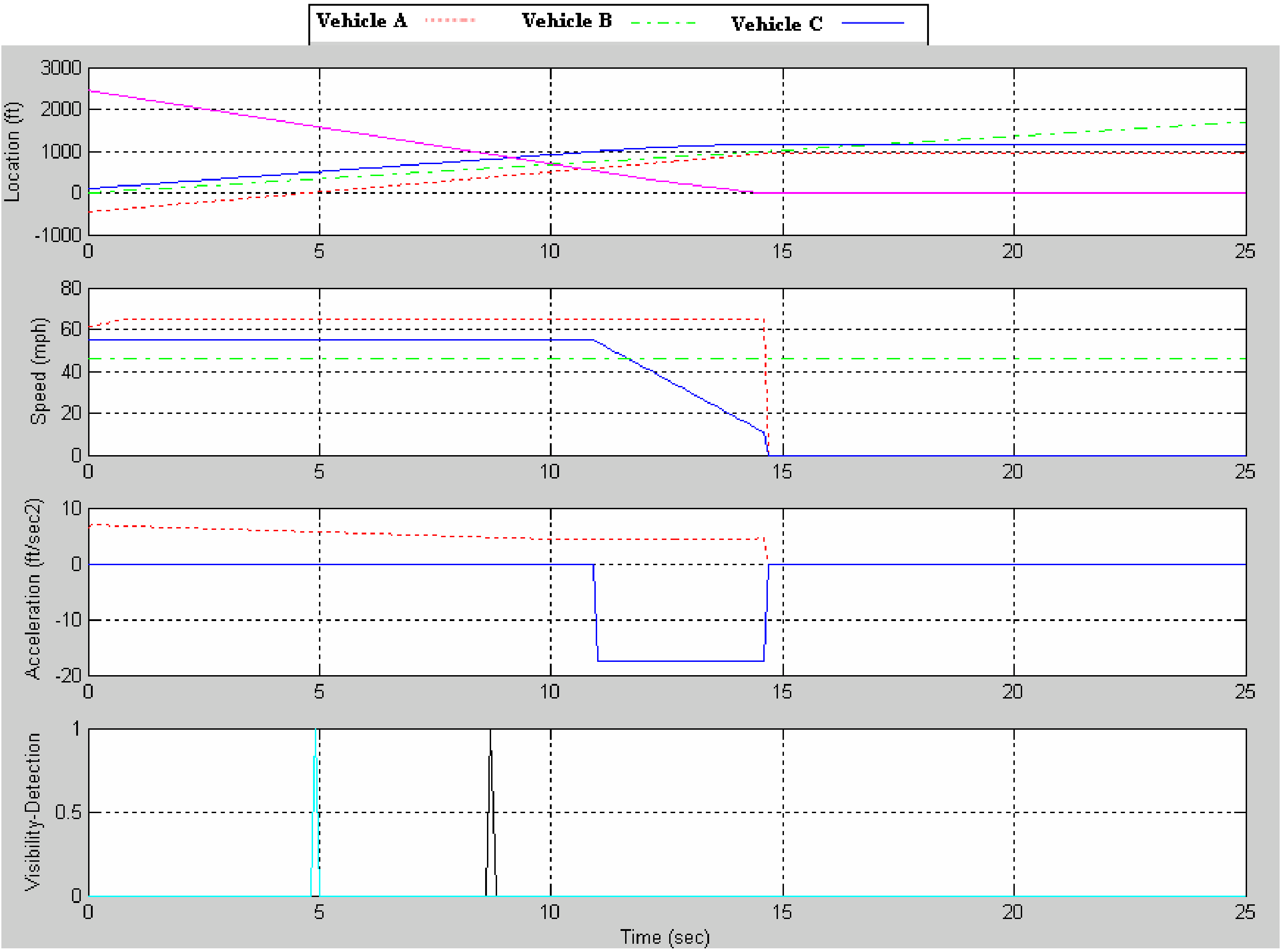


Figure 4.9 - Violation plot before system upgrade

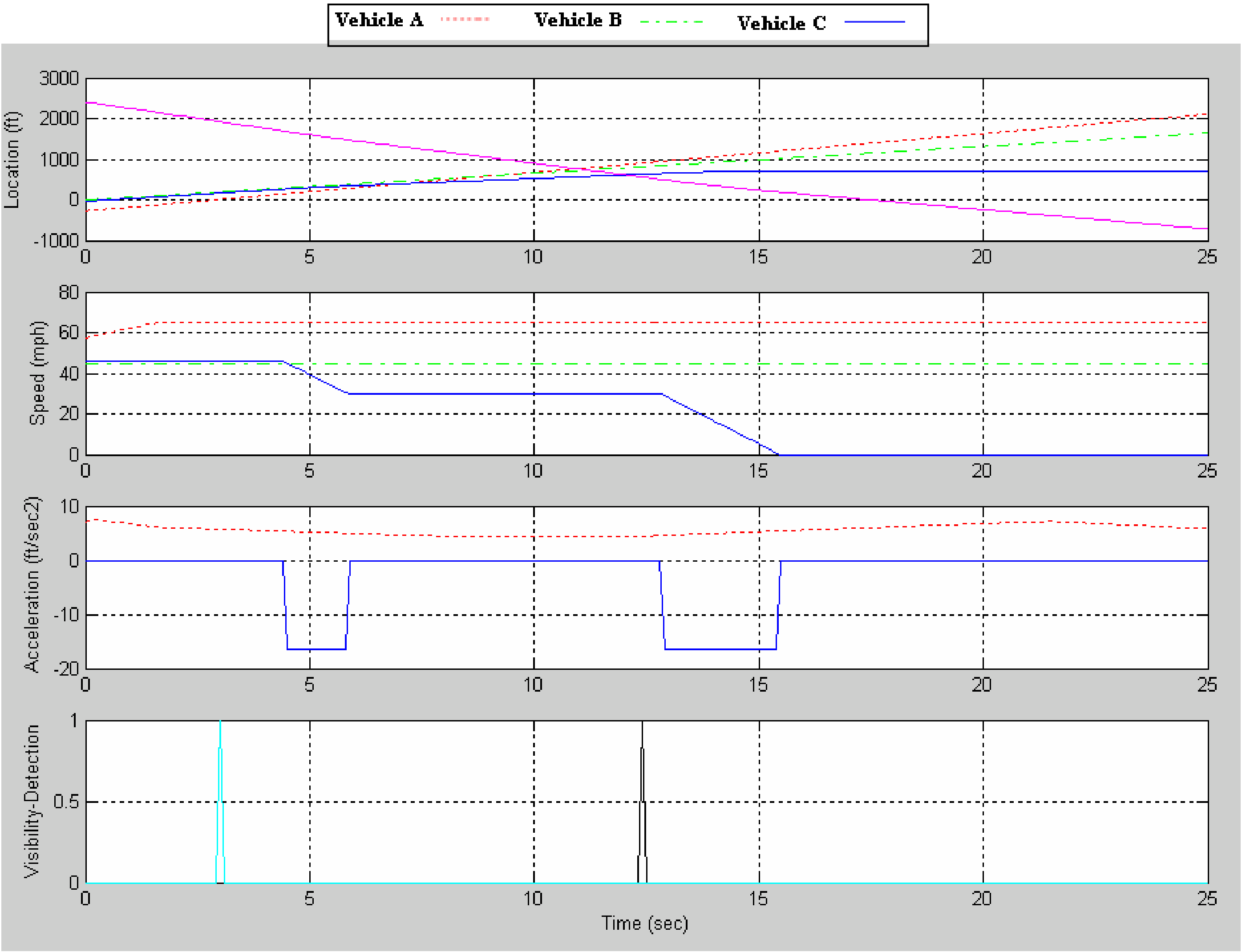


Figure 4.10 - Violation plot after system upgrade

CHAPTER 5. SYSTEM EVALUATION

5.1 Introduction

As stated earlier, a computer simulation model can be very helpful in improving decision making even when information on the structure and functioning of certain systems is lacking. We have used the extended simulation to duplicate a real-life passing maneuver where the opposing vehicle is being warned in addition to the warning of the violator. Through this simulation, it is possible to explore alternatives and to identify potential biases (and their consequences) stemming from observation error that we might have done or assumed. That is why sensitivity analyses are conducted to assure the robustness of the system to such varying conditions or parameters. The general goal of performing the sensitivity analysis is to determine how sensitive some state variables are to perturbations of the model parameters. One way to evaluate this is to individually perturb each parameter value, run the model, and determine how this changed the state variable of interest (number of resulting crashes). Thus, sensitivity analysis can be defined as an analytical procedure to determine how the results of a study would change if the input parameters were different.

