2006

Using Augmented Reality For Studying Left Turn Maneuver At Un-signalized Intersection And Horizontal Visibility Blockage

Ghada Moussa
University of Central Florida

STARS Citation

Moussa, Ghada, "Using Augmented Reality For Studying Left Turn Maneuver At Un-signalized Intersection And Horizontal Visibility Blockage" (2006). *Electronic Theses and Dissertations, 2004-2019*. 896.
https://stars.library.ucf.edu/etd/896

USING AUGMENTED REALITY FOR STUDYING LEFT TURN MANEUVER AT UN-SIGNALIZED INTERSECTION AND HORIZONTAL VISIBILITY BLOCKAGE

by

GHADA SALAH MOUSSA
B.S. Assiut University, 2000
M.Sc. University of Central Florida, 2003

A dissertation submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy
in the Department of Civil and Environmental Engineering
in the College of Engineering and Computer Science
at the University of Central Florida
Orlando, Florida

Fall Term
2006

Major Professor: Dr. Essam Radwan

ABSTRACT

Augmented reality "AR" is a promising paradigm that can provide users with real-time, high-quality visualization of a wide variety of information. In AR, virtual objects are added to the real-world view in a real time. Using the AR technology can offer a very realistic environment for driving enhancement as well as driving performance testing under different scenarios. This can be achieved by adding virtual objects (people, vehicles, hazards, and other objects) to the normal view while driving in a safe controlled environment.

In this dissertation, the feasibility of adapting the AR technology into traffic engineering was investigated. Two AR systems; AR Vehicle "ARV" system and Offline AR Simulator "OARSim" system were built. The systems' outcomes as well as the on-the-road driving under the AR were evaluated. In evaluating systems' outcomes, systems were successfully able to duplicate real scenes and generate new scenes without any visual inconsistency. In evaluating on-the-road driving under the AR, drivers' distance judgment, speed judgment, and level of comfort while driving were evaluated. In addition, our systems were used to conduct two traffic engineering studies; left-turn maneuver at un-signalized intersection, and horizontal visibility blockage when following a light truck vehicle. The results from this work supported the validity of our AR systems to be used as a surrogate to the field-testing for transportation research.

ACKNOWLEDGMENTS

I would first like to extend my thanks to my advisor Dr. Essam Randwan, for his support, direction, generosity, encouragement, and passion throughout this research. I could not ask for a better advisor than him. I also express my appreciation to the members of my committee, Dr. Mohamed Abdel-Aty, Dr. Amr Oloufa, Dr. Nizam Uddin and Dr. Niels Lobo for serving in my committee.

I would like to express my sincere appreciation to my lovely husband Dr. Khaled Hussain, for all of his assistance in designing and building the system, and for always being extremely helpful through out the path of this research. His assistance could not have been replaced.

I would also like to thank the Center for Advanced Transportation Systems Simulation "CATSS" for financially supporting the project.

My thanks especially go to Mr. Rusty Marcus, the manager of the Orlando Speed World oval racetrack, for allowing us to use the racetrack. I also would like to thank Mr. Don Harbor for lending us his GPS to be used in our experiments.

Most importantly, I would like to thank my parents for their love, support, and guidance over the years. I can not thank them enough for that.

Especial thanks to my lovely son Aburahman, his smile kept my spirits up in rough times.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

1.1 Overview

A useful and very significant jump in simulation technology is to be able to evaluate synthetic simulated conditions in realistic settings (Gelenbe et al. 2005). This technology is based on Augmented Reality "AR". Augmented reality is a paradigm which creates a combination of real and virtual objects in real-time in which the user cannot tell the difference between the real and augmented world (Hussain et al. 2004). Figure 1.1 shows an example of a view that the user might see from an AR system showing a real scene with a virtual vehicle.

(a) (b)

Figure 1.1: a) real scene, b) the result of inserting a virtual vehicle into the real scenes.

The AR technology has the ability to improve the user's perception and interaction with the real world (Bonsor 2001). Information expressed by the virtual objects can help the user to perform real-world tasks (Azuma 1997). Performing a real experiment to evaluate human performance under certain traffic scenarios might be very expensive with high degree of risks to drivers. The AR technology can offer a very realistic environment for driving enhancement as well as driving performance testing under different scenarios. This can be achieved by adding virtual objects (people, vehicles, hazards, and other objects) to the normal view while driving in a safe controlled environment. That makes applying the AR technology into traffic engineering applications a promising approach.

The AR technology can be applied in many potential areas in traffic engineering for both research and real world applications. AR can be used to study human performances under different traffic situations. With the use of AR, current road designs as well as any proposed designs can be evaluated. With the great leap forward in technology and developing different Intelligent Transportation Systems (ITS), it is important to test those systems before implementing them in the real world. The AR technology can be applied for assessing the benefits of using ITS and evaluating different information systems, static and/or dynamic, in and/or out of vehicle. In addition, it can be used to evaluate the new collision preventing systems. Besides, the AR technology can be used to assist driving under inclement weather conditions such as; rain, fog, and snow. In addition, it can help in drivers' training, by allowing drivers to drive a real vehicle in a real safe environment, which makes drivers' training easier and safer without the risk of hitting objects.

1.2 Research Objectives

Applying the Augmented Reality "AR" technology for traffic studies is a new and challenging task. Our main goal from this research is to investigate the feasibility of applying AR technology into traffic engineering area. In order to achieve that goal, the following tasks were defined;

1. **Build** two systems based on the AR technology; AR Vehicle system, and Offline AR Simulator system.
2. **Evaluate** the AR systems' outcomes.
3. **Evaluate** on-the-road driving under the AR.
4. **Use** our AR systems for conducting two traffic studies;
    (a) Left-turn maneuver at non-signalized intersection study.
    (b) Horizontal visibility blockage problem due to following an LTV study.

CHAPTER 2: LITERATURE REVIEW

2.1 Augmented Reality Technology

With enhancements in computer graphics, coupled with decreasing the cost and increasing computers' processing power, a significant leap forward in the AR technology has been achieved. The basic idea of the AR technology is to add virtual (computer-generated) objects, audio and other sense enhancements to a real-world environment (Hussain et al. 2004). These enhancements are added in a way that the viewer cannot tell the difference between the real and augmented world.

2.1.1. Augmented Reality Techniques

In AR technology, real world and virtual objects are combined in a real time. There are two main techniques for combining real and virtual objects; optic technique and video technique (Johansson et al. 2002). While the optic technique uses an optical combiner for combining the real and virtual objects, the video technique uses a computer or a video mixer for combining the video of the real world, from video cameras, with the virtual images (computer-generated) (Azuma 1997). Both AR techniques (optic and video) can display the final view to the user using a Head Mounted Display "HMD", monitor-based display, and/or hand-held display. The Augmented reality system with a Head Mounted Display (HMD) can be closed-view or see-through HMDs. While the closed-view HMDs do not allow any direct view of the real world, the see-through HMDs allow the user to see the real world, with virtual objects added using optical or video techniques (Azuma 1997). Using the Head mounted displays provides a good extent of presence as the user is inside the actual environment.

Figure 2.1 shows an optical see-through HMD, in which an optical combiner is placed in front of the user's eyes. This combiner is partially transparent, so that the user can see the real world through them, as well as partially reflective, so that the user can see the imposed virtual images (Azuma 1997). In addition, a monitor-based optical configuration is also possible. This is similar to the see-through HMD except that the user does not wear the HMD, but the monitor and combiner are fixed in space, and the user moves his/her head to look through the combiner (Peuchot 1995). An example of an optic AR system with both HMD and hand-held display is presented in Figure 2.2.

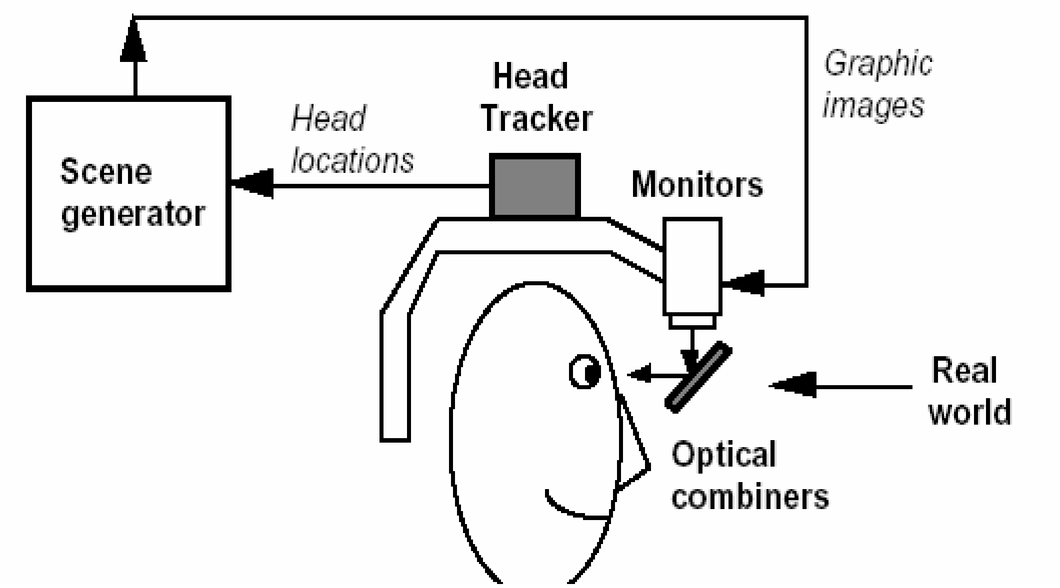


Figure 2-1: See-Through HMD optic technique AR system conceptual diagram (Azuma 1997).

Figure 2-2: Mobile optic AR system with HMD and a hand-held display (Feiner et al. 1997).

Figure 2.3 shows a conceptual diagram of a video see-through HMD, in which one or two video cameras are fixed in the head mounted display. These video cameras provide a video of the user's view of the real world, this video is combined with the virtual images created by the scene generator. The video with the added virtual images is sent to monitors in front of the user's eyes in the HMD (Azuma 1997). An example of a mobile video AR system with HMD is presented in Figure 2.4. The monitor-based with video configuration technology is shown in Figure 2.5. In this case, the user does not wear the display device but there is a monitor fixed in front of the user. Like the video see-through HMD case, one or two video cameras view the real world, then the video from those cameras and the virtual images, generated by a scene generator, are combined and displayed in the monitor in front of the user (Azuma 1997). Figure 2.6 shows an example of a real monitor-based video technology AR system. In some cases, the combined video with the images might be displayed in a stereo on the monitor, which requires the user to wear a pair of stereo glasses as seen in Figure 2.6. An example of a video AR system with a hand-held display is presented in Figure 2.7. It could be used for many applications such as games and 3D navigation (guide a user through an unfamiliar building to their destination).

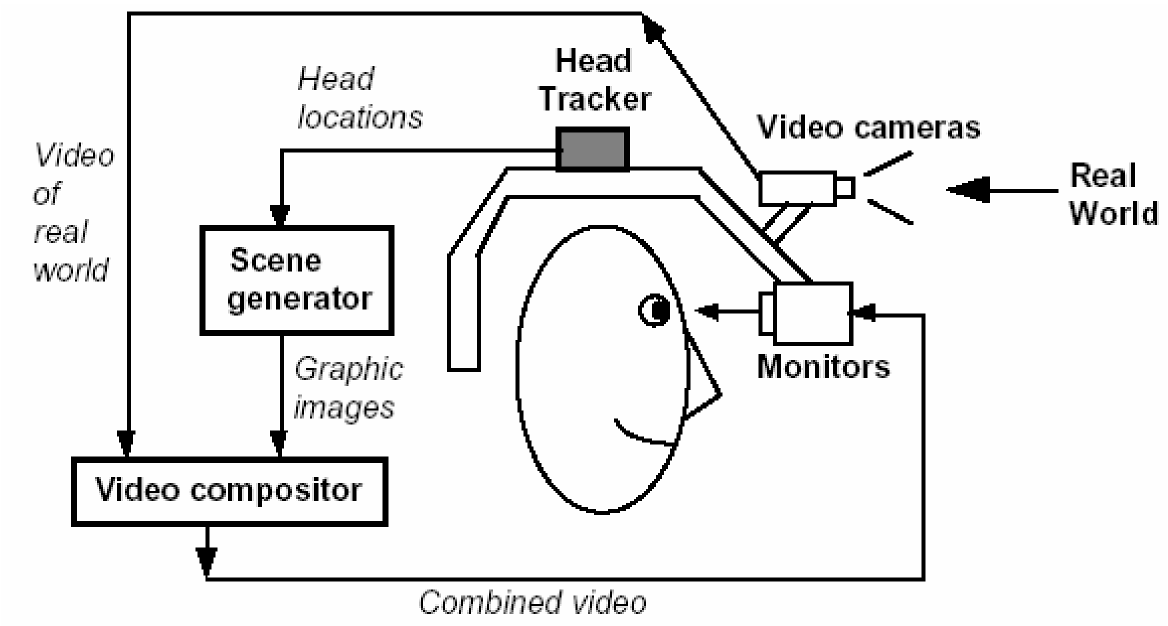


Figure 2-3: See-Through HMD video technique AR system conceptual diagram (Azuma 1997).

