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Red-light Running and Limited Visibility Due to LTV's using the UCF Driving Simulator

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16. Abstract

The UCF Driving simulator was used to test a proposed pavement-marking design. This marking is placed upstream of signalized intersections to assist the motorists with advance warning concerning the occurrence of the clearance interval. The results of the experiment have indicated promising results for intersection safety. Firstly compared to regular intersections, the pavement marking could results in a 74.3 percent reduction in red-light running. In comparison, the pavement marking reduced the number of occurrences where drivers chose to continue through an intersection when it was not safe to proceed compared to the without marking, and this result is correlated to less red-light running rate with marking. According to survey results, all of the tested subjects gave a positive evaluation of the pavement-marking countermeasure and nobody felt confused or uncomfortable when they made stop-go decision. In comparison between scenarios without marking and with marking, there is no significant difference found in the operation speeds and drivers brake response time, which proved that the marking has no significantly negative effect on driver behaviors at intersections.

The UCF driving simulator was also used to test vertical and horizontal visibility blockages. For the horizontal visibility blockage, two sub-scenarios were designed, and the results confirmed that LTVs contribute to the increase of rear-end collisions on the roads. This finding may be contributed to the fact that LTVs cause horizontal visibility blockage. Indeed, the results showed that passenger car drivers behind LTVs are prone to speed more and to keep a small gap with the latter relatively to driving behind passenger cars. From the survey analysis 65% of the subjects said that they drive close to LTVs in real life.

As for the vertical visibility blockage, three sub-scenarios were designed in the driving simulator, and the results confirmed that LSVs increase the rate of red light running significantly due to vertical visibility blockage of the traffic signal pole. However, the behavior of the drivers when they drive behind LSVs is not different then their behavior when drive behind passenger cars. The suggested addition of the traffic signal pole on the side of the road significantly decreased the red light running rate. Moreover, 65% of the subjects driving behind an LSV with the proposed additional traffic signal pole said that the traffic signal pole is effective and that it should be applied to real world.

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Executive Summary

The UCF Driving simulator was used to test a proposed pavement-marking design to reduce red-light running rate. This marking is placed upstream of signalized intersections to assist the motorists with advance warning concerning the occurrence of the clearance interval. An experiment utilized a within-subjects repeated measures factorial design to test effectiveness of the pavement-marking countermeasure on red-light running. The three treatment design factors include speed limit, pavement-markings and yellow phase onset distance. There are two levels for speed limits (30 mph and 45 mph), two levels for program types (with marking or without marking), and eight yellow phase onset distances (at the test intersections) for each speed-limit type measured from the position of the approaching vehicle when yellow phase starts to the stop bar of the intersection approach. Data analysis was based on the responses and decisions made by the 42 subjects approaching 32 signalized intersections. Each subject responded to 16 test signalized intersections with marking and 16 regular signalized intersections without marking for a total of 1344 driver-intersection encounters. The results of the experiment have indicated promising results for intersection safety. Firstly compared to regular intersections, the pavement marking could results in a 74.3 percent reduction in red-light running. In comparison, the pavement marking reduced the number of occurrences where drivers chose to continue through an intersection when it was not safe to proceed compared to the without marking, and this result is correlated to less red-light running rate with marking. Furthermore, for those running red-light drivers, the marking tends to reduce the red-light entry time. Logistic regression models attest that the marking is helpful to

improve driver stop-go decision at intersections. Compared to without marking, if the drivers located near to the stop bar, drivers tend to cross the intersection with the marking; if the drivers located farther to the stop bar, drivers tend to stop at the intersection with the marking. The results showed that the uncertainty distances between 20% and 80% probability of stopping with marking are about 23 ft for the 30 mph and 50 ft for the 45 mph shorter in comparison with regular intersections. It was also found that for those stopping drivers, the brake deceleration rate without marking is 1.959 ft/s^2 significantly larger than that with marking for the higher speed limit. With the marking information, the probability that drivers make a too conservative stop will decrease if they are located in the downstream of marking at the onset of yellow, which resulted in the gentler deceleration rate with marking. At intersections, the smaller deceleration rate may contribute to the less probability that rear-end crashes happen.

Moreover, according to survey results, all of subjects gave a positive evaluation of the pavement-marking countermeasure and nobody felt confused or uncomfortable when they made stop-go decision. In comparison between scenarios without marking and with marking, there is no significant difference found in the operation speeds and drivers brake response time, which proved that the marking has no significantly negative effect on driver behaviors at intersections.

Vertical and horizontal visibility blockages and their consequences on the safety of traffic are of major concern. To study the seriousness of these two issues, 5 sub-scenarios were designed in the UCF driving simulator and the resulting data were thoroughly analyzed and conclusions were made. For the horizontal visibility blockage, two sub-scenarios were designed, and the results confirmed that LTVs contribute to the increase of rear-end collisions on the roads. This finding may be contributed to the fact that LTVs cause horizontal visibility blockage. Indeed, the results showed that passenger car drivers behind LTVs are prone to speed more and to keep a small gap with the latter relatively to driving behind passenger cars. This behavior is probably due to drivers' frustration and their eagerness to pass the LTV. Moreover, the trend of the impact velocities shows a higher impact velocities when vehicles follow an LTV, therefore rear-end collisions with LTVs are more severe than rear-end collisions when following a passenger car. From the survey analysis 65% of the subjects said that they drive close to LTVs in real life.

As for the vertical visibility blockage, three sub-scenarios were designed in the driving simulator, and the results confirmed that LSVs increase the rate of red light running significantly due to vertical visibility blockage of the traffic signal pole. However, the behavior of the drivers when they drive behind LSVs is not different then their behavior when drive behind passenger cars.

The suggested addition of the traffic signal pole on the side of the road significantly decreased the red light running rate. Moreover, 65% of the subjects driving behind an LSV with the proposed additional traffic signal pole said that the traffic signal pole is effective and that it should be applied to real world.

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Chapter 1. Introduction

1.1 Traffic facts of red-light running in the U.S.

Red light running contributes to substantial numbers of motor vehicle crashes and injuries on a national basis. Retting et al reported that drivers who run red lights were involved in an estimated 260000 crashes each year, of which approximately 750 are fatal, and the number of fatal motor vehicle crashes at traffic signals increased 18% between 1992 and 1998, far outpacing the 5% rise in all other fatal crashes (Retting et al., 2002). According to the Federal Highway Administration, the following traffic facts about red light running were posted in its main website:

- Each year, more than 1.8 million intersection crashes occur.
- In 2000, there were 106,000 red light running crashes that resulted in 89,000 injuries and 1,036 deaths.
- Preliminary estimates for 2001 indicate 200,000 crashes, 150,000 injuries, and about 1,100 deaths were attributed to red light running.
- Overall, 55.8 percent of Americans admit to running red lights. Yet ninety-six percent of drivers fear they will get hit by a red light runner when they enter an intersection.

Red-light running is not only a highly dangerous driving act but also it is the most frequent type of police-reported urban crash. A study provided 5,112 observations of drivers entering six traffic-controlled intersections in three cities. Overall, 35.2% of observed light cycles had at least one red-light runner prior to the onset of opposing traffic. This rate represented approximately 10 violators per observation hour (Bryan et al., 2000).

1.2 Rear-End Issues Related To LTV View Blockage

During the past decade, with the rapid growth in light truck vehicle (LTV) sales, including minivans, sports utility vehicles (SUVs), and light-duty trucks, a profound shift in the composition of the passenger vehicle fleet has been realized in the United States. By the end of 2000, the number of registered LTVs in the United States exceeded 76 million units or approximately 35 percent of registered motor vehicles in the U.S. The majority of LTVs are used as private passenger vehicles and the number of miles logged in them increased 26 percent between 1995 and 2000, and 70 percent between 1990 and 2000 (NHTSA VEHICLE SAFETY RULEMAKING PRIORITIES: 2002-2005). LTVs are generally larger than common passenger cars and able to take on additional tasks. LTVs usually ride higher and wider than the common passenger cars, which likely affect the visibility of passenger car drivers.

1.3 Objective

The main objectives of this study are:

1. Test a new design of road marking to alert drivers of signal clearance interval occurrence and ultimately reduce red-light running frequency.

2. Design an experiment to test the horizontal blockage visibility of passenger car drivers following Large Truck Vehicles.
3. Design an experiment to test the vertical blockage visibility of passenger car drivers following a school bus.

Chapter 2. Literature Review

2.1 Safety Issues Related to Red-light Running Accidents

Red-light running contributes to substantial numbers of motor vehicle crashes and injuries on a national basis. Retting et al reported that drivers who run red-lights were involved in an estimated 260000 crashes each year, of which approximately 750 are fatal, and the number of fatal motor vehicle crashes at traffic signals increased 18% between 1992 and 1998, far outpacing the 5% rise in all other fatal crashes (Retting et al., 2002). Motorists are more likely to be injured in crashes involving red-light running than in other types of crashes, according to analyses of police-reported crashes from four urban communities; occupant injuries occurred in 45% of the red-light running crashes studied, compared with 30% for all other crashes in the same communities.

In Texas, a report showed that the number of people killed or injured in red-light running crashes had increased substantially over the years. The increase (79 percent from 1975 to 1999) is similar to the increase in the number of people killed or injured in motor vehicle crashes in general, and is also similar to the increase in vehicle miles traveled in the state. About 16 percent of people killed in intersection crashes and 19–22 percent of people injured in intersection crashes are involved in red-light running (Quiroga et al., 2003).

According to the Federal Highway Administration (FHWA), the following traffic facts about red-light running were posted in its main website:

- Each year, more than 1.8 million intersection crashes occur.
- In 2000, there were 106,000 red-light running crashes that resulted in 89,000 injuries and 1,036 deaths.
- Preliminary estimates for 2001 indicate 200,000 crashes, 150,000 injuries, and about 1,100 deaths were attributed to red-light running.
- Overall, 55.8 percent of Americans admit to running red lights. Yet ninety-six percent of drivers fear they will get hit by a red-light runner when they enter an intersection.

Red-light running is a highly dangerous driving act and also it is the most frequent type of police-reported urban crash. A study provided 5,112 observations of drivers entering six traffic-controlled intersections in three cities. Overall, 35.2% of observed light cycles had at least one red-light runner prior to the onset of opposing traffic. This rate represented approximately 10 violators per observation hour (Porter and England, 2000). Another study conducted over several months at a busy intersection (30,000 vehicles per day) in Arlington, VA revealed violation rates of one red-light runner every 12 min. and during the morning peak hour, a higher rate of one violation every 5 min. A lower volume intersection (14,000 vehicles per day), also in Arlington, had an average of 1.3 violations per hour and 3.4 in the evening peak hour (Retting et al., 1998).

Thus, based on both previous research and accident data, red-light running crashes represent a significant safety problem that warrants attention.

2.1.1 Characteristics of red-light running

Retting, Ulmer, and Williams (1999) analyzed drivers' characteristics involving fatal red-light running accidents using 1992–1996 data from the FARS and GES databases. For the analysis, they only considered fatal crashes for which one driver had committed a red-light running violation and both drivers were going straight prior to the crash. The following were the main findings of the study:

- Some 57 percent of fatal red-light running crashes occurred during the day. By comparison, 48 percent of other fatal crashes occurred during the day. However, fatal red-light running crashes that involved drivers less than 70 years old peaked around midnight, whereas fatal red-light running crashes that involved drivers 70 years old or older occurred primarily during the day.
- On average, 74 percent of red-light runners and 70 percent of non-runners were male. Of all nighttime red-light runners, 83 percent were male. Of all daytime red-light runners, 67 percent were male. It may be worth noting that male drivers accounted for roughly 61 percent of the vehicle miles traveled on U.S. roads, according to results from the 1995 Nationwide Personal Transportation Survey.
- Some 43 percent of red-light runners were younger than age 30. By comparison, 32 percent of non-runners were younger than age 30.
- Red-light runners were much more likely to drive with suspended, revoked, or otherwise invalid driver licenses. Younger drivers were more likely to be unlicensed.

From the perspective of crash types of red-light running, while most red-light running crashes involve at least two vehicles, crashes involving a single vehicle and an alternative transportation mode (pedestrian or bicyclist) can occur. A single vehicle, hit fixed object crash could occur when either the running-the-red violator or the opposing legal driver takes evasive action to avoid the other and crashes into an object, e.g. a signal pole. Also, a running-the-red violator can hit a pedestrian or bicyclist who is legally in the intersection.

A comprehensive report (FHWA, 2003) on red-light running issue concluded that the following crash types could be possible target crashes for a red-light study: Right-angle (side impact) crashes, Left turn (two vehicles turning), Left turn (one vehicle oncoming), Rear end (straight ahead), Rear end (while turning), and other crashes specifically identified as red-light running.

2.1.2 Reasons of red-light running

The FHWA report also pointed out that researchers reviewed the police reports of 306 crashes that occurred at 31 signalized intersections located in three states. Traffic-signal violation was established as a contributing factor and the reason for the violation was provided in 139 of the crashes. The distribution of the reported predominant causes is as follows:

- 40 percent did not see the signal or its indication;

- 25 percent tried to beat the yellow-signal indication;
- 12 percent mistook the signal indication and reported they had a green-signal indication;
- 8 percent intentionally violated the signal;
- 6 percent were unable to bring their vehicle to a stop in time due to vehicle defects or environmental conditions;
- 4 percent followed another vehicle into the intersection and did not look at the signal indication;
- 3 percent were confused by another signal at the intersection or at a closely spaced intersection; and
- 2 percent were varied in their cause.

The above research results show that red-light running is a complex problem. There is no simple or single reason to explain why drivers run red lights. However, they can be classified into two types, intersection factors and human factors.

A study's objective was to examine selected intersection factors and their impact on RLR crash rates and to establish a relationship between them. The results obtained from the model show that the traffic volume on both the entering and crossing streets, the type of signal in operation at the intersection, and the width of the cross-street at the intersection are the major variables affecting red-light running crashes (Mohamedshah, 2000). The FHWA report summed that, among intersection factors are intersection flow rates, frequency of signal cycles, vehicle speed, travel time to the stop line, type of signal control, duration of the yellow interval, approach grade, and signal visibility (FHWA, 2003).

Bonneson et al. (2002) concluded that the following factors influence the frequency of red-light-running and related crash frequency:

- flow rate on the subject approach (exposure factor),
- number of signal cycles (exposure factor), phase termination by max-out (exposure factor)
- probability of stopping (contributory factor),
- yellow interval duration (contributory factor),
- all-red interval duration (contributory factor),
- entry time of the conflicting driver (contributory factor), and
- flow rate on the conflicting approach (exposure factor).

Human factors that can contribute to the occurrence of crashes include physical or physiological factors (e.g., strength, vision), psychological or behavioral factors (e.g., reaction time, emotion), and cognitive factors (e.g., attention, decision making) (Quiroga et al., 2003).

How intersection factors and human factors interact to increase or decrease the risk of red-light running varies considerably from intersection to intersection. Those factors point to the need to implement engineering countermeasures to improve traffic flow, improve visibility, help drivers make driving maneuvers and reduce conflicts. Other factors, especially related to deliberate illegal driving behaviors, point to the need to also implement strategies such as improved enforcement and public awareness.

Bonneson (2001) also discussed the factors that affect the driver's decision to stop or proceed through the intersection upon seeing the onset of the yellow. There are three main components of the decision process: driver behavior (expectancy and knowledge of operation of the intersection), estimated consequences of not stopping and estimated consequences of stopping. What if the driver makes his decision to proceed through the intersection based on the factors above, but ends up running the red light? Bonneson divides red-light runners into two categories. The first is the intentional violator who, based on his/her judgment, knows they will violate the signal, yet he/she proceeds through the intersection. This type of driver is often frustrated due to long signal delays and perceives little risk by proceeding through the intersection. The second type of driver is the unintentional driver who is incapable of stopping or who has been inattentive while approaching the intersection. This may occur as a result of poor judgment by the driver or a deficiency in the design of the intersection. Bonneson further indicates that intentional red-light runners are most affected by enforcement countermeasures while unintentional red-light runners are most affected by engineering countermeasures.

2.2 Current Engineering Countermeasures for Red-Light Running

2.2.1 Overview of current engineering countermeasures

According to characteristics and reasons of red-light running, traffic engineers are trying to develop a number of methods to reduce the red-light running rate. Currently, engineering countermeasures include signal operation countermeasures (e.g., increasing the yellow interval duration, providing green extension, improving signal coordination, and improving signal phasing), motorist information countermeasures (e.g., improving sight distance, improving signal visibility and conspicuity, and adding advance warning signs), and physical improvement countermeasures (e.g., removing unneeded signals, adding capacity with additional traffic lanes, and flattening sharp curves). Signal operation countermeasures can effectively reduce the incidence of red-light running by improving traffic flow characteristics and by reducing the exposure of individual vehicles to situations that might result in red-light running. Motorist information countermeasures that focus on attracting the attention of drivers to the signal can effectively reduce the incidence of red-light running.

In recent years, a lot of researches are related to evaluation on effects of red-light camera implementation. In one side, the review of the effectiveness of those systems reveals that red-light cameras are effective deterrence tools and have a positive safety impact; even where the implementation of engineering countermeasures had not preceded the installation and operation of cameras. On the other side, the review also shows that red-light cameras can contribute to an increase in the number of rear-end crashes; however, this effect is relatively small and temporary and camera presence (or the presence of warning signs) had no significant effect on red-running behavior (Quiroga et al., 2003). Furthermore, some report (The Red-light Running Crisis: Is it Intentional, 2001) questions whether motorists identified in Institute studies as red-light violators are, in fact, innocent drivers who were unable to stop in time to comply with the signals. The fact is that red-light cameras are designed to identify only deliberate violators, those who enter intersections well after the end of a yellow signal phase.

In this research, the purpose of pavement marking method is to help drivers make a clear decision at the onset of yellow phase to reduce red-light running and intersection accident rates, which also belong to motorist information countermeasures. Therefore, in the following section of this literature review, other motorist information countermeasures are paid more attentions to.

To help drivers make their decision at the onset of yellow, some motorist information countermeasures are implemented by enhancing the signal display or by providing advance information to the driver about the signal ahead. With the additional information, the probability that a driver will stop for a red signal may increase. Among them, the two most prevailing and controversial countermeasures are pre-yellow signal indication and advance warning signs.

2.2.2 Advance warning sign and Advance warning flashers

Advance warning signs forewarn drivers that they are approaching a signalized intersection. Figure 2-1 shows two types of warning signs. Figure 2-1a shows a sign that uses a "signal ahead" symbolic message. Flashing beacons sometimes accompany this sign to ensure drivers detect and interpret the sign's meaning. Figure 2-1b shows a "Be Prepared to Stop When Flashing" sign. This sign has the beacons flashing only during the last few seconds of green. It is sometimes referred to as an "advance warning sign with active flashers." In this mode, the flashing indicates when the signal indication is about to change from green to yellow. When flashing beacons accompany these advance warning signs, they are also named advance warning flashers (AWF). The purpose of AWF is to forewarn the driver when a traffic signal on his/her approach is about to change to the yellow and then the red phase. An effective AWF implementation is intended to minimize the number of vehicles in the dilemma zone during the change interval. In North America, there are three general types of advanced warning devices and the decision of which to use is based on engineering judgment. These AWFs include:

- Prepare to stop when flashing (PTSWF)—A warning sign, BE PREPARED TO STOP with two yellow flashers that begins to flash a few seconds before the onset of the yellow and continue to flash throughout the red phase. A WHEN FLASHING plaque is recommended in addition to the sign.
- Flashing symbolic signal ahead (FSSA)—Similar to previous type except the wording on the sign is replaced by a schematic of a traffic signal. The flashers operate as above.

- Continuous flashing symbolic signal ahead (CFSSA)—The sign displays a schematic of a traffic-signal symbol but in this case, the flashers operate continuously (i.e. they are not connected to the signal controller).

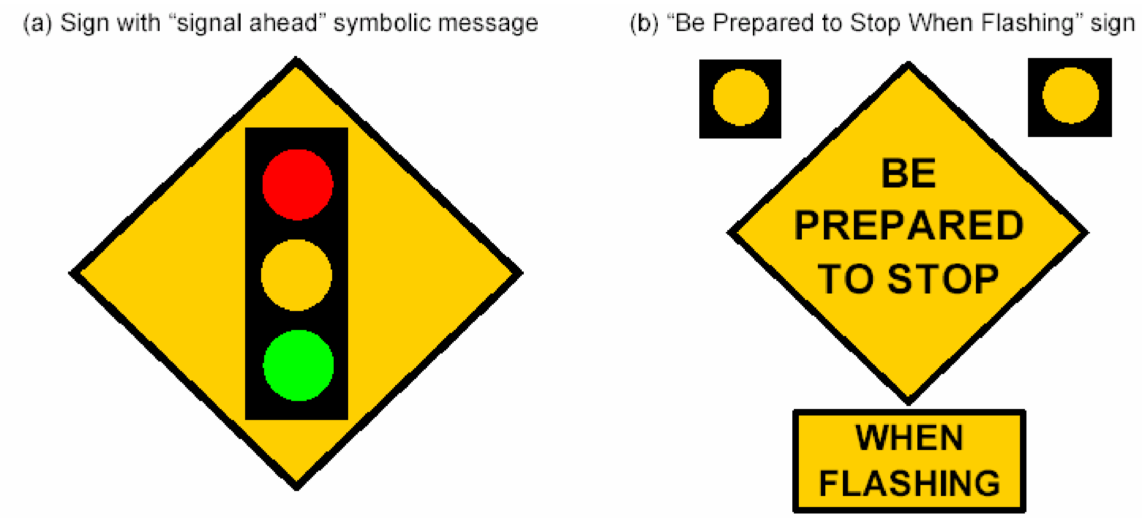


Figure 2-1: Advance warning sign and advance warning flashers

The location and timing of AWF are key considerations for the sign installation. The distance from AWF location to a signalized intersection must be equal to or greater than that required to perceive and react to the flasher and stop the vehicle safely. The timing refers to the length of time before the yellow interval of the downstream-signalized intersection at which the AWF starts flashing. Sayed et al. (1999) indicated that engineering judgment is often the principal guide for AWF installation according their literature findings. However, they also introduced practical guidelines for AWF implementation used in British Columbia, which are recommended at provincial intersection s where one of the following conditions is satisfied:

- The posted speed limit on the roadway is 70 km/h or greater,
- The view of the traffic signals is obstructed because of vertical or horizontal alignment (regardless of he speed limit) so that a safe stopping distance not available,
- There is a grade in the approach to the intersection that requires more than the normal braking effort, or
- Drivers are exposed to many kilometers of high-speed driving (regardless of posted speed limit) and encounter the first traffic signal in a developed community.

Location of AWFs is calculated by the following equation:

$$D = VT + \frac{V^2}{2g(f \pm G)} \tag{2-1}$$

Where

V = 85th percentile operating speed or posted speed limit (m/s)

T = reaction time (1.0 s)

g = gravitational acceleration (9.81 m/s^2)

f = friction factor for wet surfaces, and

G = grade (m/100m)

The length of the advanced warning time before the yellow interval of the downstream-signalized intersection at which the AWF starts flashing is calculated by the following equation:

$$AW = \frac{D + D_p}{V} \tag{2-2}$$

Where

AW = advanced warning time

D = Distance between the AWF and the signal's stop line

D_p = Minimum distance at which the flashers can be perceived (21.3m)

Studying drivers' reactions to advance warning flashers in the field is highly problematic because these devices are relatively uncommon and because it is difficult or impossible to establish a controlled experimental environment in which variable parameters can be tested individually. Smith (2001) employed the Human Factors Research Lab's driving simulator to investigate effects of Advance Warning Flashers at signalized intersections on simulated driving performance. After analysis of the large volume of experimental data, the researchers concluded that AWFs often improve stopping behavior at suitable intersections. But as is often seen in human factors research, human response to a complex situation is not as simple as a linear relationship. In this case, variability in human response resulted in some drivers making a more aggressive—and risky—decision to proceed through the intersection. This finding has obvious implications for field implementation of advance warning flashers at dangerous intersections (Smith, 2001).

Sayed et al. (1999) utilized and analyzed data from British Columbia using two different methods. Models were used to develop expected accident rates at 106 signalized intersections for total, severe and rear-end accidents. Twenty-five of these intersections had AWFs. Although the results indicate that intersections with AWFs have a lower frequency of accidents, the difference between those with AWFs and those without is not statistically significant. An additional before-and-after study was performed for the 25 intersections equipped with AWFs to estimate the accident reduction specific to each location and its approach volumes. A correlation was found between the magnitude of the minor approach traffic volumes and the accident reduction capacity of AWFs, showing that AWF benefits exist at locations with moderate to high minor approach traffic volumes (minor street AADT of 13,000 or greater).

2.2.3 Traffic light change anticipation system

The Traffic Light Change Anticipation System (TLCAS) utilizes flashing amber during the last few seconds of the green phase. The flashing amber is considered to be a legal green signal, and is used to warn drivers of the impending termination of the green phase. Some findings indicated that this pre-yellow signal indication could help drivers react more safely to the impending onset of yellow; however, other evaluations showed that the flashing amber phase was associated with an increase in rear-end accidents and negligible changes in right-angle collisions (Quiroga et al., 2003).

A research study used a driving simulator to study the efficiency of TLCAS. Eighteen males and twenty-three females were drawn from the student and staff population at Arizona State University (Newton, 1997). The simulator uses an IBM 486 platform, and incorporates a rear projection system that projects the roadway, intersections, and buildings. The results of the experiment showed an increased variability in first response five times larger than the regular program. This finding, in conjunction with traditional measures, indicates that the new system performs comparably to an increased amber duration by increasing the potential for conflicting decisions between successive drivers approaching an intersection. Altogether, the results suggested that this alternative signal phasing program would not improve intersection safety.

Another study evaluating the effect of TLCAS using collected data in three different countries, Austria, Switzerland and Germany (Koll et al., 2002). The researchers discussed the results of extensive measurements of the stopping behavior of drivers during signal programs with and without flashing green before amber. The analysis showed that the flashing green increases the number of early stops, as drivers tend to underestimate the duration of the time to the end of yellow. However they also indicated that it produces a large option zone, where drivers can both safely stop and cross. This large option zone generates a period of uncertainty, where a following driver cannot easily predict, if the car in front will stop or cross, so that it could lead to an increased number of rear end collisions.

2.2.4 Rumble strips

Another warning device that has been used to alert drivers to the presence of a signal is transverse rumble strips (FHWA, 2003). Rumble strips are a series of intermittent, narrow, transverse areas of rough-textured, slightly raised, or depressed road surface. The rumble strips provide an audible and a vibro-tactile warning to the driver. When coupled with the SIGNAL AHEAD warning sign and also the pavement marking word message— SIGNAL AHEAD—the rumble strips can be effective in alerting drivers of a signal with limited sight distance. There are no known studies reporting on how this treatment can reduce red-light violations or the resulting crashes; hence their use should be restricted to special situations. If used, they should be limited to lower-speed facilities (less than 40 mph) and be reserved for locations where other treatments have not been effective.

However, according to literature findings, there is no related pavement marking countermeasure to provide drivers yellow phase information and diminish the likelihood of red-light running rate. This research introduced a pavement marking design to help driver*s* make a clear decision at the onset of yellow phase to reduce red-light running and intersection accident rates.

2.3 Safety Issues Related to Driver View Blockage Due to LTV and LSV

Vertical and horizontal visibility blockages are real life problems causing violations of traffic laws like red light running and creating an environment conducive to traffic crashes. Horizontal view blockage occurs when a driver's visibility is inhibited to his left or/and right at an intersection. This can occur when someone is driving a passenger car, which could be any Sedan type car such as Honda Accord, Nissan Sentra, or Ford Taurus, closely behind a Light Truck Vehicle (LTV), such as vans and SUVs. A number of reports (Graham, 2000; Sayer et al. 2000; and Mohamed, 2003) had pointed out that the following car's driver view blockage due to the lead vehicle large size can contribute to a rear-end collisions.

According to the National Center for Statistics and Analysis (NCSA), in 2003 alone, there were 6,267,000 crashes in the U.S. from which 1,915,000 were injury crashes, including 38,764 fatal crashes and 43,220 human casualties. Wang et al. (1999) stated that the most abundant crash category is rear-ending collisions. Rear-end collisions are the most common forms of traffic crashes in the U.S. accounting for nearly third of the 6 million crashes reported annually nationwide. In the past two years, the National Transportation Safety Board investigated nine rear-end collisions in which 20 people died and 181were injured. Common to all nine crashes was the rear following vehicle drivers' degraded perception of traffic conditions ahead.

One of the main reasons of rear-end collisions relies on the abundance of the Light Truck Vehicles (LTVs) on the U.S. highways nowadays. For year 2000, Motor vehicle registrations show 77.8 million light trucks in the U.S., a 63.8% increase from 1990. During the same period, there was 1% decrease in the number of passenger cars (PCs). LTVs now present 40% of all registered vehicles.

Sayer et al. (2000) examined the effect that the lead vehicle sizes such as height and width has on a passenger car driver's gap maintenance under near optimal driving conditions characterized by daytime, dry weather, and free-flowing traffic. The data were obtained from a random sample of licensed drivers who drove an instrumented passenger car, unaccompanied, as their personal vehicle 2-5 weeks. Results showed that passenger car drivers followed LTV at shorter distance than they followed passenger cars, but at the same velocities. Also, the results of this study suggested that knowing the state of the traffic behind the lead vehicle, even by only one additional vehicle, affects gap length. Specifically, it appears that when dimensions of lead vehicles permit following drivers to see through, over, and around them, drivers maintain significantly longer distances. Acierno (2004) related the mismatch in weight, stiffness, and height between LTV and PC to the increase in fatalities among Passenger car occupants when their vehicle collides with LTV. Cases of vehicle mismatch collisions were studied in the Seattle Crash Injury research and Engineering Network (CIREN) database to establish patterns and source of injury. Of the first 200 Seattle CIREN cases reviewed, 32 collisions with 41 occupant cases were found to involve LTV versus PV. In conclusion, Acierno associated vehicle mismatch with death and serious injury in automotive crashes an also recommended design improvement to both PV and LTV.

Aty et al. (2004) investigated the effect of the increasing number of LTV registration on fatal angle collisions trends on the U.S. The analysis investigates the number of annual fatalities that result from angle collisions configuration (car-car, car-LTV, LTV-car, LTV-LTV). The analysis uses the Fatality Analysis Reporting System (FARS) crash databases covering the period 1975-2000. Results showed the death rates differ based on the collision configuration. Forecast showed that the total number of annual deaths is expected to reach 6300 deaths by year 2010 (an increase of 12% over 2000).

Modeling results showed that the coefficient of LTV percentage in the system of regression equations was significant because of the instantaneous effect (time lag equals to 0) of LTVs on the annual fatalities resulting from angle collisions.

In the United States, rear-end is the most common type of traffic crashes accounting for about a third of the US traffic crashes. This high accident rate shows the urgent need to study the contribution of LTV view blockage to rear-end crashes. The previous study mainly based on the accident data to conclude that rear-end collisions may be owing to LTVs view blockage to the following car's driver. However, the literature lacks information about controlled studies that specifically deals with the view blockage by an LTV as an important reason in causing rear-end collisions especially using driving simulators. In a controlled environment, a driving simulator experiment can be designed to directly investigate drivers' response, driving habit, and behavior characteristics when following an LTV compared to following a passenger car. The comparison study of following LTVs or passenger cars can test if LTVs will have more contributions to a rear-end collision due to the limited visibility.

On the other hand, vertical view blockage occurs when traffic light visibility is inhibited. For example, if someone is driving a passenger car closely behind a larger size vehicle (LSV) such as large trucks semis or buses, through a signalized intersection, the traffic light will not be visible until the driver is almost directly under it. Therefore, the driver won't be aware of any traffic signal change until it is too late, which could lead to red light running. However, according to the current literature, there is no previous study found to focus on the vertical sight blockage problem and the related safety issue.

2.4 Driving Simulator Issues

2.4.1 Benefits and limitations of simulator research

With the progress of computer science and electronic engineering in recent years, driving simulators used for training and research are being rapidly developed. A modern driving simulator can give a driver on board impression that he/she drives an actual vehicle by predicting vehicle motion caused by driver input and feeding back corresponding visual, motion, audio and proprioceptive cues to the driver. A driving simulator is a virtual reality tool which enables researchers to conduct multi-disciplinary investigations and analyses on a wide range of issues associated with traffic safety, highway engineering, Intelligent Transportation System (ITS), human factors, and motor vehicle product development. The use of a modern advanced driving simulator for human factors research has many advantages over similar real world or on-road driving research. These advantages include experimental control, efficiency, expense, safety, and ease of data collection. Especially, a simulation experiment has the ability to reproduce dangerous driving conditions and situations in a safe and controlled environment to test driver behaviors. In addition, many researches (Alicandri, 1986 and Stuart, 2002) indicated that simulator measures are valid for sign detection and recognition distances, speed, accelerator position changes and steering wheel reversals, because of a high correspondence between real world and simulator data sets.