5.2 Sensitivity Analysis

Seven tests have been conducted in the sensitivity analysis. In every test, the value of only one input parameter has been changed from its original value. Then, 20 years runs have been made after which the averaged output is compared with that of the original scenario in terms of number of crashes by direction for different vehicle C's minimum speed. For every sensitivity test, the results are presented to display the average number of crashes compared to the original mean and consequently the percent reduction/increase in crashes are calculated. In addition, the standard deviation of the obtained average is calculated to show how the resulting values vary over the twenty years interval. A final table is also depicted to summarize the overall sensitivity of the results.

5.2.1 Test 1: Increase Maximum Speed of Vehicle A

In this test, the maximum speed that vehicle A can attain while violating is increased from 65 mph to 70 and 75 mph, consecutively. The results are presented in tables 5.1 and 5.2, and portrayed in figure 5.1 as well.

The results presented in table 5.1 show that the number of crashes per direction has decreased dramatically. This is an anticipated result since it will take the vehicle A less time to complete the passing violation and merge ahead of vehicle B with an increase in the maximum speed of. Note that this improvement in the results is because the simulation at this point is only concerned with action 3 where the violator persists to complete the passing maneuver. The crash results in the East bound direction and in the West bound direction show an average reduction of 47% and 49%, respectively, which is a substantial value. The setback to this is that the speed of vehicle A at crash time is higher with a mean and standard deviation of 70 mph and 0 mph for the first case and 75mph and 0 mph for the second case, respectively. That is the severity of the resulting crashes has increased with the increase in crash speed.

Table 5.1 – Crashes When Vehicle A Maximum Speed = 70 mph

	East Bound Direction				West Bound Direction			
Simulated Violations	**720**				**170**			
Vehicle C minimum Speed (mph)	**Base Case**	**10**	**20**	**30**	**Base Case**	**10**	**20**	**30**
Number of Crashes	302	149	163	167	68	34	35	35
Standard Deviation	8.7	9.8	8.5	7.6	7.2	5.9	4.9	5.0
Percent Crashes of Total Violations	41.9%	20.7%	22.6%	23.2%	40.0%	20.0%	20.6%	20.6%
Reduction from Base Case	–	50.7%	46.1%	44.7%	_	50%	48.5%	48.5%

Similarly, table 5.2 shows that the results have improved if vehicle A maximum speed has increased to 75 mph which further illustrates the consistency in the results. Vehicle A now needs even less time to finish the maneuver and clear the opposing lane for vehicle C. On the average, the percent reduction of the number in crashes from the base scenario is 61.3% and 63.7% for the East bound and West bound directions, respectively. It is important to note that the percent reduction for both directions is highly comparable per scenario, that is, the number of reduced crashes is proportional to the total number of crashes per direction.

Table 5.2 – Crashes When Vehicle A Maximum Speed = 75 mph

	East Bound Direction				West Bound Direction			
Simulated Violations	**720**				**170**			
Vehicle C minimum Speed (mph)	**Base Case**	**10**	**20**	**30**	**Base Case**	**10**	**20**	**30**
Number of Crashes	302	116	118	117	68	25	24	25
Standard Deviation	8.7	7.2	8.3	9.2	7.2	4.7	3.8	4.9
Percent Crashes of Total Violations	41.9%	16.1%	16.4%	16.3%	40.0%	14.7%	14.1%	14.7%
Reduction from Base Case	–	61.6%	60.9%	61.3%	_	63.2%	64.7%	63.2%

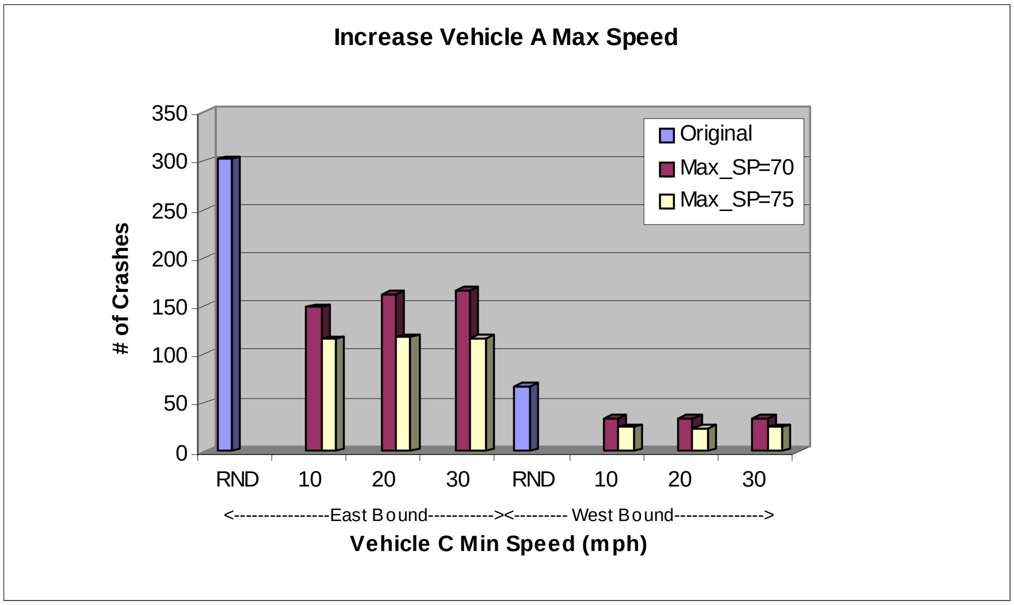


Figure 5.1 – Number of Crashes With Increase of Vehicle A Max Speed

Another way to compare the results is to compare the sensitivity test results to the results obtained from the extended simulation before the test variable was changed. Thus, two cases are recognized for each vehicle C minimum speed class which are the "before" and "after" cases. Table 5-3 presents the results comparison that verifies the fact that by increasing the maximum attainable speed the violator can get away with his action more often than the base case. Figure 5.2 portrays the result outcomes.

Table 5.3 - Comparison of Crashes to Extended Case for Test 1

# of Crashes	East Bound Direction			West Bound Direction		
Simulated Violations	**720**			**170**		
VehicleC_Min_Sp(mph)	**10**	**20**	**30**	**10**	**20**	**30**
Before(Max_Sp=65mph)	212	222	236	43	44	49
After (Max_Sp=70mph)	149	163	167	34	35	35
% Reduction/Increase*	29.7%	26.6%	29.2%	20.9%	20.5%	28.6%
After (Max_Sp=75mph)	116	118	117	25	24	25
% Reduction/Increase*	45.3%	46.9%	50.4%	41.9%	45.5%	49.0%

* A negative sign means that there was an increase in the # of crashes.

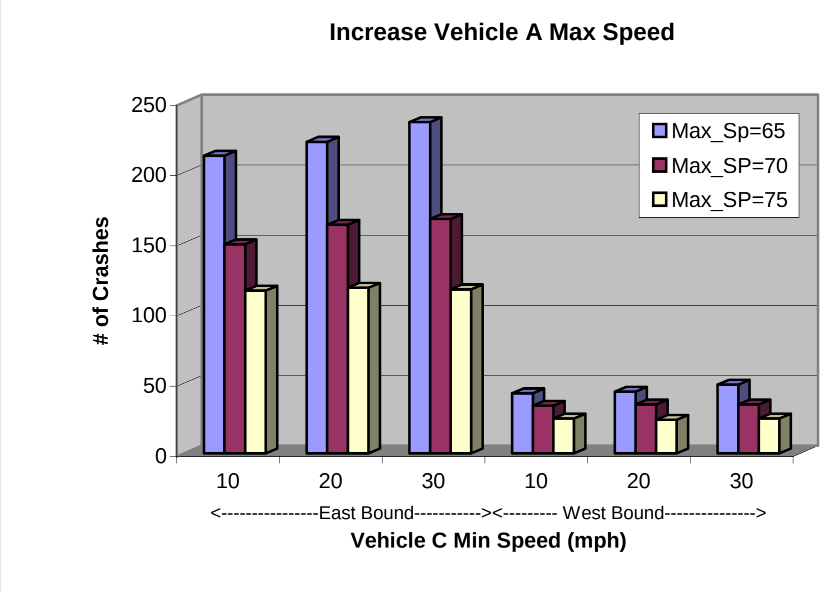


Figure 5.2 – Number of Crashes With Increase of Vehicle A Max Speed

5.2.2 Test 2: Decrease Driving Under Influence (DUI) Percentage

This test deals with comparing the outcome of crashes when the percent of DUI is changed to 15 and 10 %, consecutively, from 20 % in the base case. The results of this test are shown in tables 5.4 and 5.5, and portrayed in figure 5.3. The decrease in the number of crashes as the DUI percentage decreases is logically understood since less DUI drivers that require high perception and reaction times (PRT) are being simulated. However, the percentage reduction in crashes shown hereunder are not only the result of the decrease in DUI percentage but also the effect of warning vehicle C, which is the focus of the extended simulation. In addition, a further comparison that depicts the results of the extended base case versus the results of reducing the DUI percentage are actually shown in table 5.6 as well as in figure 5.4.