Figure 2-4: Mobile video AR system with HMD (Wagner et al. 2005)

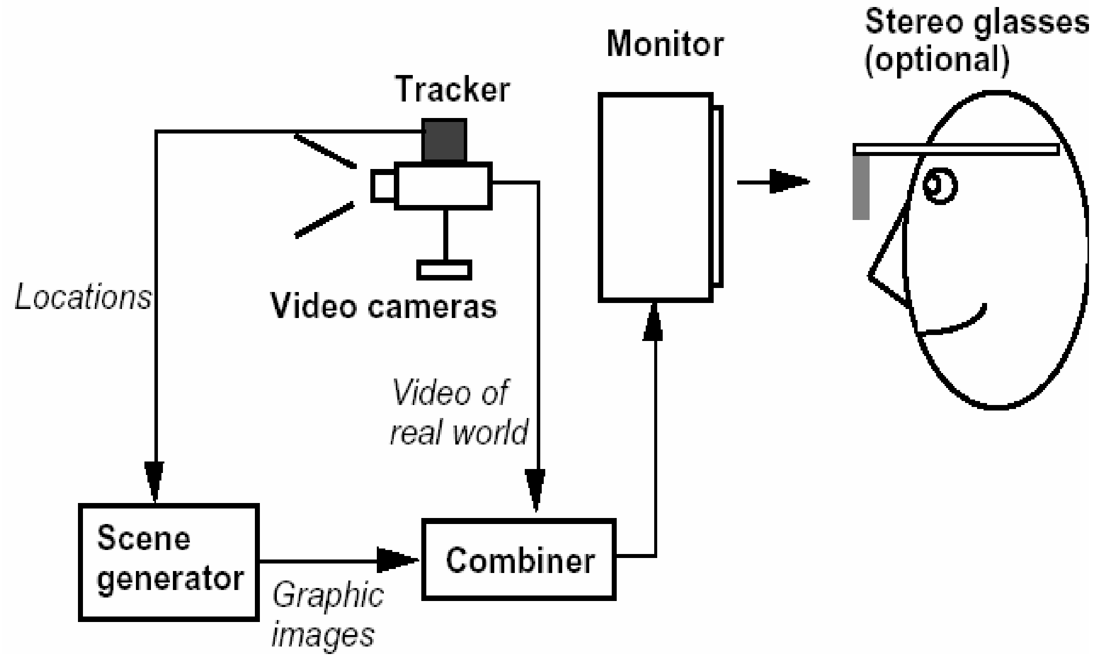


Figure 2-5: Monitor-based video technique AR system conceptual diagram (Azuma 1997).

Figure 2-6: An example of monitor-based video technique AR system (Drascic 1993).

Figure 2-7: Video handheld display AR System (Wagner et al. 2005).

Both optical and video techniques have advantages and disadvantages. Azuma et al. (1994) and Rolland et al. (1994) discussed some of both techniques' advantages and disadvantages. In the following paragraphs, we briefly touch on them.

Safety:

If the power is cut off from optical see-through HMDs, the user still has a direct view of the real world. In the other hand, if the power is cut off from the regular video see-through HMDs then the user cannot see anything. Using a moveable video see-through HMD in which the user can easily flip the glasses up and down might be a good solution for this problem, as shown in Figure 2.8.

Figure 2-8: video see-through HMD with flip able glasses (i-glasses website).

Obscure the real world objects:

Since the optical combiners allow light from both virtual and real sources, virtual objects might not be completely obscure the real world objects which causes the virtual objects to appear like ghost or semi-transparent objects that breaks the illusion of the reality. Building an optical see-through HMD that can effectively shut out the light from the real world is much more difficult and complex, that may be why optical see-through are growing less popular (Bonsor, 2001). On the other hand, in the video technology both the real and virtual objects are available in digital form, that makes them displayed with the same clarity. This advantage makes the video see-through appear to be ultimately more convenient in producing the environment then the optical see-through technology.

Wide field-of-view:

In optical systems, distortions are a function of the radial distance away from the optical axis, i.e. further the user looks away from the center of the view, the larger the distortions he/she gets. In order to build a wide field-of-view display with optical see-through techniques, a more complex optical system is needed. This is not a problem for the video technique.

Delay between the virtual and the real views:

In the optical see-through, the view of the real world is instantly offered but the virtual image stream is delayed. This chronological delay between the virtual and real views can cause problems. In the video technique, it is possible to match the delay of the two views (virtual and real).

Match the brightness of real and virtual objects:

Under the ideal case, the brightness of both real and virtual objects should be matched. In the optical technique, since the user has a direct view of the real world, it might be a problem to match the brightness of both real and virtual objects. While the real environment will wash out the virtual if the real environment is too bright, the virtual image will wash out the real world if the real environment is too dark. In the video technique, since the computer generates the view of both the real and virtual objects, matching the brightness is not a problem.

After studying the advantages and disadvantages of each system it was decided that the video see-through HMD technology deemed more appropriate for this research. For safety reasons, the HMD with flip-able glasses was adapted.

2.1.2. Augmented Reality Challenges

There are three main challenges face the AR techniqes; registration, non-rigid objects, and different terrain (Azuma 1997, Hussain & Kaptan 2004, Gelenbe et al. 2005).

1. Registration

The word “Registration” refers to the need to align real and virtual objects, in position, orientation, and scale, with each other. Small errors in registration generate visual inconsistencies, which can easily be detected by the user as shown in Figure 2.9.

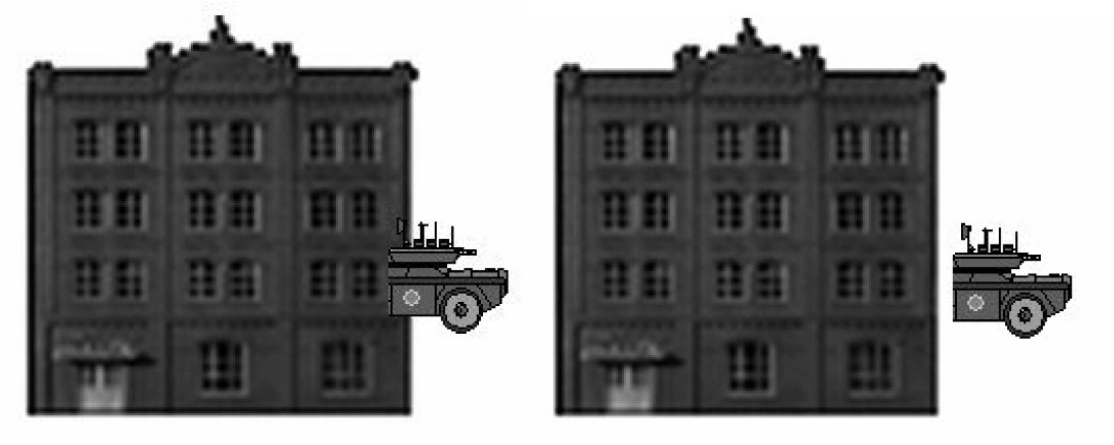


Figure 2-9: Small errors in registration cause visual inconsistencies (Hussain et al. 2004)

2. Non-Rigid Object

Almost all AR techniques assume that virtual objects and live objects have exactly the same detailed shape. This assumption is only valid for rigid objects such as roads and buildings. However, in case of non-rigid real objects (e.g., trees) a problem might occur when a virtual object appears behind them as shown in Figure 2.10.

Figure 2-10: Non-Rigid objects cause visual inconsistencies (Hussain et al. 2004).

3. Different Terrain

When the real world terrain is not a level terrain, then the simulated terrain might differ from the real terrain. This difference in terrain might cause a vertical different between objects in the real view and their corresponding objects in the simulation as shown in Figure 2.11.

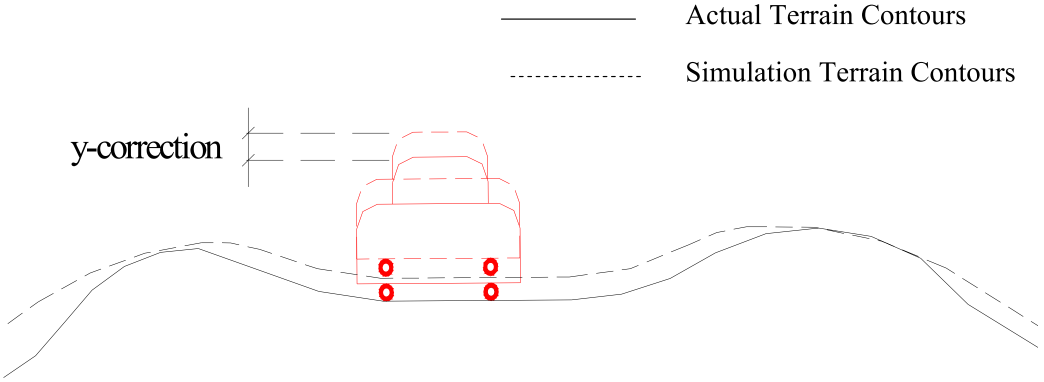


Figure 2-11: Different terrain problem required a vertical correction.

There are no absolute solutions for these problems and it still an open research (Hussain et al. 2004).

2.1.3. Augmented Reality Applications

Augmented reality is a promising paradigm for providing users with real-time, high-quality visualization of a wide variety of information. Augmented reality can be applied into a wide range of applications in many areas. For instance, augmented reality can be applied into medical visualization and training, manufacturing and assembling, maintenance and construction, design and modeling, military training and warfare, commercial applications, various forms of entertainment, navigation and information guidance. The common thing between all AR applications is the requirement to align virtual images with objects in the real world (Suthau et al. 2002). In this section, a brief discussion of some of those applications is presented.

In Medicine:

Using AR technology for medicine applications has gained the interest of researchers for several years (Fisher et al. 2004). AR can be used for visualization, guidance, and training purposes. AR can help doctors to visualize internal human anatomy with the view of the patient. This would guide surgeons in performing precision tasks, like displaying where to make a hole in the patient's head for brain surgery, as shown in Figure 2.12 (Azuma 1997). Also, it would be very useful during small incision surgeries like minimally-invasive surgeries (Suthau et al. 2002). This would give an internal view of the patient without the need for larger cut. Researchers at the University of North Carolina have investigated superimposing three-dimensional images over the patient's body for visualizing internal patient anatomy (Azuma 1997). While wearing HMD an ultrasound scan of a fetus inside a woman is superimposed over the women stomach, allowing perspective 3D observation of the fetus as well as locating its position relative to the other internal organs, as shown in Figure 2.13. In addition, AR can be very helpful tool for surgery guidance and training. In which the visual images can help the surgeon to visualize the path through the patient's anatomy to the affected part that needed to be removed (Suthau et al. 2002, Uenohara 1995). Also in breast biopsy operations, virtual images using AR technology can help the surgeon to identify the location of the tumor and guide the needle to its target, as shown in Figure 2.14.

Furthermore, AR can be used for psychological disorders treatments. In which the environment around the patient is real but objects that the patient fears of are virtual. A research group at the University of Melbourne, Australia, have built an AR system that can be used for a cockroaches phobia treatment then they tested it on a patient (Juan et al. 2004). They reported that, at the beginning, the patient was not able to come near a real cockroach but after using their AR system, the patient was able to approach, interact, and kill cockroaches as shown in Figure 2.15.

Figure 2-12: AR guidance for brain surgery (Grimson et al. 1996)

Figure 2-13: Virtual fetus inside womb of pregnant patient using AR. (State et al. 1994)

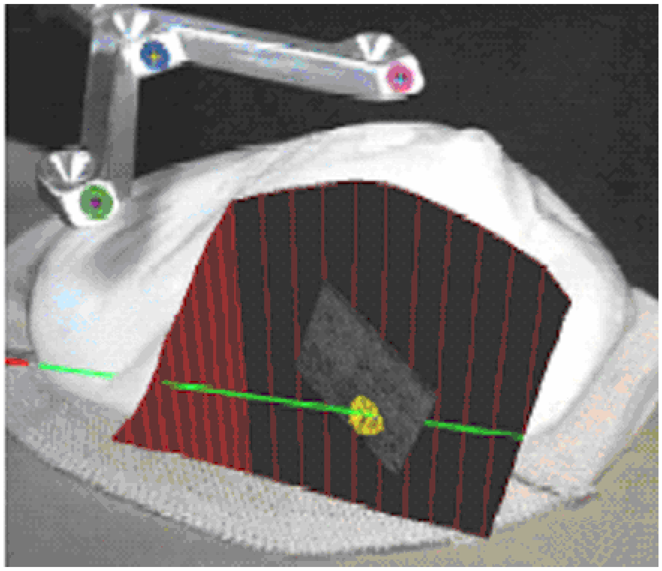


Figure 2-14: 3-D graphics guide needle insertion in breast tumor surgery (Henry et al. 1996).