However, there are also some limitations of simulation research. An important limitation of simulator research is simulator sickness (also euphemistically known as simulator discomfort). In a driving simulator research (Yan, 2003), it is reported that due to driving simulator sickness, about 10% of the younger male subjects and 20% of the younger female subjects were unable to complete the experiment and about 10% of the older male subjects and 40% of the older female subjects could not complete the experiments. Simulator sickness is not identical to motion sickness, although it is sometimes described as such (e.g. Nilsson, 1993). Motion is essential for motion sickness, but simulator sickness can occur without motion (Kolasinski, et al., 1995). It is related to driving task such as sharp turn or stop, experiment time, and complexity of visual elements. In the proposed simulator experiment, only what can be done to weaken Simulator sickness is to reduce the experiment time.

2.4.2 UCF driving simulator

The UCF driving simulator housed in the Center for Advanced Transportation Systems Simulation (CATSS) is an I-Sim Mark-II system with a high driving fidelity and immense virtual environments. The simulator cab it is a Saturn model that has an automatic transmission, an air condition, a left back view mirror and a center back view mirror inside the cab, as shown as Figure 2-2. The simulator is mounted on a motion base capable of operation with 6 degrees of freedom. It includes 5 channels (1 forward, 2 side views and 2 rear view mirrors) of image generation, an audio and vibration system, steering wheel feedback, operator/instructor console with graphical user interface, sophisticated vehicle dynamics models for different vehicle classes, a 3-dimensional road surface model, visual database with rural, suburban and freeway roads plus an assortment of buildings and operational traffic control devices, and a scenario development tool for creating real world driving conditions. The output data include detailed events pertaining to every car’s steering wheel, accelerator, brake, every car’s speed and coordinates, and a time stamp. The sampling frequency is 60Hz.

Figure 2-2: UCF driving simulator-Saturn cab

The simulator session is controlled from an operator's console in an adjacent control room. Scenarios are created with the scenario editing software on a screen showing the locations of roads, buildings, traffic control devices, pedestrians, etc. The five video channels are monitored on computer screens in the control room. A road map of the database is viewable on the operator's console showing movement of the simulator vehicle and other vehicles which are present (Harold, 2003).

The new simulator is capable of supporting research in driving simulation, driver training, human factors and traffic engineering.

Chapter 3. Driving Simulator Experiment for Testing Pavement Marking Countermeasure

According to literature findings, there is no related pavement marking countermeasure to provide drivers yellow phase information and diminish the likelihood of red-light running rate. In this study, a pavement marking countermeasure is proposed to help driver*s* make a clear stop/go decision at the onset of yellow phase to reduce red-light running and ultimately minimize intersection accident rates. A pavement marking with word message ‘SIGNAL AHEAD’ (see Figure 3-1) is placed on the pavement of the upstream approach of a signalized intersection and is sufficient to permit vehicles cruising around speed limit to stop safely before reaching the intersection stop bar. The proposed policy is that, when drivers are located upstream of the marking at the yellow onset, they are encouraged to stop at the intersection if they are cruising around speed limit. On the other hand, when drivers are located downstream the marking at the yellow onset, they are encouraged to cross the intersection if they are cruising around speed limit.

Figure 3-1: Pavement-marking design for reduce red-light running rate

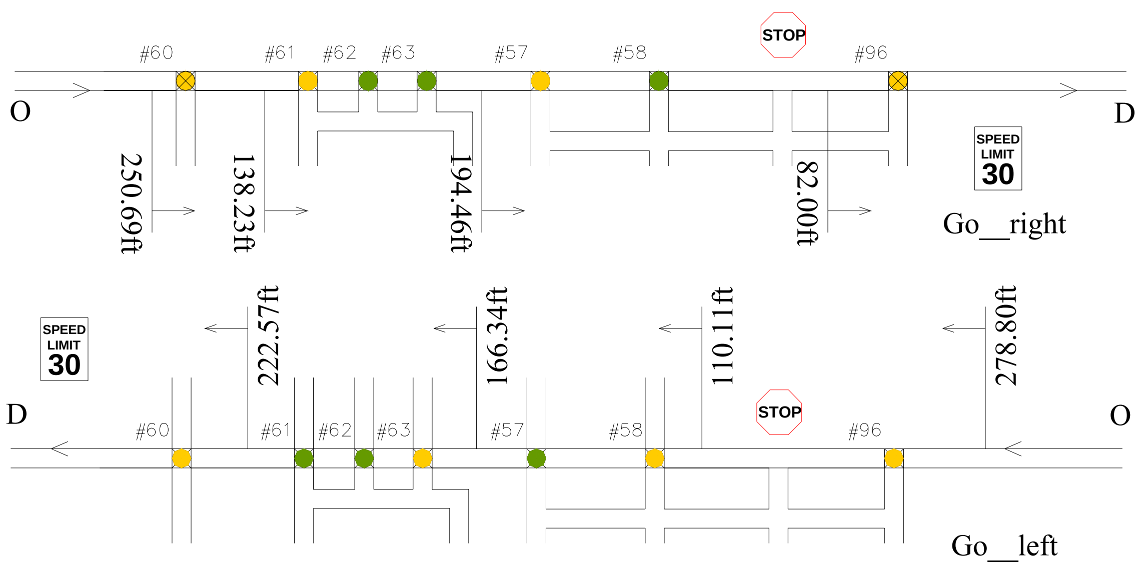
To test the effectiveness of the pavement-marking countermeasure on red-light running, this section documented an experiment study based on the UCF driving simulator. The purposes of the research are to test the theory behind pavement marking countermeasure and to find the tendency of driver behaviors during the signal changing at intersections.

3.1 Driving Simulator Experimental Design

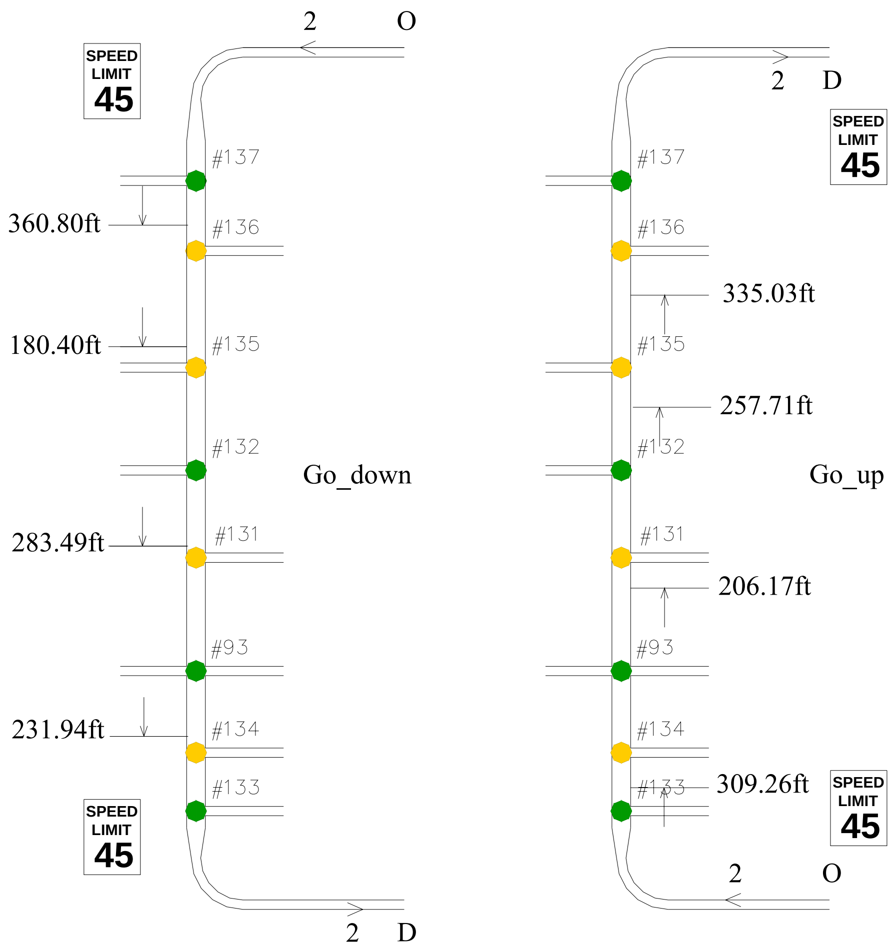
3.1.1 Experiment factors

This experiment utilized a within-subjects repeated measures factorial design to test effectiveness of the pavement-marking countermeasure on red-light running. The three treatment design factors include speed limit, pavement-markings and yellow phase onset distance. There are two levels for speed limits (30 mph and 45 mph), two levels for program types (with marking or without marking), and eight yellow phase onset distances for each speed-limit type measured from the position of the approaching vehicle when yellow phase starts to the stop bar of the intersection approach. The factorial manipulation of the three factors described above (speed, pavement-markings, and yellow onset distance) resulted in 32 unique intersection-approach types.

With the different onset distances, a total of 8 test-signalized intersections in the driving simulator's visual database were identified, as shown in Figures 3-2-a and 3-2-b. Among those, half of the intersections are along an urban street in a downtown area with 30 mph speed limit and the other 4 intersections are along a suburban arterial with 45 mph speed limit. The experimental intersections are indicated by light color in the figure. There were additional signalized intersections, intermingled with the test intersections, which display continuous green phase. These locations are displayed by dark color in the figure. The continuous green intersections are designed to keep the subject from continually expecting a signal change at every intersection.



(a) Downtown scenarios with 30 mph speed limit



(b) Suburban scenarios with 45 mph speed limit

Figure 3-2: Arrangement for test signalized intersection with different yellow onset distance

In a pilot study (Yan, et al., 2005), for the 30 mph speed limit, the eight points for yellow onset distances range from 49.2 to 278.8 ft with 32.8 m increment; for the 45 mph speed limit, the eight points range from 164 to 393.6 ft also with 32.8 ft increment. The results based on 12 subjects showed that for the 30 mph speed limit, there were no stops happened for yellow onset distances 49.2 ft and 114.8 ft. For the 45 mph speed limit, there were no stops happened at intersections with 164 ft yellow onset distances, and for the 328 ft, 360.8 ft, and 393.6 ft yellow onset distances, those stop rates were very close. The pilot experiment results suggested that for this future design, the ranges of yellow onset distance for both speed limits should shrink and the yellow onset distance for each test intersection need be adjusted correspondingly.

Therefore, in this formal experiment design, for the 30 mph speed limit, the eight points for yellow onset distances range from 82 to 278.8 ft with 28.11 ft increment; for the 45 mph speed limit, the eight points range from 180.4 to 360.8 ft with 25.77 ft increment. The yellow onset distances were identical for both program types (with and without marking) and were randomly assigned to those approaches of test-signalized intersections, as shown in Figure 3-2-a and 3-2-b.

To evaluate the effect of the proposed pavement marking, a without-with study was conducted. In the "Without" scenarios, none of the intersection approaches had the pavement marking and in the "With" scenarios all had them. Since two directions of each road can be used as two routes (see Figure 3-2), totally there are 4 routes and 8 different (without-with) scenarios to test. For each scenario, the experiment elapsed time was designed not to exceed 3 minutes.

3.1.2 Yellow change interval

In the current edition of ITE's *Traffic Engineering Handbook* (*8*), a standard equation is provided as a method to calculate the yellow change interval, *YT*, is as follows:

$$YT = t + \frac{V}{2a + 64.4g} \tag{3-1}$$

Where,

t = reaction time (1.0 s)

V = the 85th percentile speed or speed limit (ft/sec)

a = gravitational acceleration (10 ft/s^2)

g = grade of the intersection approach (g = 0, since level road is assumed).

According to the equation (3-1), the duration time of the yellow change interval calculations for 30 mph and 45 mph intersections are shown as the following:

For 30 mph speed limit: YT = 3.2 sec, round up to 3.5 sec

For 45 mph speed limit: YT = 4.3 sec, round up to 4.5 sec

3.1.3 Pavement-marking position

The marking position is related to speed limit and vehicle's deceleration rate. The distance from the marking to the intersection stop bar should be sufficient to permit vehicles to stop safely before reaching the intersection stop bar. According to the deceleration rate suggested by ITE, the distance from the marking to the stop bar is calculated by the following equation:

$$X = Vt + \frac{V^2}{2a + 64.4g} \tag{3-2}$$

Where

X = distance from the marking to the stop bar (ft)

V = the 85th percentile speed or speed limit (ft/sec)

t = reaction time (1.0 s)

a = gravitational acceleration (10 ft/s^2)

g = grade of the intersection approach (g = 0, since level road is assumed).

According to the equation (3-2), the results of the marking-stop bar distance calculations for 30 mph and 45 mph intersections are shown as the following:

For 30 mph speed limit:	X= 140.8 ft (42.9 m)
For 45 mph speed limit:	X= 283.8 ft (86.5 m)

3.1.4 Experiment procedure

Upon arrival, the subjects were given an informational briefing about the driving simulator. Subjects were specifically advised to adhere to traffic laws, and to drive as if they were in normal everyday traffic surroundings. Then, a practice course was programmed on the driving simulator. During this process, subjects exercised driving to become familiar with the basic simulator operation.

Before proceeding to the formal experiment, each subject was informed that they would be driving under simulated conditions through a course that contained both conventional intersections and experimental intersections with pavement markings. Computer demo and paper handouts were shown to help them understand the purpose of the pavement marking design.

Next, the subjects performed the red-light running experiment with the 8 scenarios, of which 4 scenarios have the pavement marking and 4 scenarios did not have pavement marking. Those with or without-marking scenarios were randomly loaded for each driver so as to eliminate the time order effect and bias from subjects to the experiment results. During the course of the experiment subjects were routinely checked for simulator sickness. Whenever sickness was found, the subject quit the experiment and the related data collected was removed. Finally, when subjects completed the formal experiments, a survey was used to gather information about their opinions of the proposed pavement marking and red-light running. Specifically, the survey investigated the red-light running reason and frequency of the potential violators in the real world, dilemma zone's hazard at signalized intersections, and subjects' attitude to the safety significance of the proposed pavement marking.

3.1.5 Subjects

As shown in Table 3-1, a total of 42 paid test subjects in two age groups, 18 younger subjects (<26 years), 24 middle-age subjects(26-55 years) were recruited and completed the experiment. According to gender, there were 24 male subjects and 18 female subjects for this research. The ratios of male to female and the younger group to the middle-age group closely represent Florida driver population distribution in Qausi-induced exposure method.

As shown in Table 3-1, the ratio of male to female not-at-fault drivers is around 59% to 41% and the ratio of the younger group to the middle-age group is around 40% to 60%.

Every participant has a full driving license with a minimum of 1-year driving experience. Most of subjects were recruited from students/faculties in the University of Central Florida. Data analysis was based on the responses and decisions made by the 42 subjects approaching 32 signalized intersections. Each subject responded to 16 test signalized intersections with marking and 16 regular signalized intersections without marking for a total of 1344 driver-intersection encounters.

Table 3-1: Age and Sex Structure of the Subject Sample

AGE	<26 YEARS	26-55 YEARS	TOTAL
Male	10	14	24 (57.1%)
Female	8	10	18 (42.9%)
Total	18 (42.9%)	24 (57.1%)	42 (100%)

3.2 Data Collection

Data logging includes experiment sampling time, vehicle positions, speeds, accelerations, information of driver's braking behavior, and records of signal phase status. Independent measurements include red-light running rate, probability to stop during yellow, deceleration rate, and reaction time after termination of green. To organize and easily process data generated from the experiments, a FORTRAN program was developed to manipulate the experiment data output files.

3.2.1 Red-light Running Rate

Red-light running rate is percentage of illegal entering intersections during red phase in the number of drivers meeting yellow phase onset. For example, if we hypothetically compare running red-light rate between scenarios with marking and without marking, one may observe the effect of the pavement marking countermeasure, as shown in Figure 3-3.

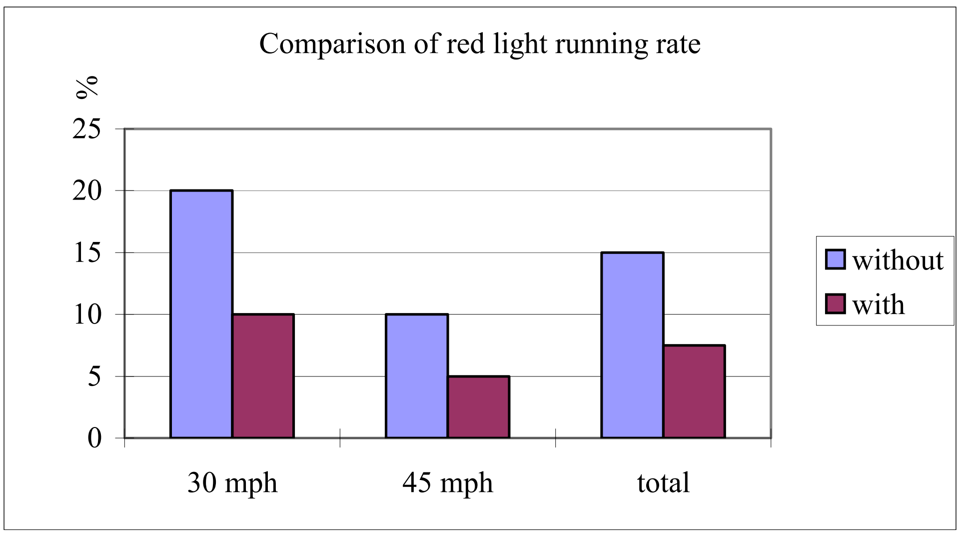


Figure 3-3: Comparison of running red-light rate between before and after study

3.2.2 Probability to stop during the yellow phase

Another important question is how the marking influences the stopping behavior at the decision point, onset of the yellow. Does it improve the ability of the drivers to make stop-go decision? Does it encourage safe stopping and reduce unsafe crossing? Probability of stopping as a function of the distance to the intersection from the onset of yellow will help to analyze the driving behavior with pavement marking program.

According to Logistic Regression method, probability of stopping as a function of the distance to the intersection from the onset of yellow can be developed. When drivers encounter yellow onset distances that are near or far from the intersection, most drivers will choose similar courses of action; either most will stop or most will cross the intersection. In these situations, a driver's behavior is highly predictable, and easily anticipated by other drivers. In contrast, yellow onset distances where 50% of the drivers choose to stop may result in situations where stopping behavior is least predictable, and the likelihood of two successive drivers being in a region where they make conflicting decisions is greatest. For this reason, the region surrounding the 50% probability of stopping has been defined as the most hazardous portion of the intersection approach. Traffic signal change intervals are designed to minimize this region of uncertainty.

In a simulation study, Newton (1997) analyzed probability of stopping as a function of the distance for two traffic signal programs, with or without Traffic Light Change Anticipation System. The results are regressed as logit curves (See Figure 3-4). The uncertainty regions between the probabilities of 0.25 and 0.75 were calculated around the point of highest uncertainty. The analysis showed that for both of 40.3 km/hr and 72.5 km/hr approach speeds, larger uncertainty regions was also found in TLCAS intersection than the regular one, which indicated that the new system increased the potential for rear-end collision between successive drivers approaching an intersection.

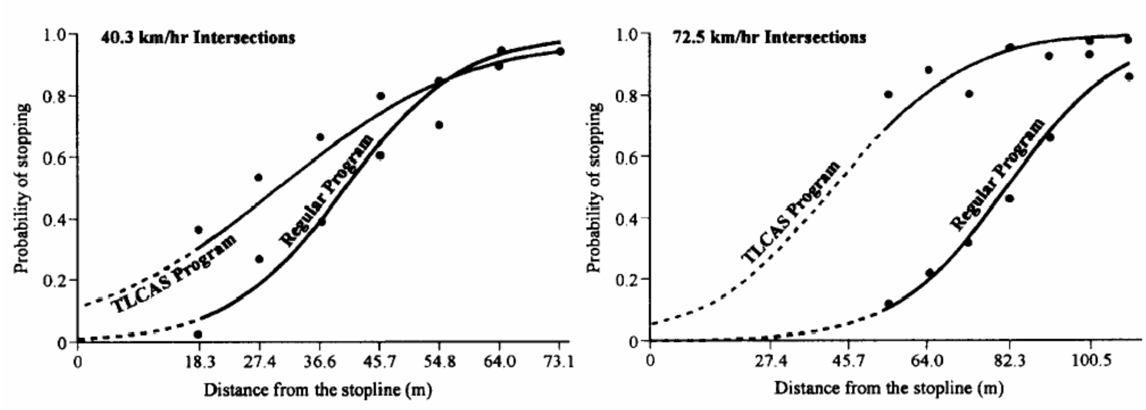


Figure 3-4: Probability of stopping as a function of the yellow onset distance

In another road study, Köll et al. (2002) tested the effect of TLCVAS through analyzing probability of stopping as a function of potential time to the intersection from the onset of yellow, which is the time to the stop line if the driver continues with unchanged speed from the first possible decision point (start of yellow), As shown in Figure 3-5, the uncertainty duration between 20% and 80% probability of stopping is about a second longer with TLCVAS program in comparison without ones.

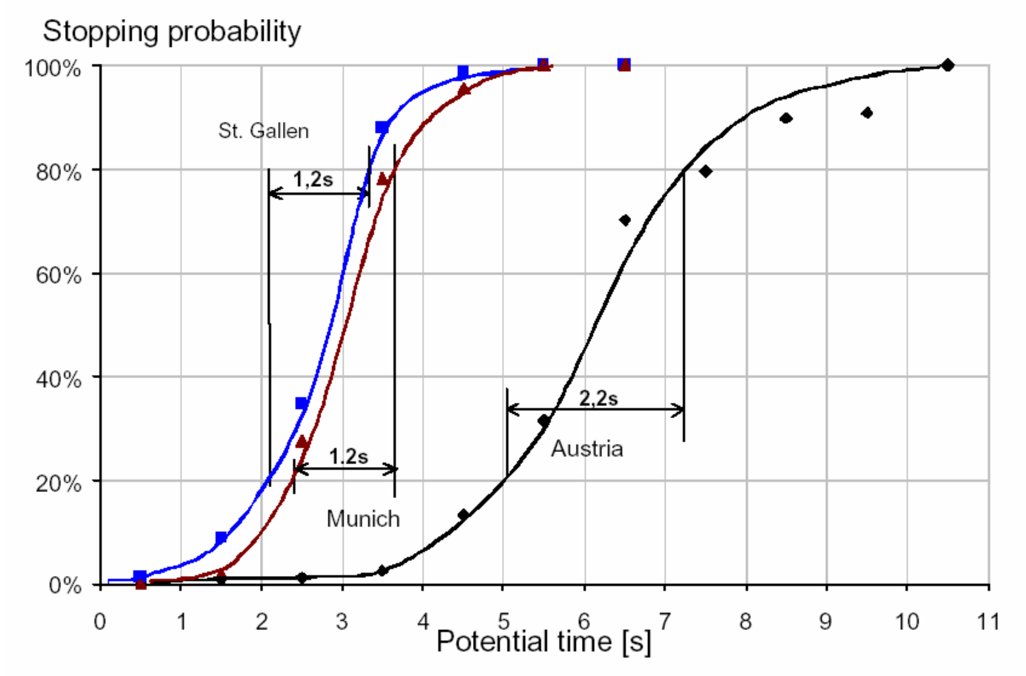


Figure 3-5: Probability of stopping as a function of potential time

For the pavement marking program, both methods of stopping probability as a function of yellow onset distance and as a function of potential time will be used to analyze the driving behavior of stop-go decisions.

3.2.3 Driver's brake response time and deceleration rate

Another measure of effectiveness is the reaction time of the driver following the yellow onset. The time following the appearance of the yellow phase until the driver steps on the brake will also be compared for significant differences in human response attributable to the new situation. The shorter reaction time takes drivers to make decisions of deceleration or acceleration, the better effectiveness of the new countermeasures.

Deceleration rate at the yellow onset will also be compared for significant differences attributable to the presence of the markings. They are measured from vehicle's position in which driver begins to step on brake after yellow onset to the stop bar of the intersection approach. Those values can be used to check if there will be some abnormal driving behaviors for the new program. For example, too large deceleration can contribute to rear-end collisions.

3.2.4 Dilemma zone analysis

Considering the approaching speed (*V*) of vehicles, the maximum distance (X_c) to safely cross the intersection is calculated by Equation 3-3:

$$X_c = V * YT = V(t_R + \frac{V_{SL}}{2a}) \qquad (3\text{-}3)$$

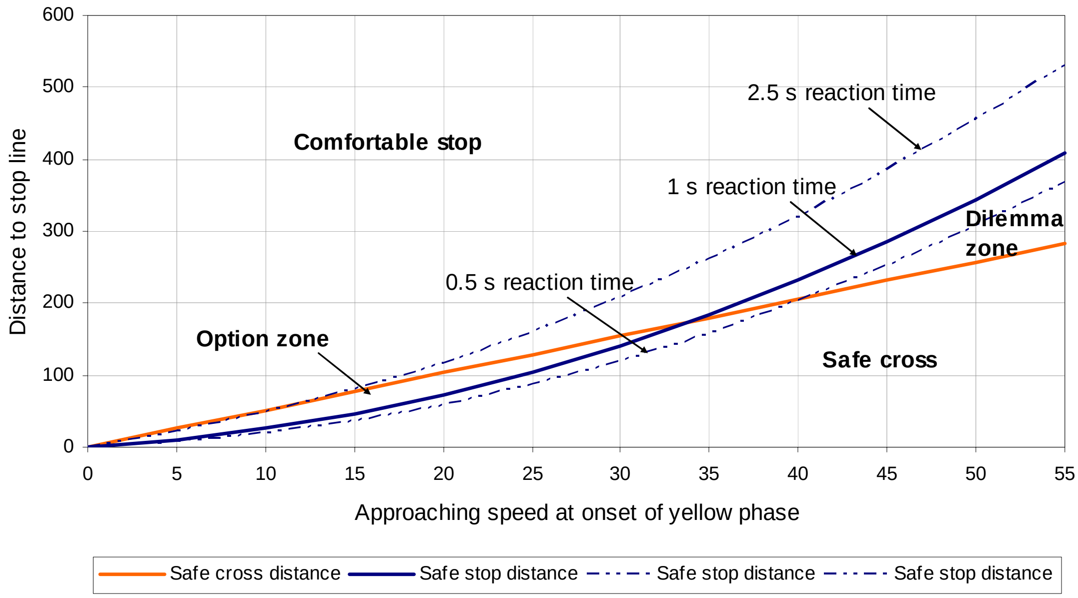
The minimum distance (X_S) to safely stop at the intersection is calculated by Equation 3-4:

$$X_S = V(t_R + \frac{V}{2a}) \qquad (3\text{-}4)$$

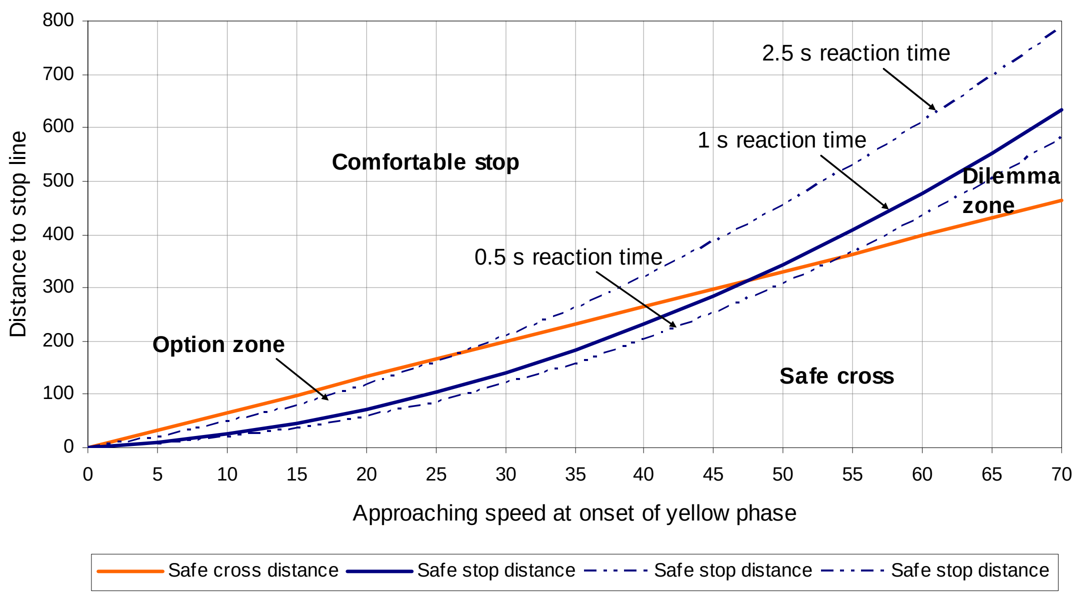
When a motorist is approaching to the intersection at the onset of yellow change interval, they must decide whether to stop or cross the intersection. Figures 3-6-a and 3-6-b illustrates the tendency of driver stop/go decision at onset of the yellow at signalized intersections with 30 mph and 45 mph speed limits. The decision to stop is easy to make when the approach distance to the intersection is larger than X_S at the onset of yellow change. Similarly, most of drivers tend to continue to travel through the intersection when the approach distance to the intersection is less that X_c. However, a vehicle can possibly execute neither crossing nor stopping maneuvers safely and comfortably if it happens to be located within the dilemma zone if the approach distance is larger than X_S but less that X_c. There is also a possible option area as shown in the figures where the driver can either stop or cross the intersection safely. The length of the dilemma zone is dynamic and increases with the increment of approaching speeds, which can be calculated by Equation 3-5. So, the speeding drivers are most likely involved in the dilemma zone problem.

$$X_s - X_c = V(t_R - YT + \frac{V}{2a}) \qquad (3\text{-}5)$$

Moreover, the length of the dilemma zone can also increase as the driver reaction time increase. As shown in Figure 3-6-a for the 30 mph speed limit, a vehicle with 15 mph approaching speed and around 80 ft from the intersection may fall within a dilemma zone if the driver reaction time is 2.5 seconds. For the 45 mph speed limit in Figure 3-6-b, the dilemma zone can happen at 200 ft to the intersection for the drivers with 2.5 seconds reaction time. However, based on the ITE standard in Equation, the designed perception-reaction time to the signal change is generally 1 sec. A driver’s reaction time may personally be larger than the design value, which could be affected by a number of factors, including driver age and gender, driver experience, the distance to intersections, speed limits, and other factors.



a) Dilemma zone analysis for 30 mph speed limit



b) Dilemma zone analysis for 45 mph speed limit

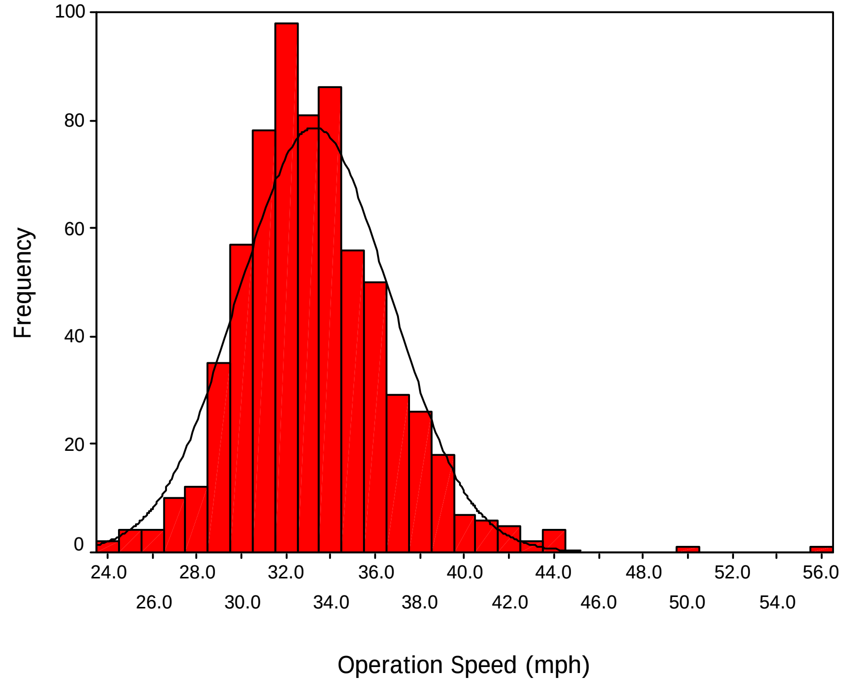
Figure 3-6: Driver stop/go decision at onset of the yellow at signalized intersections (Source: A conference paper of Köll et al. (2002))

Dilemma zone analyses of comparison between with marking and without may help find the effect of the pavement marking countermeasure.