Table 5.4 – Number of Crashes When DUI Percent = 15%

	East Bound Direction				**West Bound Direction**			
Simulated Violations	**720**				**170**			
Vehicle C minimum Speed (mph)	**Base Case**	**10**	**20**	**30**	**Base Case**	**10**	**20**	**30**
Number of Crashes	302	229	232	238	68	47	48	50
Standard Deviation	8.7	13.2	11.3	11.0	7.2	5.1	3.7	4.6
Percent Crashes of Total Violations	41.9%	31.8%	32.2%	33.1%	40.0%	27.6%	28.2%	29.4%
Reduction from Base Case	–	24.1%	23.2%	21.2%	–	30.9%	29.4%	26.5%

Similarly, table 5-5 shows that the results have improved by the further decrease in the percentage of impaired drivers with alcohol. The reduction in the total number of crashes is about 25% and 29% for the East and West bound directions, respectively.

Table 5.5 – Number of Crashes When DUI Percent = 10%

	East Bound Direction				West Bound Direction			
Simulated Violations	**720**				**170**			
Vehicle C minimum Speed (mph)	**Base Case**	**10**	**20**	**30**	**Base Case**	**10**	**20**	**30**
Number of Crashes	302	211	233	238	68	47	48	50
Standard Deviation	8.7	11.2	11.3	11.0	7.2	5.1	3.7	4.6
Percent Crashes of Total Violations	41.9%	29.3%	32.4%	33.1%	40.0%	27.6%	28.2%	29.4%
Reduction from Base Case	–	30.1%	22.8%	21.2%	–	30.9%	29.4%	26.5%

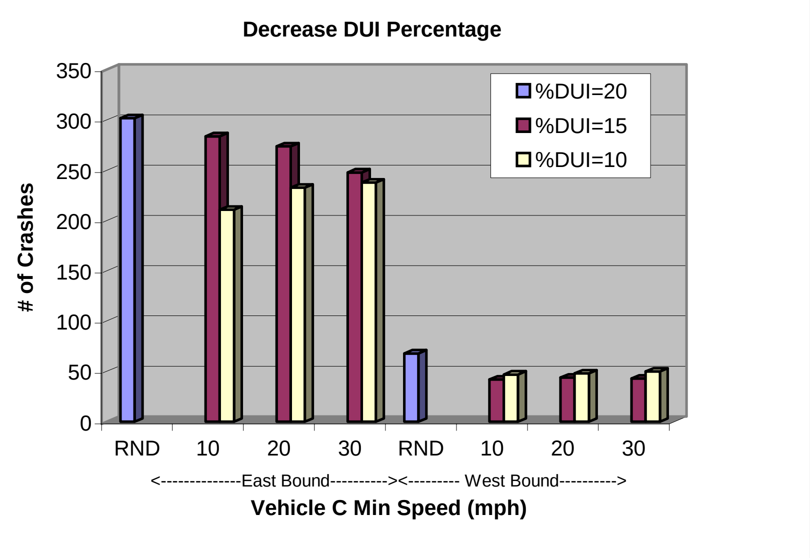


Figure 5.3 - Decrease Percentages of DUI Drivers

Table 5.6 below presents the comparison of the extended base case results to the results obtained after changing the DUI percentage, which is also portrayed in Figure 5.4. Because the simulation is mainly based on stochastic processes and random number generations, the results were sometimes higher than expected while other times lower. But, the noticeable thing is that the results were close and that the effect of varying this parameter is minimal in most cases.

Table 5.6 - Comparison of Crashes to Extended Case for Test 2

# of Crashes	**East Bound Direction**			**West Bound Direction**		
Simulated Violations	**720**			**170**		
VehicleC_Min_Sp(mph)	**10**	**20**	**30**	**10**	**20**	**30**
Before(%DUI=20%)	212	222	236	43	44	49
After (%DUI=15%)	229	232	238	47	48	50
% Reduction/Increase*	-8.0%	-4.5%	-0.8%	-9.3%	-9.1%	-2.0%
After (%DUI=10%)	211	233	238	42	44	43
% Reduction/Increase*	0.5%	-5.0%	-0.8%	2.3%	0.0%	-12.2%

* A negative sign means that there was an increase in the # of crashes.

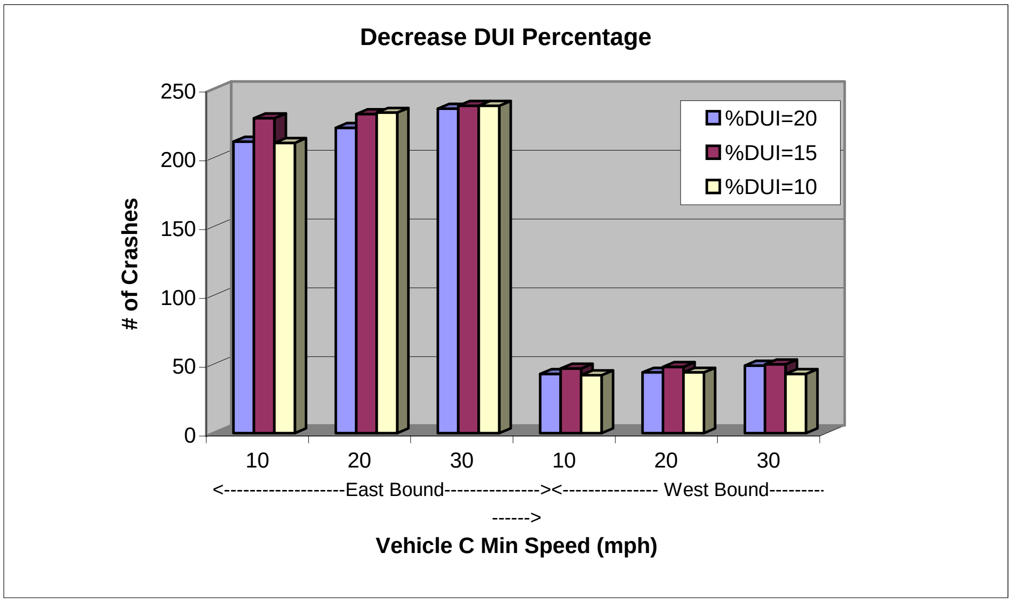


Figure 5.4 - Decrease Percentages of DUI Drivers

5.2.3 Test 3: Increasing DUI Impairment Effect

The purpose of this test is to evaluate the possible variations resulting from increasing the DUI impairment effect of drivers from the original case of 0.5 sec to 1.0 and 1.5 sec, consecutively. The DUI impairment effect is usually proportional to the blood alcohol content (BAC) of a person, and thus, simulating different values of DUI perception delay is, in a way, simulating drivers with various levels of BAC.

The results of this test are presented in tables 5.7 and 5.8 relative to 1.0 sec and 1.5 sec of impairment effect, respectively. Figure 5.5 portrays the results of both tests. The results of increasing the impairment of drivers is not substantial compared to that of increasing the maximum speed, since this test is only affecting the percentage of drivers with DUI levels, and those account for only 20% of the total population of drivers. The tables show that there is a reduction in the number of crashes, which is not logical after increasing the impairment effect. However, the reasoning for this is that the benefits accrued from warning vehicle C in the extended simulation surpass the setbacks of increasing the DUI impairment effects by 21 % and 5% on average for the East and West directions, respectively.

Table 5.7 - Increasing DUI Impairment Effect (1.0 sec)

	East Bound Direction				West Bound Direction			
Simulated Violations	**720**				**170**			
Vehicle C minimum Speed (mph)	**Base Case**	**10**	**20**	**30**	**Base Case**	**10**	**20**	**30**
Number of Crashes	302	236	243	234	68	59	64	64
Standard Deviation	8.7	10.5	13.7	11.2	7.2	6.4	6.7	7.4
Percent Crashes of	41.9%	32.8%	33.8%	32.5%	40.0%	34.7%	37.6%	37.6%

Total Violations								
Reduction from Base Case	–	21.9%	19.5%	22.5%	–	13.2%	5.9%	5.9%

Similarly, table 5-8 shows that the number of crashes even after increasing further the DUI impairment penalty to 1.5 sec are still less than the original case, which emphasizes more the benefits of the extended simulation in reducing the total number of crashes in the system. On the other hand, the number of crashes has increased as opposed to the first case of 1.0 sec of impairment penalty, which is logically expected. Overall, the average reduction in the number of crashes for the East bound and West bound directions is approximately13% and 8%, respectively.