Figure 2-15: An image of the exposure session using AR system (Juan et al. 2004).

In Mechanical and Repair:

Another application domain that has been explored using AR technology is mechanical maintenance and repair. AR technology can assist mechanics to perform hard tasks by providing variety of information without the need to go to the manual. A brief description of each part name, function, or any other important information can be presented to the mechanic in real time as shown in Figure 2.16 (Vallino 1998). Moreover, safety information can be provided, by highlight parts that present some danger to the mechanic like electrified or hot parts. In addition, applying AR technology can guide mechanics through complicated tasks. A step-by-step tasks as well as brief descriptions of how to do them can be presented to the mechanic, using three-dimension virtual graphics superimposed over the machine (Azuma 1997).

Several research groups worked in building AR systems to help mechanics carrying out their work. A research group at the University of Southern California built an AR system to guide technicians through maintenance and repair processes (Neumann and Cho 1996). Another research group at the European Computer-Industry Research Centre (ECRC) built an AR system that can display engine parts' names once the user point at them (Rose 1995). Moreover, researchers at Boeing, an aircraft manufacturer, developed a see-through HMD system based on the AR technology. Their system is able to guide technicians in building a wiring harness, which is an important part of the airplane's electrical system (Vallino 1998).

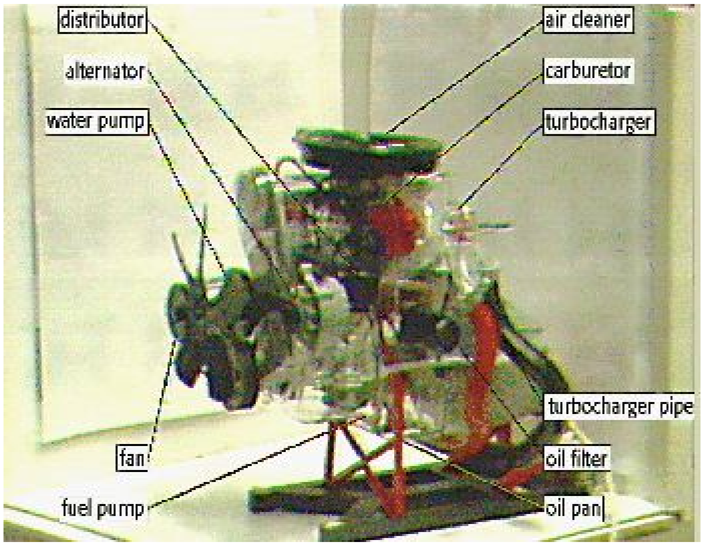


Figure 2-16: Using AR, notations for parts' name, their functions can be presented to the mechanic (Breen 1994).

In Commercials and Entertainments:

Recently, AR technology has been used for broadcasting sport events in real time (Azuma et al. 2001). Princeton Electronic Billboard has developed an AR system that can help games' broadcasting by overlaying virtual images of advertisements on the outfield wall of the stadium in a baseball game (National Association of Broadcasters 1994). Also in car racing games, with AR technology some notations are added to help game broadcasting. Those notations are virtual images overlaid in the scene in real-time as shown in Figure 2.17. SporTVision has used AR technology in superimposing the first down line in football game (Bonsor, 2001). Where people observe a yellow or orange line in the field, which is a virtual line (computer-generated), presents the first down line, where the offense has to reach, as shown in Figure 2.18.

AR technology can also collaborate in entertainment by enhancing games that people play. Jebara et al. (1997) have developed an AR system using a HMD and wearable computer for billiard's players. The system can overlay virtual images of possible shots of the ball and their paths over the table, which can help players to make their shots. Moreover, Wagner et al. (2005) developed a handheld AR system with keyboard-less Personal Digital Assistants (PDAs). They applied their system for a four-user interactive game "Invisible Train Game". In the game, players are able to see and control virtual trains over a real wooden small railroad track through their PDA's video see-through display, as shown in Figure 2.19. Players are able to switch and adjust their virtual train via touching their PAD's screen as shown in Figure 2.20. All players are updated with other players' actions via wireless networking. The game ends once a collision happens. Furthermore, Fox network has developed an AR system "FoxTrax Sytem" which highlights the path of a hockey puck as it moves rapidly across the ice, as the speed of the puck changes the color of the path changes (Cavallaro 1997).

Figure 2-17: Augmented notations on racecars for forecasting (NASCAR website).

Figure 2-18: The first down line (yellow line) is inserted in real time (SporTVision website).

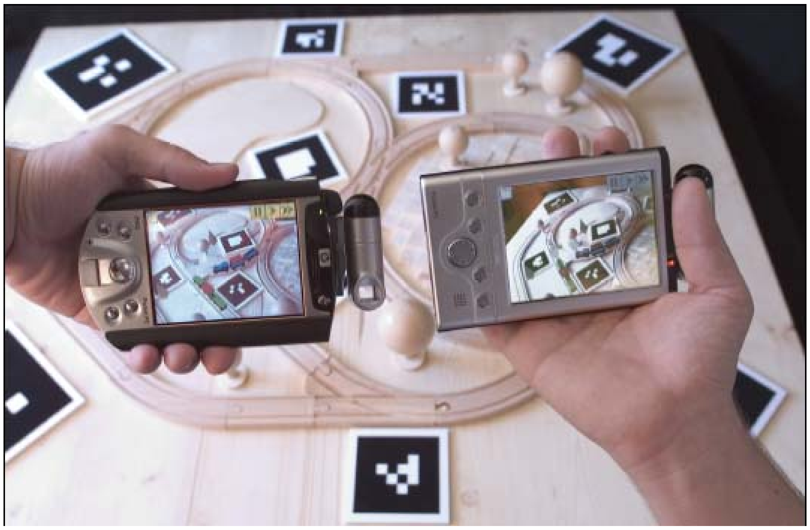


Figure 2-19: Two video see-through PADs run Invisible Train Game (Wagner et al. 2005)

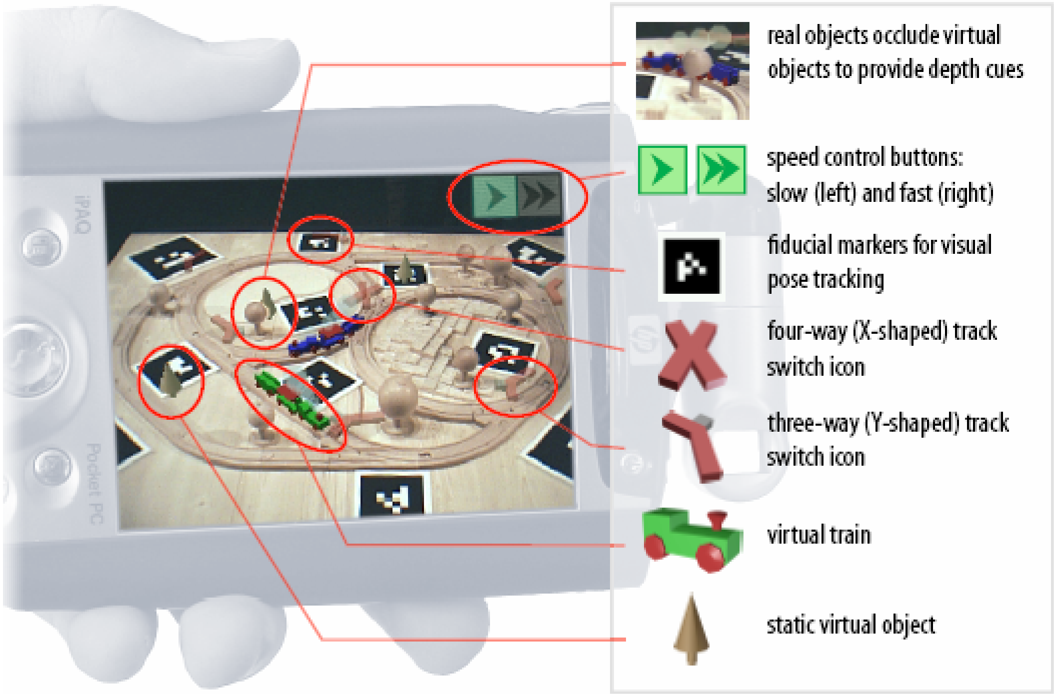


Figure 2-20: Player's interface elements, as seen from his perspective (Wagner et al. 2005).

Navigation and Information Guidance

Researchers at Siemens and the University of Linz in Austria have developed an augmented reality navigational system for vehicles (Staedter 2005). Their system displays transparent route markers onto an actual image of the road ahead, directing the driver even in unfamiliar surroundings in a more convenient way than birds-eye view maps, as shown in Figure 2.21.

Researchers at the University of Columbia build a Mobile AR System “MARS” that can provide users with information about their surrounding environment (Feiner et al. 1997). Their AR system can present the information on a HMD as well as hand-held device as shown in Figure 2.21.

Research group at The University of Melbourne, Australia, developed an AR system to enable drivers to see the road and surrounding vehicles in spite of poor visibility (Scott-Young et al. 2003. Their AR system combines a virtual image of highlighted road boundaries and surrounding vehicles with a real time video of the road, and displays them on a laptop as shown in Figure 2.22.

Another research group, at Nara Institute of Science and Technology, Japan, built an AR system for unmanned helicopter control assistance (Koeda et al. 2004). In which, the operator watches annotation view, from the helicopter, through a HMD while remotely controls the helicopter. Their annotations are virtual images (computer-generated) overlaid over the normal view from a camera fixed in the helicopter.

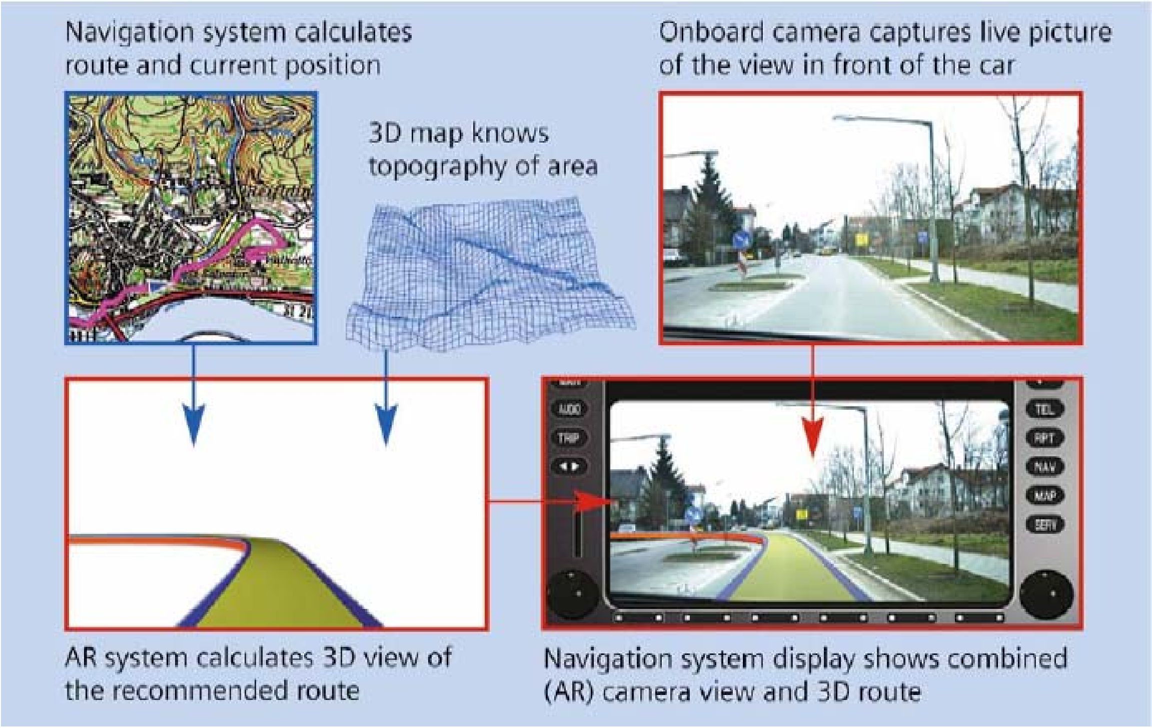


Figure 2-21: Augmented reality navigation system by Siemens and the University of Linz (Staedter 2005)

Figure 2-22: The AR system shows road edges and a near vehicle as displayed to the driver (Scott-Young et al. 2003).

Moreover, a research group at the University of Nottingham, UK, built an AR system that can help road inspection and maintenance by superimposing virtual images of main water pipes, electricity pipes, gas pipes, or any other subsystem components (DTI augmented reality project). Figure 2.23 a) and b) present a real road, and a real road with 3-D graphs of subsystem components, respectively.

a) Real world b) Augmented World

Figure 2-23: Real world vs. augmented world with 3-dimensional survey data for the sub-surface objects (DTI augmented reality project).

Also in geological inspection, Romão et al. (2002) developed an AR system “ANTS" for providing geo-referenced environmental information to the user in real time. The system can help the user in his inspection by superimposing virtual images of geological information about the user’s inspection location.