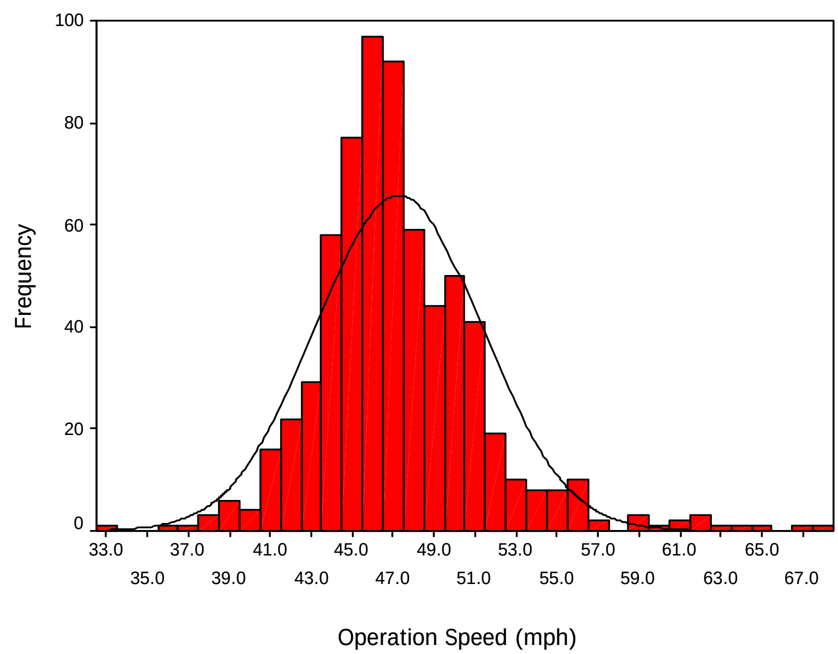
3.3 Experiment Results and Data Analyses

3.3.1 Operation speed

Operation speed is measured at each intersection at termination of the green phase. For the 30 mph speed limit, the mean of the speed was 33.26 mph; for the 45 mph speed limit, the mean of the average speed was 47.26 mph; and the histograms of the operation speed appear very close to normal distributions for both speed limits as shown in Figure 3-7. In the simulation environment, average operation speeds of drivers tend to be slightly higher than the speed limit, presumably because the simulator vehicle is always the leading vehicle in the traffic stream and the drivers were more likely to drive at free-flow speeds. Moreover, between scenarios without marking and with marking, there is no significant difference found in the operation speeds. For the 30 mph speed limit, the means of the speed without marking and with marking were 33.38 mph and 33.14 mph; for 45 mph speed limit, the means of the speed without marking and with marking were 47.47 mph and 47.05 mph (see Table 3-2). Therefore, the proposed marking design didn't have a significant effect on the speed.



(a) For the 30mph speed limit



(b) For the 45mph speed limit

Figure 3-7: Distribution of operation speed

Table 3-2: Descriptive Statistics of Operation Speed

Speed Limit	Scenario	Mean	N	Std. Deviation	Minimum	Maximu m
30 mph	Without	33.3776	336	3.5269	23.85	55.68
	With	33.1431	336	3.2774	23.98	49.53
	Total	33.2603	672	3.4039	23.85	55.68
45 mph	Without	47.4796	336	4.4003	32.76	67.87
	With	47.0461	336	3.7099	35.96	61.98
	Total	47.2628	672	4.0725	32.76	67.87

3.3.2 Red-light running rate and time

Comparison of red-light running rates between scenarios with marking and without can directly reflect the effect of the pavement marking countermeasure. As shown in Table 3-3 and Figure 3-8, red-light running rate without marking information is apparently higher than that with. For 30 mph speed limit without marking, there were 15 red-light running events representing red-light running rate of 4.5 percent; for 45 mph speed limit without marking, there were 11 red-light running events representing a rate of 3.3 percent. However, with the help of marking, there were only 4 red-light running events representing a rate of 1.2 percent for 30 mph speed limit; for 45 mph speed limit with marking, there were 5 red-light running events representing a rate of 1.5 percent. Potentially, the pavement marking could results in a 74.3 percent reduction in red-light running. Chi-square test showed that the p-value is 0.005 and the reduction in red-light running rate with the marking is statistically significant based on the 0.05 significance level.

Another important measurement for a red-light runner is the travel time to the intersection after the yellow light expires. The longer the travel time is in the upstream of the intersection at the onset of the red phase, the more likely an angle crash happens. As shown in Figure 3-9, without marking, there are 4 red-light running events of which the travel time during the red phase is lager than 1 sec and that represent 15.4 percent red-light running behaviors; with marking, all of red light entries occur in the first second after the yellow light expires. The analysis shows that the pavement marking may reduce the red light running time and the probability of angle crashes. However, since the sample size of red-light running observations is very small, one can not draw a significant conclusion from such a few data.

Table 3-3: Number of Red-light Running Violations and Red-light Running Rate Without Marking and With Marking

Speed limit	Marking	Red-light running			
			No	Yes	Total
30mph	Without	Count	321	15	336
		% of Total	95.5%	4.5%	100.0%
	With	Count	332	4	336
		% of Total	98.8%	1.2%	100.0%
	Total	Count	653	19	672
		% of Total	97.2%	2.8%	100.0%
45mph	Without	Count	325	11	336
		% of Total	96.7%	3.3%	100.0%
	With	Count	331	5	336
		% of Total	98.5%	1.5%	100.0%
	Total	Count	656	16	672
		% of Total	97.6%	2.4%	100.0%
Total	Without	Count	646	26	672
		% of Total	96.1%	3.9%	100.0%
	With	Count	663	9	672
		% of Total	98.7%	1.3%	100.0%
	Total	Count	1309	35	1344
		% of Total	97.4%	2.6%	100.0%

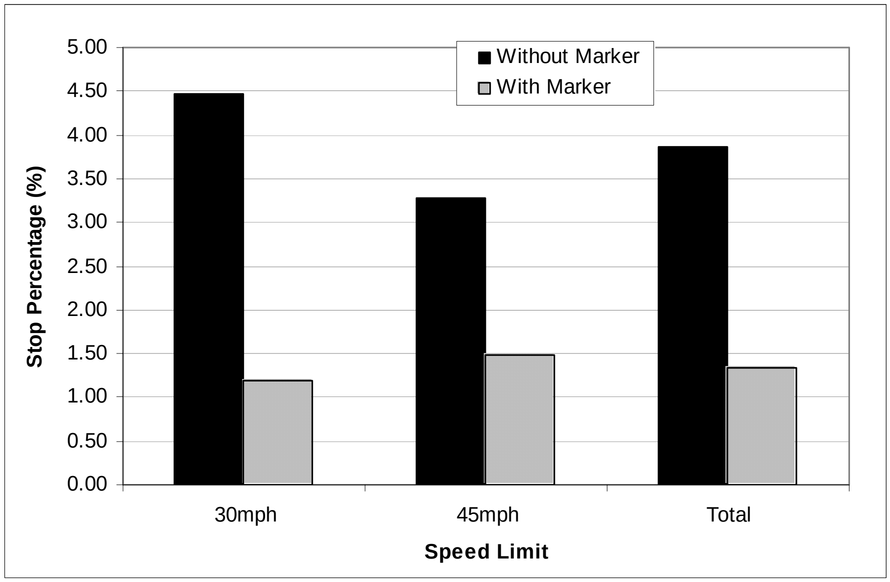
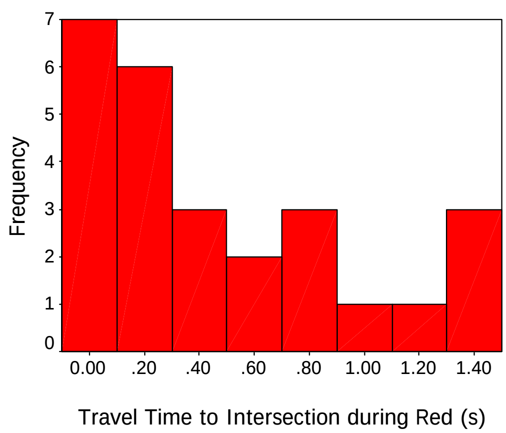
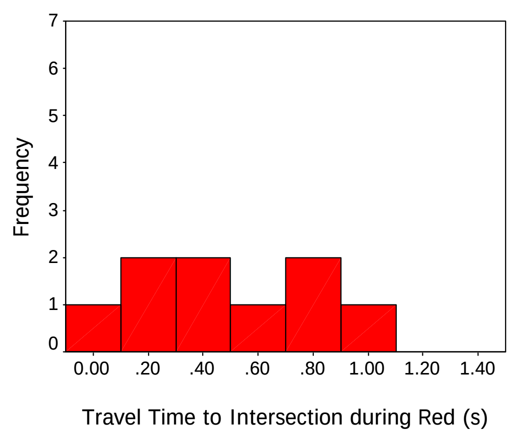


Figure 3-8: Red-light running rate comparison between with marking and without



(a) Without marking



(a) With marking

Figure 3-9: Travel time to the intersection after the yellow light expires

3.3.3 Dilemma zone analyses

Table 3-4 shows the proportions of stopping and crossing decisions at intersections with markings and without markings by drivers during the simulator experiment. The situation that drivers were located in a stop zone, cross zone, optional zone, or dilemma zone are based upon a kinematics analysis using driver velocity and distance values at the onset of the yellow phase (See Section 3.2.4). In comparison, the pavement marking reduced the number of occurrences where drivers chose to continue through an intersection when it was not safe to proceed (4.36%) compared to the without marking (10.6%). This reduction in unsafe crossings appears to be due to the marking information as drivers were located upstream of the marking. Chi-square test showed that the p-value is 0.008 and the reduction in unsafe crossings with the marking is statistically significant based on the 0.05 significance level.

Table 3-4: Dilemma Zone Analysis

		Situation that drivers are encountering				
		Stop	Cross	Optional	Dilemma	Total
Without Marking	Cross	30	271	4	5	310
		10.6%	75.7%	57.1%	20.8%	46.1%
	Stop	253	87	3	19	362
		89.4%	24.3%	42.9%	79.2%	53.9%
	Total	283	358	7	24	672
		100.0%	100.0%	100.0%	100.0%	100.0%
With Marking	Cross	12	276	6	2	296
		4.3%	79.8%	35.3%	7.4%	44.0%
	Stop	270	70	11	25	376
		95.7%	20.2%	64.7%	92.6%	56.0%
	Total	282	346	17	27	672
		100.0%	100.0%	100.0%	100.0%	100.0%

In the other hand, the pavement marking reduced the number of occurrences where drivers chose to stop at an intersection when it was not safe to stop (20.2%) compared to the without marking (24.3%). This reduction in unsafe stops appears to be due to the marking information as drivers were located downstream of the marking. However, the Chi-square test showed that the p-value is 0.301 so that the reduction in unsafe stops with the marking is not significant. Further, situations in which a driver could not safely stop or safely cross an intersection were defined as dilemma situations and situations in which the driver could either safely choose to stop or choose to cross the intersection were defined as option situations. It appears that when they are located in option zones, drivers are more likely stop at intersections with markings (64.7% Vs 42.9%) but the tendency is not statistically significant (P=0.601); when they are located in dilemma zones, the drivers are more likely stop at intersections with marking (92.6% Vs 79.2%) but the difference is not statistically significant (P=0.226).

3.3.4 Driver’s stop/go decision based on yellow onset distances

Driver’s stop/go decision is the most essential behavior at signalized intersection because wrong stop/go judgments are directly related to traffic crashes happening such as red-light running or rear-end crashes. From the experiment results, generally, as the yellow onset distances increase, the cross rate decreases and the stop rate increases. Tables 3-5 and 3-6 show the comparisons of stop rates between with marking and without for different yellow onset distances at the 30 mph and 45 mph speed limits.

Table 3-5: Drivers' Stop/cross Decision According to Yellow Onset Distance for 30 mph

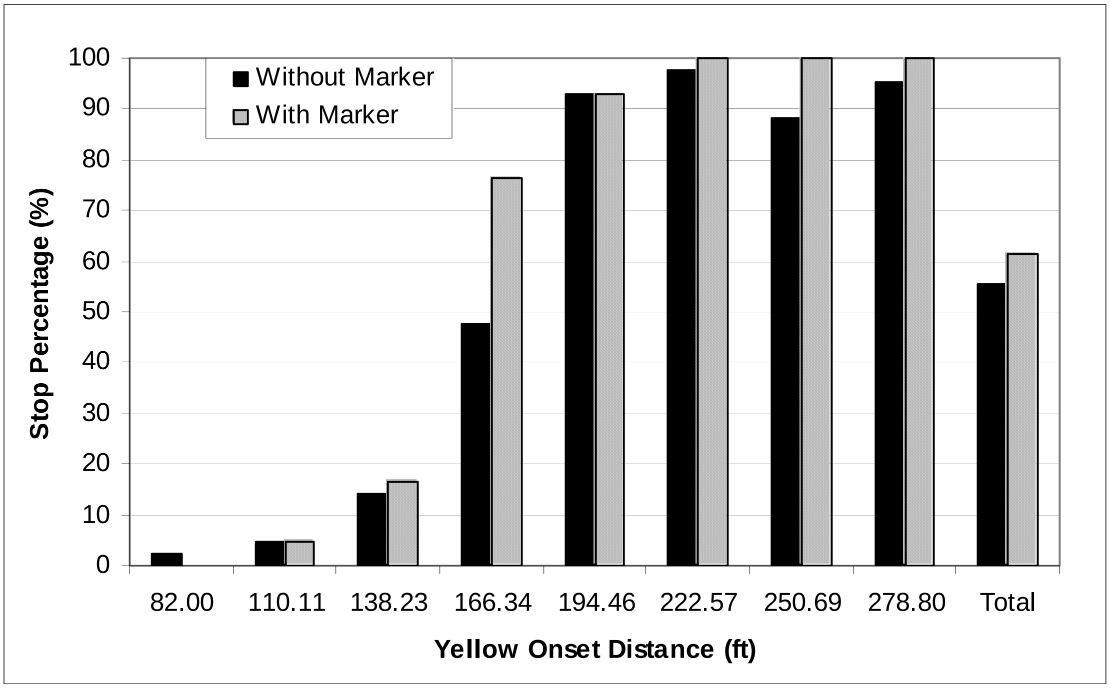
A. Without Pavement Marker Study										
Yellow Onset Distance		82.00	110.11	138.23	166.34	194.46	222.57	250.69	278.80	Total
Cross	Count	41	40	36	22	3	1	5	2	150
	% within Distance	97.6%	95.2%	85.7%	52.4%	7.1%	2.4%	11.9%	4.8%	44.6%
Stop	Count	1	2	6	20	39	41	37	40	186
	% within Distance	2.4%	4.8%	14.3%	47.6%	92.9%	97.6%	88.1%	95.2%	55.4%
Total	Count	42	42	42	42	42	42	42	42	336
B. With Pavement Marker Study										
Yellow Onset Distance		82.00	110.11	138.23	166.34	194.46	222.57	250.69	278.80	Total
Cross	Count	42	40	35	10	3				130
	% within Distance	100.0%	95.2%	83.3%	23.8%	7.1%				38.7%
Stop	Count		2	7	32	39	42	42	42	206
	% within Distance		4.8%	16.7%	76.2%	92.9%	100.0%	100.0%	100.0%	61.3%
Total	Count	42	42	42	42	42	42	42	42	336

Table 3-6: Drivers' Stop/cross Decision According to Yellow Onset Distance for 45 mph

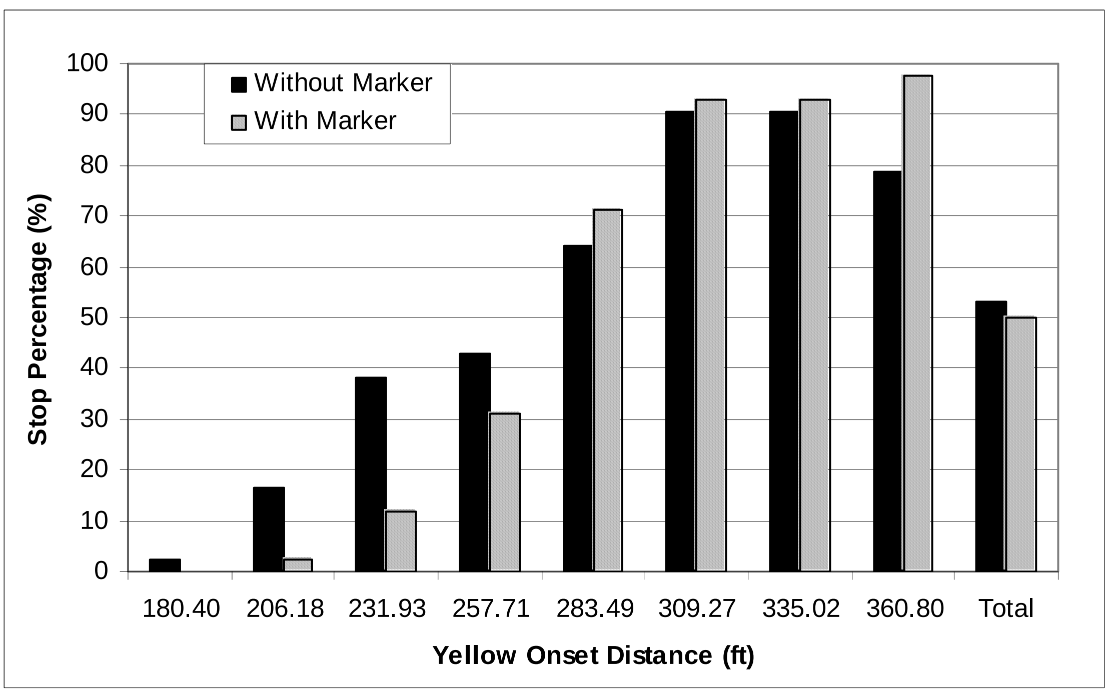
A. Without Pavement Marker Study										
Yellow Onset Distance		180.40	206.18	231.93	257.71	283.49	309.27	335.02	360.80	Total
Cross	Count	41	35	26	24	15	4	4	9	158
	% within Distance	97.6%	83.3%	61.9%	57.1%	35.7%	9.5%	9.5%	21.4%	47.0%
Stop	Count	1	7	16	18	27	38	38	33	178
	% within Distance	2.4%	16.7%	38.1%	42.9%	64.3%	90.5%	90.5%	78.6%	53.0%
Total	Count	42	42	42	42	42	42	42	42	336
B. With Pavement Marker Study										
Yellow Onset Distance		180.40	206.18	231.93	257.71	283.49	309.27	335.02	360.80	Total
Cross	Count	42	41	37	29	12	3	3	1	168
	% within Distance	100.0%	97.6%	88.1%	69.0%	28.6%	7.1%	7.1%	2.4%	50.0%
Stop	Count		1	5	13	30	39	39	41	168
	% within Distance		2.4%	11.9%	31.0%	71.4%	92.9%	92.9%	97.6%	50.0%
Total	Count	42	42	42	42	42	42	42	42	336

For the 30 mph speed limit, most of stop rates with marking at eight yellow onset distances except the 82, 110.11, and 194.46 feet ones were found to be higher than those without, as shown in Figure 3-10-a. Without marking, there were 44.6% crosses and 55.4% stops; with marking, there were 38.7% crosses and 61.3% stops and no stop happened at the 82 ft yellow onset distance. On the whole, drivers tend to stop at the larger onset distances with the marking compared to the without.

Totally, for the 45 mph without marking, there were 47% crosses and 53% stops; for that with marking, there were 50% crosses and 50% stops. As shown in Figure 3-10-b, there are significant differences in the stop-go decision between with markings and without at different yellow onset distances. If the distances are smaller than 270 ft, the stop rates without marking are higher than those with marking; and if the distances are larger than 270 ft, the stop rates without marking are lower than those with marking. Generally, if drivers decide to stop when they are close to the intersection at the onset of yellow phase, it is more likely to be involved in rear-end crashes since the deceleration distance tends to be insufficient. On the other hand, if drivers decide to cross the intersection when they are far from the intersection at the onset of yellow phase, it is more likely to be involved in angle crashes since they have a higher chance of red-light running. It appears that with the help of marking information, drivers tend to get better stop/go decision: stop at farther distance and cross at shorter distances.



(a) 30 mph speed limit



(b) 45 mph speed limit

Figure 3-10: Stop rate without-with comparison according to yellow onset distances

3.3.5 Stopping probability analysis based on logistic regression method

In this step, to more accurately analyze drivers' behavior at intersections, two logistic regression models for the 30mph speed limit and the 45mph speed limit are developed to predict drivers' probability based on more independent parameters related to the driver's stop-go decision.

Logistic regression is proper to be used in this study because the stop/go decision at intersections can be described as a typical dichotomy dependent variable, Y=1 when the driver stopped and Y=0 when the driver crossed the intersection. Logistic regression can be applied to predict a dependent variable on the basis of independence; to rank the relative importance of the independent variables; to assess interaction effects; and to understand the impact of covariate control variables. Logistic regression applies maximum likelihood estimation after transforming the dependent into a logit variable (the natural log of the dependent variable). In this way, logistic regression estimates the probability of a certain event occurring.

The probability that a driver will stop or not is modeled as logistic distribution in Equation 3-6:

$$\pi(x) = \frac{e^{g(x)}}{1 + e^{g(x)}} \tag{3-6}$$

The Logit of the multiple logistic regression model (Link Function) is given by Equation 3-7:

$$g(x) = \ln\left[\frac{\pi(x)}{1-\pi(x)}\right] = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \ldots + \beta_n x_n \quad (3\text{-}7)$$

where, $\pi(x)$ is conditional probability of a red-light running crash, which is equal to the number of stops divided by the total number of stop/go observations. x_n are independent variables which can be either categorical or continuous. Both main effects and interactions can generally be accommodated. β_n are model coefficients, which directly determines odds ratio that drivers stop at intersections.

Five independent variables (Age, Gender, Marking, Distance, and Speed) were chosen as potential factors that might be associated with the stop probability at intersections and they are described in the Table 3-7.

Table 3-7: Variable Description

Variable	**Variable Description**	**Variable Coding**
Age	Subject age	0=younger drivers 1=middle-age drivers
Gender	Subject gender	0=Male 1=Female
Marking	If there is a Pavement Marking or not	0=Without marking 1=With marking
Distance	Yellow onset distance to the intersection	Continuous (feet)
Speed	Approaching speed at onset of the yellow	Continuous (mph)

Screening all 5 given variables, Table 3-8 lists the logistic regression results of main effect models for the 30 mph and 45 mph speed limits respectively. For the 30 mph speed limit, the significant independent variables include Distance, Speed, and Marking, but the Age and Gender are not significant; for the 45 mph speed limit, only Distance and Speed are significant variables.

Table 3-8: Summary of Main Effect Logistic Regression Models

(a) Main effect model for the 30 mph speed limit					
Parameter	DF	Coefficient	Standard Error	Wald Chi-Square	Pr> ChiSq
Intercept	1	-1.3176	1.6027	0.6758	0.411
Speed	1	-0.2612	0.0511	26.1688	<.0001
Distance	1	0.1933	0.0158	150.5307	<.0001
Marking	1	0.8456	0.291	8.4442	0.0037
(b) Main effect model for the 45 mph speed limit					
Parameter	DF	Coefficient	Standard Error	Wald Chi-Square	Pr> ChiSq
Intercept	1	-5.1295	1.3936	13.5485	0.0002
Speed	1	-0.096	0.0287	11.2006	0.0008
Distance	1	0.1183	0.00845	195.9297	<.0001

Based on above variables, hypothesis test with a 0.05 significance level is used to decide on the significant factors for the final models. As shown in Table 3-9, all those parameters' P-values are less than 0.05 and there is an interaction effect found between Distance and Marking for both speed limits. The model equations are shown as following:

- For the 30 mph speed limit

$$g(x) = 0.8199 - 0.2766 \times \text{Speed} + 0.1618 \times \text{Distance} - 3.9918 \times \text{Marking} + 0.0992 \times \text{Distance} * \text{Marking}$$

- For the 45 mph speed limit

$$g(x) = \text{-}2.8981 - 0.0915 \times \text{Speed} + 0.0899 \times \text{Distance} - 7.2509 \times \text{Marking} + 0.0851 \times \text{Distance} * \text{Marking}$$

Table 3-9: Summary of Final Logistic Regression Models

(a) Final model for the 30 mph speed limit					
Parameter	DF	Coefficient	Standard Error	Wald Chi-Square	Pr> ChiSq
Intercept	1	0.8199	1.7162	0.2282	0.6328
Speed	1	-0.2766	0.0526	27.6343	<.0001
Distance	1	0.1618	0.0168	92.2608	<.0001
Marking	1	-3.9918	1.7334	5.3031	0.0213
Distance* Marking	1	0.0992	0.0354	7.8394	0.0051
(b) Final model for the 45 mph speed limit					
Parameter	DF	Coefficient	Standard Error	Wald Chi-Square	Pr> ChiSq
Intercept	1	-2.8981	1.4076	4.239	0.0395
Speed	1	-0.0915	0.0282	10.5208	0.0012
Distance	1	0.0899	0.00947	90.0191	<.0001
Marking	1	-7.2509	1.7086	18.0092	<.0001
Distance* Marking	1	0.0851	0.0206	17.0743	<.0001

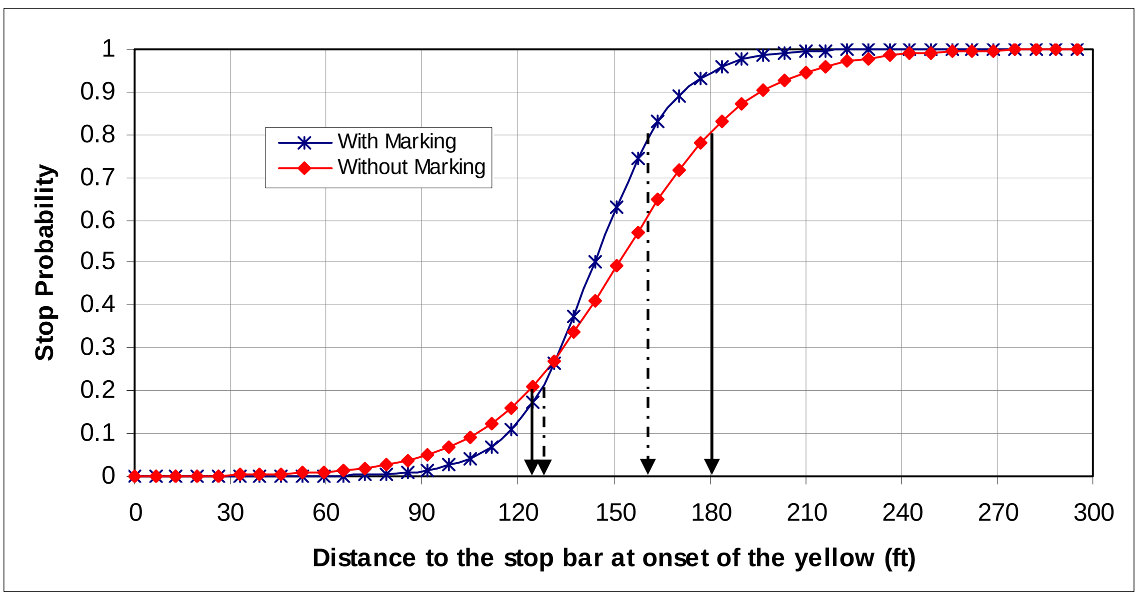
According to the final models, not only yellow onset distances are significantly related to drivers' stopping probability at intersections, but also the approaching speed is the other important factor that influences driver's stop-go decision. The larger approaching speeds are, the less possibly drivers stop. For the 30 mph, the odds ratio estimator for Speed is Exp. (-2.766) =0.758 and its interval under the 95% confidence is [0.684, 0.841]; without considering other factors, drivers with the larger approaching speed might be 24.2% less likely to stop at the intersection compared to those with the speed that is 1 mph smaller. For the 45 mph, the odds ratio estimator for Speed is Exp. (-0.0915) =0.913 and its interval under the 95% confidence is [0.863, 0.964]; without considering other factors, drivers with the larger approaching speed might be 13.7% less likely to stop at the intersection compared to those with the speed that is 1 mph smaller.

For the final models with Distance* Marking interaction variable, the Marking effect on the driver stop decision is correlated to the yellow onset distance. The odds ratio estimators for the intersection with a marking could be Exp. (-3.9918+0.0992*Distance) for the 30 mph and Exp. (-7.2509+0.0851*Distance) for the 45 mph times compared to that without adjusting other factors. The distance is positively related to the odds ratio estimators for the marking, as shown in Table 3-10. For the 30 mph, if the distances are shorter than 130 ft, drivers tend to cross the intersection with the marking; for the distances larger than 130 ft meters, drivers tend to stop at the intersection with the marking. For the 45 mph, if the distances are shorter than 280 ft, drivers tend to cross the intersection with the marking; for the distances larger than 280 ft, drivers tend to stop at the intersection with the marking.

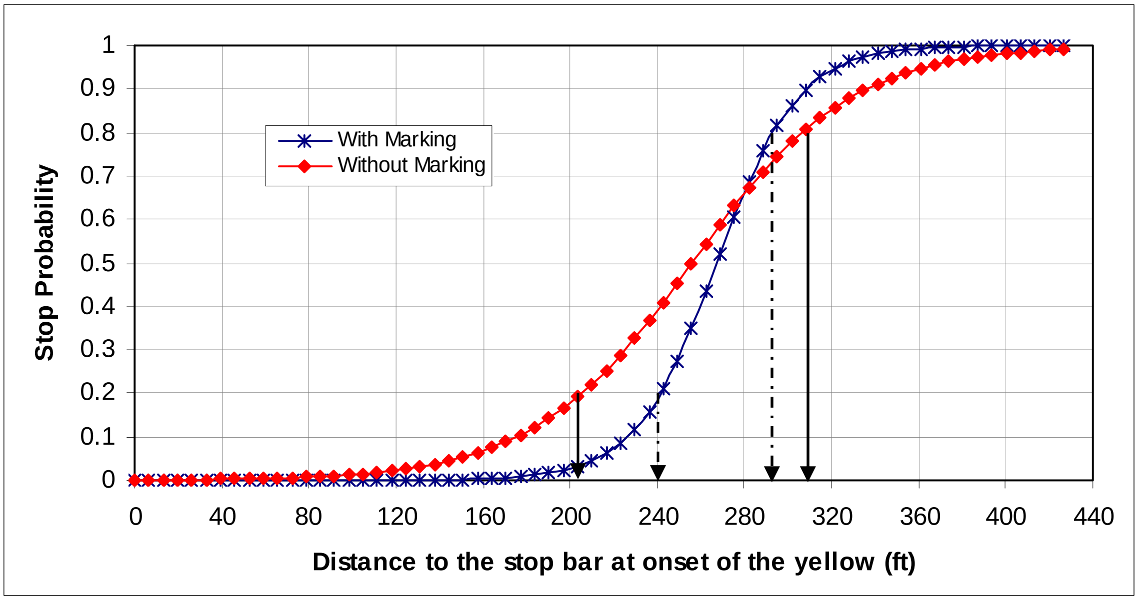
Table 3-10: Interaction Effect of Yellow Onset Distance on the Marking

(a) For the 30 mph speed limit			**(a) For the 45 mph speed limit**		
Distance (ft)	Coefficient of Marking	Odds ratio estimator for Marking	Distance (ft)	Coefficient of Marking	Odds ratio estimator for Marking
82.00	-1.512	0.221	180.40	-2.570	0.077
110.11	-0.662	0.516	206.17	-1.902	0.149
138.23	0.189	1.208	231.94	-1.233	0.291
166.34	1.039	2.827	257.71	-0.564	0.569
194.46	1.889	6.615	283.49	0.104	1.110
222.57	2.740	15.481	309.26	0.773	2.166
250.69	3.590	36.231	335.03	1.441	4.227
278.80	4.440	84.792	360.80	2.110	8.249

According to the previous study, the region surrounding the 50% probability of stopping has been defined as the most hazardous portion of the intersection approach. The results showed that the uncertainty distances between 20% and 80% probability of stopping are about 23 ft for the 30 mph (56 ft Vs 33 ft) and 50 ft for the 45 mph (102 ft Vs 52 ft) shorter with markings compared to without ones as shown in Figure 3-11. The analysis indicates that the marking information can help to reduce driver hesitated region to decide to stop or cross the intersection, which possibly results in higher accident rates.



(a) For the 30 mph speed limit and assuming that approaching-vehicle speed is 30 mph



(b) For the 45 mph speed limit and assuming that approaching-vehicle speed is 45 mph

Figure 3-11: Probability of stop based on the logistic regression models.

3.3.6 Brake response time

The time following the appearance of the yellow phase until the driver steps on the brake is measured as brake response time. Four independent variables (Age, Gender, Marking, and Distance) were chosen as potential factors that might have an effect on driver brake response time and the basic descriptive results are described in the Table 3-11.