Table 5.8 - Increasing DUI Impairment Effect (1.5 sec)

	East Bound Direction				**West Bound Direction**			
Simulated Violations	**720**				**170**			
Vehicle C minimum Speed (mph)	**Base Case**	**10**	**20**	**30**	**Base Case**	**10**	**20**	**30**
Number of Crashes	302	257	264	264	68	66	64	63
Standard Deviation	8.7	11.3	11.0	10.0	7.2	5.8	3.7	4.8
Percent Crashes of Total Violations	41.9%	35.7%	36.7%	36.7%	40.0%	38.8%	37.6%	37.1%
Reduction from Base Case	–	14.9%	12.6%	12.6%	–	2.9%	5.9%	7.4%

Obviously the DUI penalty time inflicted on those drivers under influence of alcohol has much more impact on the resulting number of crashes than varying the DUI percentage as shown in the previous tables. Table 5-9 below shows that the number of crashes increase noticeably for the west direction as opposed to the east direction. By analyzing the results of the latter table, it is clear that the number of crashes has increased with the increase of the impairment penalty on DUI drivers. On average, the percent increase in crashes is 29% and 38% for the East and West direction, respectively, for the first scenario and 7% and 42% for the East and West direction, respectively, for the second scenario.

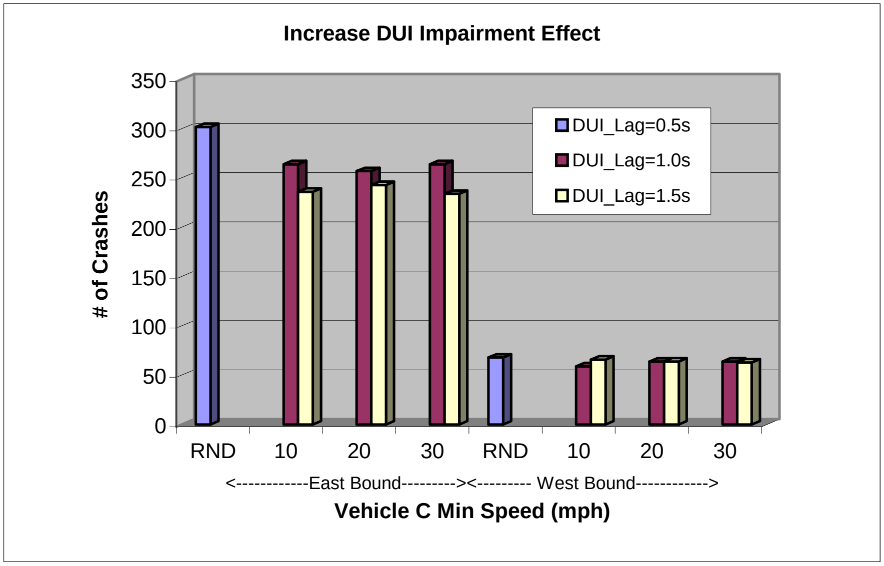


Figure 5.5 - Increase DUI Impairment Effect

Table 5.9 - Comparison of Crashes to Extended Case for Test 2

# of Crashes	East Bound Direction			West Bound Direction		
Simulated Violations	720			170		
VehicleC_Min_Sp(mph)	10	20	30	10	20	30
Before(DUI Lag=0.5sec)	212	222	236	43	44	49
After (DUI Lag=1.0sec)	236	243	234	59	64	64
% Reduction/Increase*	-11.3%	-9.5%	-1.0%	-37.2%	-45.5%	30.6%
After (DUI Lag=1.5sec)	257	264	264	66	64	63
% Reduction/Increase*	-21.2%	-18.9%	-11.9%	-53.4%	-45.5%	-28.6%

* A negative sign means that there was an increase in the # of crashes.

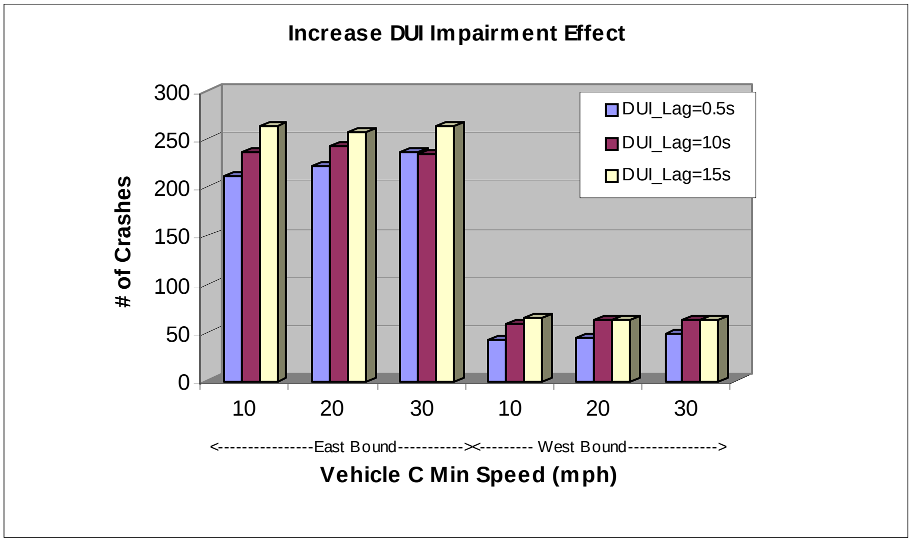


Figure 5-6 Increase DUI Impairment Effect

5.2.4 Test 4: Overtaking Vehicle B Ahead on the Slope

In this scenario, the violation maneuver is assumed to start ahead on the crest curve as opposed to the original scenario where it has been assumed that violators take decision, start acceleration and launch their illegal passing at the sag area of the curve. The original scenario is mostly supported by the collected data of crashes that occurred on that curve, which showed that usually violators take advantage of the longer sight distance, and higher acceleration that the sag provides. However, such scenario cannot eliminate the possibility of having violations that could start further ahead of the upward slope of the road. Hence, for this test purposes, vehicle B is randomly located in the first 500 feet of the upward slope for both directions.

Table 5-10 presents the crashes outcome of this scenario followed by figure 5-5 that portrays the same results. The average reduction in the number of crashes for the East bound and West bound directions is about 4.6 % and 36.7%, respectively. The difference in the resulting effect of this variable variation on the East and West directions can be attributed to the difference in the lengths of the crest curves for each direction.

Table 5.10 – Crashes With Vehicle A Overtaking Vehicle B Ahead on the Slope

	East Bound Direction				West Bound Direction			
Simulated Violations	**720**				**170**			
Vehicle C minimum Speed (mph)	**Base Case**	**10**	**20**	**30**	**Base Case**	**10**	**20**	**30**
Number of Crashes	302	288	278	298	68	42	42	45
Standard Deviation	8.7	14.4	9.7	15.3	7.2	7.1	7.3	5.1
Percent Crashes of Total Violations	41.9%	40.0%	38.6%	41.4%	40.0%	24.7%	24.7%	26.5%
Reduction from Base Case	–	4.6%	7.9%	1.3%	–	38.2%	38.2%	33.8%

The outcome of crashes based on changing this variable does not show much variation form the base case for the West direction as presented in table 5-11 as well as in figure 5-8. However, the effect is more significant of the East side and has increased the number of crashes by an average of 29%. This can be also attributed to the fact that the East direction suffer 5 times as much violations as the West direction does.

Table 5.11 - Comparison of Crashes to Extended Case for Test 4

# of Crashes	**East Bound Direction**			**West Bound Direction**		
Simulated Violations	**720**			**170**		
VehicleC_Min_Sp(mph)	**10**	**20**	**30**	**10**	**20**	**30**
Before (X_B = 0 ft)	212	222	236	43	44	49
After (X_B = 500 ft)	288	278	298	42	42	45
% Reduction/Increase*	-35.8%	-25.2%	-26.3%	2.3%	4.5%	8.2%

* A negative sign means that there was an increase in the # of crashes.