Furthermore, Bonanni et al. (2004) built an AR kitchen, which is a typical house kitchen supplied with vision-based senses that projects three-dimensional multi-modal interfaces as shown in Figure 2.24. They also evaluated their system’s efficiency, ease of use, and safety for users.

Figure 2-24: Augmented reality kitchen, information is projected on the refrigerator (1), the rang (2), the cabinet (3), the faucet (4), and the drawer (5) (Bonanni et al. 2005).

In this dissertation, we are investigating the feasibility of applying the AR technology into traffic engineering area. Therefore, two AR systems were built based on the video see-through HMD AR technology.

2.2 Left Turn Maneuver at Un-Signalized Intersection

Two-way stop-controlled intersections are the most common type of intersection in the United States (Gattis and Low 1989). A two-way stop-controlled intersection is an un-signalized intersection with the right-of-way assigned to one of the two streets that intersect. Left-turn at two-way stop-controlled intersections, where left-turn vehicles don't have the right-of-way, left turn become a complex and driver decision procedure (Harwood et al. 1996). Left-turn drivers in the major road need to find acceptable gaps between vehicles in the opposing through traffic to inter the minor road as shown in Figure 2.25. Misjudged gaps might cause serious accidents and/or high intersection delay (Mitchell 1972, Hanna et al. 1976, David et al. 1979). About one third of left-turn intersections' accidents can be due to misjudging gaps (Chovan et al., 1994).

Left turning accident is considered one of the most dangerous accidents, as relative impact forces are high so the potential of injury and damage is great (Caird & Hancock, 2002). In 1999, the fatalities resulted from left-turning accidents, which present 5.9% of all U.S. traffic fatalities for that year (National Highway Traffic Safety Administration, 1999). Moreover, left-turn accidents account for 12.8 % of all injuries and 9.6% of all property damage only "PDO" accidents with cost of about 15.4 billion dollars. In total crash severity; fatalities, injuries, and PDO, left-turning accidents come in the second crash severity just after straight accidents.

A study done by Yan and Radwan (2005) using Florida 1999-2001 crash data, they found that about 29% of two-vehicle crashes at signalized intersections were left-turn crashes. More then 50% of those left-turn crashes were due to unprotected left-turning drivers who failed to yield the right-of-way to oncoming vehicles. About 60% of those left-turn crashes occurred in urban area causing about 14% injuries and almost 1% fatalities.

Chovan et al., 1994, conducted an analysis using all police reported crashes for 1991; they found that about 7% of the 413,000 accidents were left-turn across path "LTAP" crashes, where left-turn vehicles attempt to cross oncoming traffic. Of these LTAP accidents, 48.8 % occurred at un-signalized intersections. Most of LTAP accidents happened at intersections where the speed limit is 35mph (60kph) or higher. More male (86%) were involves in LTAP than females. Most crashes occurred in daylight (73%), in non-adverse weather (86%), and on a dry pavement (80%).

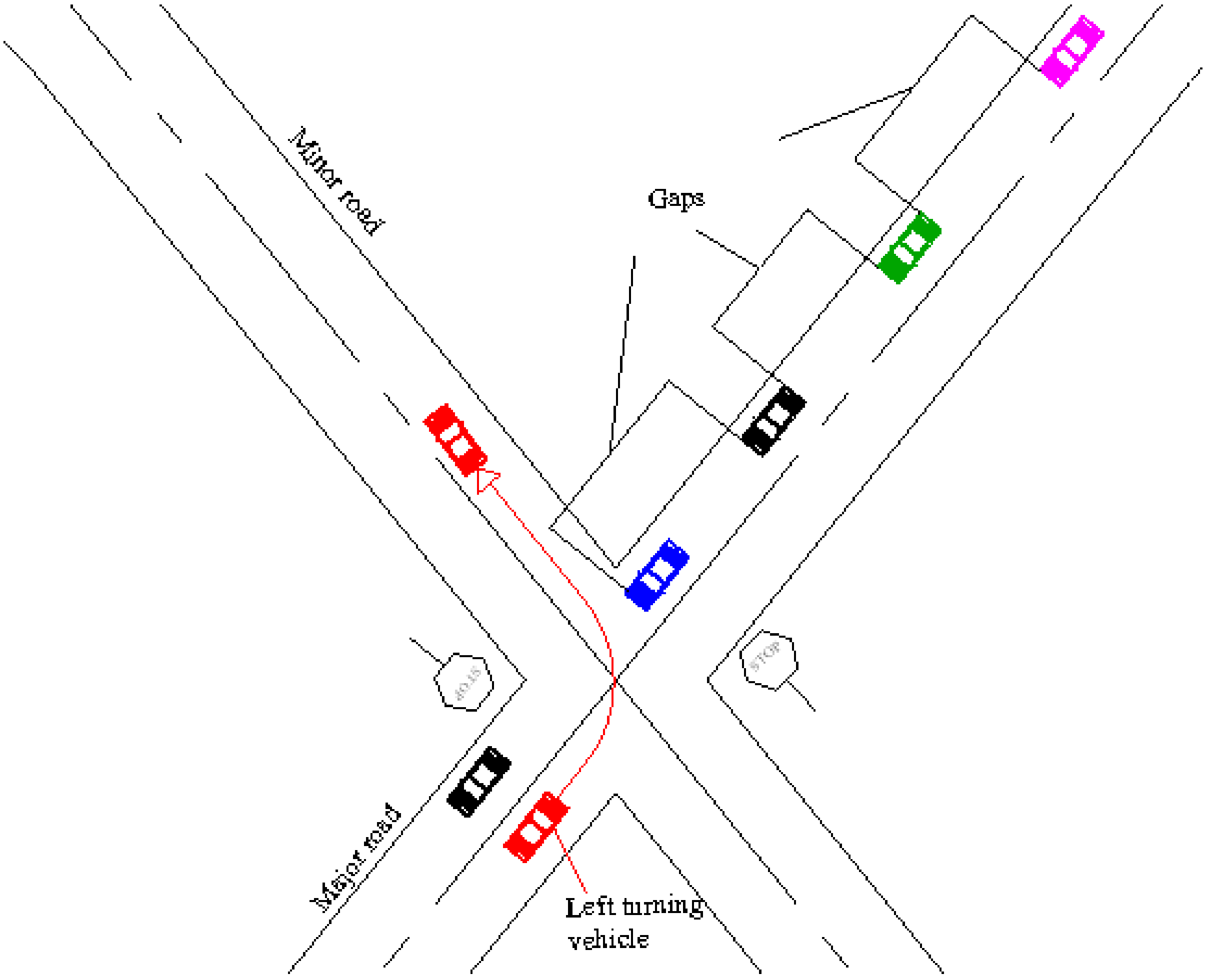


Figure 2-25: Left turn gaps in a two-way stop-controlled intersection.

Several studies have examined drivers' behaviors at un-signalized intersections for performing right-turn, left-turn or straight across maneuvers. Based on police-reported accidents in Michigan and Pennsylvania, USA, Lyles and Staplin (1991) pointed out that turn left cross on-coming traffic and cross or turn into a traffic stream are found to be the most dangerous maneuvers for elderly drivers.

There are several factors that significantly effect left-turn drivers' behaviors at un-signalized intersections, including drivers' characteristics (age and gender), driver's distractions, opposing vehicle (type and speed), waiting time, day time, and the intersection geometry (Yan & Radwan, 2005; Gattis 1998).

Abdel-Aty et al. (1999) examined police-report accident data, and they indicated that old drivers are over-represented in right-turn, left-turn and angle accidents. Moreover, using crash data for the 1999-2001 periods in Florida, USA, Yan and Radwan (2005) conducted a logistic regression model to study effect of driver characteristics, environments, and vehicle type on left-turn crashes' risks. They indicated that not only elderly drivers are over-represented in those crashes but also learner drivers. They also found that crashes at divided highway have higher risks than crashes in undivided ones, and they attributed that to the sight distance problem.

Laberge-Nadeau et al. (2003) conducted an experiment using a driving simulator to test cell phone effects on the driving performance, they concluded that the use of cell phones, while driving, affects driver's performance specially the reaction time and lateral control of the vehicle. In addition, Cooper and Zheng (2002) performed experiments that confirmed the negative affect of driver's distraction on left-turn maneuver's decision-making.

Alexander et al. (2002) conducted a study using the TRL driving simulator with 60^0 screens and they concluded that both age and gender might affect the size of the selected gap as well as the time taken to cross the traffic stream. In addition, Yan (2003) performed an experiment using a six-degree of freedom driving simulator to study left-turn from a minor road into a major road. He concluded that the driver's age and gender had a significant impact on the selected gap.

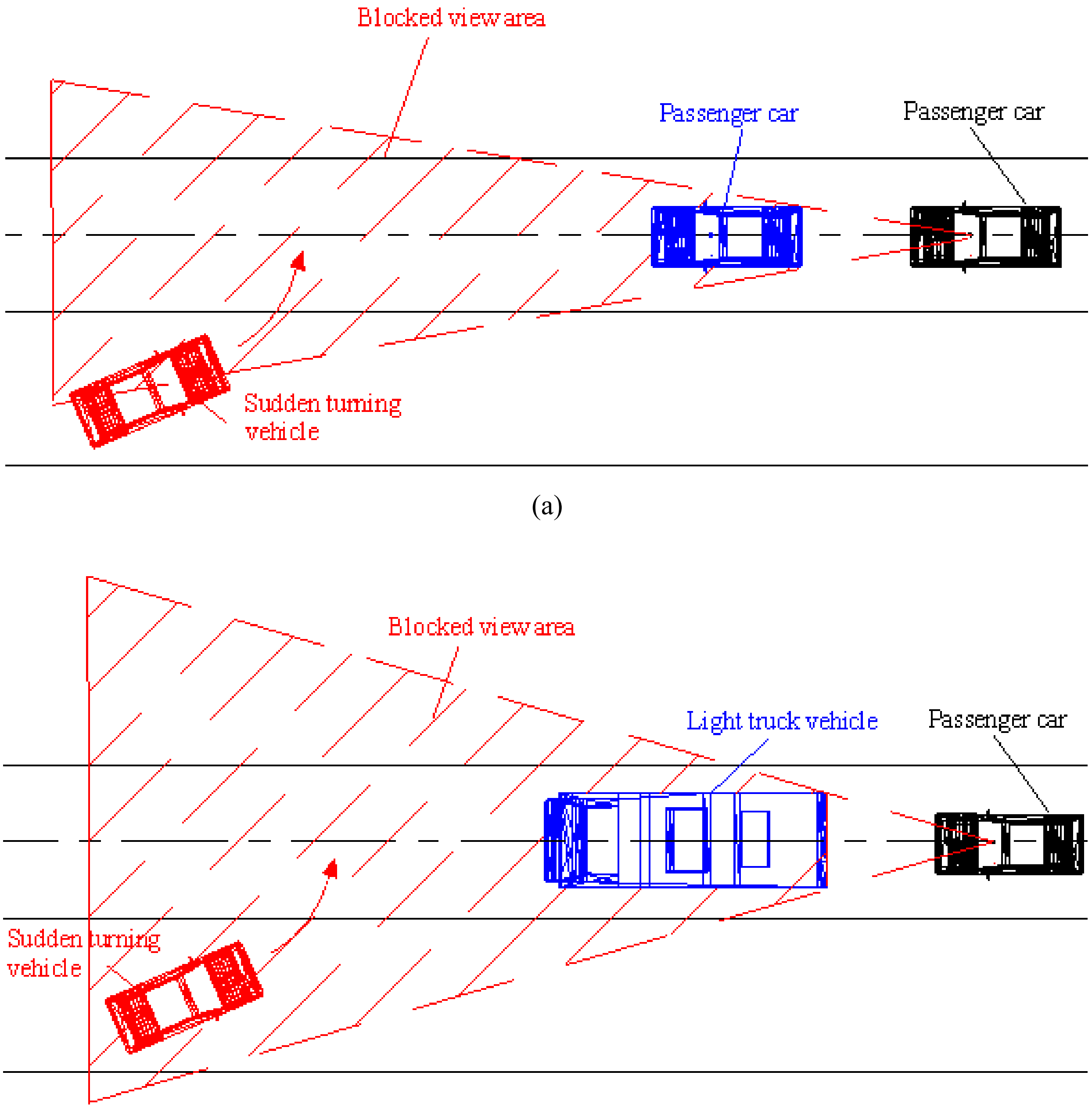
Lerner et al. (1995) performed a field study of gap-acceptance evaluations for through, right-turning, and left-turning maneuvers. He indicated that, in the daytime, male drivers were observed to accept gaps that were shorter by approximately 1 s than those accepted by females.

In this dissertation, we focused on studying effects of left-turn driver’s characteristics (age and gender) on left-turn maneuver at two-way stop-controlled intersection.