Table 3-11: Descriptive Statistical Results of Brake Response Time for Age, Gender, Marking, and Distance

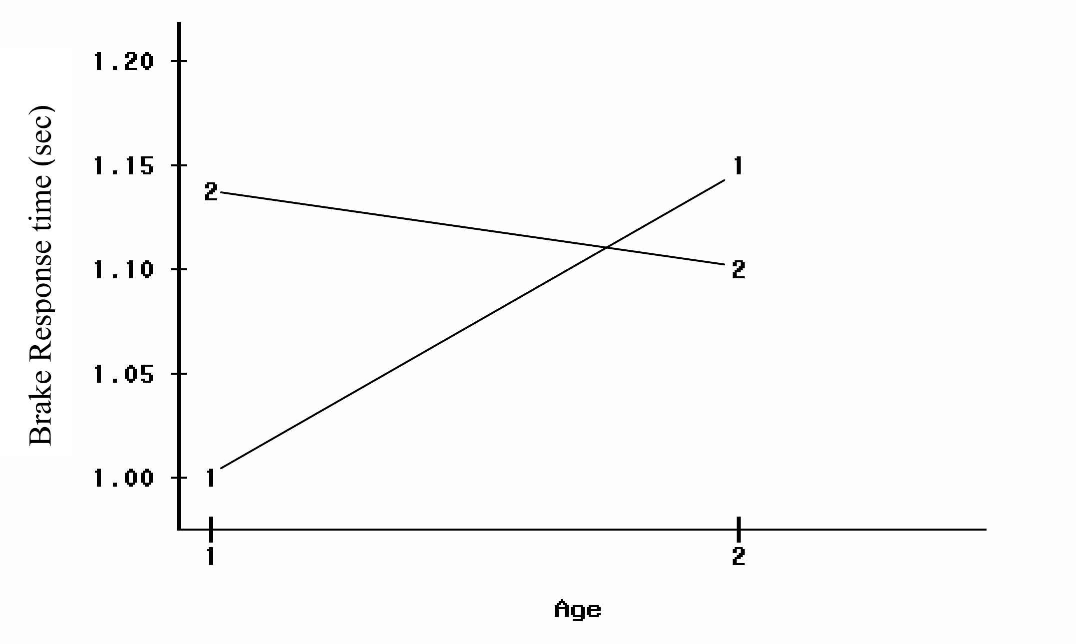
(a) For the 30 mph speed limit								
Variable		N	Mean	Std. D	95% C.I.		Min	Max
Age	Younger	169	1.0609	.3723	1.0044	1.1175	.20	2.40
	Middle	217	1.1330	.4003	1.0794	1.1865	.35	2.72
Gender	Male	221	1.0902	.4006	1.0371	1.1433	.20	2.72
	Female	165	1.1164	.3747	1.0589	1.1740	.23	2.40
Marking	Without	180	1.1148	.3984	1.0562	1.1734	.20	2.72
	With	206	1.0897	.3820	1.0373	1.1422	.23	2.40
Distance	82.00	1	.6830	--	--	--	.68	.68
	110.11	4	.8125	.4025	.1720	1.4530	.38	1.35
	138.23	13	.9025	.1807	.7933	1.0117	.52	1.22
	166.34	52	.9305	.2258	.8676	.9933	.32	1.62
	194.46	78	1.0254	.2880	.9605	1.0903	.45	1.77
	222.57	82	1.0547	.3165	.9851	1.1242	.20	2.15
	250.69	79	1.1192	.3875	1.0324	1.2060	.52	2.72
	278.80	77	1.3794	.5072	1.2643	1.4946	.23	2.55
(b) For the 45 mph speed limit								
Variable		N	Mean	Std. D	95% C.I.		Min	Max
Age	Younger	154	.9911	.2949	.9442	1.0381	.45	2.55
	Middle	186	1.0652	.3352	1.0167	1.1136	.23	2.62
Gender	Male	193	1.0228	.3253	.9766	1.0690	.28	2.62
	Female	147	1.0432	.3119	.9924	1.0941	.23	2.28
Marking	Without	174	1.0216	.3298	.9723	1.0710	.23	2.55
	With	166	1.0421	.3085	.9948	1.0894	.50	2.62
Distance	180.40	1	.9000	--	--	--	.90	.90
	206.17	8	.8125	.2231	.6260	.9990	.53	1.28
	231.94	21	.9643	.3446	.8074	1.1212	.28	1.68
	257.71	30	.9139	.2188	.8322	.9956	.57	1.52
	283.49	57	1.0261	.2583	.9576	1.0946	.50	2.05
	309.26	75	1.0831	.3699	.9980	1.1682	.45	2.55
	335.03	75	1.0067	.2951	.9388	1.0746	.23	2.08
	360.80	73	1.1022	.3461	1.0215	1.1830	.43	2.62

A four-factor analysis of variance (ANOVA) for each speed limit type was conducted using the general linear model procedure (GLM) of the SAS software to determine the statistical significance of these trends. For the 30 mph speed limit, the ANOVA model was significant ($P < 0.0001$) at the 0.05 level. Table 3-12 lists the ANOVA variance analysis for independent variables from SAS, which shows that distance and two-way interaction between age and gender are significant factors but marking is not under the 95% confidence level.

Table 3-12: ANOVA Variance Analysis of Brake Response Time for the 30 mph

SOURCE	DF	TYPE III SS	MEAN SQUARE	F VALUE	PR>F
Gender	1	0.258735	0.258735	2.04	0.1539
Age	1	0.413003	0.413003	3.26	0.0719
Distance	7	9.468899	1.3527	10.67	<.0001
Gender*Age	1	0.958521	0.958521	7.56	0.0063

A Scheffe test for multiple comparisons on the distance factor showed that the response time for the 278.8 ft is significantly larger than those for other distances except for the 82 ft and 110.11 ft. Although there is no significant difference between the other distances, there is an obvious tendency that the response time for farther distances is larger than those for shorter ones. This tendency does make sense because drivers at larger yellow onset distance have more space and time to decide to stop or to cross the intersection. A Scheffe test on the age factor showed that the response time for the middle group is 0.072 second significantly larger than the younger group. However, the age effect is confounded by the gender. As shown in Figure 3-12, for the younger group, the response time for male drivers is less than female; for the middle group, the response time for male drivers is larger than female.



Symbol is value of Gender: 1=male and 2=female

Figure 3-12: Plot of interaction between age and gender

For the 45 mph speed limit, the ANOVA model was significant (P = 0.0104) at the 0.05 level. Table 3-13 lists the ANOVA variance analysis for significant independent variables from SAS, which shows that distance and age are significant factors but gender, marking and any two-way interactions are not under the 95% confidence level. A Scheffe test on the age factor showed that the response time for the middle group is 0.074 second significantly larger than the younger group. A Scheffe test for multiple comparisons on the distance factor did not show any significant difference in the response time among those eight levels of yellow onset distance. However, the ANOVA analysis confirmed the trend that that the response time increases as the yellow onset distances increase.

Moreover, since the result comparisons between with marking and without are not significantly different for both speed limits, the marking did not have an effect on the human factor related to driver response time.

Table 3-13: ANOVA Variance Analysis of Brake Response Time for the 45 mph

SOURCE	DF	TYPE III SS	MEAN SQUARE	F VALUE	PR>F
Age	1	0.483524	0.483524	4.92	0.0273
Distance	7	1.545209	0.220744	2.24	0.0305

3.3.7 Brake deceleration rate

Deceleration rates of the stopping vehicles after the yellow onset were compared between the with-experiment and without-experiments in an attempt to explore a significant change in the drivers' behavior attributable to the presence of the markings. The deceleration rate was measured for speeds ranging from the speed of the vehicle following the appearance of the yellow phase to a speed of 5 mph. Zero mph was not used because few drivers maintained a crawling speed until they reached the stop bar, which would bias the experiment results. Four independent variables (Age, Gender, Marking, and Distance) were chosen as potential factors that might have an effect on driver brake deceleration rate and the basic descriptive results are described in the Table 3-14.

Table 3-14: Descriptive Statistical Results of Brake Deceleration Rate for Age, Gender, Marking, and Distance

(a) For the 30 mph speed limit								
Variable		N	Mean	Std. D	95% C.I.		Min	Max
Age	Younger	172	9.4591	3.0672	8.9974	9.9207	4.50	19.51
	Middle	220	10.1764	4.2548	9.6111	10.7418	2.24	23.67
Gender	Male	221	9.8340	3.6929	9.3444	10.3236	4.28	23.67
	Female	171	9.8975	3.9276	9.3046	10.4904	2.24	21.68
Marking	Without	184	9.5439	3.6338	9.0153	10.0724	3.71	21.94
	With	208	10.1428	3.9143	9.6077	10.6779	2.24	23.67
Distance	82.00	1	17.1270	.	.	.	17.13	17.13
	110.11	4	16.3443	2.8086	11.8751	20.8134	14.05	20.18
	138.23	13	15.2815	3.9393	12.9010	17.6619	9.51	22.33
	166.34	52	13.2235	3.9301	12.1293	14.3176	6.78	21.61
	194.46	78	9.5635	2.8734	8.9156	10.2113	3.75	18.39
	222.57	83	8.6764	2.6751	8.0922	9.2605	2.24	17.73
	250.69	79	9.6530	3.6455	8.8364	10.4695	4.50	21.94
	278.80	82	8.1503	3.1598	7.4560	8.8446	3.71	23.67
(b) For the 45 mph speed limit								
Variable		N	Mean	Std. D	95% C.I.		Min	Max
Age	Younger	155	11.7172	3.3460	11.1863	12.2481	5.56	23.47
	Middle	191	12.2639	4.6847	11.5953	12.9325	2.72	27.19
Gender	Male	197	12.0225	3.8045	11.4880	12.5571	5.02	26.19
	Female	149	12.0143	4.5639	11.2754	12.7531	2.72	27.19
Marking	Without	178	12.9701	4.7566	12.2665	13.6737	2.72	27.19
	With	168	11.0112	3.0791	10.5422	11.4802	4.62	24.17
Distance	180.40	1	26.1860	.	.	.	26.19	26.19
	206.17	8	20.9659	3.2349	18.2614	23.6703	13.96	23.47
	231.94	21	17.7077	5.7409	15.0945	20.3209	8.87	27.19
	257.71	31	14.5951	3.6493	13.2566	15.9337	8.78	22.28
	283.49	57	13.5334	3.7533	12.5375	14.5293	5.19	25.47
	309.26	77	11.0867	2.9489	10.4174	11.7560	4.05	20.17
	335.03	77	10.3862	2.2078	9.8851	10.8873	5.05	15.03
	360.80	74	9.6693	2.4256	9.1073	10.2312	2.72	17.47

A four-factor analysis of variance (ANOVA) for each speed limit type was conducted using the general linear model procedure (GLM) of the SAS software to determine the statistical significance of these trends for brake deceleration rate. For the 30 mph speed limit, the ANOVA model was significant ($P < 0.0001$) at the 0.05 level. Table 3-15 lists the ANOVA variance analysis for independent variables from SAS, which shows that distance and age are significant factors but marking, gender and any two-way interactions are not under the 95% confidence level. A Scheffe test for multiple comparisons on the distance factor showed that most of deceleration rates for the larger distance are significantly less than those for the smaller distance except for the 82.00 feet. This tendency does make sense because drivers at larger yellow onset distance have more space and time to slowly decelerate their vehicles to stop safely. A Scheffe test on the age factor showed that the deceleration rate for the middle group is 0.717 ft/s^2 significantly larger than the younger group. However, since the result comparisons between with marking and without are not significantly different, the marking did not have an effect on the driver behavior related to the brake deceleration rate for the 30 mph limit.

Table 3-15: ANOVA Variance Analysis of Deceleration Rate for the 30 mph Speed Limit

SOURCE	DF	TYPE III SS	MEAN SQUARE	F VALUE	PR>F
AGE	1	49.67349	49.67349	4.72	0.0304
DISTANCE	7	1542.812	220.4017	20.94	<.0001

For the 45 mph speed limit, the ANOVA model was significant ($P < 0.0001$) at the 0.05 level. Table 3-16 lists the ANOVA variance analysis for significant independent variables from SAS, which shows that distance and marking are significant factors but gender, age and any two-way interactions are not under the 95% confidence level. A

Scheffe test for multiple comparisons on the distance factor showed that most of deceleration rates for the larger distances are significantly less than those for the smaller distance except for the 166.34 ft. A Scheffe test on the marking factor showed that the deceleration rate without marking is 1.959 ft/s^2 significantly larger than that with marking. With the marking information, the probability that drivers make a too conservative stop will decrease if they located in the downstream of marking at the onset of yellow, which contributes to the gentler deceleration rate with marking. Generally, when drivers stop at intersections, the smaller deceleration rate is, the less likely rear-end crashes happen. Therefore, the marking countermeasure may have a positive effect on improving traffic safety for rear-end crashes at signalized intersection with the higher speed limits.

Table 3-16: ANOVA Variance Analysis of Deceleration Rate for the 45 mph Speed Limit

SOURCE	DF	TYPE III SS	MEAN SQUARE	F VALUE	PR>F
MAKING	1	331.6474	331.6474	34.01	<.0001
DISTANCE	7	2301.959	328.8513	33.73	<.0001

3.3.8 Subject survey for the pavement-marking experiment

When subjects completed the formal experiments, a survey was used to gather information about their opinions of this proposed pavement marking and red-light running. Specifically, the survey is to investigate the red-light running reason and frequency of the potential violators in the real world, dilemma zone's hazard at signalized intersections, and subjects' attitude to the safety significance of the proposed pavement marking. The investigation form is attached as appendix A in this report.

Based on the survey results from 42 subjects, there were 90.5% drivers who admitted that they did run a red-light in the real road before. For those red-light runners, 54% drivers run a red-light at least per month and 32% drivers run a red-light at least per week. As shown in Figure 3-13, more than 54% subjects thought that red-light running problem may result from incapability of stopping during the yellow signal phase because of poor judgment and 28% subjects thought the traffic delay is an important reason. Moreover, according to the investigation results after the experiment, all of subjects gave a positive evaluation on the pavement-marking countermeasure. All of subjects thought that the marking design can help them easily make stop-go decision at signalized intersections without any confusion. 91% of the subjects agreed that the pavement marking should be applied to the real road. Two subjects (one younger male and one younger female) who did not agree with road application explained that the marking should be helpful but their stop-go decisions would rely on the traffic situation and they might still ignore the marking information to beat a red-light so they would not be delayed. Another subject suggested that it should be necessary to conduct more related researches before the road application. Moreover, several subjects reported that they used the solid lane line to make stop-go decision: they crossed when the signal turned amber and they were within the solid lane line; otherwise, they stopped at the intersection. Additionally, subjects gave a whole evaluation on fidelity of the simulator system in the questionnaire as shown in Figure 3-14. More than 70% subjects thought that the simulator fidelity is good or excellent, 14% subjects thought it need improvement, but nobody gave "poor" evaluation.

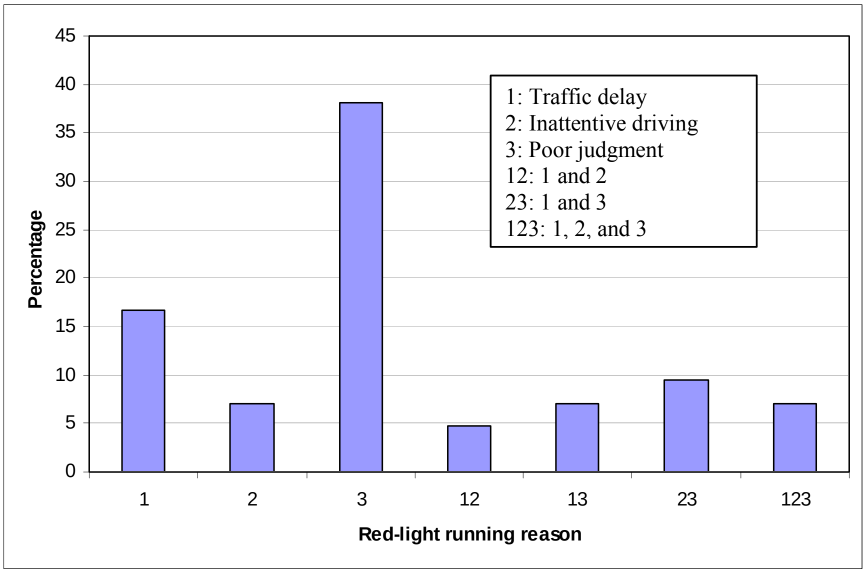


Figure 3-13: Red-light running reason

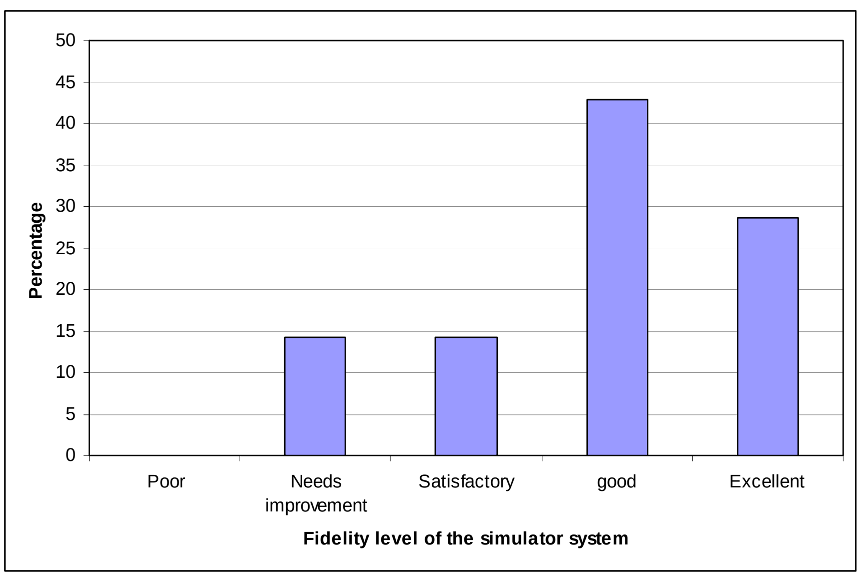


Figure 3-14: Evaluation on fidelity of the simulator system

3.4 Conclusions and Discussions

According to the result analyses of the driving simulator experiment, the pavement-marking countermeasure has a significantly positive effect on the signalized-intersection safety. Firstly compared to regular intersections, the pavement marking could results in a 74.3 percent reduction in red-light running because of poor stop-go judgment. In comparison, the pavement marking reduced the number of occurrences where drivers chose to continue through an intersection when it was not safe to proceed compared to the without marking, and this result is correlated to the less red-light running rate with marking. Further, for those running red-light drivers, the marking tends to reduce the red-light entry time. The results may contribute to reducing the probability of angle crashes.

Secondly, logistic regression models confirmed that the marking is helpful to improve driver stop-go decision at intersections. Compared to without marking, if the drivers located near to the stop bar, drivers tend to cross the intersection with the marking; if the drivers located farther to the stop bar, drivers tend to stop at the intersection with the marking. The results showed that the uncertainty distances between 20% and 80% probability of stopping with marking are about 23 ft for the 30 mph and 50 ft for the 45 mph shorter in comparison with regular intersections. The analysis indicates that the marking information can help to reduce driver hesitated region to decide to stop or cross the intersection, which possibly results in higher accident rates.

Thirdly, it was found that for those stopping drivers, the brake deceleration rate without marking is 1.959 ft/s^2 significantly larger than that with marking for the higher speed limit. With the marking information, the probability that drivers make a too conservative stop will decrease if they are located in the downstream of marking at the onset of yellow, which resulted in the gentler deceleration rate with marking. At intersections, the smaller deceleration rate may contribute to the less probability that rear-end crashes happen.

Moreover, according to survey results, all of subjects gave a positive evaluation on the pavement-marking countermeasure and nobody felt confused or uncomfortable when they made a stop-go decision with marking. In comparison between scenarios without marking and with marking, there is no significant difference found in the operation speeds and drivers brake response time, which proved that the marking has no significantly negative effect on driver behaviors at intersections.

Although, it was found that the pavement marking is useful to improve intersection safety based on the simulator test, there are still several issues such as effect of the red-light running reduction, education method, experiment design, driver attitude, and other factors, that need to be discuss if applying the marking to the real world.

Red light runners can be divided into two categories, intentional violators and unintentional violators. The pavement marking may effectively help those unintentional drivers who may be incapable of stopping for a red signal because of poor judgment by the drivers or a deficiency in the design of the intersection. The marking may not be useful for that intentional violator at all, who are most affected by enforcement countermeasures or traffic education program. However, some previous accident studies admitted a connection between red-light cameras and rear-end accidents. Some additional rear-end crashes might result from non-uniform changes in the driver behavior. If drivers stop more often and too conservatively for red lights, they may be struck from behind by drivers not intending to stop. The pavement marking countermeasure is a low-technology and inexpensive solution to reduce the number of motorists that run red lights. Therefore, the combination of the marking and red-light cameras may be more effective for both countermeasures.

For this experiment, a simple education and training would be required for drivers to learn the basic knowledge about the purpose of marking. In the real world, the new driver may get the knowledge from license-training procedures and the licensed driving population may get to know the marking policy from media and other drivers. Therefore, there could be a shorter or longer period that the whole driving population gets used to it. However, if installing some type of warning signs beside the marking, such as a sign with word message of “if yellow prepare to stop”, that might help to reduce the learning period. In addition, if a digital clock is installed on this sign that would display how many seconds remain in the green phase before the signal turns amber, the motorist may have additional information to help him/her make better decision.

Chapter 4. Safety Issues Related to Driver View Blockage Due to LTV and LSV

4.1 Horizontal Visibility Blockage Experimental Design

A typical rear-end collision due to horizontal view blockage occurs as the procedure described in Figure 4-1. Initially, the leading vehicle is traveling at a cruising speed (35mph) followed by another vehicle keeping following-car headway. At the time (T0), a hazardous event hinders the leading vehicle, which is an opposing vehicle unexpectedly and suddenly turning left in front of the leading vehicle in our scenario design as shown in the AutoCAD drawings below (Figure 4-2 and Figure 4-3). At moment (T1), the driver in the leading vehicle starts to sharply decelerate to avoid the accidents after reaction time (T1-T0). For the following vehicle, there are two possibilities in response to this event. One is that the following driver could not see what happened beyond the leading vehicle, and then he/she had to decelerate at T2 moment to avoid collision after realizing the leading vehicle's urgent deceleration. The other possibility is that the following driver can see the event happened beyond the leading vehicle at T0 and also realizes the potential danger ahead, and he/she decelerates at T3 after his/her reaction time (T3-T0). Generally, T3 is earlier than T2, even maybe earlier than T1 because the following-car driver also makes a direct reaction to the first event happened in front of the leading vehicle. Therefore, if the time interval T3-T1 (it can be a negative value) is smaller than T2-T1, one can conclude that view blockage of the leading vehicle has more contributions to the potential rear-end collision.

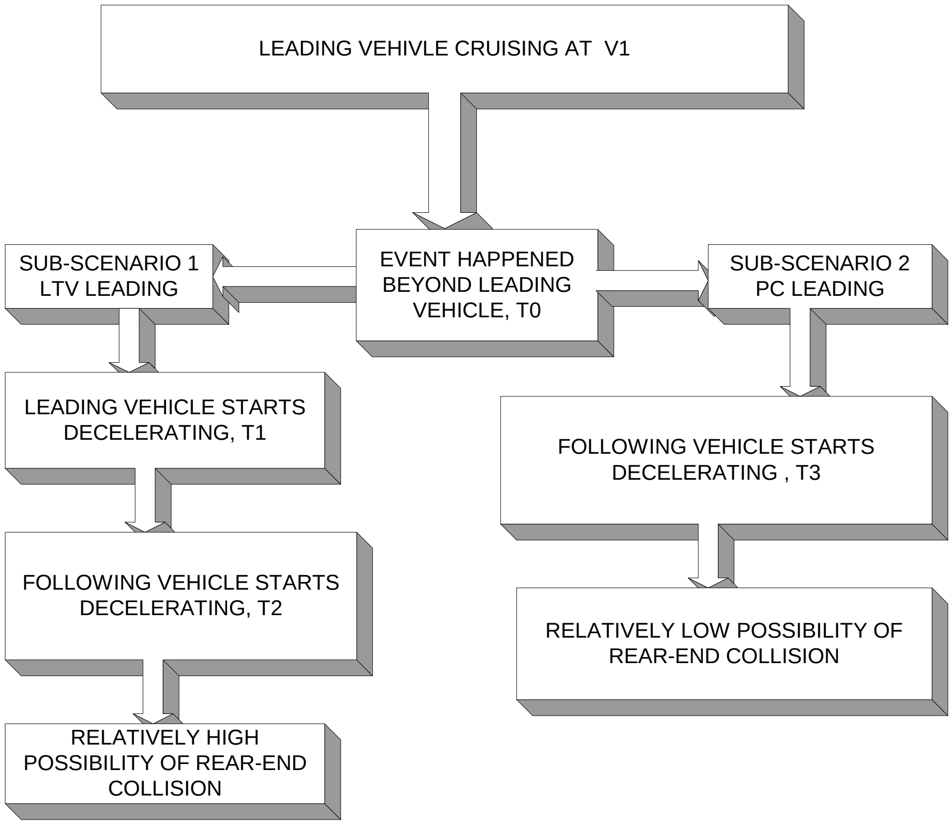


Figure 4-1: Diagram for first scenario (horizontal view blockage)

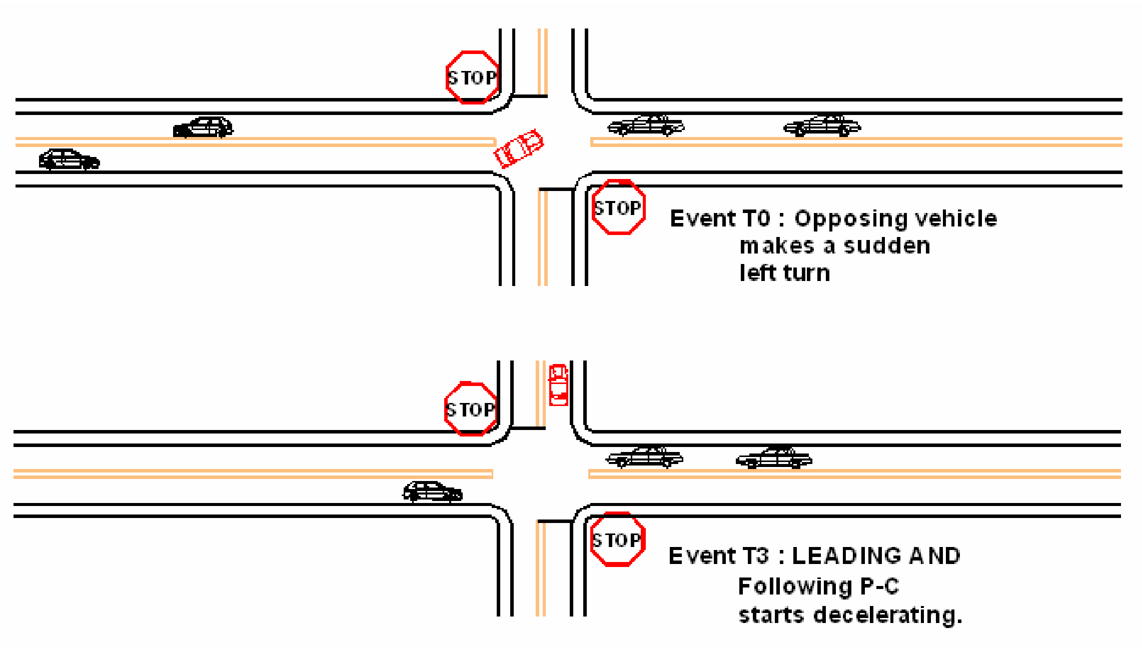


Figure 4-2: Sub-Scenario 1 (simulator car following a passenger car)

As shown in sub-scenario-1 above which is the base or control sub-scenario of the horizontal visibility blockage scenario, the leading passenger car does not obstruct the following passenger car driver's visibility. Therefore, at T0 when an aggressive driver from the opposite direction makes a sudden left turn, the leading and following passenger cars drivers can react at the same time, though decreasing the probability of rear-end collision. The second picture in the above figure shows that both vehicles come to a stop without an accident.

In Figure 4-3 below, which is the test sub-scenario of the horizontal visibility blockage scenario, the front vehicle is the LSV and the rear vehicle is the passenger car (the simulator). As shown, at time T0 when the car from the opposite direction makes a sudden left turn, the leading vehicle which is the LTV reacts to the event and the following passenger car won't react until time T1 when its driver perceives the leading vehicle's braking light. The following vehicle starts braking at T2 and comes to a complete stop at T3 where there will be a high risk of rear-end collision.

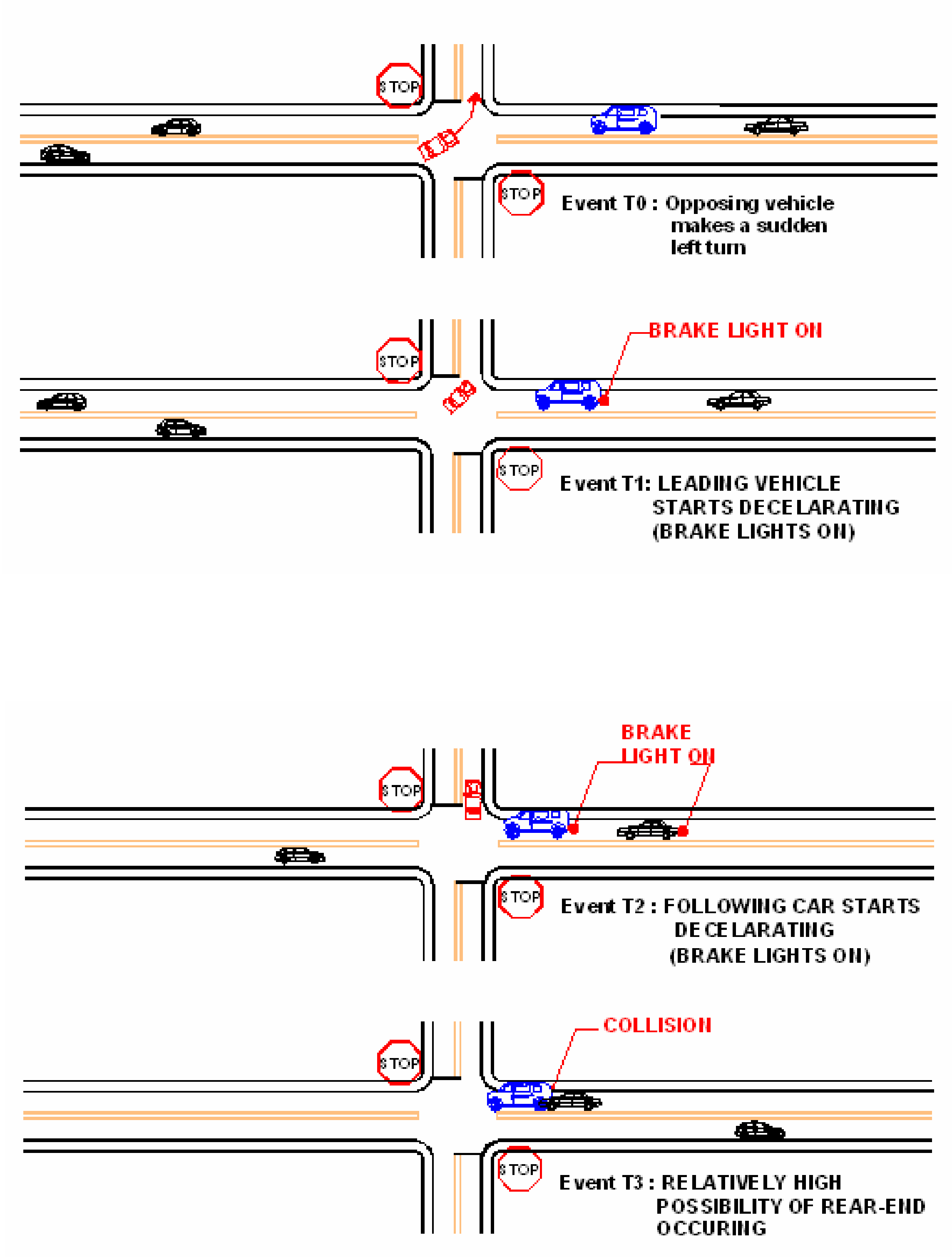


Figure 4-3: Sub-scenario 2

4.2 Vertical Visibility Blockage Experimental Design

A typical red light running due to vertical view blockage occurs as the procedure described in Figure 4-4. Initially, the leading vehicle (LSV) is traveling straight ahead at a cruising speed (35 mph) followed by another vehicle keeping following-car headway through a signalized intersection. At the time T0, the traffic signal turns from green to amber. At that time the leading vehicle which is at a safe distance to cross the intersection, decides to cross the intersection. However, the following vehicle is not at a safe distance to clear the intersection and is also not aware of the traffic signal change. At T1, 3.5 seconds (assumed time for amber light) after T0, the Traffic signal turns red leaving almost no time for the following vehicle to react and stop safely. At time T2, the following vehicle reacts and is faced with two alternatives. The drivers can either suddenly stop leading to possible rear-ends or run the red light also leading to possible accidents at the intersection.