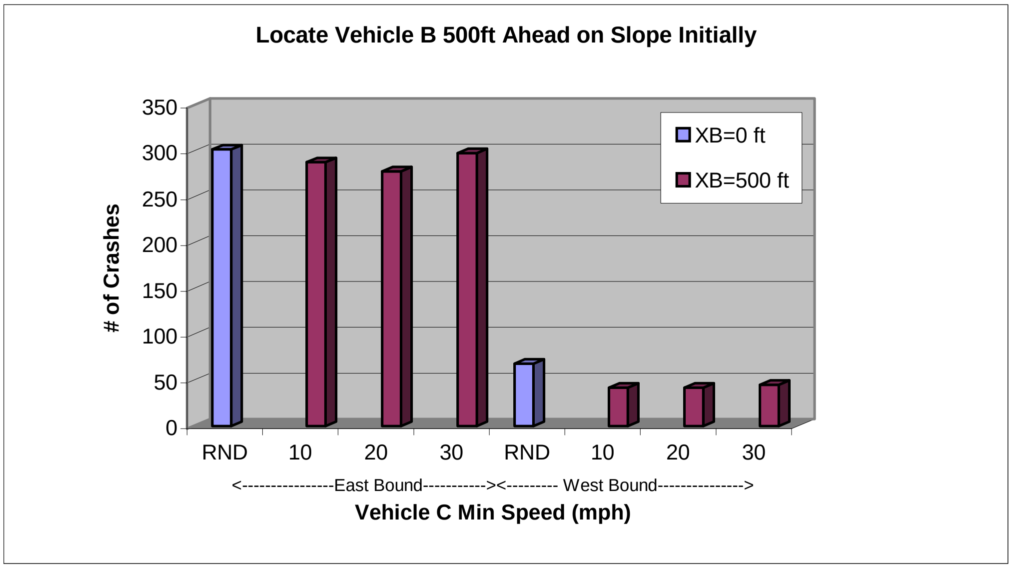


Figure 5.7 - Change Initial Location of Vehicle B

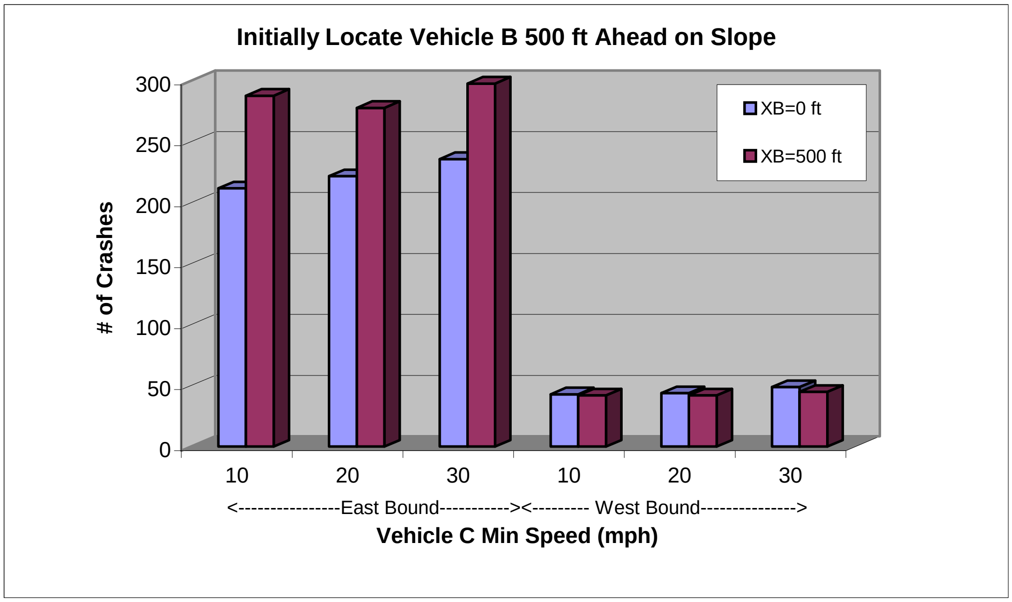


Figure 5.8 - Change Initial Location of Vehicle B

5.2.5 Test 5: Increase System Detection and Verification Time

In this scenario, the detection and verification time is increased from its base value of 0.2 sec to 0.6 and 1.0 sec, consecutively. By definition, detection and verification time is the time needed by the deployed surveillance system to detect a violator and then trigger the warning message signs. The sensitivity tests conducted on this variable do not aim at questioning the credibility of the system but to account for the discrepancies of the detectors' locations on a certain camera view. Tables 5.12 and 5.13 present the crashes outcome of this scenario followed by figure 5-9 that portrays the same results combined for better contrast. The average reduction in the number of crashes for the East bound and West bound directions is approximately 20.8% and 27%, respectively. Again, the extended simulation proves its benefits by minimizing the total number of crashes relative to the original base case even though the detection time has been extended to 0.6 and 1.0 seconds for the first and second scenarios, respectively.

Table 5.12 - Increase System Detection and Verification Time (0.6 sec)

	East Bound Direction				**West Bound Direction**			
Simulated Violations	**720**				**170**			
Vehicle C minimum Speed (mph)	**Base Case**	**10**	**20**	**30**	**Base Case**	**10**	**20**	**30**
Number of Crashes	302	241	236	241	68	49	50	50
Standard Deviation	8.7	9.1	10.8	11.0	7.2	7.8	4.6	5.1
Percent Crashes of Total Violations	41.9%	33.5%	32.8%	33.5%	40.0%	28.8%	29.4%	29.4%
Reduction from Base Case	–	20.2%	21.9%	20.2%	–	27.9%	26.5%	26.5%

Table 5-13 presents the percent of crashes reduction of the second case where the averages for the East and West directions are 4.7% and 7.9%, respectively.

Table 5.13 - Increase System Detection and Verification Time (1.0 sec)

	East Bound Direction				**West Bound Direction**			
Simulated Violations	**720**				**170**			
Vehicle C minimum Speed (mph)	**Base Case**	**10**	**20**	**30**	**Base Case**	**10**	**20**	**30**
Number of Crashes	302	291	281	291	68	60	64	64
Standard Deviation	8.7	10.0	12.3	14.0	7.2	6.1	6.3	7.9
Percent Crashes of Total Violations	41.9%	40.4%	39.0%	40.4%	40.0%	35.3%	37.6%	37.6%
Reduction from Base Case	–	3.6%	7.0%	3.6%	–	11.8%	5.9%	5.9%

The results of comparing the crashes outcome of the extended base case and those of sensitivity test 5 are presented in table 5-14 and portrayed in figure 5-10. The results conform to logic since as the detection time increases, the time to display the warning message will correspondingly increase, thus delaying the time when both vehicles A and C receive that message. That is, their reaction to the message is delayed leaving them both with less time to avoid the accident. Consequently, vehicle A has to overtake vehicle B in a shorter period of time and merge ahead, while vehicle C has less time to brake and come to a complete stop while attempting to avoid a possible crash with A. This variable plays a measurable role in the simulation since it is affecting all simulated drivers, thus all violation cases. It is clear from the displayed results in table 5-14 that increasing the detection time to 1.0 sec (5 times longer than base case), has substantially increased the number of crashes by an average of 29% and 38.5% for the East and West directions, respectively.

Table 5.14 - Comparison of Crashes to Extended Case for Test 5

# of Crashes	East Bound Direction			West Bound Direction		
Simulated Violations	720			170		
VehicleC_Min_Sp(mph)	10	20	30	10	20	30
Before (Detect = 0.2sec)	212	222	236	43	44	49
After (Detect = 0.6sec)	241	236	241	49	50	50
% Reduction/Increase*	-13.7%	-6.3%	-2.1%	-14.0%	-13.6%	-2.0%
After (Detect = 1.0sec)	291	281	291	60	64	64
% Reduction/Increase*	-37.3%	-26.6%	-23.3%	-39.5%	-45.5%	-30.6%

* A negative sign means that there was an increase in the # of crashes.