2.3 Horizontal Visibility Blockage

The horizontal visibility blockage refers to the blockage of the left and/or the right view of the driver. This blockage can occur if driving a regular passenger car, such as Saturn, Honda Accord, Nissan Sentra, or Ford Taurus, closely behind a Light Truck Vehicle “LTV”, such as van and sport utility vehicles “SUVs”. Drivers following a vehicle may have a temporarily restricted vision, especially if the lead vehicle is large vehicle as LTVs. Therefore, a sudden stop of the leading LTV might contribute to a high potential of rear-end crash.

With the fact that LTVs usually ride higher and wider than regular passenger cars, driving passenger cars behind LTVs likely affects the visibility of passenger car drivers more than driving behind a regular passenger car (Abdel-Aty and Abdelwahab 2004). As shown in Figure 2.26 (a) and (b), the wider the leading vehicle is, for the following vehicle, the bigger the blocked view area.



(a)

(b)

Figure 2-26: The horizontal visibility blockage in case of (a) following a passenger car, and (b) following an LTV.

The number of the Light Truck Vehicles (LTVs) on the U.S. highways nowadays is being on the rise. In 2002, LTV sales have soared to almost 8 million units (about 49% of new passenger vehicle sales). In 2003, the number of registered LTVs in the United States exceeded 85 million units or approximately 37 % 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 about 26% between 1995 and 2000, and about 70% between 1990 and 2000. (NHTSA VEHICLE SAFETY RULEMAKING and SUPPORTING RESEARCH PRIORITIES: 2005-2009)

A number of researchers stated that the driver's view blockage due to the lead vehicle large size can contribute to rear-end crashes (Sayer et al. 2000; Abdel-Aty & Abdelwahab, 2004; Abdelwahab & Abdel-Aty, 2004; and Harb, 2005). A sudden stop of the LTV might cause high probability of a rear-end crashes. With the high number of LTVs on the U.S. highways nowadays, rear-end crashes started to increase. Wang et al. (1998) stated that the rear-end crashes are the most abundant crash category. Moreover, rear-end crashes are the most common type of traffic crashes in the U.S., they account for about 30 % of all crashes reported annually in the U.S. In the last two years, the National Transportation Safety Board investigated nine rear-end crashes in which 20 people died and 181 were injured. The common characteristic for all nine crashes was that the driver of the succeeding vehicle was not aware of traffic conditions ahead.

Harb (2005) performed an experiment using a six-degree of freedom driving simulator to study effects of lead vehicle size on the probability of rear-end collisions, velocity and gap maintenance. Harb concluded that driving behind LTVs produce more rear-end collisions at un-signalized intersections than for driving behind PCs due to visibility blockage and following car drivers' behavior. His results also showed that passenger car's drivers following LTVs are prone to speed more and to keep a smaller gap then driving behind passenger cars. He related that behavior to drivers' frustration and eagerness to pass the LTV.

Abdel-Aty and Abdelwahab (2004) conducted a study to address the effect of the lead vehicle's size on the rear-end crash pattern. Based on their calibrated nested logistic model they concluded that the LTV blocked the succeeding PC drivers' visibility. Their results showed that the succeeding vehicle driver's visibility and inattention had the largest effect on being involved in a rear-end crash when following an LTV.

Sayer et al. (2000) carried out an experiment using an instrumented passenger car to study the effect of lead vehicle sizes, height and width, on a passenger driver's gap maintenance under nearly optimal driving conditions, i.e. daytime, dry weather, and free-flowing traffic. They concluded that passenger car drivers followed LTVs at shorter distance than they followed passenger cars, but at the same velocities.

Acierno (2004) studied the effect of mismatch in weight, stiffness, and height between LTV and PC on increasing fatalities among PC occupants when their vehicle collides with LTV. In his study, he used the Seattle Crash Injury research and Engineering Network (CIREN) database to establish patterns and source of injury. Among the first 200 Seattle CIREN cases reviewed, 32 collisions with 41 occupant cases were found to involve LTV versus PC. He related vehicle mismatch with death and serious injury in automotive crashes and recommended design improvements to both PC and LTV.

The high rate of rear-end crashes confirms the urge to study the contribution of LTV's view blockage to such type of crashes. In this research, we studied the effects of following an LTV on the succeeding car driver's performance and the contribution of rear-end crash.

CHAPTER 3: AUGMENTED REALITY SYSTEM

As discussed in Chapter one, the main goal of this dissertation is to investigate the feasibility of applying the AR technology into traffic engineering area. In order to achieve that goal, two systems based on the AR technology were built; Augmented Reality Vehicle "ARV" system, and Offline Augmented Reality Simulator "OARSim" system. While the first system (ARV system) is using an on-time video the second system (OARSim) is using a pre-recorded video. In this chapter, a detailed description of each system and a comparison with real field experiments are discussed.

3.1 Augmented Reality Vehicle "ARV" System

Our AR Vehicle system is based on the video see-through HMD technology. It has three main components connected to a powerful computer. These components are video camera, flip-able HMD, and Global Position System "GPS". The ARV system can be installed in any vehicle as shown in Figure 3.1 (a) and (b), where the video camera is fixed on the vehicle's front windshield and the driver wears the HMD while driving the vehicle. Through the HMD, the driver is able to see an augmented video. The augmented video is a combination of an in-time video of the real surrounding road (from the video camera) and virtual images (computer-generated images) of vehicles, traffic signs, traffic signals, buildings, trees, and other objects depending on the scenario. The fixed video camera is aligned with the driver's eye level as shown in Figure 3.1 (a) to get the same driver's prospective view of the real world. The fixed video camera gives the driver a wide view that enables him/her to drive easily and safely.

Combining the real video with the virtual images is done through the computer so that the driver can not tell the difference between real and virtual objects in the scene.

The block diagram that outlines the flow of data in the system is presented in Figure 3.2. In which, the **video camera** takes a real-time stream video of the real scene**.** The video camera is calibrated using the unknown-orientation checkboard plan method (Open Source Computer Vision Library). The camera calibration is required once the system is installed in the vehicle and before its first use. The calibration gives the camera's intrinsic parameters; focal length (2x1 vector), principal point (2x1 vector), skew coefficient, and distortion coefficient (5x1 vector). Before the vehicle start moving the camera's extrinsic parameters; rotations (3x3 matrix) and translations (3x1 vector) are calculated using the in-the-field marks and updated using the **GPS information** (car position information) during the journey of the vehicle. The camera's parameters; intrinsic and extrinsic are used to **align virtual camera with real camera**. Then the adjusted virtual camera position is used to render two 2-D frames; one contains the virtual objects and the other contains the virtual terrain using the **graphic rendering modules**. Afterward, the **registration module** calculates the registration error between the real frame and the 2-D virtual terrain frame. This registration error is used to adjust the virtual camera. Subsequently, the **video composition module** combines the real frame (from the video camera) and virtual objects' frame, to generate the augmented frame "final view". Finally, the augmented frame is displayed in front of the viewer's eyes through the **HMD**.

(a)

(b)

Figure 3-1: The ARV system installed in a vehicle; (a) the video camera fixed on the front windshield, the driver wears the HMD, and the laptop in the back of the vehicle, and (b) the GPS antennal fixed on top of the vehicle.

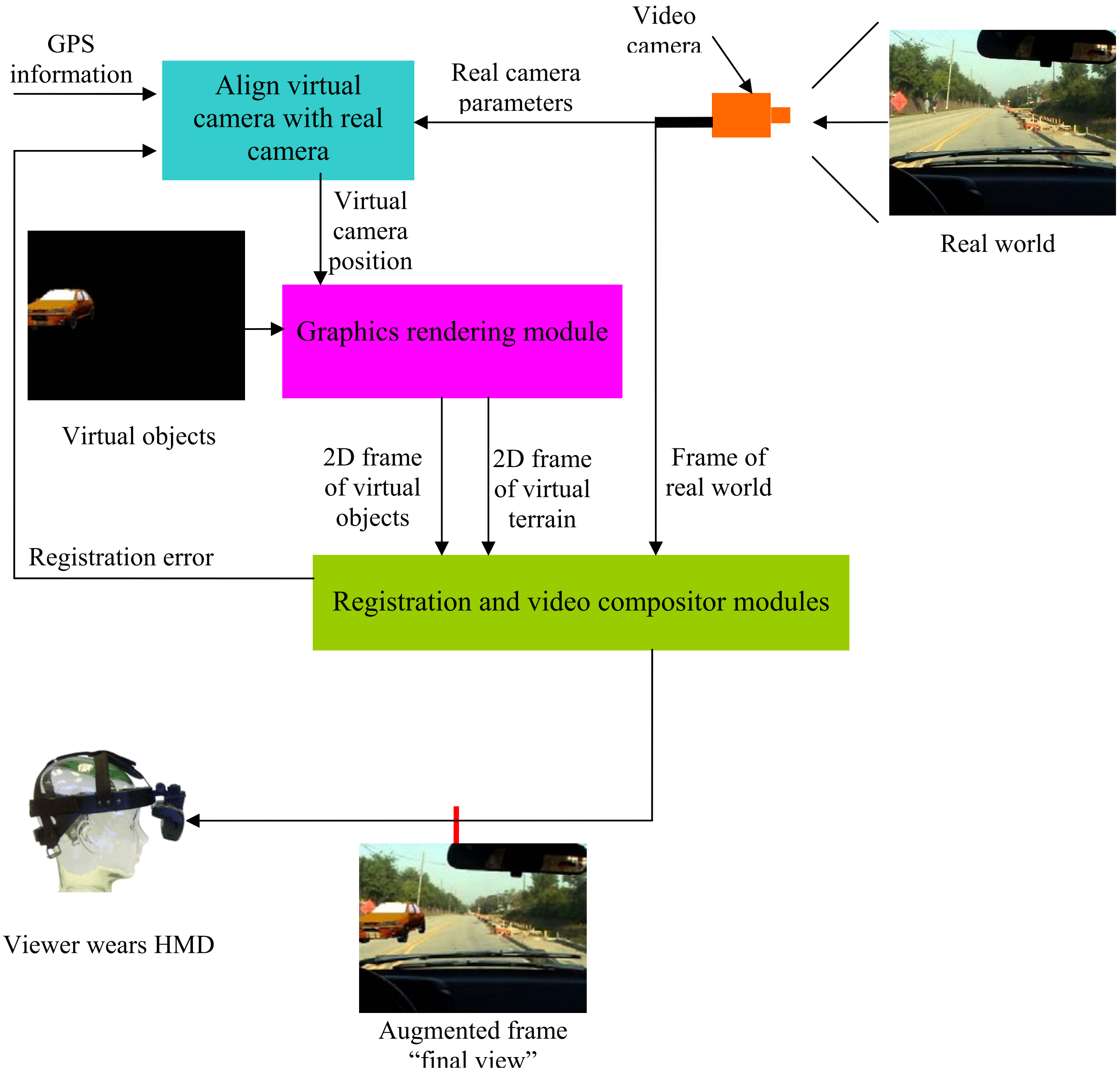


Figure 3-2: Block diagram of the ARV System.

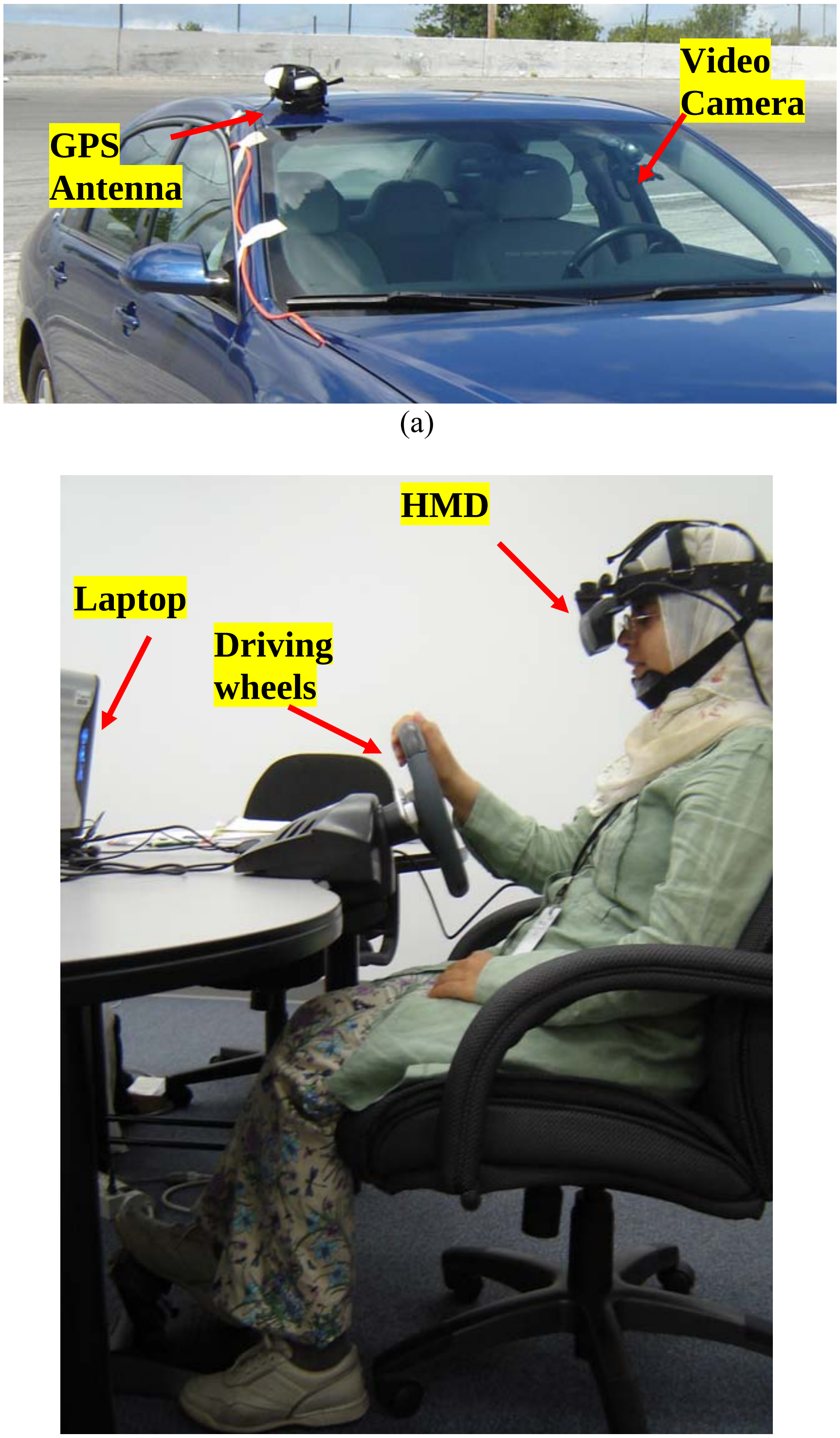
3.2 Off-line Augmented Reality Simulator "OARSim" System