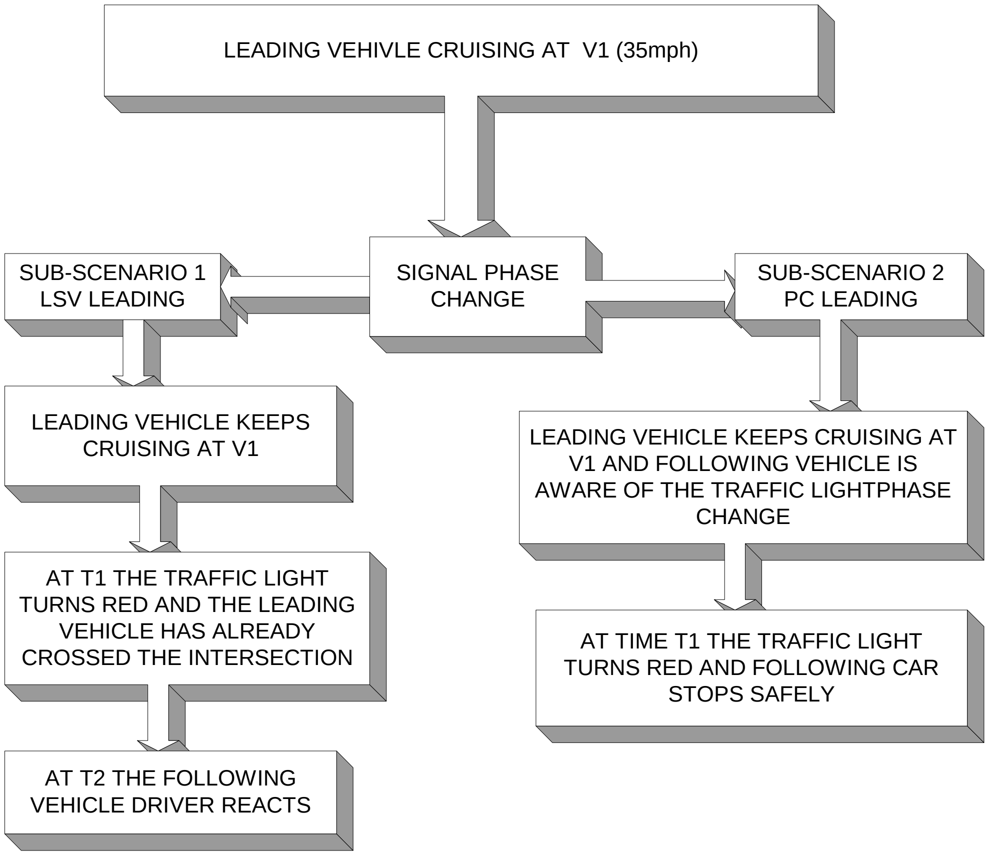


Figure 4-4: Diagram for second scenario (vertical view blockage)

Similarly to the horizontal visibility blockage scenario, the vertical visibility blockage scenario consists of two sub-scenarios. Sub-scenario 1 is illustrated in Figure 4-5 above and serves as the control or base sub-scenario.

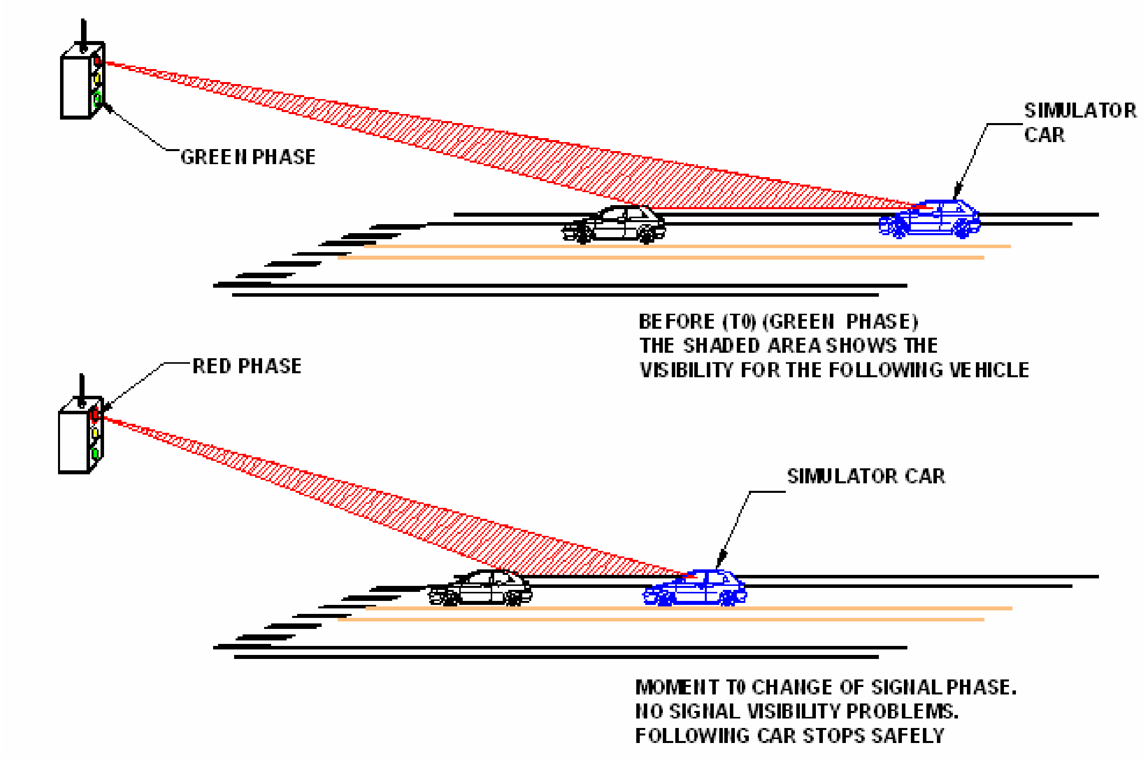


Figure 4-5: Sub-Scenario 1 (simulator following passenger car)

Sub-scenario 2, illustrated in the Figure 4-6 below, serves as the test sub-scenario. In both figures the shaded region represents the visible region for the following car driver. In the above figure, the following passenger car, the simulator car, can clearly see the traffic signal. Therefore at time T0 when the signal phase changes, both the following and the leading vehicles' perceive the event and react at time T3. However as shown in Figure 4-6 below, the LSV obstruct the vertical visibility for the following passenger car driver and disable him from seeing the traffic signal.

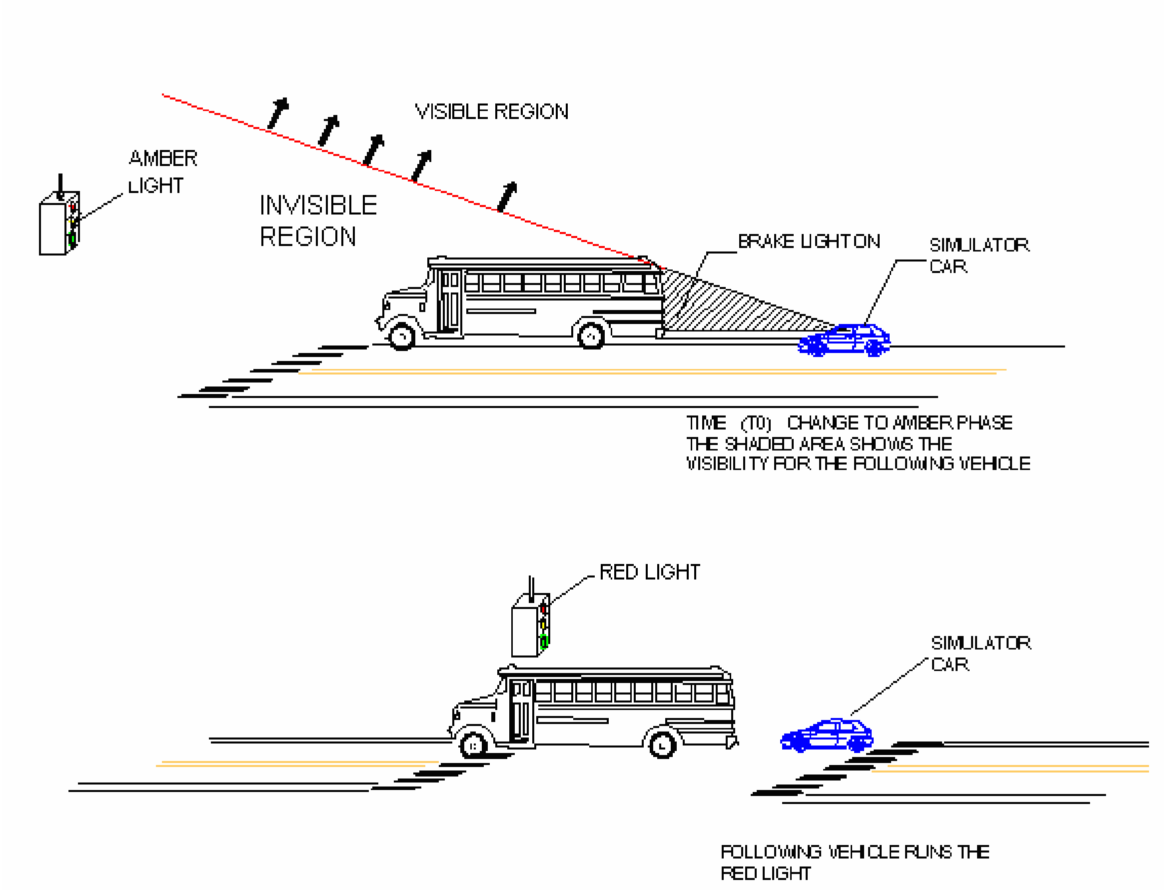


Figure 4-6: Sub-Scenario 2 (simulator following school bus)

Therefore, at time T0, when the signal phase changes, the leading vehicle, LSV, reacts at time T1, T1-T0 seconds after T0 and slams on his brakes to avoid running the red light. Therefore, the following vehicle driver who was not aware of the event happening at T0, reacts at T2 when he perceives the brake light, T2-T1 seconds after the leading vehicle reacts, and slams on his brakes at T3. Therefore, the following vehicle will have T2-T1 seconds less than the leading vehicle to come to a complete stop without colliding with the leading vehicle. These sequences of events lead to a high probability of rear-end collisions and to red light running in case the leading vehicle decides to cross the intersection.

A third scenario is suggested to solve the vertical visibility blockage, where a traffic signal pole is placed on the side of the road to the right of the drivers. Figure 4-7 describes the suggested solution.

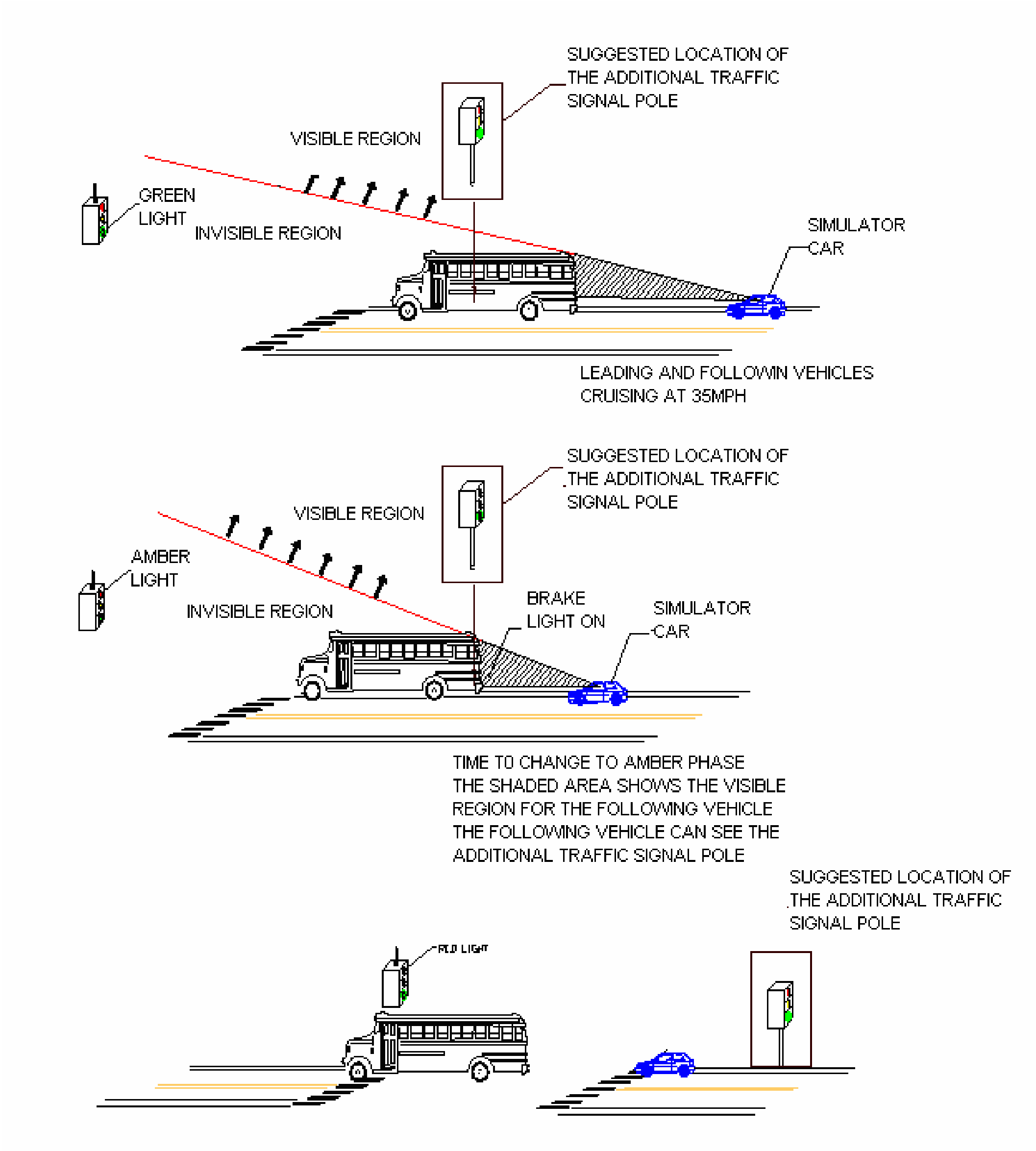


Figure 4-7: Suggested solution for the vertical visibility blockage problem

4.3 Simulation Scenario Design

4.3.1 Horizontal Visibility Blockage Scenario

The horizontal view blockage scenario consisting of two sub-scenarios, a base or control sub-scenario and a test sub-scenario discussed previously is designed in the driving simulator. The whole experiment course can be described in three stages as shown in Figure 4-8. In the first stage, the driver in the simulator car cruises on a four-lane urban road with a 45 mph posted speed limit and the traffic in the scene is assigned to flow at 45 mph. The purpose of this design is to make the simulator car divers adapt to relatively higher speed traffic. At the second stage, the simulator car approaches the signalized intersection and stops at the red phase behind the LTV, which is assigned to be there. When the light turns green the LTV is assigned to cruise at a 35 mph, following the speed limit, while the following vehicle, accustomed with the higher speed limit follows him with a velocity tending to be greater tan the speed limit. Moreover, the two-lane road in the direction of the simulator is dropped to 1 lane to inhibit any passing between vehicles. Therefore, the simulator car driver is forced to drive behind the LTV until the two-way stop intersection in the third stage. As mentioned before, the width of the LTV will be 1.88 m while the width of the passenger car will be 1.70m and the assigned deceleration rate for the leading vehicle is 0.8g.

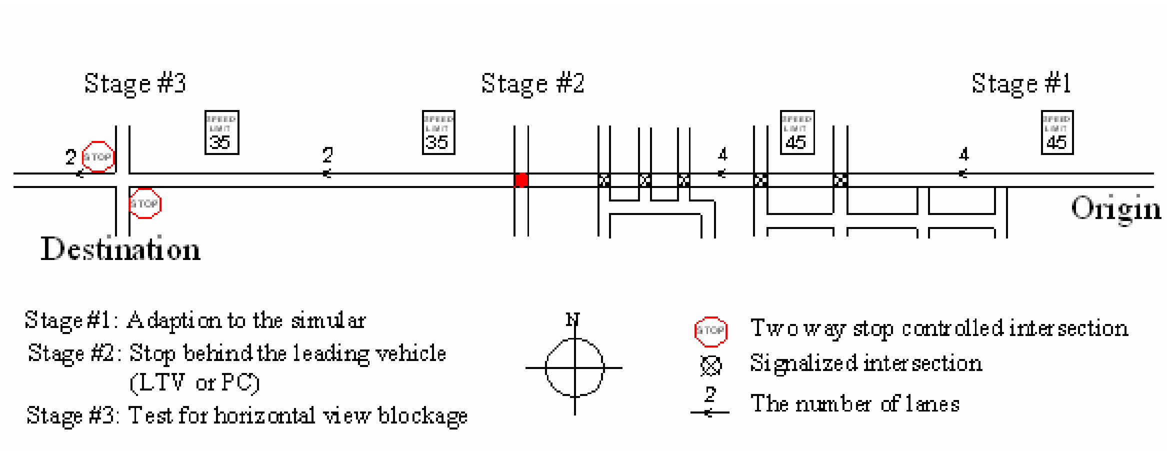


Figure 4-8: Horizontal visibility scenario three stages

Figures 4-9 and 4-10 are snapshots taken during the horizontal visibility blockage scenario and they represent the starting point of the experiment, the time where the simulator car comes behind the LTV, and the left turn the vehicle from the opposite direction makes.

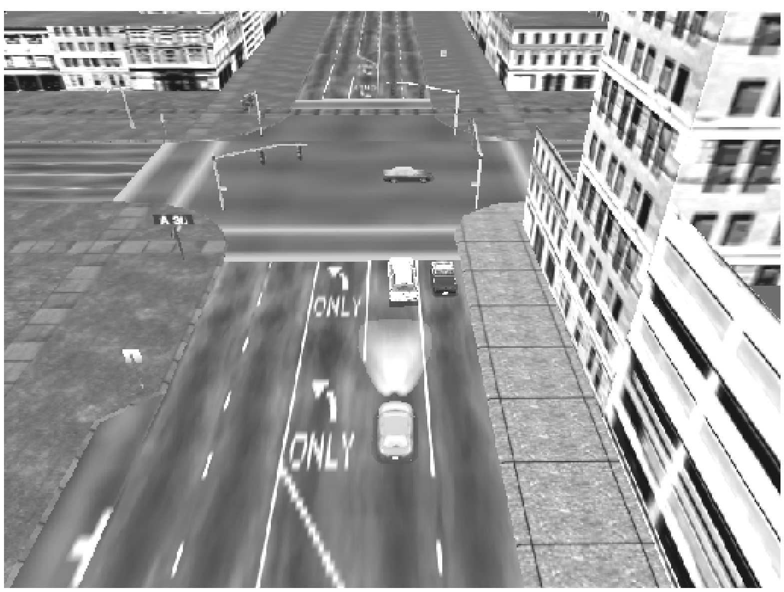


Figure 4-9: Point where simulator car comes behind the LTV (Stage 2)

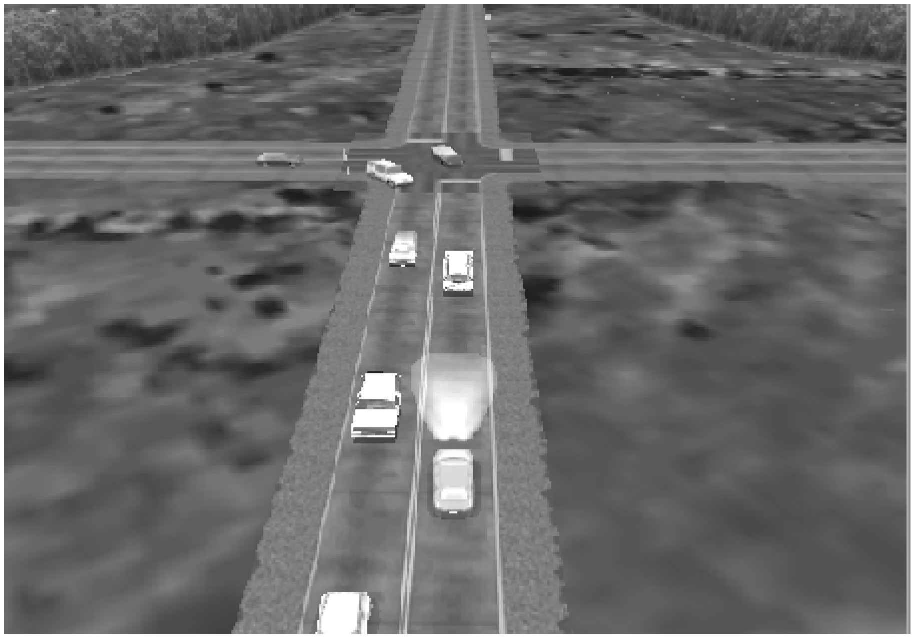


Figure 4-10: Point where opposing vehicle makes a left turn (Stage 3)

4.3.2 Vertical Visibility Blockage Scenario

The vertical view blockage scenario that consists of two sub-scenarios, a base or control sub-scenario and a test sub-scenario, as discussed previously, is designed in the driving simulator. The whole experiment course can be described in three stages as shown in Figure 4-11. In the first stage, the subject drives his car to a T-intersection where he/she is instructed to make a left. The purpose of this design is to make the simulator diver drive slowly until he gets to stage 2. At the second stage, the simulator car approaches the signalized intersection, where the phase has just turned green and where a school bus just started making a right turn slowly. The subject is assigned to make a right turn at that intersection. The purpose of this design is to make the simulator car drive closely behind the school bus since the latter makes very slow turns therefore the simulator will be tailing him. The speed limit at the second stage is 35 mph which will also make the subject drive closely behind the school bus since the latter reaches the cruising velocity very slowly. At the second stage also the route is one lane pr direction for the reason of inhibiting the following car from passing the leading car. Finally, in the third stage, as discussed before, the traffic signal turns amber and the behavior, such as gap and velocity, of the subjects is collected for analysis.

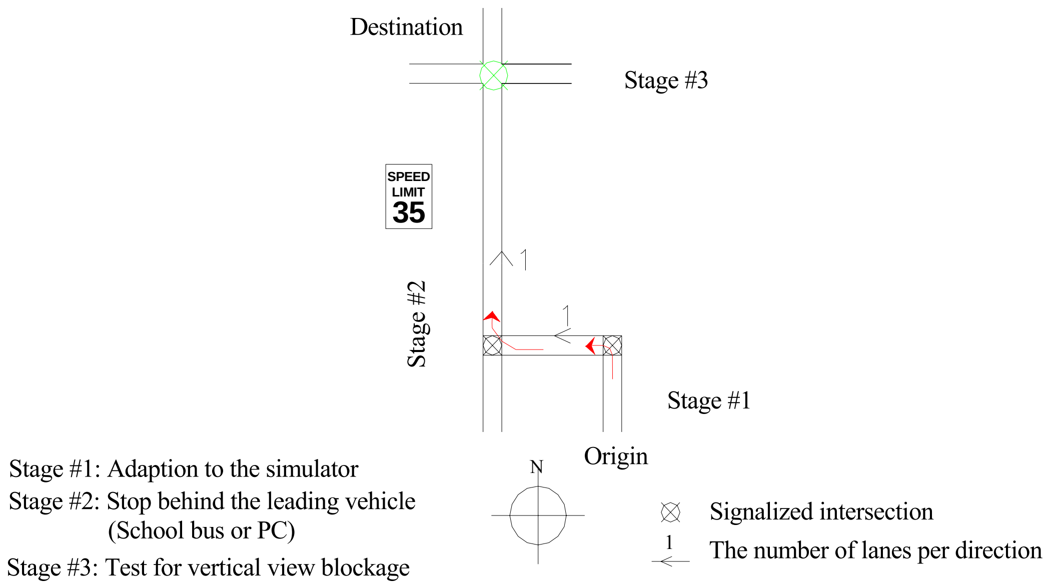


Figure 4-11: Vertical visibility scenario three stages

Figure 4-12 and 4-13 show respectively a top view when the simulator makes a left turn behind the bus and an in-cab view when the simulator approaches the intersection behind the bus. As seen in Figure 4-13 the traffic signal is invisible.

Figure 4-12: Making a right turn behind the bus

Figure 4-13: Approaching intersection behind the bus

4.4 Theoretical Calculations

4.4.1 Vertical Visibility Blockage

In this section, theoretical calculations were completed to compute the minimum gap X1, shown in the figure below, at which the traffic light is visible for the following vehicle driver. In these calculations, the height of the LSV, the eye height of the following driver, and the height of the traffic light were standard values borrowed from AASHTO standards.

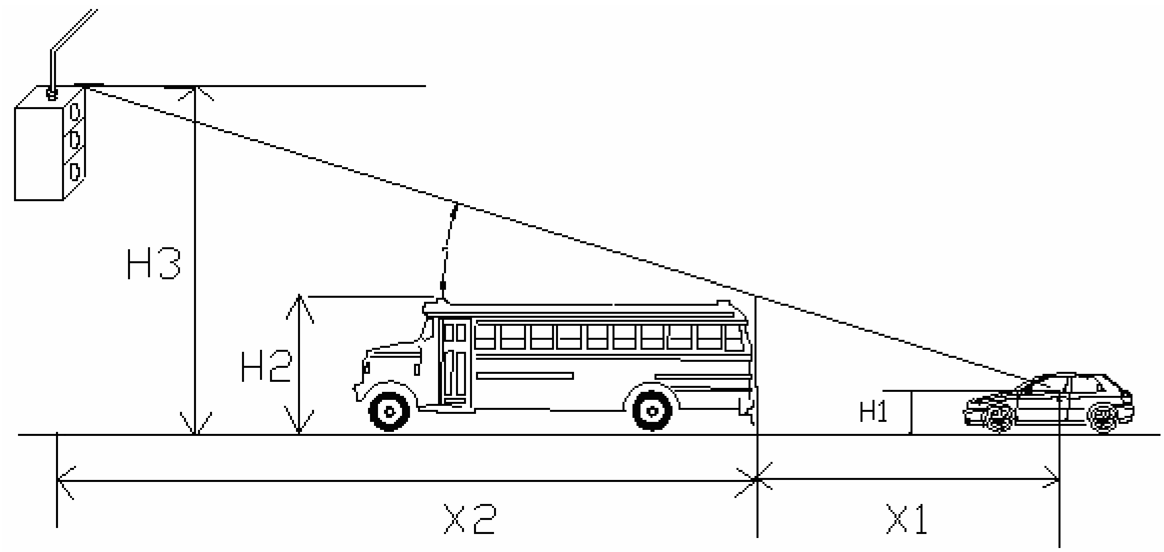


Figure 4-14: Vertical visibility blockage calculations

From the trigonometry of the figure 4-14 the following equations were computed:

$$\frac{H2 - H1}{X1} = \frac{H3 - H2}{X2}$$

$$H3 = \frac{X2}{X1}(H2 - H1) + H2$$

We would like: $\frac{X2}{X1}(H2 - H1) + H2$ to be < *H3*

$$X2 = vt + \frac{v^2}{2a} + w + L + D$$

Where,

H2 is the LSV height and an average value of 8.5 ft is used in the experiment.

H3 is the signal head height and an average value of 21 ft is used in the experiment (AASHTO).

H1 is the eye elevation equal to 3.75 ft (AASHTO)

W is the width of the intersection 40 ft (AASHTO)

L is the length of the vehicle taken 30 ft (AASHTO)

D is the set back of the stop bar from the intersection, which is 10 ft

t is the standard reaction time which is 1.0 s (AASHTO)

a is the acceleration rate taken 10 ft/s^2 (AASHTO)

X1 is the distance from the center of the car to the back of the front vehicle in ft.

X2 is the Distance from the back of the leading vehicle to the traffic signal.

V is the velocity of the vehicle taken 35 mph or 51.33 feet per second

Table 4-1 shows the minimum required distance X1, which is the gap between the leading and the following vehicle, with the variation of the traffic light height H3 and the LSV height H2 using the equations listed above. From the below Table, the value of X1 is proportional to H2 and H3. Indeed, the bigger H2 and H3 the larger X1 must be in order for the following vehicle driver to see the traffic light. In the formal experiment we used H2 = 8.5 ft and H3= 21ft.

Table 4-1:Variation of X1 with H2 and H3

V	T	W	A	L	D	H1	H2	H3	X2	X1
51.33	1	40	10	30	10	3.75	9	18	320	187
51.33	1	40	10	30	10	3.75	9	20	320	153
51.33	1	40	10	30	10	3.75	9	22	320	129
51.33	1	40	10	30	10	3.75	10	18	320	250
51.33	1	40	10	30	10	3.75	10	20	320	200
51.33	1	40	10	30	10	3.75	10	22	320	167

4.4.2 Horizontal visibility blockage

For the horizontal visibility blockage similar trigonometry calculations were applied. Several assumptions were made; the width of the LSV will be 1.8 m (or 5.91 ft) and the width of each leg of the intersection is 24 assuming that each lane is only 12 ft.

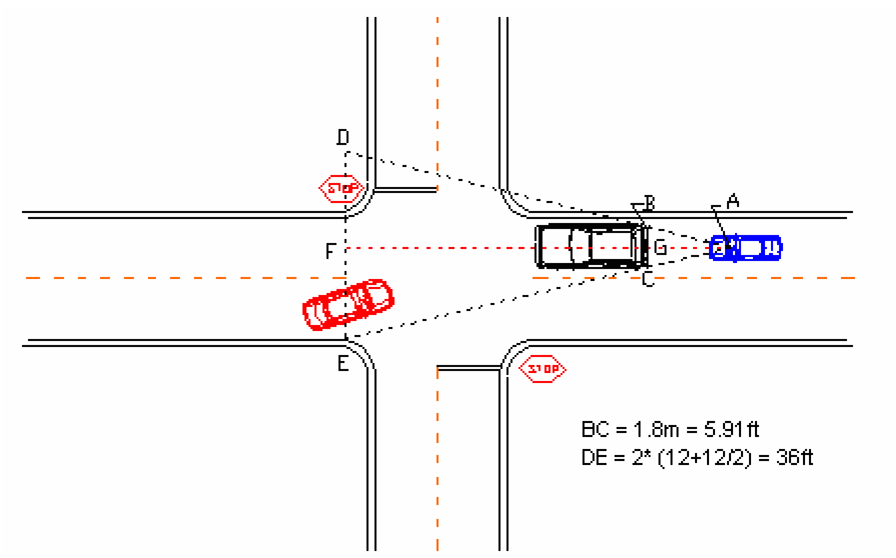


Figure 4-15: Horizontal visibility blockage calculations

Therefore, assuming that the simulator vehicle drives in the center of the lane, the length of DE is $2*(12+\frac{12}{2})=36\,ft$. In the triangles ABC and ADE the following ratios can be applied:

$$\frac{BC}{DE}=\frac{AG}{AF}=\frac{AF-GF}{AF} \qquad (4.2.1)$$

We would like $\frac{(BC*AF)}{(AF-GF)}<DE$ → $\frac{(5.91*AF)}{(AF-FG)}<36$

$$GF=vt+\frac{v^2}{2a}+w+L+D \qquad (4.2.2)$$

Where,

w is the width of the intersection 24 ft (each lane is assumed to be 12 ft)

L is the length of the vehicle taken 30 ft (AASHTO)

D is the set back of the stop bar from the intersection, which is 10 ft

t is the standard reaction time which is 1.0 s (AASHTO)

a is the acceleration rate taken 10 ft/s2 (AASHTO)

AG is the distance from the center of the car to the back of the front vehicle in ft.

GF is the Distance needed to clear the intersection during the amber phase.

v is the velocity of the vehicle taken 35 mph or 51.33 feet per second

$$GF=(51.33*1)+\frac{51.33^2}{2*10}+24+30+10=247.07\text{ ft}$$

$$\frac{(5.91*AF)}{(AF-247.07)}<36 \;\rightarrow\; 5.91*AF<36*(AF-247.07)$$

$$AF<295.60\,ft$$

Form our calculation, if AF is less or equal to 295.60 ft the following car driver cannot see a vehicle making a sudden left turn in front of the lead vehicle.