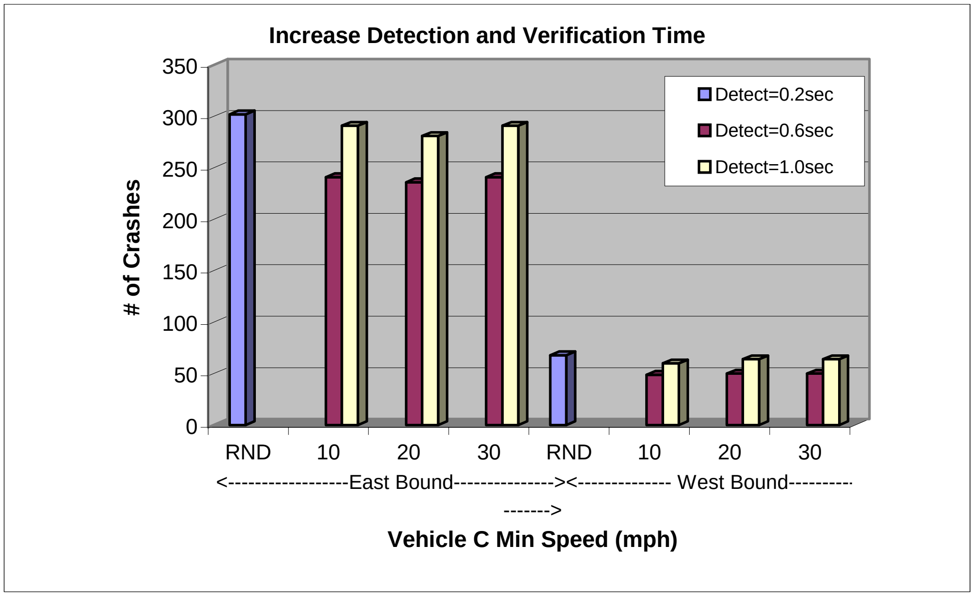


Figure 5.9 - Increase Detection and Verification Time

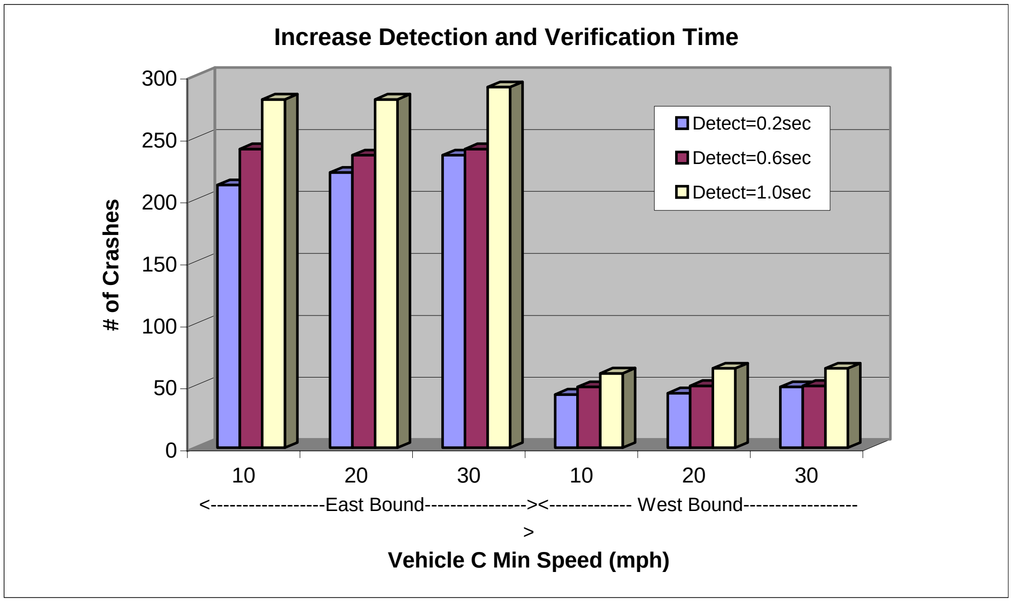


Figure 5.10 - Increase Detection and Verification Time

5.2.6 Test 6: Increase Reading Time Allowance

The reading time allowance is the time needed by a familiar commuter (drivers of that route are assumed regular commuters) to read the displayed message sign. In this scenario, the reading time allowance that has been assumed for the original case to be about 1.0 sec is to be increased to 1.3 and 1.6 sec, consecutively. By doing so, more concern is given to those who are not completely familiar with the road signage and those who are using it for the first time. Nevertheless, slower readers are also accounted for through this test since not all drivers can read such signs within the average reading time that has been assumed for the base case.

Tables 6-15 and 6-16 present the crashes results of this scenario for the two cases followed by figure 5-11 that portrays the same output combined in one frame for better contrast. The average reduction in the number of crashes for the East bound and West bound directions is approximately 12.6% and 3.9%, respectively, for the first case and 3.2% and 0.0% for the second case.

Table 5.15 - Increase Reading Time Allowance (1.3 sec)

	East Bound Direction				**West Bound Direction**			
Simulated Violations	**720**				**170**			
Vehicle C minimum Speed (mph)	**Base Case**	**10**	**20**	**30**	**Base Case**	**10**	**20**	**30**
Number of Crashes	302	244	247	301	68	62	65	69
Standard Deviation	8.7	15.0	11.2	16.0	7.2	8.8	3.7	6.1
Percent Crashes of Total Violations	41.9%	33.9%	34.3%	41.8%	40.0%	36.5%	38.2%	40.6%
Reduction from Base Case	–	19.2%	18.2%	0.3%	–	8.8%	4.4%	-1.5%

Table 5.16 - Increase Reading Time Allowance (1.6 sec)

	East Bound Direction				**West Bound Direction**			
Simulated Violations	**720**				**170**			
Vehicle C minimum Speed (mph)	**Base Case**	**10**	**20**	**30**	**Base Case**	**10**	**20**	**30**
Number of Crashes	302	300	286	291	68	67	65	72
Standard Deviation	8.7	16.0	13.6	20.4	7.2	5.8	6.2	9.7
Percent Crashes of Total Violations	41.9%	41.7%	39.7%	40.4%	40.0%	39.4%	38.2%	42.4%
Reduction from Base Case	–	0.7%	5.3%	3.6%	–	1.5%	4.4%	-5.9%

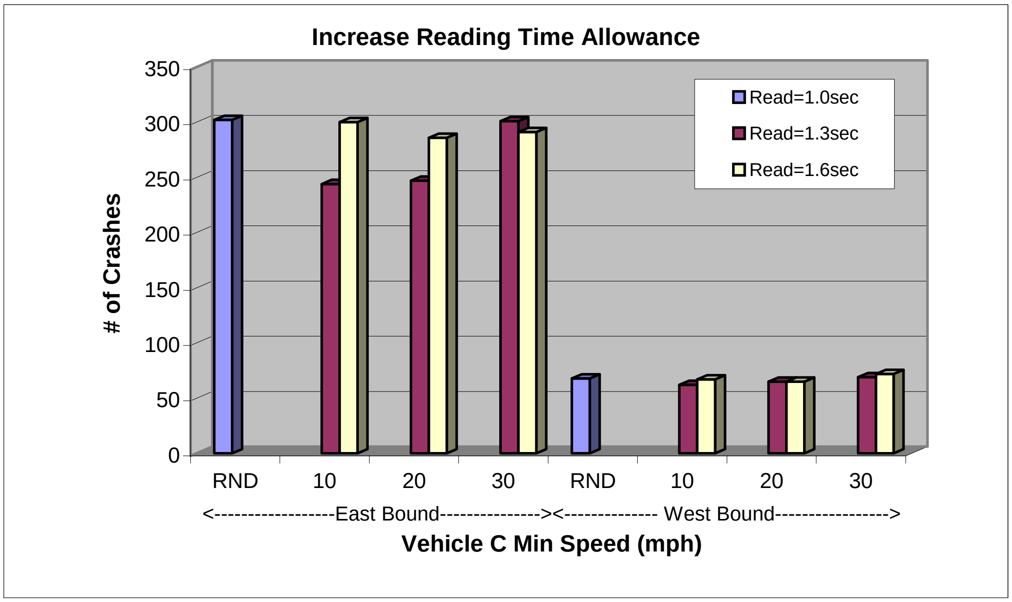


Figure 5.11 - Increase Reading Time Allowance

Reading time allowance has the same effect as the detection and verification time since both enter into the calculation of the reaction time in a way to determine when drivers are going to decelerate/accelerate in response to the violation situation. That is why the effect of such variable on the crashes results is considerable since it influences all drivers' reactions. Table 5-17 presents the output results of sensitivity test 6 while figure 5-12 portrays them. On Average, the percentages of crashes increase of the West bound direction are 44% and 50% for the first and second case, respectively, while that of the East bound direction are 18.0% and 31.2% for the first and second cases, respectively.

Table 5.17 - Comparison of Crashes to Extended Case for Test 6

# of Crashes	**East Bound Direction**			**West Bound Direction**		
Simulated Violations	**720**			**170**		
VehicleC_Min_Sp(mph)	**10**	**20**	**30**	**10**	**20**	**30**
Before (Reading=1.0sec)	212	222	236	43	44	49
After (Reading= 1.3sec)	244	247	301	62	65	69
% Reduction/Increase*	-15.1%	-11.3%	-27.5%	-44.2%	-47.7%	-40.8%
After (Reading= 1.6sec)	300	286	291	67	65	72
% Reduction/Increase*	-41.5%	-28.8%	-23.3%	-55.8%	-47.7%	-46.9%

* A negative sign means that there was an increase in the # of crashes.

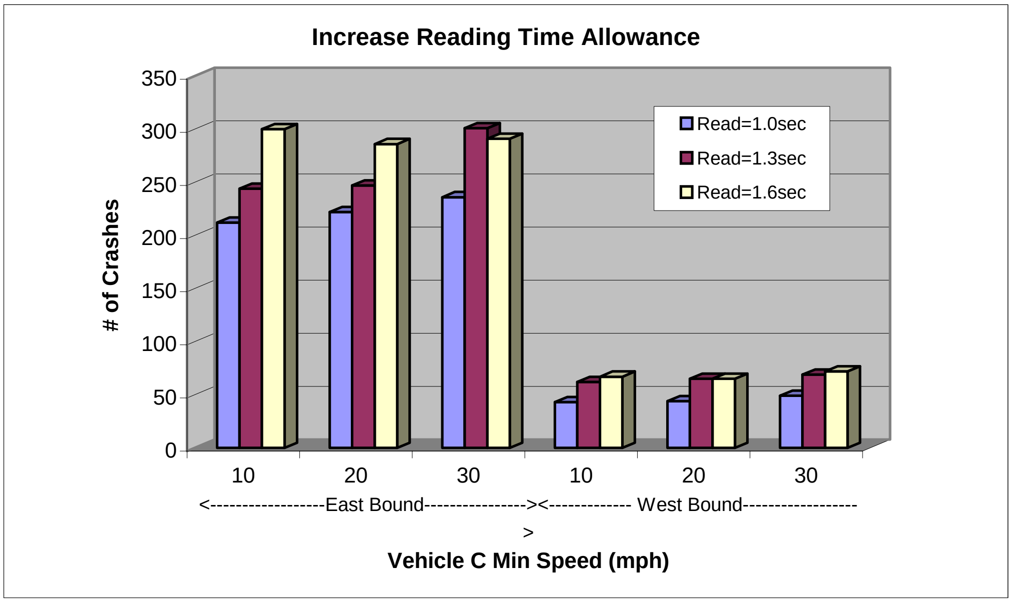


Figure 5.12 - Increase Reading Time Allowance

5.2.7 Test 7: Locate Vehicle C Within (+d_d) and (-d_d), (-d_d<X_C<+d_d)

Originally, the location of vehicle C has been assumed to be within (+ or -) half the desired distance (**$d_d/2$**) from the start of the detection zone based on the calculated flow for that direction. This test is concerned with the variation of vehicle C's location within a wider range and its effect on the overall crashes outcome. Thus, vehicle C is now located within double the previous range **(-d_d<X_C<+d_d)**. The point behind this test is to evaluate what if vehicle C was further away or closer on the opposite direction to the violating driver A.