The Off-line AR Simulator system is also based on the video see-through HMD technology. It has the same main components as the ARV system (video camera, GPS, HMD, and computer) besides having a driving wheel and brake and gas pedals. The OARSim system can be divided into two main stages; recording stage and testing stage. In the recording stage, the video camera and the GPS are connected to the computer and installed in a vehicle where the video camera is fixed on the vehicle's front windshield as shown in Figure 3.3 (a). During the journey of the vehicle, the video camera records a video of the real-world.

In the testing stage, a driver wears the HMD while taking control over the gas and brake pedals, and the steering wheel as shown in Figure 3.3 (b). Through the HMD, the driver is able to see an augmented video. The augmented video is a combination of the pre-recorded video, from the recording stage, and virtual images (computer-generated images) of vehicles, traffic signs, traffic signals, buildings, trees, and other objects depending on the scenario. This combination is done through the computer so that the driver will not be able to tell the difference between real and virtual objects in the scene. Based on the driver's application on brake, gas pedals and the steering wheel the frame in front of his eyes changes accordingly using the computer.

In addition, the block diagram that outlines the flow of data in the OARSim system has two main parts; one for the recording stage, and one for the testing stage as outlined in Figure 3.4 (a) and (b). In the recording stage, the **video camera** takes a real-time stream video of the real scene and before its first use it is calibrated using the unknown-orientation checkboard plan method. The camera's parameters; intrinsic and extrinsic parameters are calculated the same way as in the ARV system. In which the intrinsic parameters (focal length, principal point, skew coefficient, and distortion coefficient) are calculated from the camera calibration and the extrinsic parameters (rotations and translations) are first calculated using the in-the-field mark and updated using the **GPS information** (car position information) during the journey of the vehicle. Finally the computer saves the recorded video, the camera's parameters (intrinsic and extrinsic), and the GPS information (vehicle position) into files that can be used in the testing stage.

In the block diagram that outlines the flow of the data in the testing stage, the output from the recording stage is used as input for the testing stage as shown in Figure 3.4 (b). GPS information, real camera parameters, gas and brake pedals' and steer wheel's information are used to **align virtual camera with real camera.** Then using the adjusted virtual camera position the **graphic rendering module** renders two 2-D frames; one for the virtual objects and one for the virtual terrain. Afterward, the registration error between the pre-recorded real frame (obtained from the recording stage) and the 2-D virtual terrain frame can be calculated using the **registration module**. This registration error is used to adjust the virtual camera. Consequently, the augmented frame "final view" is generated using the **video composition module** that combines the pre-recorded real frame (obtained from the recording stage) and the virtual objects' frame. Finally, the augmented frame is displayed in front of the viewer's eyes through the **HMD**.



(a)

(b)

Figure 3-3: The OARSim system with its two stages; (a) recording stage, and (b) testing stage.

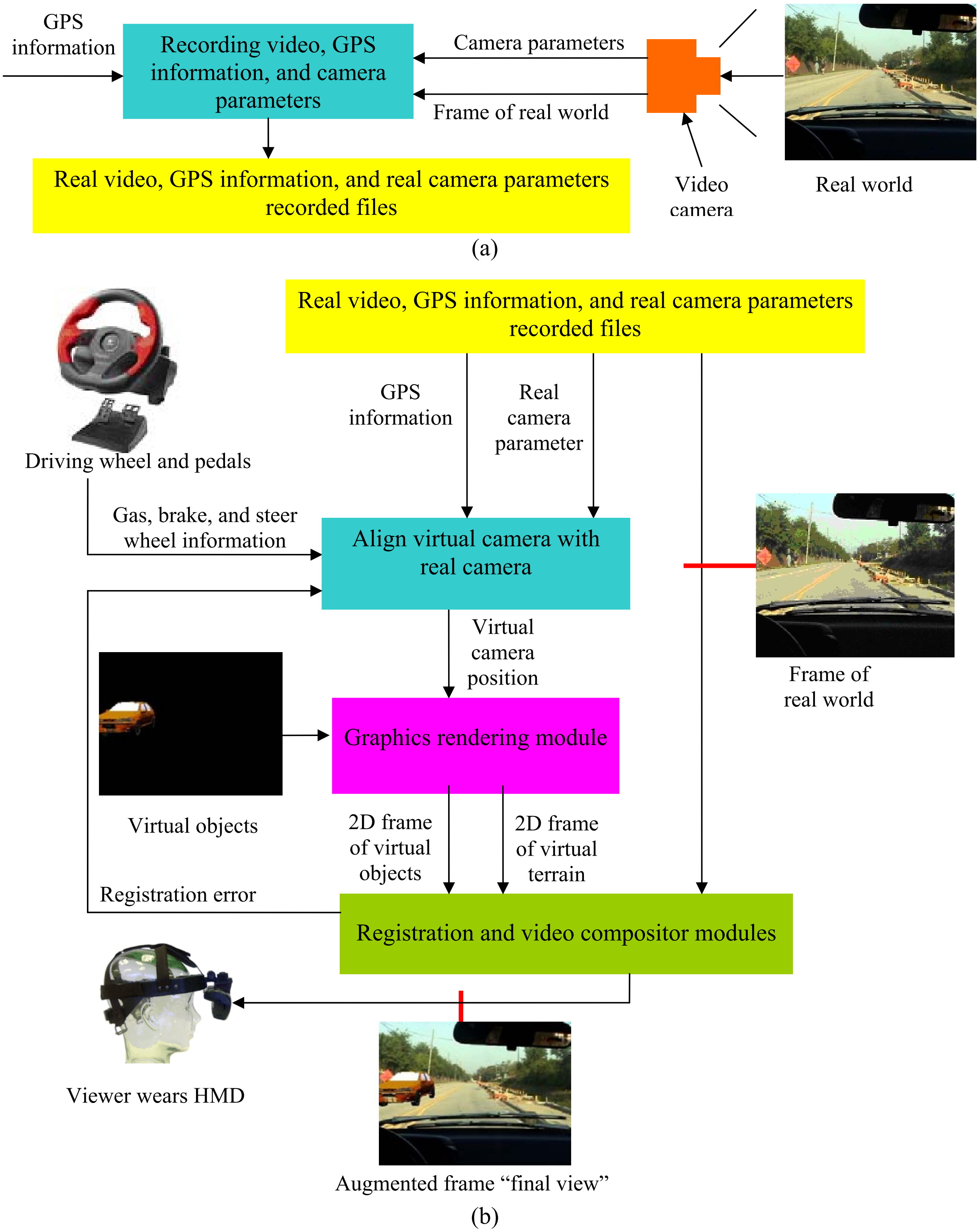


Figure 3-4: Block diagram of OARSim system; (a) recording stage, and (b) testing stage.

3.3 On-The-Field-Testing vs. ARV System vs. OARSim System

For in-the-field testing subjects are driving real vehicle in a real road with a completely real environment. Using the ARV system subjects are driving real vehicle in a real safe road while seeing through a HMD an augmented video of in-time video and virtual objects (computer generated objects) of people, vehicles, or any kind of hazards according to the scenario. Using the OARSim system, subjects are sitting in the lab driving a fixed simulator (controlling a steering wheel and gas & brake pedals) while seeing through a HMD an augmented video of a pre-recorded video, of a real world, and virtual objects (computer-generated objects) of people, vehicles, or any kind of hazards according to the scenario. In this section we are comparing the in-the-field real testing with our new AR systems; ARV system, and OARSim system in conducting an experiment. Table 3.1 is summarizing this comparison.

For both in-the-field testing and using ARV system, **driving real vehicle on a real road** offers high degree of **realism** to the experiment with high degree of motivation to drivers which is not the case when the OARSim system is used. That driving the OARSim system leave subjects under the impression that they are in a game even with the real pre-recorded video. This might be because of the fact that trustworthiness of the testing is significantly affected by the real driving feeling that comes from the continuous interaction with the vehicle's steering wheel, braking and gas pedals as well as the surrounding environment.

For the level of **risk**, the in-the-field testing offers high degree of risks to participants because of the possibility of involving in a real crash. Using the ARV system offers small or no risk to participants since all hazardous objects are virtual objects. On the other hand, sitting in the lab driving the OARSim system does not offer any kind of risk to participants.

Considering the **time**, the **cost**, and the **effort** in term of preparing for the experiment and getting and testing subjects, in-the-field real testing requires the longest time, highest cost and effort, than comes using the ARV system and finally the OARSim system.

While changing the **weather** has a significant effect on the in-the-field testing and using the ARV system it does not affect using the OARSim system.

Table 3.1: In-the-field testing vs. ARV system vs. OARSim system

Comparison Factors	**In-The-Field Testing**	**ARV System**	**OARSim System**
On Road Driving	√	√	---
Testing Realism	1	1	3
Risk*	1	2	3
Time*	1	2	3
Cost*	1	2	3
Effort*	1	2	3
Weather Effect	√	√	---

* From the highest to the lowest; 1 is the highest and 3 is the lowest.

CHAPTER 4: EXPERIMENTAL METHODOLOGY

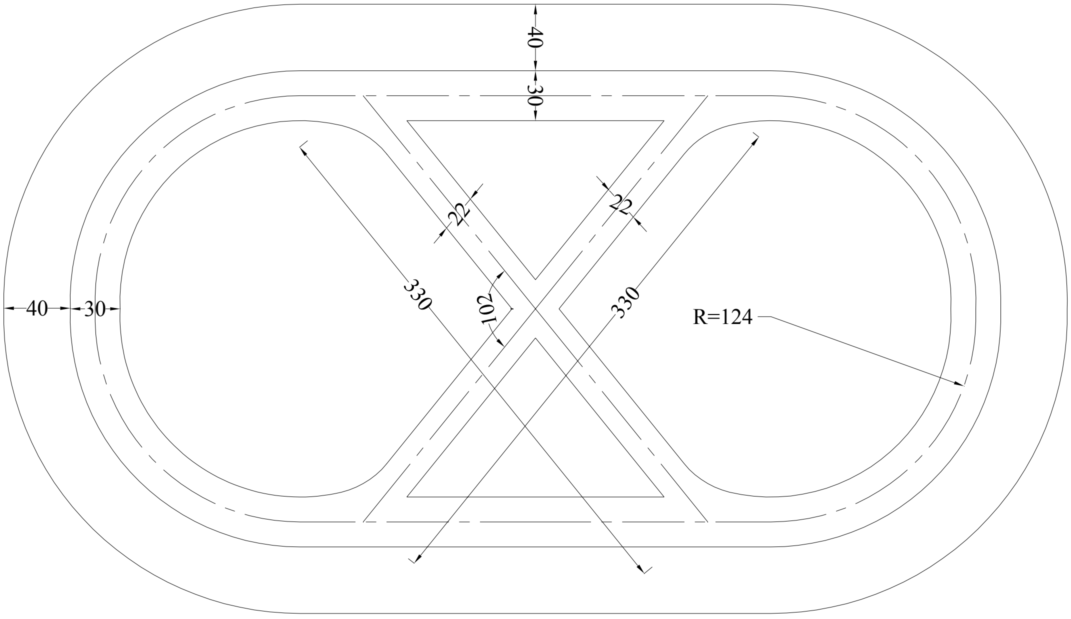
As indicated earlier in chapter 1, our main goal from this dissertation is to investigate the feasibility of applying the AR technology into traffic engineering applications. Therefore two AR systems were built (ARV system, and OARSim system) based on the AR technology. Both, AR systems' outcomes and the on-the-road driving under the AR were evaluated. Afterward, two studies were conducted using AR systems; the left-turn maneuver at non-signalized intersection, and the horizontal view blockage problem due to following a large truck vehicle.