4.5 Statistical Issues for Experiments

4.5.1 Sample size

The pilot study was performed for the sake of testing the experiment and enhancing the scenario design. The pilot study demonstrated that the data collection is very sensitive and must be completed carefully. Moreover, from the pilot study, the required number of subjects was determined. There was no significant difference between the numbers of potential rear-end collisions between SIM-LTV (simulator car following an LTV) and SIM-PC (simulator car following a regular passenger car) sub-scenarios for the horizontal visibility blockage scenario using a 95% confidence interval. The obtained P-value was 0.138 which is greater than α =0.05. However, the sample size N =10 is quite small. The size of the sample that leads to a P-value < 0.05 is calculated below.

$$n = \frac{(Z_\alpha + Z_\beta)^2 (p_1 q_1 + p_2 q_2)}{(p_1 - p_2)} \qquad (5.3\text{-}1)$$

Where:

n = Estimated necessary sample size.

Z α = Z-coefficient for the false-change (Type I) error rate from the table below. In our case with 95 % confidence interval, α=0.05 and Z α= 1.96 from Table 4-2.

Z β = Z-coefficient for the missed-change (Type II) error rate from the table below. In our case with 95 % confidence interval, β =0.05 and Z β = 1.64 from Table 4-2.

p1 = the value of the proportion for the first sample as a decimal. In our case, the first sample is Sequence 1 defined previously as (SIM-LSV)/ (SIM-PC) in Table 4-2. And p1 is defined in the equation below:

$$p1 = \frac{Number\_of\_LTV\_Accients}{Total\_Number\_of\_Trials} = \frac{4}{5} = 0.8$$

q1 = 1 - p1. =1- 0.8 = 0.2

p2 = the value of the proportion for the second sample as a decimal. In our case, the first sample is Sequence 2 defined previously as (SIM-PC)/ (SIM-LSV). And p2 is defined in the equation below:

$$p2 = \frac{Number\_of\_PC\_Accients}{Total\_Number\_of\_Trials} = \frac{2}{5} = 0.4$$

q2 = 1 - p2. = 1 – 0.4 = 0.6

$$n = \frac{(1.96+1.64)^2(08*0.2+0.6*0.4)}{(0.8-0.4)} = 12.96 = 13$$

With the minimum required sample size calculated above, the occurring error is 5% with the 95%confidence interval. In order to decrease the error interval, the same calculation completed above is repeated with 99% confidence interval. The parameters of equation 5.3-1 introduced above are going to keep the same value except for Zα = and Z β. With

α=0.01, Z α =2.58 and Z β =2.33 from Table 4-2

$$n = \frac{(2.58 + 2.33)^2 (0.8 * 0.2 + 0.6 * 0.4)}{(0.8 - 0.4)} = 24.18 = 25$$

From the above equation the minimum required sample size consists of 25 subjects to obtain a 99% confidence interval However, to reduce further the error interval, we are going to recruit 40 individuals for each 2 sub-scenario.

Table 4-2: Standard Normal Deviates α and ß

Table of standard normal deviates for *Z* α		Table of standard normal deviates for Z_β		
False-change (Type I) error rate (α)	*Z* α	Missed-change (Type II) error rate (ß)	Power	Z_β
0.40	0.84	0.40	0.60	0.25
0.20	1.28	0.20	0.80	0.84
0.10	1.64	0.10	0.90	1.28
0.05	1.96	0.05	0.95	1.64
0.01	2.58	0.01	0.99	2.33

In order to make the selected subjects closely duplicate the actual Florida drivers population, and since it is very hard to estimate the age and gender percentage on the roads, the distribution of the age and gender of the subjects were borrowed from the Florida crash database where males represent 60% versus females 40%, and middle age represent 60% versus young 40 % of the population. It is assumed that the young age group varies between the ages of 18 and 25 and the middle age group varies between 25 and 55. Table 4-3 below represents the final gender and age breakdown of the subjects that completed the experiment.

4.5.2 Subjects distribution for groups A, B, and C

As shown in Table 4-3, groups A, B, and C consisted of 20 subjects each. Table 4-3 also shows the age and gender distribution of each group and the sub-scenarios driven by each group.

Table 4-3: Group A, B, and C distributions

GROUP	AGE	MALE	FEMALE	TOTAL	SUB-SCENARIO DRIVEN PER GROUP
GROUP A	YOUNG	5	3	20	SIM-PC FROM HVBS
	MIDDLE AGE	7	5		SIM-LSV FROM VVBS
GROUP B	YOUNG	5	3	20	SIM-PC FROM VVBS
	MIDDLE AGE	7	5		SIM-LTV FROM HVBS
GROUP C	YOUNG	5	3	20	SIM-LSV FROM VVBS WITH
	MIDDLE AGE	7	5		ADDITIONAL TRAFFIC LIGHT

HVBS= Horizontal View Blockage Scenario

VVBS= Vertical View Blockage Scenario

4.6 Analyses of Horizontal Visibility Experiment Data

4.6.1 Operating Cruising Velocity of the Simulator

The cruising velocities of the simulator car following PC and following LTV versus the 35 mph speed limit, as shown in Figure 4-16, show that the drivers were following the speed limit which suggests that they drove the simulator car as they drive their own vehicles in real life.

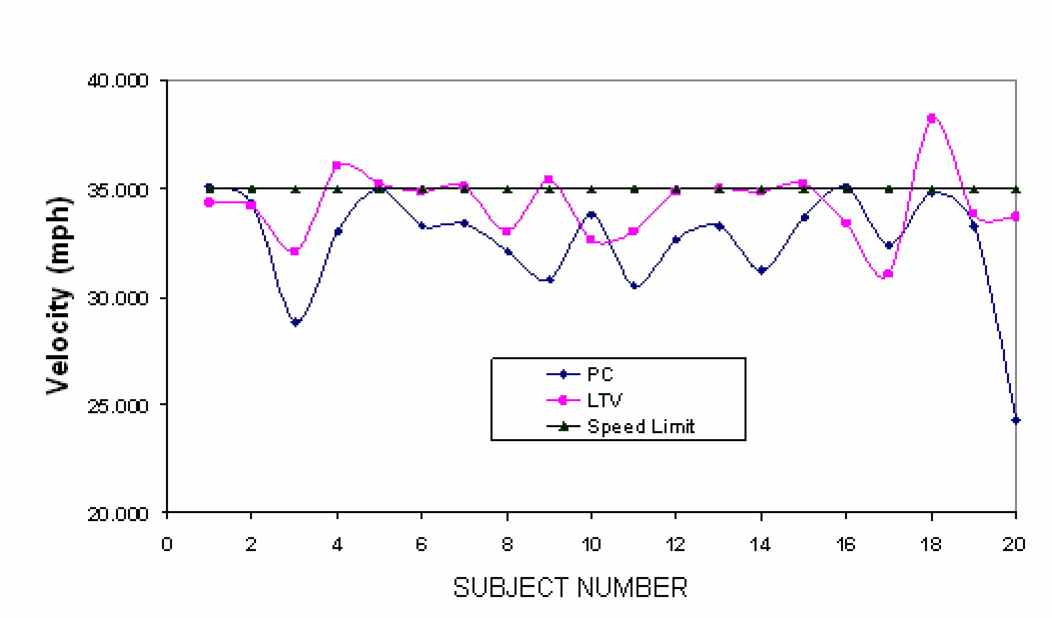


Figure 4-16: Cruising velocity of the simulator car

4.6.2 Rear-end collisions for following an LTV and following a PC

From the collected data, 2 subjects out of 20 subjects driving the simulator behind the PC were involved in a rear-end collision with the PC. However, 8 subjects out of the 20 subjects driving the simulator car behind an LTV got in a rear-end collision with the LTV. Therefore, the probability of getting in an accident following PC: $p = \frac{2}{20} = 0.1 = 10\%$, and the probability of getting in an accident following LTV**:**

$$p = \frac{8}{20} = 0.4 = 40\% .$$

To determine whether there is a significant statistical difference between the two ratios a chi-square test was completed.

Table 4-4 below is the output from MINITAB for the chi-square test with 95 % confidence interval. The resulting P-value is equal to 0.013 which is less than α=0.05. As a conclusion, there is a significant statistical difference between the accident ratios for following an LTV and following a PC with the accident ratio for following an LTV higher than the accident ratio following a PC.

Table 4-4: MINITAB output: Chi-Square test for accident ratios

```
CHI-SQUARE TEST FOR C1 AND C2

EXPECTED COUNTS ARE PRINTED BELOW OBSERVED COUNTS
CHI-SQUARE CONTRIBUTIONS ARE PRINTED BELOW EXPECTED COUNTS

          C1      C2  TOTAL
    1     18       2     20
       14.50    5.50
       0.845   2.227

    2     11       9     20
       14.50    5.50
       0.845   2.22
TOTAL     29      11     40

CHI-SQ = 6.144, DF = 1, P-VALUE = 0.013
```

4.6.3 Deceleration rates for following a PC and following an LTV

The deceleration rate is an important indication of accidents risk. If the deceleration rate of the simulator car is high, it means that there is a potential for rear-end collision with the leading vehicle and that there is a potential rear-end collision with a possible vehicle following the simulator car. Therefore, if the deceleration rate of the simulator car following an LTV is higher than deceleration rate of the simulator following a PC, one can conclude that driving behind an LTV produces a higher potential of rear-end collision with the leading. Figure 4-17 below shows the deceleration rates in ft/sec/sec of the simulator car for each of the scenarios, with the deceleration rate for following an LTV higher than the deceleration rate for following a PC.

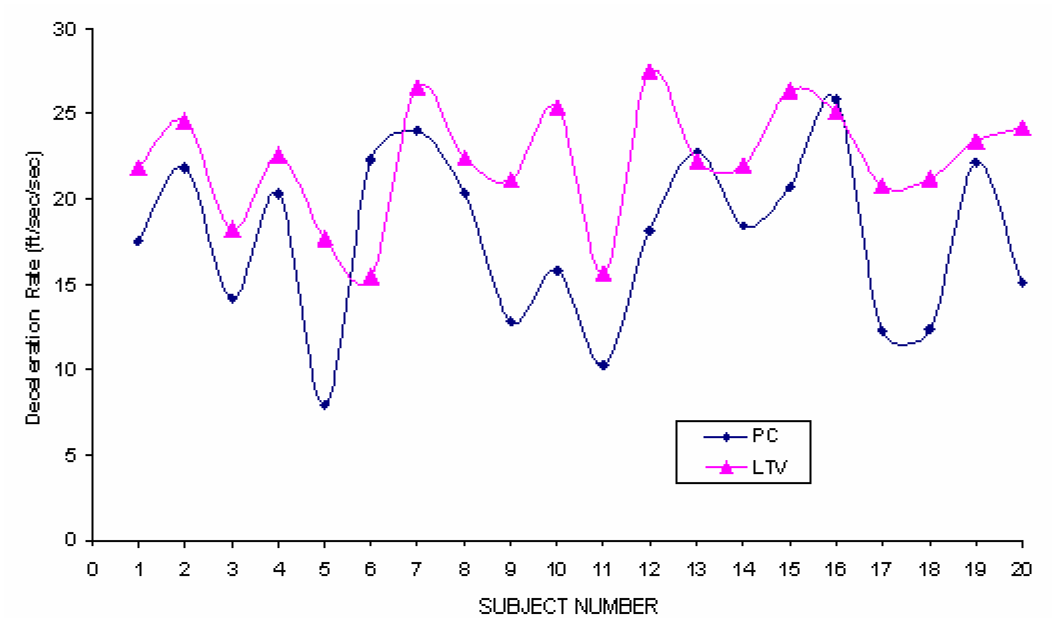


Figure 4-17: Deceleration rates for following a PC and following an LTV

A 2 sample t-test was computed in MINITAB to check for a statistical significant difference between the means of both samples with the following null and alternative hypotheses:

$$Ho: \mu_{ltv} = \mu_{pc}$$
$$H1: \mu_{ltv} \neq \mu_{pc}$$

From the MINITAB output below the p-value is equal to 0.002 which means that there is a statistical significant difference between the deceleration means of following a PC and following an LTV. The deceleration mean for following an LTV is equal to 22.23 ft/sec/sec and the deceleration mean for following a PC is equal to 17.77 ft/sec/sec.

Table 4-5: MINITAB output for deceleration rates t-test

TWO-SAMPLE T-TEST AND CI: C1, C2

```
TWO-SAMPLE T FOR C1 VS C2

     N   MEAN  STDEV  SE MEAN
PC   20  17.77   4.96      1.1
LTV 20  22.23   3.43     0.77


DIFFERENCE = MU (C1) - MU (C2)
ESTIMATE FOR DIFFERENCE:  -4.46206
95% CI FOR DIFFERENCE:  (-7.20335, -1.72078)
T-TEST OF DIFFERENCE = 0 (VS NOT =): T-VALUE = -3.31  P-VALUE = 0.002  DF = 33
```

4.6.4 Gap test for following a PC and LTV

Gap is also one of the important variables in our research. For example, if the gap of following a vehicle is smaller than the gap of following another vehicle, the vehicle followed with the smaller gap is more likely to get in an accident. From Figure 4-18 below, the gap for following a PC looks larger than the gap for following an LTV. Therefore, it is suggested following an LTV has a higher potential of rear-end collision with the leading vehicle.

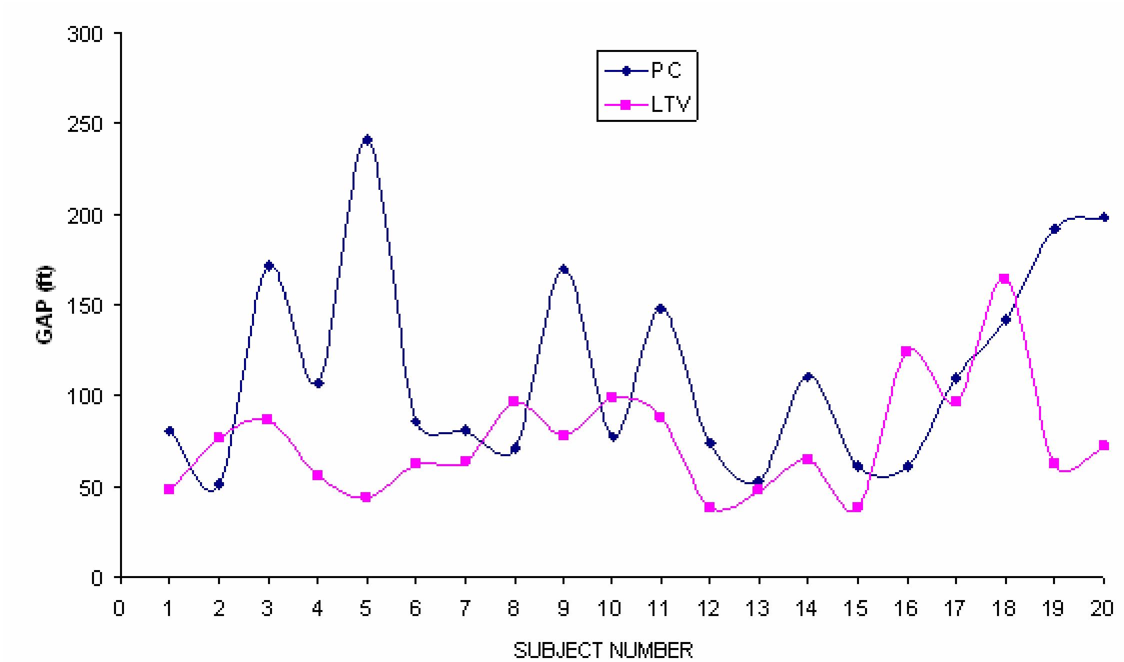


Figure 4-18: Gap for following a PC and LTV

A 2 sample t-test was performed to compare the gap means of both sub-scenarios with a 95% confidence interval. From the MINITAB output in Table 4-6, the resulting p-value is 0.01 which is smaller than 0.05. Therefore, there is a statistical difference between the gap means of both sub-scenarios with the mean gap of following an LTV equal to 75.6 ft and the mean of following a PC equal to 114.6 ft.

The subjects drove closer to an LTV than to a passenger car because when they drive behind an LTV they feel uncomfortable and anxious to pass it due to the visibility blockage the latter causes.

Table 4-6: MINITAB output for 2 sample t-test, following an LTV and PC

TWO-SAMPLE T-TEST AND CI: C1, C2

```
TWO-SAMPLE T FOR PC VS LTV

     N   MEAN  STDEV  SE MEAN
PC  20  114.6   55.6       12
LTV  20   75.6   31.0      6.9


DIFFERENCE = MU (PC) - MU (LTV)
ESTIMATE FOR DIFFERENCE:  39.0721
95% CI FOR DIFFERENCE:  (9.9469, 68.1973)
T-TEST OF DIFFERENCE = 0 (VS NOT =): T-VALUE = 2.74  P-VALUE = 0.010  DF = 29
```

4.6.5 Reaction delay time for following a PC and following an LTV

The reaction delay time is a tool to test the view blockage the LTV causes. Indeed, if the reaction delay time when following an LTV is higher than the reaction delay time when following a passenger car, it means that it took the subject driving behind the LTV a longer time to see and react to a hazard, which is caused by a visibility blockage problems. In the horizontal visibility blockage scenario, the higher ratio of rear-end collisions for following and LTV is suggested to be linked to a visibility blockage problem caused by the LTV. Figure 4-19 shows the reaction times for both following a PC and following an LTV sub-scenario.

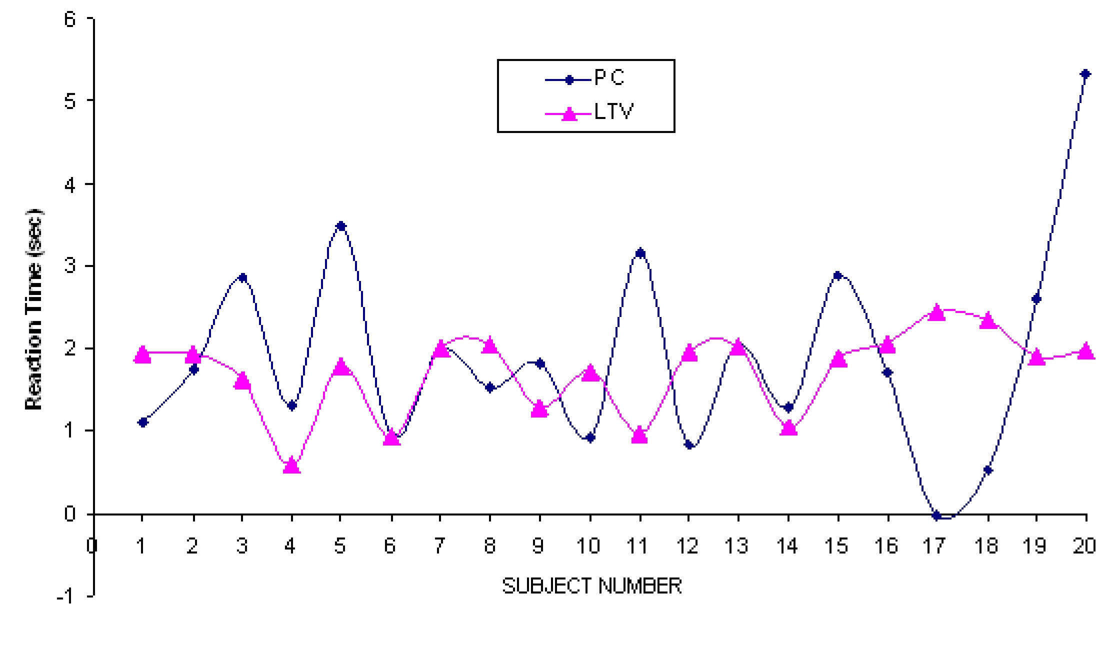


Figure 4-19: Reaction delay time for following an LTV and following a PC

From Figure 4-19, the reaction delay time for following a PC is higher than reaction delay time for following an LTV in some cases. This can be explained by the fact that when the gap is relatively very large, the derived reaction delay time is not actually the reaction delay time, but it is the reaction delay and decision braking time. Therefore, when a subject is driving at a large gap from the PC, he might see the opposing vehicle making a left turn but he won't brake until he gets close to the leading PC. The time it took the driver to get close and brake is called decision braking time. For instance, from Figure 4-18, subject number 20 was driving at 199ft behind the PC which resulted in a reaction time of 5.33 seconds and subject number 5 was driving at 242 ft from the leading vehicle which led to a reaction time of 3.47 sec.

A 2 sample t-test was computed to compare the means of reaction delay time of both sub-scenarios and the resulting P-value of 0.551 is greater than 0.05 which means that there is no significant statistical difference between the reaction delay time means of the two samples.

4.6.6 Cruising Velocity means for following a PC and following an LTV

The velocity is another important variable in studying the horizontal visibility blockage scenario. For instance, if the simulator car driver drives behind an LTV at a relatively higher velocity than he drives behind a passenger car, it is suggested that driving behind an LTV produces a higher potential of rear-end collision. From Figure 4-20 below, one can see that the cruising velocities behind an LTV are higher than the velocities behind PC.

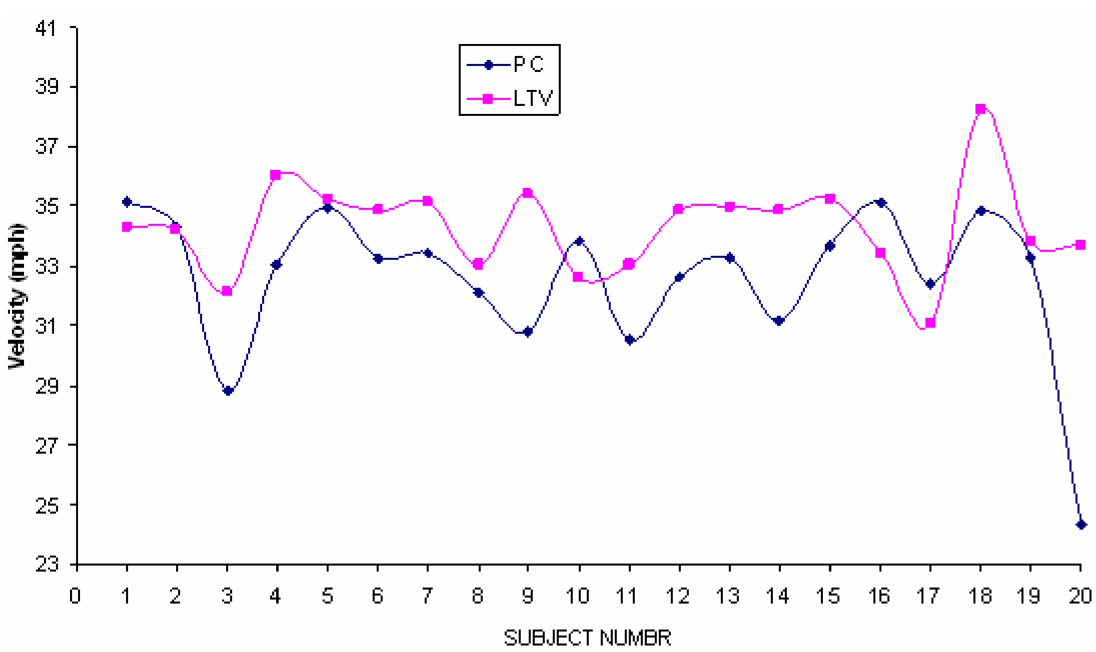


Figure 4-20: Cruising velocity for following a PC and LTV

A 2 sample t-test was computed to compare the means of the two samples for a 95 % confidence interval with the following hypotheses:

$$Ho: \mu_{ltv} = \mu_{pc}$$
$$H1: \mu_{ltv} \neq \mu_{pc}$$

From the MINITAB output below, the P-value is 0.013 which is less than 0.05. Therefore, there is a statistically significant difference between the two sample means with the mean of following an LTV equal to 34.30 mph and the mean of following a PC equal to 32.54 mph. The higher velocity mean for following an LTV can be explained by the fact that subjects driving behind the LTV are uncomfortable and anxious to pass it since they cannot see beyond the latter.

Table 4-7: MINITAB output for 2 sample t-test, following an LTV and PC

TWO-SAMPLE T-TEST AND CI: C1, C2

```
TWO-SAMPLE T FOR PC VS LTV

     N   MEAN  STDEV  SE MEAN
PC  20  32.54   2.55     0.57
LTV  20  34.30   1.57     0.35


DIFFERENCE = MU (PC) - MU (LTV)
ESTIMATE FOR DIFFERENCE:  -1.75804
95% CI FOR DIFFERENCE:  (-3.12319, -0.39290)
T-TEST OF DIFFERENCE = 0 (VS NOT =): T-VALUE = -2.63  P-VALUE = 0.013  DF = 31
```

4.6.7 Impact velocity

The impact velocity is velocity at which the simulator car hits the PC or the LTV. The impact velocity shows the severity of the accident. Indeed, if the impact velocity is greater so is the severity of the accident. From Figure 4-21 below, the impact velocities with LTV seem to be higher than the impact velocity with PC. The two samples are small and are not valuable to make conclusions. However, they can show a trend of the results. From the trend of the results, one can conclude that not only driving behind an LTV can produce more rear-end collisions than driving behind a passenger car but also that rear-end collisions with LTV are more severe than rear-ends with PC.

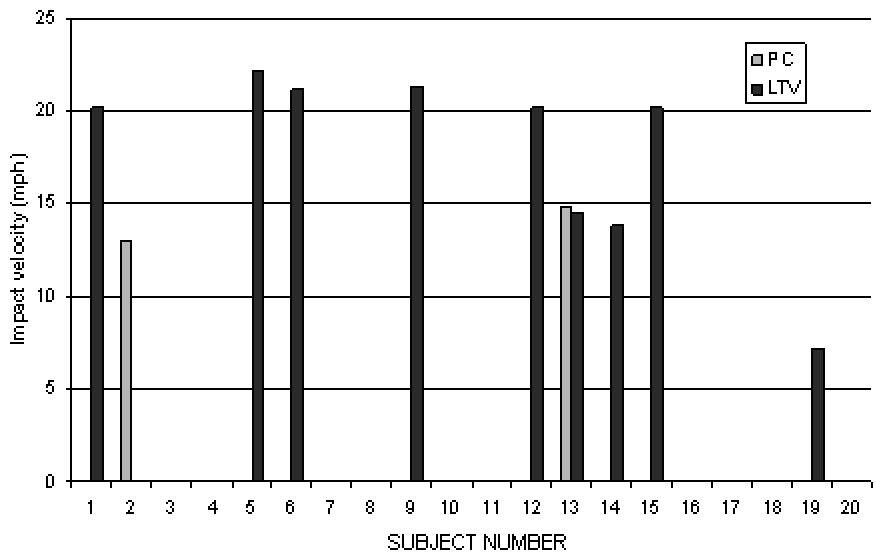


Figure 4-21: Impact velocities for following a PC and LTV

4.6.8 Logistic regression

Logistic regression is a statistical technique for developing predictive models for the probability that an event (such as the rear-end collision) will or will not occur. The probability that a driver will get in a rear-end collision is modeled as logistic distribution in the following equation:

$$\pi(x) = \frac{e^{g(x)}}{1 + e^{g(x)}}$$

The Logit of the multiple logistic regression model is given by the following:

$$g(x) = \ln\left[\frac{\pi(x)}{1 - \pi(x)}\right] = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \ldots + \beta_n x_n$$

Five potential independent variables, shown in Table 4-8, suspected to be related to the rear-end collision probability were used to construct the logistic model in SPSS 13.0 statistical software.

Table 4-8: Logistic regression independent factors

Variable	**Variable Description**	**Variable Unit**
PCLTV	Following a PC or Following an LTV	0=Following a PC 1=Following an LTV
RT	Reaction delay time	Continuous (sec)
DR	Deceleration rate	Continuous (ft/sec/sec)
Vel	Cruising velocity	Continuous (mph)
Ratio	(Reaction delay time(sec))/(Gap(sec))	Dimensionless

A new variable, the ratio of reaction delay time over gap in seconds, was derived and added to the statistical model independent variables. The above variables were incorporated in SPSS to create a logistic model. Table 4-9 shows the results of the first trial. The independent variables seem to be insignificant for the model with P-values >>

0.05. Even though each variable independently was related to the probability of rear-end collision from the completed t-test, the table below shows that all the variables together are not significant to the model because there is a high correlation between each variable.

Table 4-9: SPSS 13.0 output for Logistic regression model

		B	S.E.	Wald	Df	Sig.	Exp(B)
Step 1(a)	DR	-.129	.119	1.179	1	.277	.879
	RT	1.779	1.448	1.510	1	.219	5.924
	Vel	.289	.294	.966	1	.326	1.335
	Gap	-.034	.028	1.475	1	.225	.967
	Ratio	-1.898	1.743	1.186	1	.276	.150
	Pcltv(1)	-1.440	.962	2.238	1	.135	.237
	Constant	-5.415	9.132	.352	1	.553	.004

Variables in the Equation

The independent variables with the highest p-value were eliminated one at a time and the observed p-value of each new model was still >> 0.05 which can be explained by the high correlation between the variables. Therefore, there was no good model that combines LTV and PC. A model was created that comprises LTV and the 5 independent factors and the same procedure was completed in SPSS. After several trials and eliminations, the final model is shown in Table 4-10 where the p-values< 0.05. The final model consists of one factor which is the ratio of reaction delay time over gap in seconds.

Table 4-10: SPSS 13.0 output for Logistic regression model

		B	S.E.	Wald	Df	Sig.	Exp(B)
Step 1(a)	Ratio1	2.323	1.074	4.674	1	.031	10.202
	Constant	-3.198	1.430	4.999	1	.025	.041

Variables in the Equation

$$g(x)=\ln\left[\frac{\pi(x)}{1-\pi(x)}\right]=-3.198+2.323x_1$$

From the equation above one can conclude the bigger the ratio of reaction delay time (in seconds) over gap (in seconds) the larger the probability of rear-end collisions.

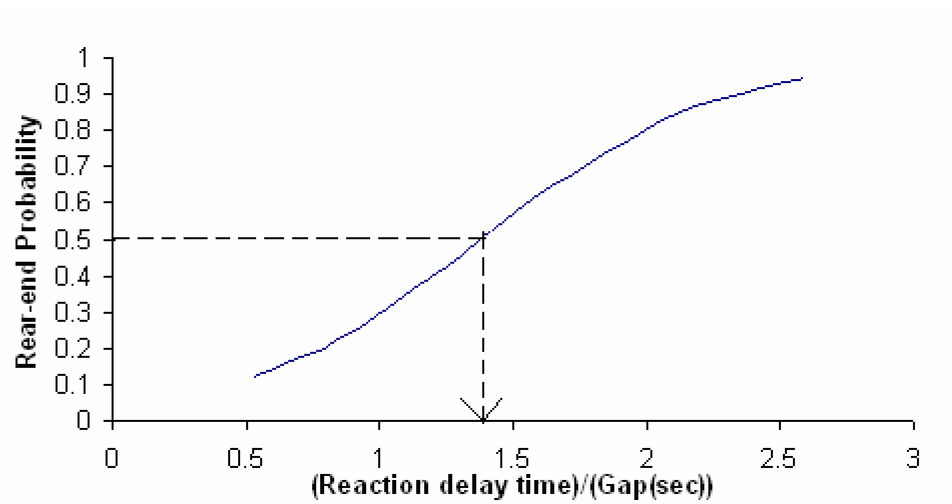


Figure 4-22: Rear-end collision probability

The critical ratio (approximately 1.375) can be determined from Figure 4-22 as the 50% probability of rear-end collision occurs. It means that the subjects with a ratio of reaction delay time over gap in seconds equal or greater to 1.375 have at least 50 % or higher chance of getting in a rear-end collision. And the Graph also shows that the higher the reaction delay time over gap the higher the probability of getting in a rear-end. Indeed, if the reaction delay time is 1.375 times greater than the gap in seconds, the subjects are very likely to get in a rear-end collision.

4.6.9 Survey Analysis

As mentioned before, the subjects were asked to take a survey at the end of the experiment. One of the survey questions asked the subjects if they drive closely behind a passenger car or LTV in real life. From group A, which consisted of 20 subjects driving behind a passenger car, 30 % answered that they drive closely to passenger cars in real life and the 70% remaining answered that they don't drive closely to a passenger car in real life. However, from group B, which consisted of 20 subjects, 45% answered that they drive closely to an LTV in real life and 55% answered that they don't drive closely to LTV in real life as shown in Figure 4-23.