Table 5-18 presents the crashes results of this scenario for the two directions followed by figure 5-13 that portrays the same output. The average reduction in the number of crashes for the East bound and West bound directions is approximately 23.7% and 4.4%, respectively.

Table 5.18 - Change Location of Vehicle C

	East Bound Direction				**West Bound Direction**			
Simulated Violations	**720**				**170**			
Vehicle C minimum Speed (mph)	**Base Case**	**10**	**20**	**30**	**Base Case**	**10**	**20**	**30**
Number of Crashes	302	226	225	240	68	67	64	64
Standard Deviation	8.7	10.2	10.3	13.5	7.2	4.2	9.2	5.9
Percent Crashes of Total Violations	41.9%	31.4%	31.3%	33.3%	40.0%	39.4%	37.6%	37.6%
Reduction from Base Case	_	25.2%	25.5%	20.5%	_	1.5%	5.9%	5.9%

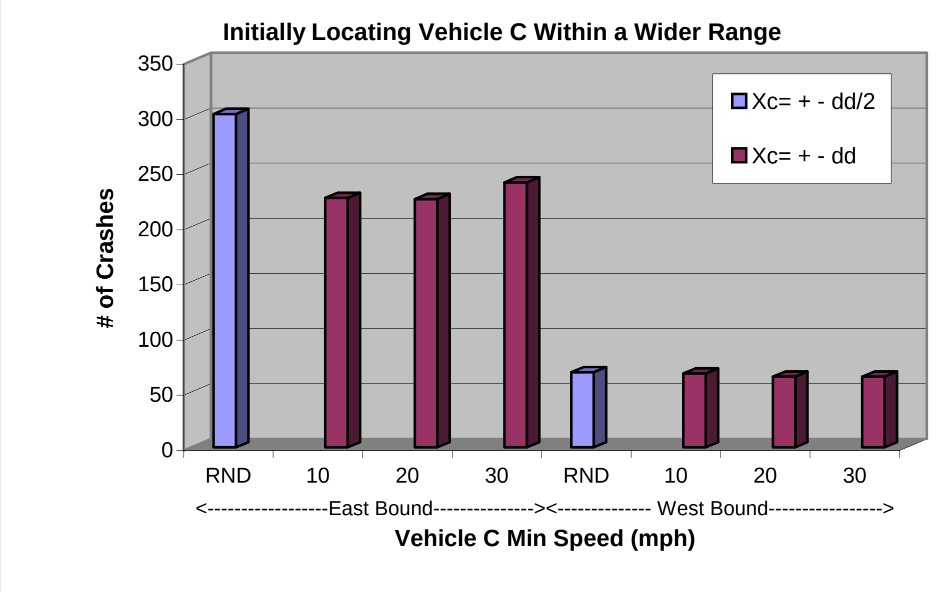


Figure 5.13 - Vary Initial Location of Vehicle C

Table 5-19 presents the big difference in the effect of varying vehicle C's location on the average number of crashes between the East and West directions. This difference can be merely attributed to the fact that the length of the Crest vertical curve in the East direction is significantly longer than that of the West curve and thus would less probably be affected by the location of vehicle C. While for the West direction, the length of the curve is shorter and thus placing vehicle C anytime ahead on the curve will increase the chances of a collision with the violator since it is very close to it now. On Average, the percentage of crashes increase for the West bound direction is 44% , while for the East direction it is 3.2%.

Table 5.19 - Comparison of Crashes to Extended Case for Test 7

# of Crashes	**East Bound Direction**			**West Bound Direction**		
Simulated Violations	**720**			**170**		
VehicleC_Min_Sp(mph)	**10**	**20**	**30**	**10**	**20**	**30**
Before ($-d_d/2<X_C<+d_d/2$)	212	222	236	43	44	49
After ($-d_d<X_C<+d_d$)	226	225	240	67	64	64
% Reduction/Increase*	-6.6%	-1.4%	-1.7%	-55.8%	-45.5%	-30.6%

* A negative sign means that there was an increase in the # of crashes.

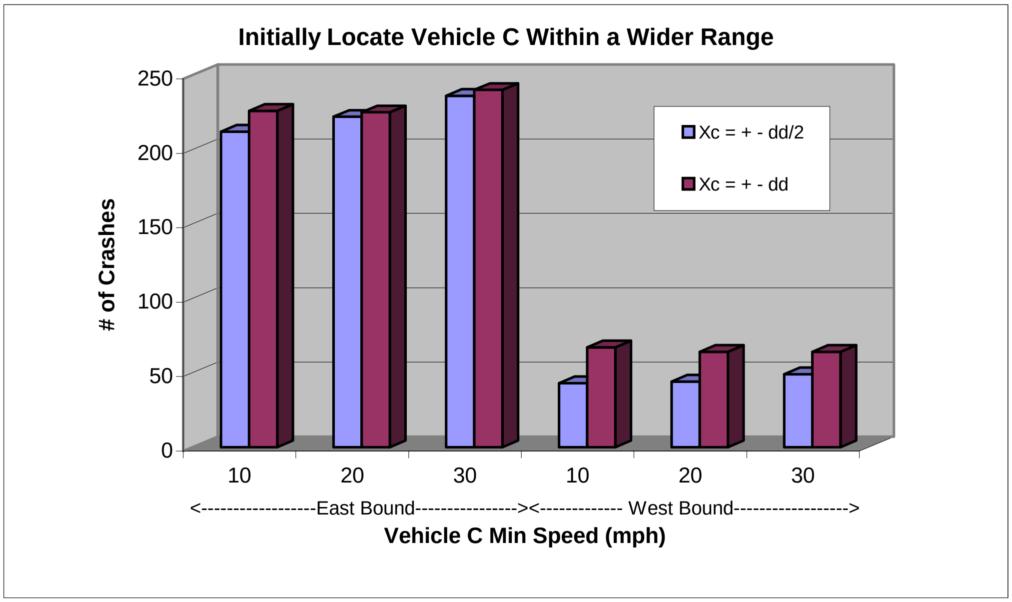


Figure 5.14 - Vary Initial Location of Vehicle C

5.2.8 Summary Table

Table 5.20 below summarizes the results of the sensitivity tests as well as the base case scenario.

Table 5.20 – Summary of Average Number of Crashes Per Scenario

		East Bound Direction			**West Bound Direction**		
	Simulated Violations	**720**			**170**		
	Base Case	302			68		
	Vehicle C Min Speed (mph)	**10**	**20**	**30**	**10**	**20**	**30**
	Extended Base Case	212	222	236	43	44	49
Test #1	**Max Speed =70mph**	149	163	167	34	35	35
	Max Speed =75mph	116	118	117	25	24	25
Test #2	**% DUI = 15%**	229	232	238	47	48	50
	% DUI = 10%	211	233	238	42	44	43
Test #3	**DUI Penalty = 1.0 sec**	236	243	234	59	64	64
	DUI Penalty = 1.5 sec	257	264	264	66	64	63
Test #4	**Change Initial X_B**	288	278	298	42	42	45
Test #5	**Detection Time = 0.6 sec**	241	236	241	49	50	50
	Detection Time = 1.0 sec	291	281	291	60	64	64
Test #6	**Reading Time = 1.3 sec**	244	247	301	62	65	69
	Reading Time = 1.6 sec	300	286	291	67	65	72
Test #7	**Change Initial X_C**	226	225	240	67	64	64

CHAPTER6. CONCLUSIONS AND FUTURE RESEARCH

6.1 Research Conclusions

A unique simulation has been developed that represents the illegal passing maneuver of a vehicle in a no-passing zone on a two lane rural road. The simulation considers the characteristics of the driver, the vehicle, and the roadway. It also considers the responses of the violating vehicle to warning messages deployed by an ITS system that detects the violating vehicle in real time. In addition, the opposing vehicle in the same lane as the violating vehicle is being warned at the same time the violating vehicle is warned to avoid possible crashes. The results of the simulation have shown that warning the opposing driver would reduce the probability of a crash if the violating vehicle disobeyed the warning sign and continues its passing maneuver. The comparison results of the simulation indicate that warning the opposing driver would reduce the possible crashes from the base case, even if the violator persists on passing in spite of the warning sign, by a mean of 26.3% in the eastbound direction and 33.3% in the westbound direction. The system can play a role in preventing crashes on rural roads as well as in alleviating crashes severity in the worst cases.