A paved oval racetrack was used in conducting experiments using the ARV system. In this chapter detail descriptions of the design of each experiment and the procedure followed to conduct them are discussed

4.1. The Racetrack

The Orlando SpeedWorld oval racetrack, located in 19164 E. Colonial Dr., Orlando, Fl. 32833, was used in two of our experiments; evaluating on-the-road driving under AR and studying left-turn maneuver. Figure 4.1 shows an aerial photo of the race track. An AutoCAD drawing of the racetrack with all dimensions is shown in Figure 4.2. The racetrack has an outer steep oval track with a width of 50 ft, and a 30 ft inner track with a normal supper elevation. In the center of the track there are two 22 ft width crossed roads as shown in Figure 4.1, and 4.2. In our studies only the inner track and the crossed roads were used.

Figure 4-1: An aerial photo of the Orlando SpeedWorld oval race track.



Note: All dimensions are in feet

Figure 4-2: An AutoCAD drawing of the Orlando World Oval race track with dimensions.

4.2. Experimental Design

4.2.1. Scenario Design

4.2.1.1. AR Systems Evaluation

After building the AR systems, two stages need to be performed before using them in real traffic studies:

1. Evaluate AR systems' outcomes.
2. Evaluate the on-the-road driving under AR.

In evaluating AR systems' outcomes, the systems' abilities to duplicate real scenes and generate new scenes were assessed. When comparing real-world's images with their corresponding augmented images "final view", we were able to verify that both systems are compatible, as will be discussed in Chapter 6.

In evaluating the on-the-road driving under AR, i.e. drivers' distance and speed judgments as well as their level of comfort, the ARV system was used that allows drivers to drive a real vehicle on a real road under the AR. In this experiment, two scenarios were conducted; driving the vehicle without the ARV system, and driving the vehicle with the ARV system. For the two scenarios, drivers drove the vehicle on a real safe two-lane road (a paved racetrack) and asked to perform certain tasks while driving as follows;

a) Stop the vehicle at a certain point (white stop line), with what they perceived, to be the front bumper of the vehicle over the white stop line in the pavement. Their initial stopping point was recorded.
b) Drive at a constant speed (25 mph) and as close to the center of the lane as possible.

Drivers' path is shown in Figure 4.3, where drivers started at point A and asked to stop at point B, where a stop sign located, than followed the path B-C-A. As shown in Figure 4.3, the driving path has two parts; a straight segment and a curved segment. Figures 4.4, 4.5, and 4.6 show three real photos taken during the field verification experiments. Figure 4.4 shows the rented vehicle at the beginning of the experiment (point A). Figure 4.5 shows the vehicle reaching the stop sign at point B. Figure 4.6 shows the vehicle while driving along the curve. The posted speed limit through the experiment was 25 mph (40 kph). During the experiment, drivers were given instructions to instruct them about their path.

Some performance measures were captured over the course of the entire drive. Measures included distance to the stop line, average cruising velocity on the straight segment and on the curved segment, and the average offset from the center of the lane along the straight segment and along the curved segment

To get a more subjective view regarding AR systems realism, a survey was handed to participants after successfully completing the experiment. The survey included questions regarding quality of images, scene visibility, scenario realism, driving comfort, HMD comfort, and system fidelity. In addition, subjects were asked question related to their driving experience; whether they felt any motion sickness while driving or not, whether they felt safe while driving or not. Furthermore, subjects were asked about their opinion of how the AR system affected their comfort driving the system and its appropriateness for other use in future research.

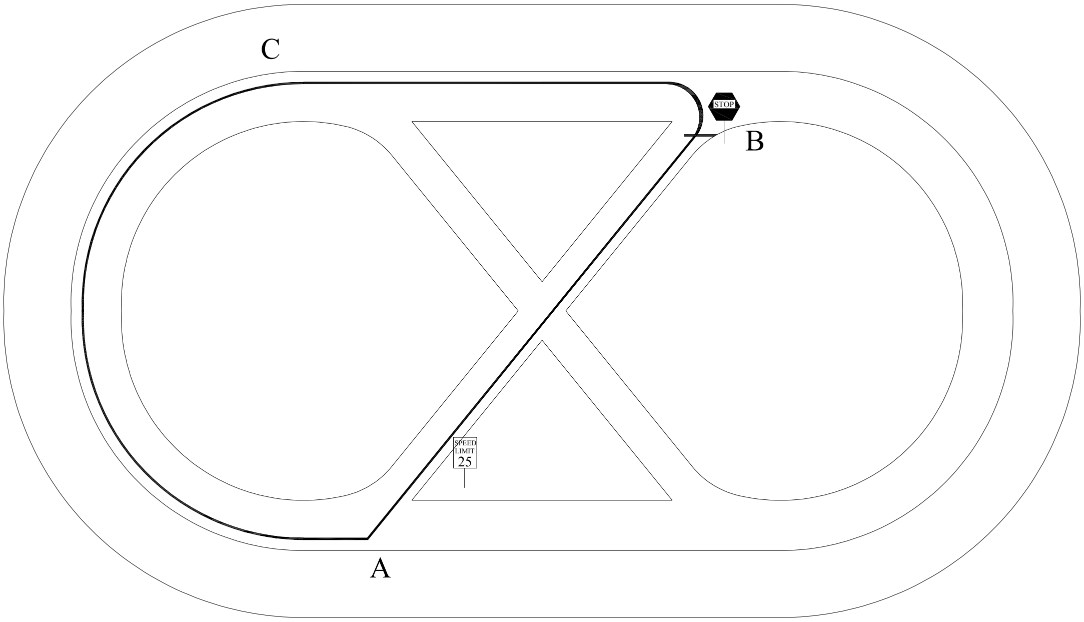


Figure 4-3: An AutoCAD drawing of the on-the-road driving evaluation experiment's driving path.

Figure 4-4: Photo taken at the beginning of on-the-road driving under AR experiment.

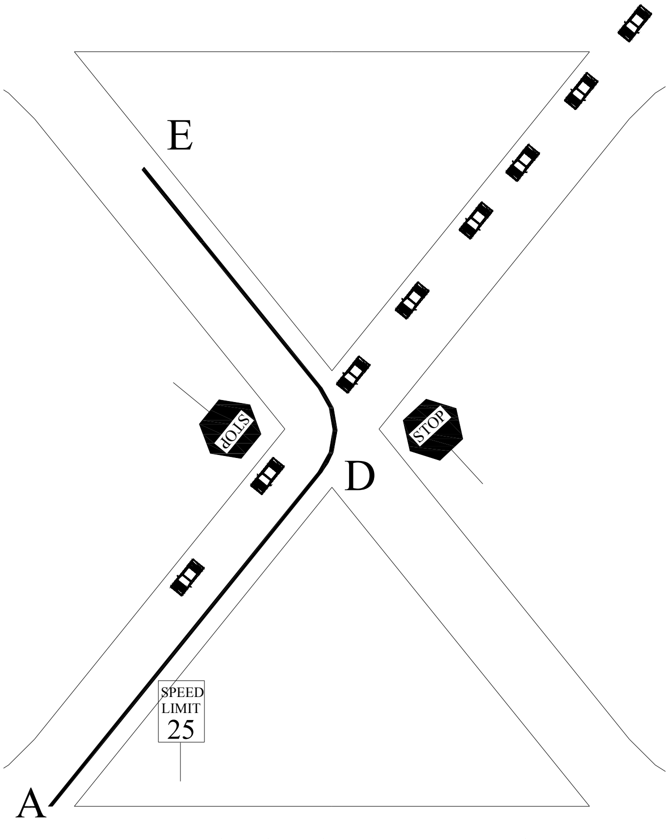
Figure 4-5: Photo taken when vehicle reaching the stop sign in on-the-road driving under AR experiment.

Figure 4-6: Photo taken while driving along the curve in on-the-road driving under AR experiment.

.

4.2.1.2. Left-Turn Maneuver

In studying effects of left-turner driver's characteristics (age and gender) on the left-turn maneuver at non-signalized intersection, the ARV system and the OARSim system were used. Two experiments were performed; one using the ARVsystem and, one using the OARSim system. In both experiments, one scenario was conducted. Drivers' path A-D-E, during the scenario, is shown in Figure 4.7, where drivers started at point A and drove until reaching a two-stop controlled intersection at point D and asked to select an appropriate gap between the oncoming virtual vehicles to make the left turn. During the scenario, the posted speed limit as well as the opposing virtual vehicles speed was 25 mph (40 kph). During the experiment, drivers were given instructions to instruct them about their path.



Note: The drawing is not to scale.

Figure 4-7: AutoCAD drawing of the left-turn maneuver scenario with driving path.

In the scenario design, to insure that drivers select their minimum acceptable gaps between opposing virtual vehicles and to make traffic appear random as in the real world situation, the oncoming virtual traffic was formed in two classes of mixed gaps as shown in Figure 4.8. The first class was very small gaps (less than 3 seconds) that were unlikely to be accepted by left-turn drivers. The second class consisted of increasing gaps in which the succeeding gap was one second larger than the previous one. Kettleson and Vandehey, 1991, noted that it is obvious that most drivers will accept 15-second gaps. Therefore, in our experiment, uniformly increasing gaps ranged from 3 seconds to 15 seconds were used, to accommodate all drivers.

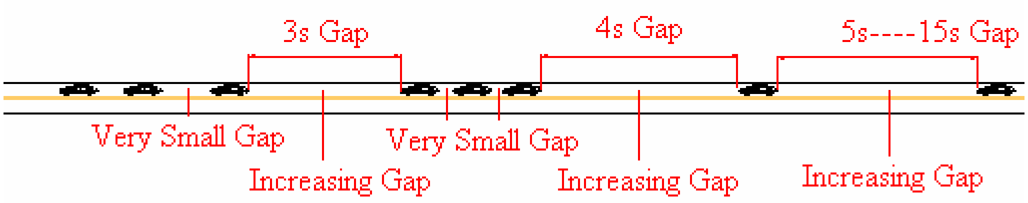


Figure 4-8: Design of the virtual opposing traffic

For each driver, the acceptable gap between opposing vehicles, the left-turn time, the left-turn acceleration, the left-turn angular velocity were recorded.

4.2.1.3. Horizontal Visibility Blockage

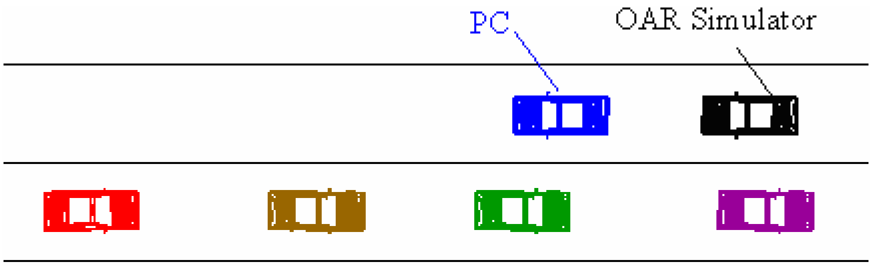
In order to study effects of following an LTV on the succeeding passenger car driver's performance and the contribution of a rear-end crash, the OARSim system was used. Two scenarios were conducted using the OARSim system; following a PC (PC-PC), and following an LTV (LTV-PC). Due to some technical and cost issues related to this experiment, the ARV system was not used to conduct this experiment. This included the high cost needed for renting a long straight segment of a paved racetrack, and getting a very expensive GPS.

To account for the bias in the results that might occur due to the same subject driving both scenarios, subjects were divided into two groups; A, and B. Group A drove first scenario (PC-PC) and group B drove second scenario (LTV-PC). Both groups drove the OARSim system while seeing through the HMD an offline video of a real two-way road with virtual vehicles. The posted speed limits as well as the virtual vehicles speed were 35mph (56 kph).

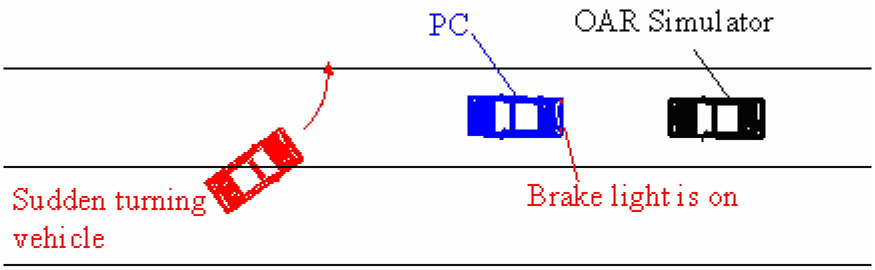
At the beginning of both scenarios (PC-PC and LTV-PC) participants were forced to follow a leading vehicle (a PC for group A and an LTV for group B) and drive on a two-way road for a bout 100ft. At the time T1, a hazardous incident hinders the leading vehicle (an opposing vehicle lost control and turned in front of the leading vehicle) causing it to brake suddenly at time T2. Responding to this incident, the following vehicle's driver (OARSim driver) decelerated at time T2. For each subject's response, there were two possibilities; a) stop the OARSim without hitting the leading vehicle, and b) involving in a rear-end collision with the leading vehicle. From scenarios' design, both scenarios can be divided into three stages as summarized in Table 4.1. AutoCAD drawings of both scenarios (PC-PC and LTV-PC) with their stages are shown in Figure 4.9 and Figure 4.10.