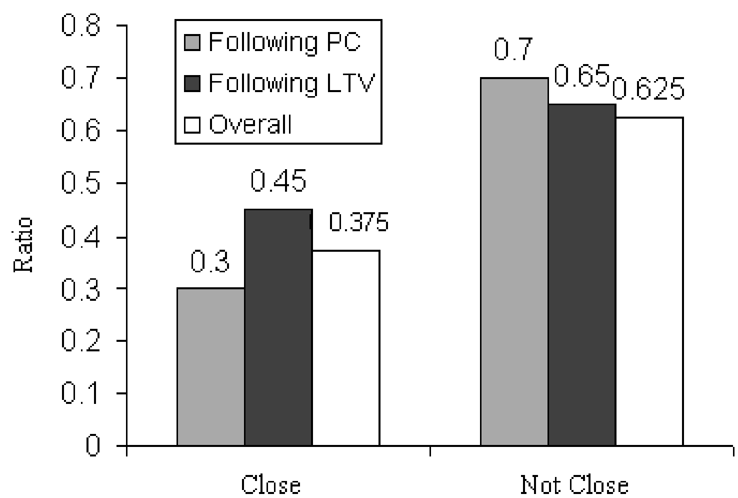


Figure 4-23: Driving close to leading vehicle (LTV and PC)

The Subjects from group A and B were asked if they saw the car making a left turn. 50% of the subjects following an LTV answered that they did not see the vehicle from the opposite direction making a left turn and 30 % of the subjects following the passenger car answered that they did not see the vehicle from the opposite direction making a left turn as shown in Figure 4-24.

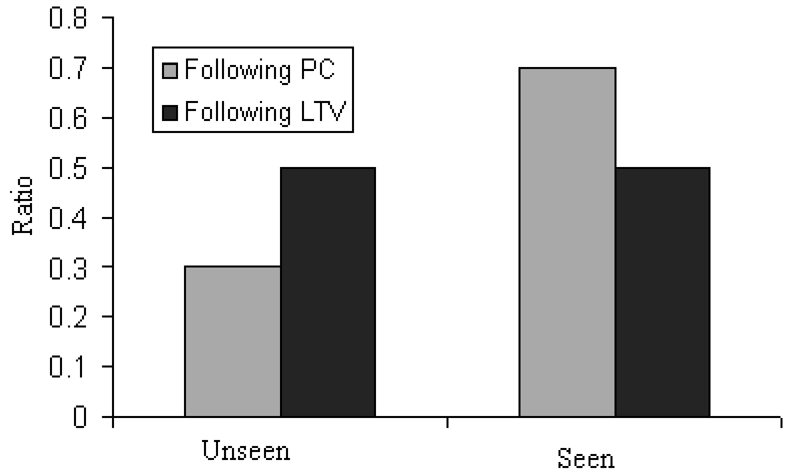


Figure 4-24: Seen or Unseen car making a left turn from the opposite direction

The subjects from group B were also asked if they encounter the same visibility problem in real life when the drive behind an LTV in similar circumstances. 65% of the subjects that were said that they encounter similar visibility problem in real life and 35% said that don't encounter similar visibility problems in real life.

4.6.10 Conclusions

As mentioned before, one of the thesis objectives was to study whether driving behind an LTV increases the probability of rear-end collisions. Therefore, from the conducted analysis it was confirmed that there is a statistically significant difference between the rear-end collisions for following an LTV and following a PC with a higher percentage of rear-ends for following LTVs. Finally, driving a passenger car behind an LTV produces a higher probability of rear-end collisions due to visibility blockage.

Another objective was to study the behavior of the subjects driving behind LTVs and whether that behavior contributed to the increase of rear-end collisions probability. Therefore, from the analysis conducted, the velocities for following an LTV and following a PC were compared and it was confirmed that there is a statistically significant difference between the velocity means with a higher mean for following LTVs. Then, one can relate the speeding behavior to the fact that subjects drive uncomfortably behind an LTV because they cannot see beyond it, therefore they feel the urge to pass it. This behavior contributes to the rear-end probability increase for following an LTV. The gaps for following an LTV and following a PC were compared and it was confirmed that there is a statistically significant difference between the means of the gap of both samples with the mean gap for following an LTV smaller than the mean gap for following a PC. This behavior can be explained by the same reasons that the drivers drive uncomfortably behind LTVs because they cannot see beyond them. Therefore, subjects speed and stay close behind LTVs waiting for a chance to pass them. Finally one can conclude that the probability of rear-end collisions for driving behind an LTV is higher than the probability of rear-end collision for driving behind a PC due to visibility blockage that obstructed the visibility of the hazard and due to the driver behavior caused by the visibility blockage.

4.7 Analyses of Vertical Visibility Experiment Data

4.7.1 Vertical visibility blockage problem

This part of the report focuses on comparing analyzing the simulator following a passenger car sub-scenario and simulator following a school bus (LSV) sub-scenario.

4.7.1.1 Operating cruising velocity of the Simulator

The cruising velocities of the simulator car following the passenger car and the school bus versus the speed limit, 35 mph, are shown in the Figure 4-25.1 below. The majority of the cruising velocities appear to close to the speed limit. Therefore, these velocities seem realistic and reflect the same velocities driving would follow on the roads.

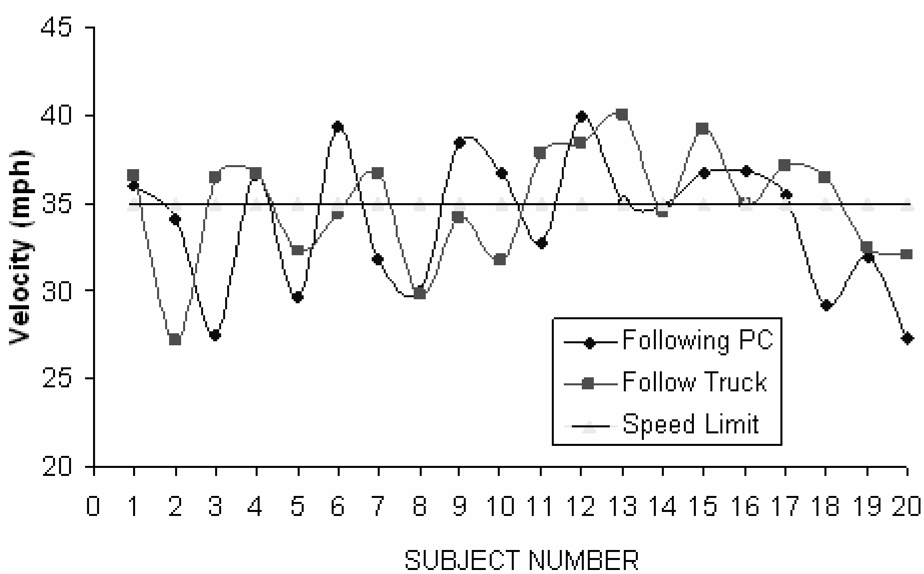


Figure 4-25: Velocities of following a school bus and a PC

4.7.1.2 Chi-square Test for Statistically significant difference between red light running between following a PC and following a truck

From the collected data, 2 subjects out of 20 subjects driving the simulator behind the PC run the red light. However, 10 subjects out of the 20 subjects driving the simulator car behind truck run the red light. Therefore, the probability of running the red light if following a PC is: $p = \frac{2}{20} = 0.1 = 10\%$, and the probability of running the red light if following a truck**:** $p = \frac{10}{20} = 0.5 = 50\%$.

To determine a significant statistical difference between the two ratios a chi-square test was completed.

Table 4-11 below is the output from MINITAB for the chi-square test with 95 % confidence interval. The resulting P-value is equal to 0.006 with is less than α=0.05. As a conclusion, there is a significant statistical difference between the red light running ratios for following a PC and following a school bus (or a truck) with red light running ratio higher for following a school bus. As a conclusion, driving behind a school bus or a large truck significantly increases the potential for red light running due to visibility problems.

Table 4-11: MINITAB output

CHI-SQUARE TEST: C1, C2

```
EXPECTED COUNTS ARE PRINTED BELOW OBSERVED COUNTS
CHI-SQUARE CONTRIBUTIONS ARE PRINTED BELOW EXPECTED COUNTS

         C1      C2  TOTAL
    1     2      18     20
       6.00   14.00
      2.667   1.143

    2    10      10     20
       6.00   14.00
      2.667   1.143
```

```
TOTAL      12      28      40

CHI-SQ = 7.619, DF = 1, P-VALUE = 0.006
```

4.7.1.3 Deceleration Rates Test

In the vertical visibility experiment, the subjects driving the simulator behind the school bus are subject to two alternatives if they see the traffic signal too late or if they don't see it at all: either they run the red light (which includes stopping in the middle of the intersection and clearing the intersection) or brake suddenly and stop on time. For the subjects driving behind the school bus who were able to stop before the intersection, it is expected that their deceleration rates are relatively high since it is assumed that those drivers perceived the traffic signal turning amber later than those driving behind a PC. Therefore, if the subjects driving behind the school bus have higher deceleration rates than those driving behind PC, it is suggested that there was a visibility problem of the traffic signal due to driving behind a larger size vehicle. To test our hypothesis, a 2 sample t-test was completed to compare the means of deceleration rates means of following a school bus and following a PC.

As mentioned before, 20 subjects drove the simulator behind the passenger car and 20 other subjects drove the simulator behind the school bus. However, if the simulator car runs the red light, its deceleration rate would be null since it did not stop. Therefore, the deceleration rates of 10 subjects that did not run the red light when they were driving behind the school bus will be compared to the deceleration rates of the 18 subjects driving behind the PC that did not run the red light.

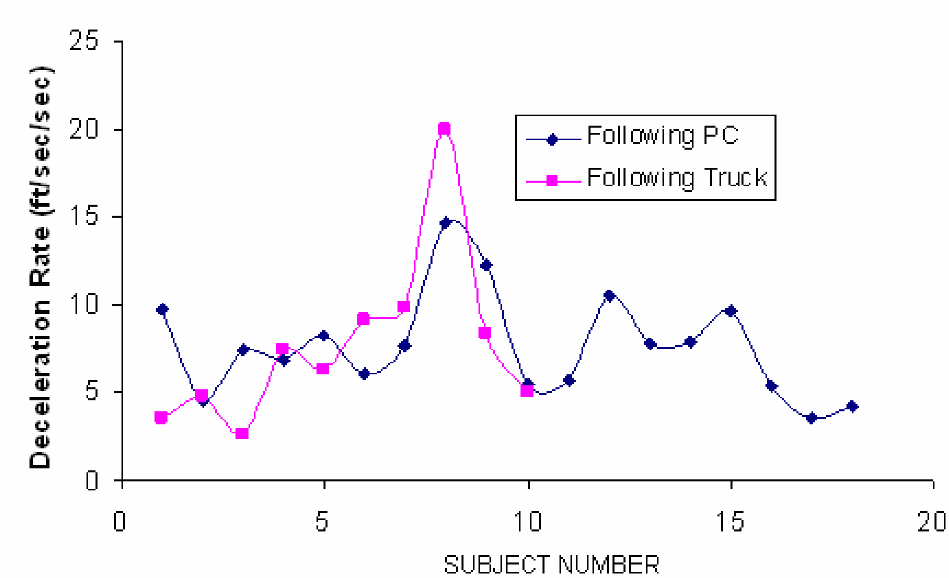


Figure 4-26: Deceleration rates of simulator for following a school bus and a PC

A 2 sample t-test was computed in MINITAB to check for a statistical significant difference between the means of both samples for 95 % confidence interval with the following hypotheses:

$$Ho: \mu_{truck} = \mu_{pc}$$
$$H1: \mu_{truck} \neq \mu_{pc}$$

From the MINITAB output below the p-value is equal to 0.97 which means that there is no significant statistical difference between the deceleration means of following a PC and following a school bus. The deceleration mean for following a truck is equal to 7.73 ft/sec/sec and the deceleration mean for following a PC is equal to 7.66 ft/sec/sec.

Table 4-12 MINITAB output

TWO-SAMPLE T FOR C1 VS C2

	N	MEAN	STDEV	SE MEAN
C1	18	7.66	2.90	0.68
C2	10	7.73	4.93	1.6

```
DIFFERENCE = MU (C1) - MU (C2)
ESTIMATE FOR DIFFERENCE:  -0.065056
95% CI FOR DIFFERENCE:  (-3.773128, 3.643017)
T-TEST OF DIFFERENCE = 0 (VS NOT =): T-VALUE = -0.04  P-VALUE = 0.970  DF = 12
```

4.7.1.4 Reaction delay time test

The reaction delay time is the time it took the driver to see and react to the traffic signal phase change. Therefore, when we compare the reaction delay times of following the school bus and following the passenger car, if the delay response times for following a school bus are greater that those following a passenger car, it is suggested that a visibility problem had occurred. Figure 4-27 below shows the reaction times for both scenarios. The reaction delay times for subjects 3 and 4 following a PC and subject 2 following a school bus are negative which means that the drivers stepped on the brake before the traffic signal turns amber. Those negative values imply that those drivers were cautious and careful when they approached the intersection and decided to slow down.

As mentioned before, 20 subjects drove the simulator behind the passenger car and 20 other subjects drove the simulator behind the school bus. However, if the simulator car runs the red light, its reaction delay time would be null since it did not stop. Therefore, the reaction delay time of 10 subjects that did not run the red light when they were driving behind the school bus will be compared to the reaction delay time of the 18 subjects driving behind the PC that did not run the red light.

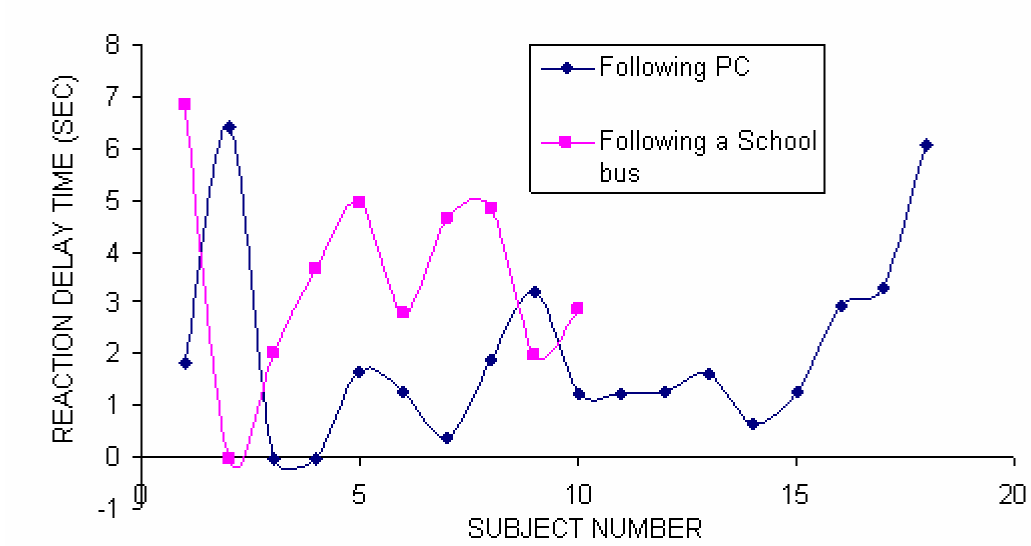


Figure 4-27: Reaction delay times of following a school bus and following a PC

As shown in Figure 4-27 the majority of reaction delay times of following a school bus are greater than the reaction delay times of following a PC. From the MINITAB output below the mean reaction delay time for following a school bus is 3.45 sec and the mean reaction delay time for following a PC is 2.02 sec.

A 2 sample t-test was computed in MINITAB to check for a statistical significant difference between the means of both samples for 95 % confidence interval with the following hypothesis and null hypotheses:

$$Ho : \mu_{truck} = \mu_{pc}$$

$$H1 : \mu_{truck} \neq \mu_{pc}$$

Table 4-13 MINITAB output

TWO-SAMPLE T FOR C1 VS C2

	N	MEAN	STDEV	SE MEAN
C1	18	2.02	1.81	0.43
C2	10	3.45	1.95	0.62

```
DIFFERENCE = MU (C1) - MU (C2)
ESTIMATE FOR DIFFERENCE:  -1.43594
95% CI FOR DIFFERENCE:  (-3.01880, 0.14691)
T-TEST OF DIFFERENCE = 0 (VS NOT =): T-VALUE = -1.91  P-VALUE = 0.073  DF = 17
```

From the MINITAB output below the p-value is equal to 0.073 which means that there is no significant statistical difference between the deceleration means of following a PC and following a school bus. However, the p-value is fairly close to 0.05 which means that there is a marginal statistical difference between the reaction delay times of following a PC and following a school bus with a higher reaction delay time for following school bus. Therefore, this marginal statistical difference implies a visibility problem for following a school bus that leads to red light running.

4.7.1.5 Test for cruising velocity

The cruising velocities collected are the average velocities of the simulator car following a PC or a school bus just before the traffic signal turns amber. The purpose of testing the cruising velocities difference between the two scenarios is to study the behavior of subjects driving behind large size vehicles and to analyze the effect of this behavior on the red light running rate. Indeed, if the subjects are frustrated because they are driving blindly behind the bus, they might have higher speeds because of their intent to pass it. From Figure 4-28 below the velocities seem fairly close. Therefore, one can conclude that the subjects' behavior while driving behind the school bus was similar to their driving behind a passenger car. Furthermore, the velocity does not have a direct impact on the red light running rate. To confirm this conclusion, a 2 sample t-test was completed to compare the velocity means of both samples with the following hypotheses:

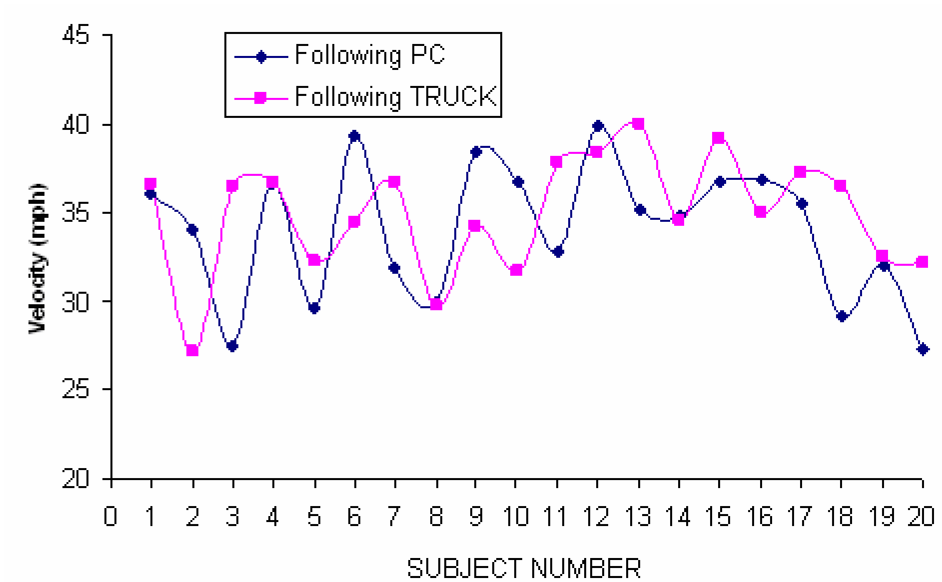


Figure 4-28: Cruising velocities for following a school bus and PC

$$Ho: \mu_{truck} = \mu_{pc}$$
$$H1: \mu_{truck} \neq \mu_{pc}$$

Table 4-14: MINITAB output

```
TWO-SAMPLE T FOR C1 VS C2

     N   MEAN   STDEV   SE MEAN
C1   20  34.00   3.80     0.85
C2   20  34.95   3.27     0.73


DIFFERENCE = MU (C1) - MU (C2)
ESTIMATE FOR DIFFERENCE:  -0.949500
95% CI FOR DIFFERENCE:  (-3.221219, 1.322219)
T-TEST OF DIFFERENCE = 0 (VS NOT =): T-VALUE = -0.85  P-VALUE = 0.403  DF = 37
```

From the above MINITAB output the P-value is 0.403 which is greater than 0.05. Therefore there is a no statistically significant difference between the two sample means with the mean of following a school bus equal to 34.95 mph and mean following PC 34.00 mph.

4.7.1.6 Test for gap

Gap is also one of the important variables in our research. For example, if the gap of following a vehicle is smaller than the gap of following another vehicle, the vehicle followed with the smaller gap is more likely to get in an accident. From Figure 4-29 below some subjects followed the school bus at a larger gap than the gap for following a passenger car.

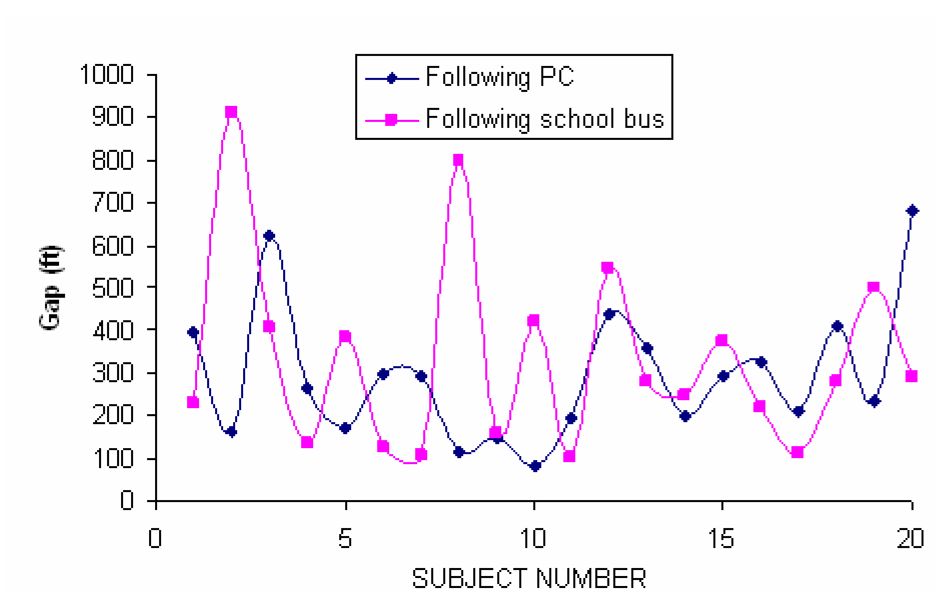


Figure 4-29: Gap for following a school bus and for following a PC

To verify this fact, a t-test was performed to compare the gap means of both samples. From the MINITAB output in Table 4-15 below p-value is 0.398 which is larger than

0.05. Therefore, there is no statistical difference between the gap means of both sample means. This result can be explained by the fact the subjects driving behind larger size vehicles do not intend to pass it because they are aware that the larger size vehicle is too long to be passed safely although they are frustrated due the visibility blockage the school bus causes.

Table 4-15: MINITAB output

TWO-SAMPLE T-TEST AND CI: PC, SCHOOL BUS

```
TWO-SAMPLE T FOR PC VS SCHOOL BUS

                              SE
             N  MEAN  STDEV  MEAN
PC          20   154    112    25
SCHOOL BUS  20   187    134    30


DIFFERENCE = MU (PC) - MU (SCHOOL BUS)
ESTIMATE FOR DIFFERENCE:  -33.3711
95% CI FOR DIFFERENCE:  (-112.5015, 45.7594)
T-TEST OF DIFFERENCE = 0 (VS NOT =): T-VALUE = -0.86  P-VALUE = 0.398  DF = 36
```

4.7.1.7 Survey Analysis

As mentioned before, subjects were asked to answer a survey after they finish driving the simulator car. For vertical visibility blockage scenarios (following a PC and following a school bus) four questions were addressed to the subjects as shown in appendix B.

To start with, the subjects were asked if they saw the traffic signal pole in both following a PC and following a school bus sub-scenarios. As shown in Figure 4-30, 10 subjects who drove behind the school bus reported that they did not see the traffic signal, and the 10 other subjects driving behind the school bus reported that they saw the traffic light.

The subjects that reported that they did not see the traffic signal ran the red light. Therefore, the cause of running the red light is a visibility problem.

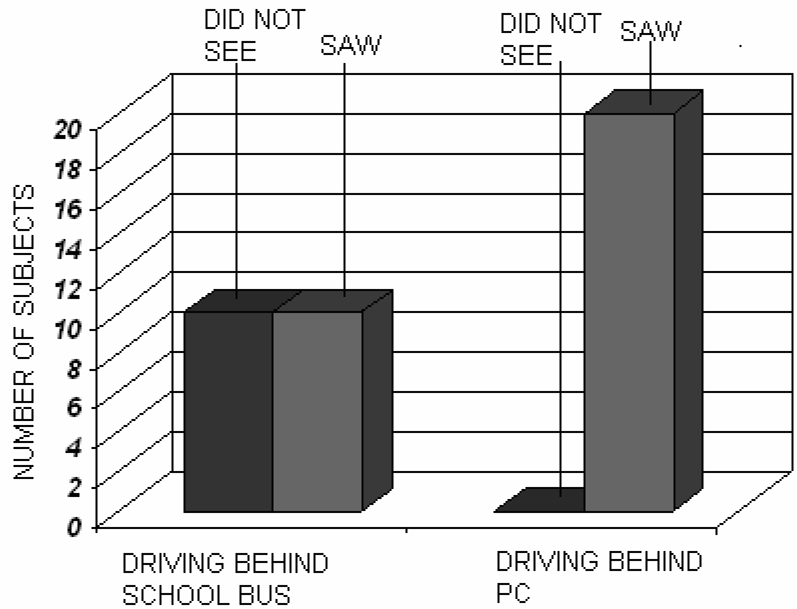


Figure 4-30: Traffic signal visibility for following a PC and following a school bus.

The same subjects were asked whether when they saw the traffic signal it was too late for them to stop. As shown in Figure 4-31, the 10 subjects who ran the red lights reported that they saw the traffic signal at some point when they were driving and that it was too late for them to stop. However, the two subjects driving behind the passenger car and ran the red light reported that they saw the traffic signal but they still ran the red light because they just decided not to stop thinking it is too late.

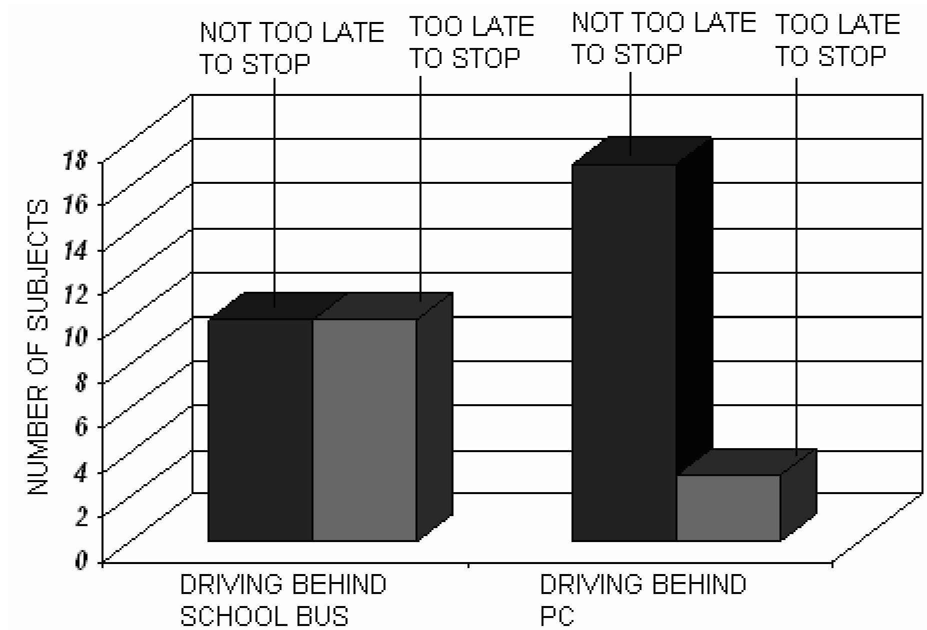


Figure 4-31: "too late to stop" following a school bus and following a PC

As shown in Figure 4-32, the 20 subjects driving behind a school bus and the other 20 subjects driving behind a passenger car were asked if they drive closely to passenger cars and buses respectively.

The ten subjects who drove behind the school bus reported that they drive close behind a large truck in daily life and the other 10 subjects who drove behind the school bus reported that they don't drive close behind large vehicle. However, 8 subjects driving behind the passenger car reported that they drive close to passenger cars in daily life and the remaining 12 subjects driving behind a passenger car reported that they keep a large distance when they drive behind a passenger car in daily life and in similar circumstances.

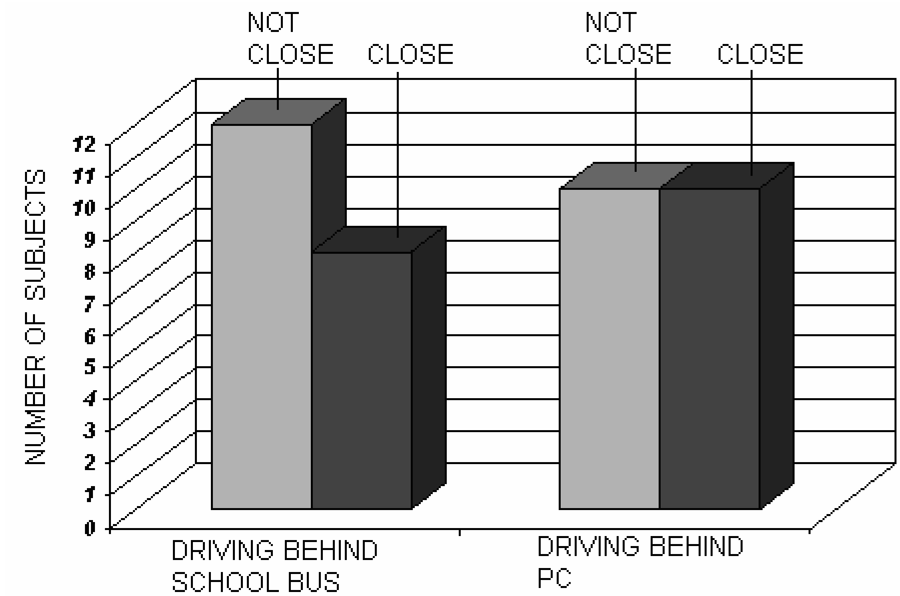


Figure 4-32: Driving close behind a school and a PC

The 20 subjects driving behind a school bus were asked if they encounter this visibility problem in their daily life. As shown in Figure 4-33, 80% of the subjects said that they come upon the vertical visibility problem in daily life causing them frustration and leading to red light running.

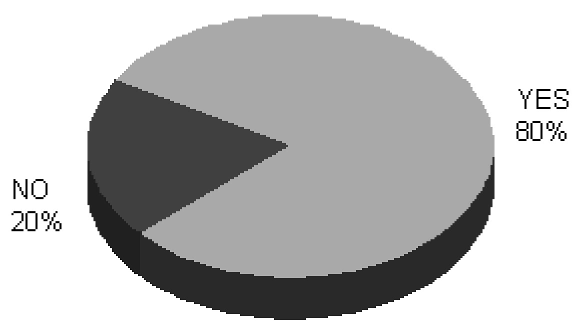


Figure 4-33: Visibility problem in daily life.

4.7.2 Vertical visibility blockage proposed solution

As seen in the previous section, larger size vehicles generate vertical visibility blockage of the traffic signal for the following passenger cars resulting in red light running.

4.7.2.1 Operating cruising velocity of the Simulator

The cruising velocities of the simulator car following the school bus and the speed of the simulator car following the school bus with the addition of the traffic signal on the right side of the road versus the speed limit, 35 mph, are shown in the Figure 4-34 below. These velocities seem realistic and reflect the same velocities driving would follow on the roads.

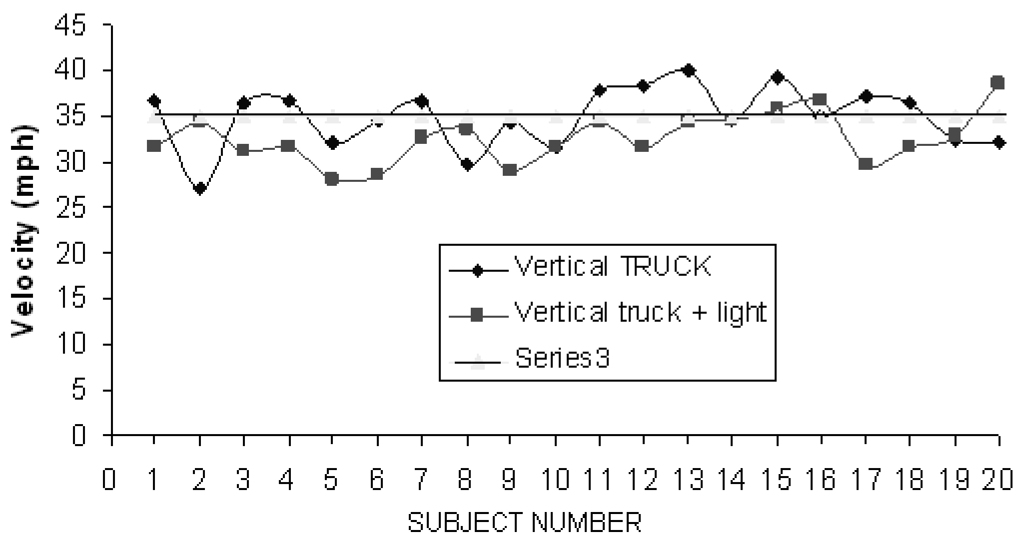


Figure 4-34: Velocities of following a school bus and a PC

4.7.2.2 Chi-Square Test for red light running between following a school bus and following a school bus with addition of traffic signal pole.