On the other hand, the system has addressed some of the issues that were not dealt with in the previous research such as the traffic data related to violations attributes like, speed distribution of the population of violating vehicle A, which are now available as presented in table 3.2. This was done through setting the data collection period to 1 minute where now the violator speed can be calculated. Nevertheless, with the help of the video recording cameras, the author will be able to assess the percentage of violators who responded to the warning message sign and the corresponding system reliability, as well as, one other important parameter that is the location where the violation was initiated.

6.2 Future Recommendations for Research

The simulation results have shown that extending the ITS deployed system to provide a warning message to the opposing vehicle is worth pursuing. Thus, like any other scientific area or field of knowledge, further researches and studies need to be accomplished in order to fill in the gaps of some assumptions that were made before a clearer idea is attained. Some of these were revealed in the context of the research development but need further efforts to be accomplished. We may specify few areas that could be helpful in better understanding and developing the system:

1- Data Collection: we need to conduct more intensive field surveys over that stretch of the road, which is a little bit more task demanding. Such collected data can aid us in refining the simulation parameters, understanding the interrelationships between the parameters, and appreciating the reliability and robustness of the system.

2- Human Factor Issues: Many questions need to be addressed and answered about human factors in such situation and the circumstances surrounding the process of violations, such as:

- Study human behavior under emergency and danger situation and how do drivers make their decisions.
- Study the environmental conditions and their effects on drivers' behavior (e.g. fog, rain, nighttime, etc.)
- Examine the conditions prevailing that might lead violators to accelerate or decelerate when they see the oncoming vehicle or get a warning (relative positions and speeds of A and B, vs. relative position and speeds of A and C), and the role of the psychological and aggressive history of the offender.
- Analyze the assumption that vehicle B is neutral all the way during the violation process, and the corresponding behavior of driver B once he/she perceives such situation.

References

1. El-Zarif, J., *Deploying an ITS Warning System For No-Passing Zones on Two Lane Rural Roads.* Doctor of Philosophy Dissertation, Virginia Tech, July 2001.
2. *A Policy on Geometric Design of Highways and Street.* AASHTO, Washington, D.C., 1994.
3. Fitzpatrick K., Lienau T., and Fambro D.B. *Driver Eye and Vehicle Heights for Use in Geometric Design.* In Transportation Research Record *1612*,TRB, Washington, D.C., 1998.
4. Halati, A., H. Lieu, and S. Walker. *CORSIM- Corridor Traffic Simulation Model.* In Traffic Congestion and Traffic Safety in the 21st Century: Challenge, Innovations, and opportunities, American Society of Civil Engineers, New York, 1997, pp. 570-576.
5. Pline, J. L. *Traffic Engineering Handbook,* 4th ed. Institute of Transportation Engineers, Washington, D.C., 1992.
6. Rakha H., Lucic I., Demarchi S., Setti J. and Van Aerde M. *Vehicle Dynamics Model for Predicting Maximum Truck Acceleration.* In Journal of Transportation Engineering, 2001,Volume 127 no. 5.
7. Fambro D. et al. *Determination of Factors Affecting Stopping Sight Distance. Working Paper I: Braking Studies* NCHRP, 1994.
8. Koppa, R.J. *Human Factors*. In Chapter 3 of the revised monograph of "Traffic Flow Theory: A state-of-the-art report", TRB, FHWA and ORNL, 1996.
9. Lerner, Neil at al. *Literature Review: Older Driver Perception-Reaction Time for Intersection Sight Distance and Object Dtetection*. FHWA, Washington D.C., 1995.
10. Dudek, C.L. *Guidelines on the Use of Changeable Message Signs*. FHWA,US DOT, Washington D.C., 1990.
11. Moskowitz H., Burns M., Fiorentino D., Smiley A., Zador P. *Driver Characteristics and Impairement at Various BAC.* NHTSA, Washington D.C., August 2000.
12. Yang Q. and Koutsopoulos H. N. *A MIcroscopic Traffic SIMulator (MITSIM) for Evaluation of Dynamic Traffic Management Systems.* In Transportation Research C, 1996, 4 (3):-129.
13. Glen Koorey. *Assessment of Rural Road Simulation Modelling Tools.* IPENZ Transportation Group Technical Conference, 2002.
14. Harwood, D. W., May, A. D., Anderson, I. B., Leiman, L., Archilla, A. R. *Capacity and Quality of Service of Two-Lane Highways.* Midwest Research Institute, November 1999.

15. Pierowicz, J., Jocoy, E., Lloyd, M., Bittner, A., Pirson, B. *Intersection Collision Avoidance Using ITS Countermeasures: Task9-Final Report.* NHTSA and USDOT, September 200.
16. Chovan, J. D., Tijerina, L., Pierowicz, J., Hendricks, D. *Examination of Signalized Intersection, Straight Crossing Path Crashes and Potential IVHS Countermeasures.* DOT-VNTSC-NHTSA-94-1, August 1994.
17. Talmadge, S., Dixon, D., Quon, B. *Development of Performance Specifications for Collison Avoidance Systems for Lane Change, Merging, and Backing.* NHTSA, May 1997.
18. Campbell, J., Hooey, B., Camey, C., Hanowski, R.,Gore, B.,Kantowitz, B.,Mitchell, E. *Investigation of Alternative Displays for Side Collision Avoidance Systems.* DOT HS 808 579, NHTSA, December 1996.
19. Hendricks, D., Mironer, M. *Examination of Single Vehicle Roadway Departure Crashes and Potential IVHS Countermeasures.* DOT-VNTSC-NHTSA-94-3, August 1994.
20. E-Squared Engineering. *State of The ARTS: Advanced Rural Transportation Systems 2001.* ITSA, 2001.
21. Westat. NHTSA Driver Distraction, Expert Working Group Meetings. NHTSA, November 200.
22. *Traffic Safety Facts 2002: A Compilation of Motor Vehicle Crash Data from the Fatality Analysis Reporting System and the General Estimates System.* NHTSA and USDOT, 2002.
23. *Intelligent Vehicle Initiative- Needs Assessment.* Federal Transit Administration and USDOT, November 1999. (www.fta.dot.gov & www.vople.dot.gov)
24. National Center for Statistics and Analysis. *Traffic Safety Facts 2001- Rural/Urban Comparison.* DOT HS 809 524, NHTSA, 2001. (www.nhtsa.dot.gov)
25. P. Fancher, L. Kostyniuk, D. Massie, R. Ervin, K. Gilbert, M. Reiley, C. Mink, S. Bogard, and P. Zoratti. *Potential Safety Applications Of Advanced Technology.* Federal Highway Administration, U. S. DOT, Report No. FHWA-RD-93-080, January, 1994.
26. Tijerina, L., Pierowicz, J., Browning, N., Mangold, S., Madigan, E., *Examination of Reduced Visibility Crashes and Potential IVHS Countermeasures.* DOT-VNTSC-NHTSA-94-6, NHTSA, January 1995.
27. *IVHS Countermeasures for Rear-End Collisions.* Task 1Volume I: Summary, NHTSA, DOT HS 808 561, February1994

28. Michalopoulos, P.G. *Vehicle Detection through Video Image Processing: The AUTOSCOPE system.* IEEE Transactions on Vehicular Technology, 40(1), 1991, 21-29.
29. Michalopoulos, P.G., Jacobson, R.D., Anderson, C.A., and DeBruycker, T.B. *Automatic Incident Detection through Video Image Processing.* Traffic Engineering & Control, Feb. 1993, pp. 66-75.
30. *Autoscope User's Guide.* Econolite Control Products, Inc., 1995.
31. http://www.its.dot.gov/ivi/ivi.htm

VITA

I was born during the year 1979 in the beautiful village of *Beau-cite*[♠] where I grew up for few years and then moved to live in Beirut at the time when I had to start school. I graduated from the *Beirut Evangelical School* in 1997. My college life started at the *University of Balamand* and lasted for three years from 1998 to 2000, when I graduated with a bachelor of science in civil engineering with honors and got the student excellence award[♣] during the graduation ceremony. To widen my university borders, I attended the Lebanese American University in Byblos for 2 extra years from 2001 till May 2002. I graduated with the highest distinction and was ranked second among all the university graduates of that year (not only engineers). My advisor, Dr. Camille Issa, recommended me to Virginia Tech, where I was accepted to further my graduate studies in Transportation engineering under Professor Antoine Hobeika's planning team. I will be receiving my Masters of Science in Civil Engineering from Virginia Tech in December 2003, and will be pursuing a Doctorate of Philosophy after that in the same school.

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[♠] Named by the French soldiers who occupied Lebanon at that time: Beau (Beautiful) & cite (place).

[♣] Award was given based on highest GPA among graduating engineers and best personality.