From the collected data, 4 subjects out of 20 subjects driving the simulator behind school bus with the additional traffic signal pole ran the red light. However, 10 subjects out of the 20 subjects driving the simulator car behind school bus ran the red light. Therefore, the probability of running the red light if following a school bus with additional traffic signal pole is: $p = \frac{4}{20} = 20\%$, and the probability of running the red light if following a school bus: $p = \frac{10}{20} = 0.5 = 50\%$.

To determine a significant statistical difference between the two ratios a chi-square test was completed.

Table 4-16 below is the output from MINITAB for the chi-square test with 95 % confidence interval. The resulting P-value is equal to 0.047 with is close to α=0.05. As a conclusion, there is a significant statistical difference between the red light running ratios for following a school bus (or a truck) with and without the additional traffic signal pole. As a conclusion, driving behind a school bus or a large truck with an extra traffic signal pole of the right side of the road decreases the potential for red light running significantly.

Table 4-16: MINITAB output

CHI-SQUARE TEST: C1, C2

```
EXPECTED COUNTS ARE PRINTED BELOW OBSERVED COUNTS
CHI-SQUARE CONTRIBUTIONS ARE PRINTED BELOW EXPECTED COUNTS

           C1      C2  TOTAL
    1       4      16     20
         7.00   13.00
        1.286   0.692
```

```
    2      10      10      20
         7.00   13.00
        1.286   0.692

TOTAL      14      26      40

CHI-SQ = 3.956, DF = 1, P-VALUE = 0.047
```

4.7.2.3 Deceleration rates test

As mentioned in the first section of chapter 6, the subjects that have a higher deceleration rate mean suffer from a visibility problem. 20 subjects drove the simulator behind the school bus without an additional traffic signal pole and 20 other subjects drove the simulator behind the school bus with additional traffic signal pole. However, if the simulator car runs the red light, its deceleration rate would be null since it did not stop. Therefore, the deceleration rates of 10 subjects that did not run the red light when they were driving behind the school bus without the additional traffic signal pole will be compared to the deceleration rates of the 16 subjects driving behind the school bus with the additional traffic signal pole that did not run the red light. Figure 4-35 shows the deceleration rates for both sub-scenarios which seem to be similar.

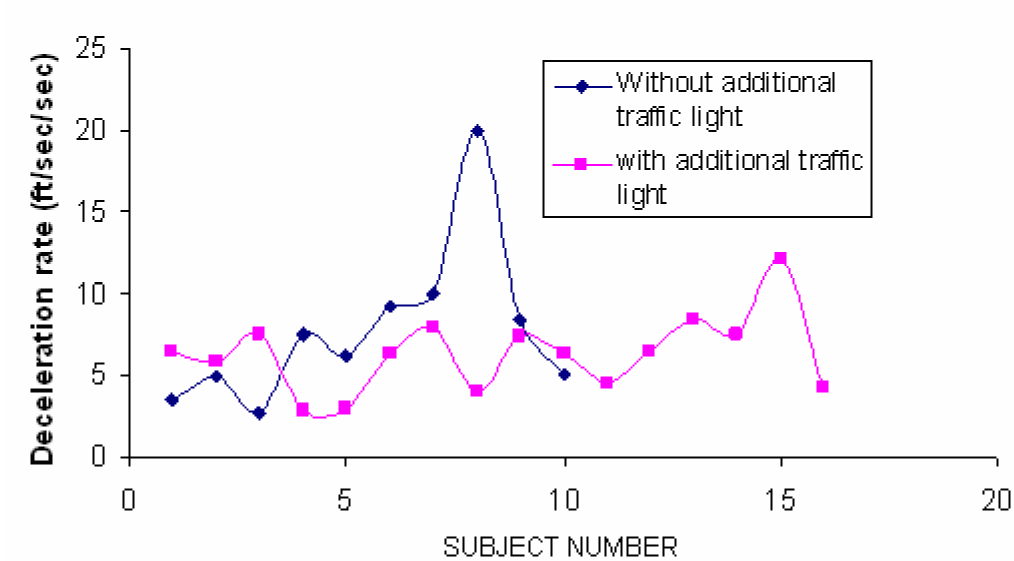


Figure 4-35: Deceleration rates of simulator for following a school bus and a PC

A 2 sample t-test was computed in MINITAB to check for a statistical significant difference between the means of both samples for 95 % confidence interval with the following hypotheses:

$$H_0 : \mu_{withlight} = \mu_{withoutlight}$$
$$H_1 : \mu_{withlight} \neq \mu_{withoutlight}$$

From the MINITAB output below the p-value is equal to 0.408 which means that there is no significant statistical difference between the deceleration means of both sub-scenarios. The deceleration mean for following the school bus is equal to 7.73 ft/sec/sec and the deceleration mean for following the school bus with additional traffic signal pole is equal to 6.30 ft/sec/sec.

Table 4-17: MINITAB output

TWO-SAMPLE T-TEST AND CI: C1, C2

```
TWO-SAMPLE T FOR C1 VS C2

     N  MEAN  STDEV  SE MEAN
C1  10  7.73   4.93      1.6
C2  16  6.30   2.32     0.58


DIFFERENCE = MU (C1) - MU (C2)
ESTIMATE FOR DIFFERENCE:  1.43188
95% CI FOR DIFFERENCE:  (-2.22794, 5.09169)
T-TEST OF DIFFERENCE = 0 (VS NOT =): T-VALUE = 0.86  P-VALUE = 0.408  DF = 11
```

4.7.2.4 Reaction delay time means test

This section compares the reaction delay times of following the school bus with and without an additional traffic signal pole. As explained earlier, when the delay response time mean for one sub-scenario is higher than the delay response time mean for another scenario, it is suggested that a visibility problem had occurred with the larger reaction delay time. Figure 4-36 below shows the reaction times for both sub-scenarios.

Similarly to the deceleration rates, if the simulator car runs the red light, its reaction delay time would be null since it did not stop. Therefore, the reaction delay time of 10 subjects that did not run the red light when they were driving behind the school bus will be compared to the reaction delay time of the 16 subjects driving behind the school bus with an additional traffic signal pole that did not run the red light.

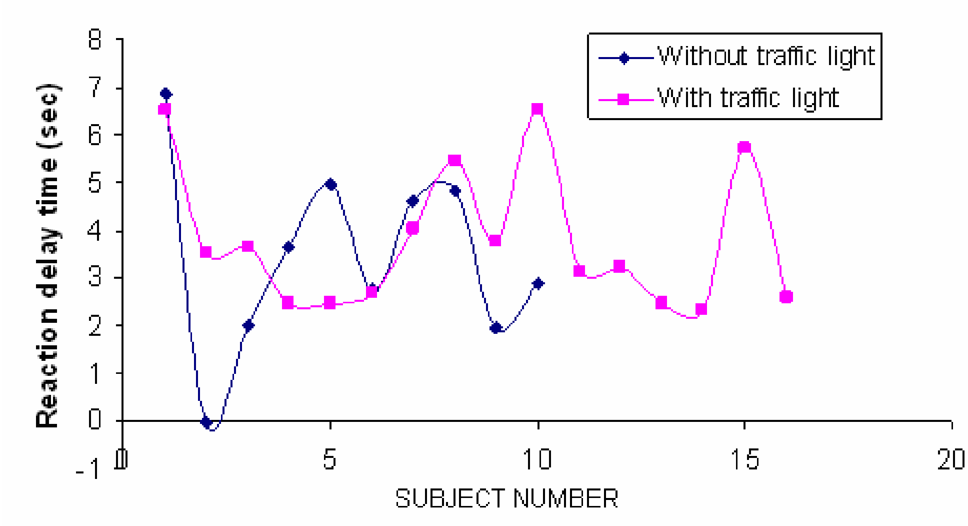


Figure 4-36: Reaction delay times of following a school bus and following a PC

A 2 sample t-test was computed in MINITAB to check for a statistical significant difference between the means of both samples for 95 % confidence interval with the following hypotheses:

$$H_0 : \mu_{withlight} = \mu_{withoutlight}$$
$$H_1 : \mu_{withlight} \neq \mu_{withoutlight}$$

Table 4-18: MINITAB output

TWO-SAMPLE T-TEST AND CI: C1, C2

```
TWO-SAMPLE T FOR C1 VS C2

     N  MEAN   STDEV  SE MEAN
C1  10  3.45   1.95      0.62
C2  16  3.79   1.47      0.37


DIFFERENCE = MU (C1) - MU (C2)
ESTIMATE FOR DIFFERENCE:  -0.333625
95% CI FOR DIFFERENCE:  (-1.864502, 1.197252)
T-TEST OF DIFFERENCE = 0 (VS NOT =): T-VALUE = -0.46  P-VALUE = 0.649  DF = 15
```

From the MINITAB output above the p-value is equal to 0.649 which means that there is no significant statistical difference between the reaction delay times of both samples. This result is reasonable since we are comparing the reaction delay time for the subjects that did not run the red light.

4.7.2.5 Test for cruising velocity

The collected cruising velocities are the average velocities of the simulator car in both sub-scenarios just before the traffic signal pole turns amber. The purpose of testing the cruising velocities difference between the two sub-scenarios is to study the behavior of subjects driving behind large size vehicles, with and without the additional traffic signal pole, and to analyze the effect of this behavior on the red light running rate. Indeed, if the subjects are frustrated because they are driving blindly behind the bus, they might have higher speeds because of their intent to pass it. However, in the same circumstances but with an additional traffic signal pole on the right side of the road, the subjects might be more careful since they see the additional traffic signal pole and consequently slow down. From Figure 4-37 below the velocities of the simulator with additional traffic signal pole seem lower than the velocity of the simulator without additional traffic signal pole. Therefore, one can conclude that the subjects' behavior while driving behind the school bus with additional traffic signal pole were more careful because of the traffic signal pole. To confirm this conclusion, a 2 sample t-test was completed to compare the velocity means of both samples with the following hypotheses:

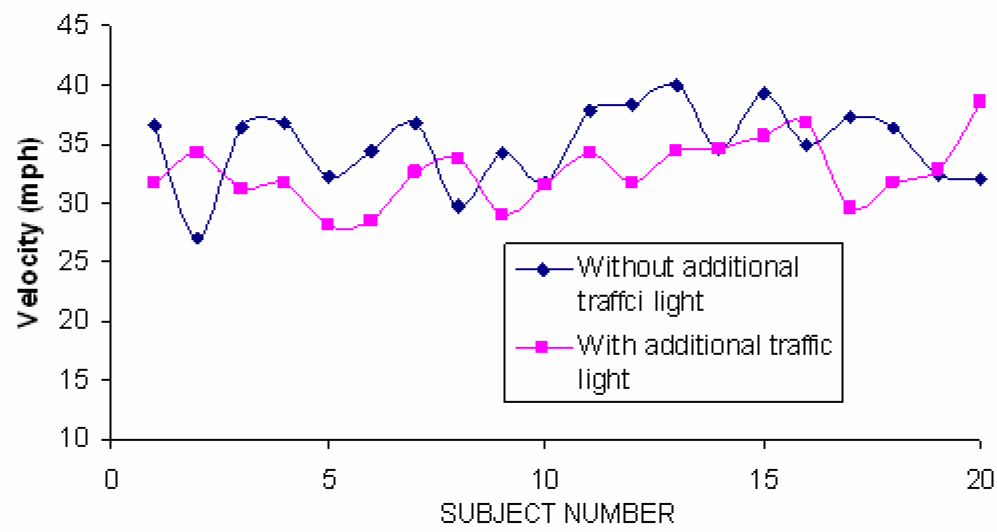


Figure 4-37: Cruising velocities for following a school with and without an additional traffic signal pole

$$H_0 : \mu_{withlight} = \mu_{withoutlight}$$
$$H_1 : \mu_{withlight} \neq \mu_{withoutlight}$$

Table 4-19: MINITAB output

TWO-SAMPLE T-TEST AND CI: C1, C2

```
TWO-SAMPLE T FOR C1 VS C2

     N   MEAN  STDEV  SE MEAN
C1  20  34.95   3.27     0.73
C2  20  32.61   2.71     0.61


DIFFERENCE = MU (C1) - MU (C2)
ESTIMATE FOR DIFFERENCE:  2.34300
95% CI FOR DIFFERENCE:  (0.41673, 4.26927)
T-TEST OF DIFFERENCE = 0 (VS NOT =): T-VALUE = 2.47  P-VALUE = 0.019  DF = 36
```

From the above MINITAB output the P-value is 0.019 which is less than 0.05. Therefore, the mean velocity of following a school bus equal to 34.95 mph and following a school bus with an additional traffic signal pole 32.61 mph. Therefore, the above conclusion is confirmed.

4.7.2.6 Test for gap

As mentioned in the first section of chapter 6, gap is also one of the important variables in our research. Figure 4-38 below most of the subjects followed the school bus with an additional traffic signal pole at a larger gap than the gap for following the school bus without an additional traffic signal pole. This also explains that the additional traffic signal pole made subjects more careful and consequently made them drive at a higher gap behind the school bus.

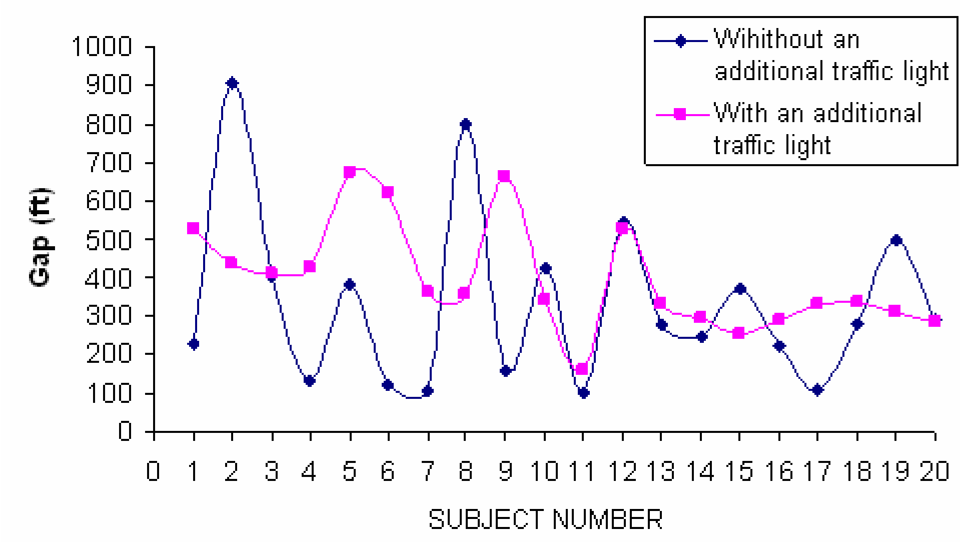


Figure 4-38: Gap for following a school bus with and without an additional traffic signal pole

To verify this fact, a t-test was performed to compare the gap means of both samples. From the MINITAB output in Table 4-20 below p-value is 0.273 which is larger than 0.05. Therefore, there is no statistical difference between the gap means of both sample means.

Table 4-20: MINITAB output

TWO-SAMPLE T-TEST AND CI: C1, C2

```
TWO-SAMPLE T FOR C1 VS C2

                        SE
     N  MEAN  STDEV  MEAN
C1  20   331    223    50
C2  20   397    140    31


DIFFERENCE = MU (C1) - MU (C2)
ESTIMATE FOR DIFFERENCE:  -65.6413
95% CI FOR DIFFERENCE:  (-185.5911, 54.3084)
T-TEST OF DIFFERENCE = 0 (VS NOT =): T-VALUE = -1.12  P-VALUE = 0.273  DF = 31
```

4.7.2.7 Survey Analysis

As mentioned before, all the subjects were asked to take a survey once they complete the experiment. One of the questions that the subjects were asked was which traffic signal pole they saw first. As shown in Figure 4-39, 70 % of the subjects said that they saw the additional traffic signal pole on the side of the road before they saw originally installed traffic signal pole and 30 % of the subject said that they saw them at the same time.

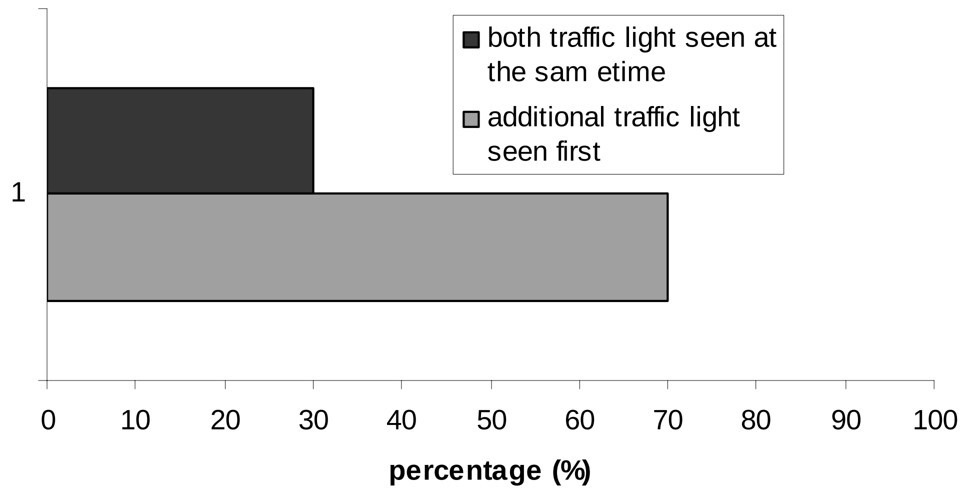


Figure 4-39: traffic signal poles visibility

The subjects were also asked if they think that the traffic signal pole addition would be profitable for the drivers' safety in real life. As shown in Figure 4-40, 65% of the subjects said that it is profitable and the remaining subjects said that it is not profitable.

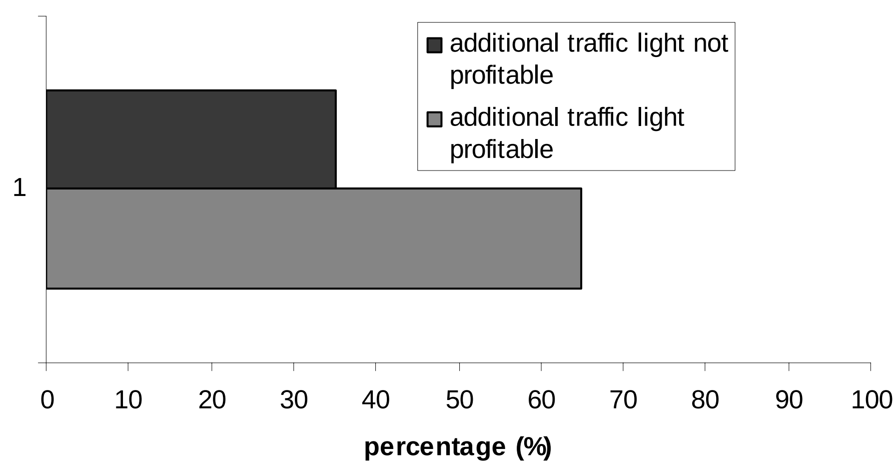


Figure 4-40: Additional traffic signal pole evaluation for real life

4.7.3 Conclusions

One of the objectives of the research is to study whether driving behind a larger size vehicle such as school buses increases the rate of red light running on signalized intersections. From the above analysis, it was confirmed that there is a significant statistical difference between the rates of red light running for following a passenger car and for following a larger size vehicle with a higher rates of red light running for driving behind a larger size vehicle due to vertical visibility blockage of the traffic signal pole.

Another objective was to study the behavior of the subjects driving behind larger size vehicles. From the analysis above it was confirmed that there is no statistical difference between the velocities of the two samples. Therefore, one can conclude that subjects driving a larger size vehicle do not speed more than they speed when they drive behind a passenger car for the reason that they know that it is hard to pass a larger size vehicle although they are frustrated because the visibility beyond the larger size vehicle is obstructed by the latter. From the above analysis, it was also confirmed that there is no statistical difference between the gap means for following a PC or following a lager size vehicle. This behavior can be explained by the same reasons that subjects know that it is too hard and dangerous to pass the school bus although they are frustrated.

From the above analysis, one can conclude that the red light running rate when following a larger size vehicle through signalized intersections is higher than the red light running rate when following a passenger due to vertical visibility blockage of the traffic. However, the behavior of the subjects does not contribute to red running rate.

The proposed addition of the traffic signal pole on the right side of the road profitability was also tested. From the above analysis, the red light running rate decreased significantly and 65 % of the subjects that completed the experiment said that the traffic signal pole would be profitable for use in real life. Finally, the addition of the traffic signal pole on the right side of the road reduces the red light running rate and consequently increases the safety of the drivers.

Chapter 5. Summary and Conclusions

The UCF Driving simulator was used to test a proposed pavement-marking design. This marking is placed in advance of the intersection to assist the motorists with advance warning concerning the occurrence of the clearance interval. The results of the experiment have indicated promising results for signalized-intersection safety. Firstly compared to regular intersections, the pavement marking could results in a 74.3 percent reduction in red-light running. In comparison, the pavement marking reduced the number of occurrences where drivers chose to continue through an intersection when it was not safe to proceed compared to the without marking, and this result is correlated to less red-light running rate with marking. Furthermore, for those running red-light drivers, the marking tends to reduce the red-light entry time. The results may contribute to reducing the probability of angle crashes.

Secondly, logistic regression models attest that the marking is helpful to improve driver stop-go decision at intersections. Compared to without marking, if the drivers located near to the stop bar, drivers tend to cross the intersection with the marking; if the drivers located farther to the stop bar, drivers tend to stop at the intersection with the marking. The results showed that the uncertainty distances between 20% and 80% probability of stopping with marking are about 23 ft for the 30 mph and 50 ft for the 45 mph shorter in comparison with regular intersections. The analysis indicates that the marking information can help to reduce driver hesitated region to decide to stop or cross the intersection, which possibly results in higher accident rates.

Thirdly, it was found that for those stopping drivers, the brake deceleration rate without marking is 1.959 ft/s^2 significantly larger than that with marking for the higher speed limit. With the marking information, the probability that drivers make a too conservative stop will decrease if they are located in the downstream of marking at the onset of yellow, which resulted in the gentler deceleration rate with marking. At intersections, the smaller deceleration rate may contribute to the less probability that rear-end crashes happen.

Moreover, according to survey results, all of subjects gave a positive evaluation of the pavement-marking countermeasure and nobody felt confused or uncomfortable when they made stop-go decision. In comparison between scenarios without marking and with marking, there is no significant difference found in the operation speeds and drivers brake response time, which proved that the marking has no significantly negative effect on driver behaviors at intersections.

Therefore, the pavement-marking countermeasure may contribute to reducing the number of red light running violations and improving traffic safety situation related to both angle and rear-end crashes at signalized intersections.

Vertical and horizontal visibility blockages and their consequences on the safety of traffic were the major issue of our research. To study the seriousness of these issues, 5 sub-scenarios were designed in the UCF driving simulator as explained before. And the resulting data were thoroughly analyzed and conclusions were made.

For the horizontal visibility blockage, two sub-scenarios were designed, and the results confirmed that LTVs contribute to the increase of rear-end collisions on the roads. This fact is due to the horizontal visibility blockage LTVs cause and consequently due to the following driver's behavior when he/she drives behind an LTV. Indeed, the results showed that passenger car drivers behind LTVs are prone to speed more and to keep a small gap with the latter relatively to driving behind passenger cars. This behavior is probably due to drivers' frustration and their eagerness to pass the LTV. Moreover, the trend of the impact velocities shows a higher impact velocities when vehicles follow an LTV, therefore rear-end collisions with LTVs are more severe than rear-end collisions when following a passenger car. From the survey analysis 65% of the subjects said that they drive close to LTVs in real life. Therefore, the horizontal visibility blockage is a problem that occurs in real life and should be taken into serious consideration for the safety of the passenger car drivers.

As for the vertical visibility blockage, three sub-scenarios were designed in the driving simulator, and the results confirmed that LSVs increases the rate of red light running significantly due to vertical visibility blockage of the traffic signal pole. However, the behavior of the drivers when they drive behind LSVs is not different then their behavior when drive behind passenger cars. In fact, the velocities and gaps were similar which is due to the fact that subjects driving behind an LSV know that the LSV is too long and that it is too hard to pass it. Therefore, although the drivers are frustrated behind the

LSVs, they know that they cannot pass it; therefore they keep normal gaps and velocities waiting for the LSV to change its path.

The suggested addition of the traffic signal pole on the side of the road significantly decreased the red light running rate. Moreover, 65% of the subjects driving behind an LSV with the proposed additional traffic signal pole said that the traffic signal pole is effective and that it should be applied to real world. Therefore, since red light running can cause accidents and safety threat for drivers and since the additional traffic signal pole decreased the red light running rate, the addition of traffic signal poles on the right side of the road is a profitable countermeasure that may help enhance driving safety at signalized intersections.

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Appendix A. Investigation Form of Red-light Running Experiment

1. DID YOU EXPERIENCE RED-LIGHT RUNNING BEFORE IN THE REAL WORLD?

YES ______ NO______

2. IF YOU DID, HOW OFTEN?

PER DAY ___ PER SEVERAL DAYS___ PER WEEK ___ PER SEVERAL WEEKS___
MORE THAN ONE MONTH___ NEVER RUN RED LIGHT ___

3. IF YOU DID, WHAT IS YOUR REASON TO DO THAT?

TO AVOID TRAFFIC DELAY AT THE INTERSECTION___
INATTENTIVE DRIVING___
INCAPABLE OF STOPPING DURING THE YELLOW SIGNAL PHASE BECAUSE OF POOR JUDGMENT___
OTHERS (PLEASE SPECIFY THE REASON)
____
____

4. IS RED-LIGHT RUNNING A DANGEROUS BEHAVIOR?

YES ______ NO______

5. IN THE REAL WORLD, WHEN YOU ARE APPROACHING A SIGNALIZED INTERSECTION, IF TRAFFIC LIGHT TURNS YELLOW, DO YOU FEEL SOMETIMES IT IS NOT EASY TO DECIDE WHETHER STOP OR CROSS THE INTERSECTION?

YES ______ NO______

6. IF THE ABOVE SITUATION DESCRIBED IN QUESTION #5 HAPPENED TO YOU BEFORE, DID IT RESULT IN YOUR RED-LIGHT RUNNING?

YES ______ NO______

6. IF THE ABOVE SITUATION DESCRIBED IN QUESTION #5 HAPPENED TO YOU BEFORE, DID IT RESULT IN YOUR UNCOMFORTABLE STOP?

YES ______ NO______

7. DO YOU THINK ADDITIONAL INFORMATION TO HELP DRIVERS DECIDE WHETHER STOP OR GO AT SIGNALIZED INTERSECTIONS IS SIGNIFICANT?

YES ______ NO______

8. DO YOU THINK THE PAVEMENT MARKING DESIGN CAN HELP YOU MAKE STOP-GO DECISION AT SIGNALIZED INTERSECTIONS?

YES ______ NO______

9. DURING THE COURSE OF THE EXPERIMENTS, WHEN YOU ENCOUNTERED YELLOW PHASES, DID THE PAVEMENT MARKING CAUSE YOU CONFUSED OR UNCOMFORTABLE WHEN YOU MADE STOP-GO DECISION?

YES ______ NO______

10. DO YOU AGREE THAT THE PAVEMENT MARKING SHOULD BE APPLIED TO THE REAL ROAD?

YES ______ NO______

11. HOW DO YOU EVALUATE THE FIDELITY OF THE WHOLE SIMULATION EXPERIMENT?

1 __	2 __	3 __	4 __	5 __
POOR	**NEEDS IMPROVEMENT**	**SATISFACTORY**	**GOOD**	**EXCELLENT**

Appendix B. Investigation Form of View Blockage Experiment

GROUP A

A- SCENARIO 1- HORIZONTAL VISIBILITY BLOCKAGE

1-) HOW DO YOU RATE THE SIMULATOR CAR DRIVING RELATIVELY TO REAL CARS DRIVING. RANGE FROM 1 TO 5

BRAKES: 1 2 3 4 5

ACCELERATION: 1 2 3 4 5

DECELERATION: 1 2 3 4 5

2-) DID YOU DRIVE THE SIMULATOR CAR SIMILARLY TO HOW YOU DRIVE YOUR CAR ON THE ROAD (ATTENTION, SPEED…)

YES NO OTHER ___________________________________

3-) DO YOU USUALLY DRIVE CLOSELY BEHIND A PASSENGER CAR IN SIMILAR CIRCUMSTANCES?

YES NO

4-) DID YOU SEE THE CAR MAKING A LEFT TURN BEFORE THE LEADING CAR STARTED BRAKING?

YES NO

5-) DO YOU ENCOUNTER SIMILAR VISIBILITY PROBLEMS IN REAL LIFE?

YES NO

6-) RATE THE SCENARIO COMPONENTS (SURROUNDING, AUDIO, AND VISUAL)

1 2 3 4 5

B- SCENARIO 2- VERTICAL VISIBILITY BLOCKAGE

1-) DID YOU SEE THE TRAFFIC SIGNAL POLE?

YES NO

2-) IF YOU SAW THE TRAFFIC SIGNAL POLE WAS IT TOO LATE TO STOP?

YES NO

3-) DO YOU USUALLY DRIVE <u>CLOSELY</u> BEHIND A TRUCK OR BUS IN SIMILAR CIRCUMSTANCES?

YES NO

4-) DO YOU ENCOUNTER THIS VISIBILITY PROBLEM IN YOUR DAILY LIFE?

YES NO

GROUP B

C- SCENARIO 1- HORIZONTAL VISIBILITY BLOCKAGE

1-) HOW DO YOU RATE THE SIMULATOR CAR DRIVING RELATIVELY TO REAL CARS DRIVING. RANGE FROM 1 TO 5

BRAKES: 1 2 3 4 5

ACCELERATION: 1 2 3 4 5

DECELERATION: 1 2 3 4 5

2-) DID YOU DRIVE THE SIMULATOR CAR SIMILARLY TO HOW YOU DRIVE YOUR CAR ON THE ROAD (ATTENTION, SPEED…)

YES NO OTHER ________________________________

3-) DO YOU USUALLY DRIVE CLOSELY BEHIND A VAN OR SUV IN SIMILAR CIRCUMSTANCES?

YES NO

4-) DID YOU SEE THE CAR MAKING A LEFT TURN BEFORE THE LEADING CAR STARTED BRAKING?

YES NO

5-) DO YOU ENCOUNTER SIMILAR VISIBILITY PROBLEMS IN REAL LIFE?

YES NO

6-) RATE THE SCENARIO COMPONENTS (SURROUNDING, AUDIO, AND VISUAL)

1 2 3 4 5

D- SCENARIO 2- VERTICAL VISIBILITY BLOCKAGE

1-) DID YOU SEE THE TRAFFIC SIGNAL POLE?

YES NO

2-) IF YOU SAW THE TRAFFIC SIGNAL POLE WAS IT TOO LATE TO STOP?

YES NO

3-) DO YOU USUALLY DRIVE CLOSELY BEHIND A PASSENGER CAR IN SIMILAR CIRCUMSTANCES?

YES NO

4-) DO YOU ENCOUNTER THIS VISIBILITY PROBLEM IN YOUR DAILY LIFE?

YES NO

GROUP C

1-) HOW DO YOU RATE THE SIMULATOR CAR DRIVING RELATIVELY TO REAL CARS DRIVING. RANGE FROM 1 TO 5

BRAKES : 1 2 3 4 5

ACCELERATION: 1 2 3 4 5

DECELERATION: 1 2 3 4 5

2-) DID YOU DRIVE THE SIMULATOR CAR SIMILARLY TO HOW YOU DRIVE YOUR CAR ON THE ROAD (ATTENTION, SPEED…)

YES NO OTHER ___________________________________

3-) DO YOU USUALLY DRIVE CLOSELY BEHIND A TRUCK OR BUS IN SIMILAR CIRCUMSTANCES?

YES NO

4-) DID YOU SEE THE TRAFFIC SIGNAL POLE IN FRONT OF YOU?

YES NO

5-) DO YOU ENCOUNTER SIMILAR VISIBILITY PROBLEMS IN REAL LIFE?

YES NO

6-) DID YOU SEE THE TRAFFIC SIGNAL POLE ON YOUR RIGHT?

YES NO

7-) DO YOU THINK THAT THE TRAFFIC SIGNAL POLE ON YOUR RIGHT IS HELPFUL?

YES NO OTHER ______________________________

8-) RATE THE SCENARIO COMPONENTS (SURROUNDING, AUDIO, AND VISUAL)

1 2 3 4 5