Table 4.1: Horizontal visibility stages descriptions

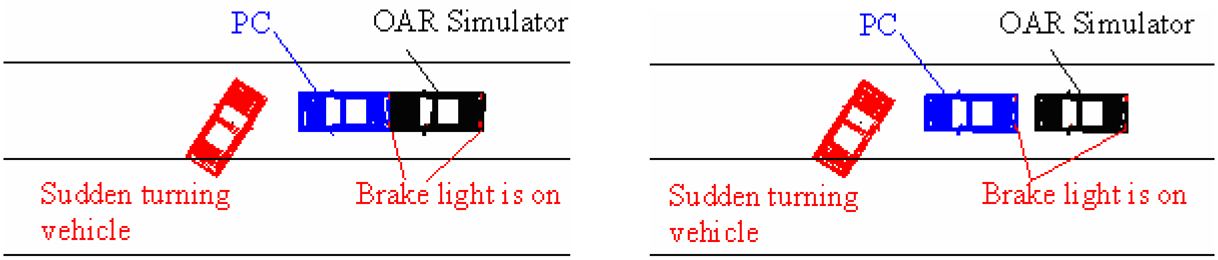
Stage	Descriptions
Stage I	Following a leading vehicle for about 100ft.
Stage II	An opposing vehicle lost control and consequently the leading vehicle started braking.
Stage III	a) The leading and succeeding vehicle (OARSim) stopped without involving in a rear-end crash.
	b) The leading and succeeding vehicle (OARSim) involved in a rear-end crash.



Stage I



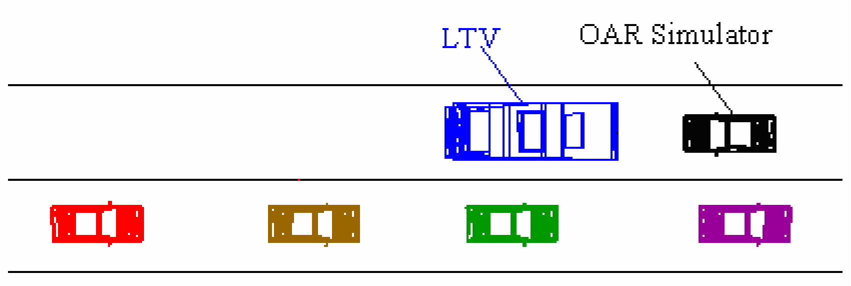
Stage II



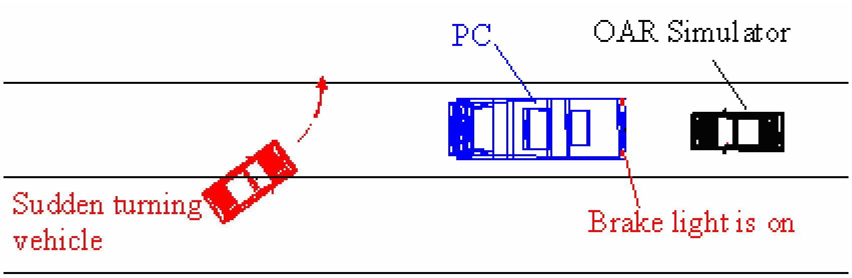
(a) (b)

Stage III

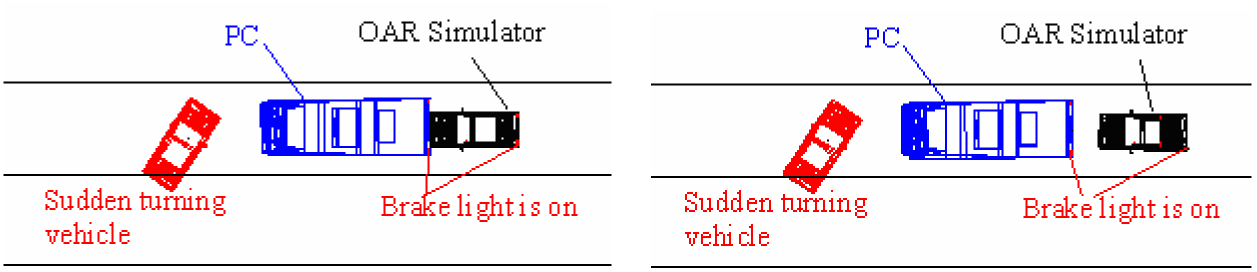
Figure 4-9: Following a PC scenario.



Stage I



Stage II



(a) (b)

Stage III

Figure 4-10: Following an LTV scenario.

Some performance measurements were recorded for each subject, in the two groups, during both scenarios. Those measurements include; subject's response time to the incident, subject's velocity at the time of the incident, the headway between the leading vehicle and the OARSim's driver at the time of the incident, and the subject's deceleration rate.

4.2.2. Sample Size

In this section the number of subjects needed for each experiment (the sample size) is discussed. Calculating the required sample size for each experiment is based on either data obtained from previous study or from our pilot study as will be discussed in Chapter 5.

4.2.2.1. Evaluate the on-the-road driving under the AR

In this experiment we are studying the effect of the AR on on-the-road driving. According to our pilot study, the variance of the average cruising velocity for driving the vehicle on the straight segment with and without the ARV system were 1.34 mph, 1.35 mph respectively, see Chapter 5. At a level of confidence 95% and estimated error of 0.5 mph the needed number of subject can be calculated based on the following equation

$$n = \left(\frac{Z_{\alpha/2}}{H} \right)^2 (\sigma_1^2 + \sigma_2^2) \text{ .... } (4.1)$$

Where, n the estimated sample size

Z_α = Z-coefficient for the false-change (Type I error rate), with 95 % confidence interval, α=0.05 and Z α/2= 1.96.

H the half-width of a large sample confidence interval (error rate) = 0.5 mph.

σ_1 the standard deviation of the cruising velocity for driving without the ARV system.

σ_2 the standard deviation of the cruising velocity for driving with the ARV system.

$$\therefore n = \left(\frac{1.96}{0.5} \right)^2 (1.34 + 1.35) = 41.3$$

From the above equation, at a level of confidence 95%, at least 42 subjects are needed for studying the effect of the AR on on-the-road driving. Finally, 44 participants successfully finished this experiment.

4.2.2.2. Left-Turn Maneuver Experiment

In this experiment we are interested in studying left-turn maneuver at non-signalized intersection. Based on previous study, the gap acceptances for left turning maneuver at non-signalized intersection ranged from 3 to 13 seconds (Tepley et al. 1997). Therefore, the standard deviation of the gap acceptance is approximately equal to the range over 6, i.e. 10/6 second. At a level of confidence 95% and estimated error of 0.5 sec, the needed number of subject can be calculated based on the following equation

$$n = \left(\frac{Z_{\alpha/2}}{H} \right)^2 \sigma^2 \quad \text{...}(4.2)$$

Where, n the estimated sample size

Z_{α} = Z-coefficient for the false-change (Type I error rate), with 95 % confidence interval, α=0.05 and Z α/2= 1.96.

H the half-width of large sample confidence interval for mean gap (error rate) = 0.5 sec.

σ the standard deviation of the gap acceptances = gap acceptance range / 6.

$$\therefore n = (\frac{1.96}{0.5})^2 [10/6]^2 = 42.7$$

From the above equation, at a level of confidence 95%, at least 43 subjects are needed for studying the left-turn maneuver at non-signalized intersection. Finally, 44 participants successfully finished this experiment.

4.2.2.3. Horizontal Visibility Blockage Experiment

In this experiment we are studying the effect of following LTV on the succeeding vehicle driver's performance and the contribution to rear-end collision. Proportions of rear-end collisions when following a PC and following an LTV obtained from our pilot study, see Chapter 5, were used to calculate the required sample size using the following equation.

$$n = \frac{(Z_\alpha + Z_\beta)^2 (p_1 q_1 + p_2 q_2)}{(p_1 - p_2)} \quad\text{..........}(4.3)$$

Where, n the estimated necessary sample size.

Z_α = Z-coefficient for the false-change (Type I) error rate, with 95 % confidence interval, α=0.05 and Z α/2= 1.96.

Z_β = Z-coefficient for the missed-change (Type II) error rate, with 95 % confidence interval, β =0.05 and Z β/2 = 1.64.

p_1 is the proportion of rear-end crashes in scenario 1 (PC-PC)

$$p_1 = \frac{Number\ of\ rear\_end\ crashes\ in\ scenari\, 1}{Total\ number\ of\ trials\ for\ scenario\, 1} = \frac{0}{6} = 0 \quad\text{..........}(4.4)$$

q_1= 1-p_1=1 ....(4.5)

p_2 is the proportion of rear-end crashes in scenario 2 (PC-LTV)

$$p_2 = \frac{Number\ of\ rear\_end\ crashes\ in\ scenari\, 2}{Total\ number\ of\ trials\ for\ scenario\, 2} = \frac{4}{6} = 0.67 \quad\text{..........}(4.6)$$

q_2= 1-p_2= 0.33 ....(4.7)

$$n = \frac{(1.96 + 1.64)^2 (0.67 * 0.33 + 0)}{(0.67 - 0)} = 4.27$$

From the above equation, at a level of confidence 95%, at least 5 participants were needed for each scenario of this experiment. With the minimum required sample size calculated above, the occurring error is 5% with the 95%confidence interval. In order to decrease the error to 1%, the same calculation completed above is repeated with 99% confidence interval. Therefore, α=0.01, Zα/2 =2.58 and Zβ/2 =2.33.

$$\therefore n = \frac{(2.58 + 2.33)^2 (0.67 * 0.33 + 0)}{(0.67 - 0)} = 10.36$$

From the above equation, at a level of confidence 99%, at least 11 participants were needed for each scenario of this experiment. Finally, 22 subjects successfully finished scenario of the horizontal visibility blockage experiment.

4.3. Experimental Procedure

After determining minimum sample size for each experiment, the three studies in a total were conducted; evaluate the on-the-road driving under the AR, study left-turn maneuver at non-signalized intersection, and study horizontal visibility blockage due to following an LTV. In evaluating the on-the-road driving performance under the effect of the AR, the ARV system was used which allows drivers to drive a real vehicle on a real road under the AR. Two scenarios; driving without the ARV system, and driving with the ARV system were built using the ARV system. In studying the left-turn maneuver at non-signalized intersection, the ARV system and the OARSim system were used. Two experiments were performed; one using the ARV system and, one using the OARSim system. In both experiments, Left-Turn scenario was conducted. In studying horizontal visibility blockage when following an LTV, the OARSim system was only used. As mentioned early, due to some technical and cost issues related to this experiment, the

ARV system could not be used to conduct this experiment. In this experiment, two scenarios were conducted using the OARSim system; following a PC, and following an LTV.

A total of eighty-eight subjects participated in our study. Participants were divided into three groups; A (22 participants), B (22 participants), and C (44 participants). Group A and B conducted horizontal visibility blockage and left-turn maneuver experiments and group C conducted the on-the-road driving under the AR evaluation and the left-turn maneuver experiments as shown in Table 4.2.

In order to make the participated subjects representing the actual Florida drivers' population, the Florida crash distribution was used; in which males represent about 60% versus females 40%, and young age represents 66% versus old 34% of the population. The younger group included ages 18-45 and the older group included ages 45-65 as shown in Table 4.2. All participants had a valid driving license for at least one year.

Table 4.2: Final study's subjects distribution

Group	**AR System used**	**Scenario Driven by Group**	**Age**	**Gender**		**Total**
				Male	**Female**	
A	OARSim System	• Left-Turn maneuver • Following a PC	**Young**	9	6	22
			Old	4	3	
B	OARSim System	• Left-Turn maneuver • Following an LTV	**Young**	9	6	22
			Old	4	3	
C	ARV System	• Driving without ARV system • Driving with ARV system • Left-Turn maneuver	**Young**	18	12	44
			Old	8	6	

Before starting experiments using the ARV system (the on-the road driving under AR and the left-turn maneuver experiments) participants were required to test-drive the vehicle, at the paved racetrack, without the ARV system for two minutes and with the ARV system for another two minutes to become familiar with the vehicle, racetrack and the ARV system. In addition, before starting experiments using the OARSim system (the left-turn maneuver and the horizontal visibility experiments) participants were asked to test drive the OARSim system for about two minutes to become familiar with the system.

In all experiments, participants were informed that the objective of the study was to assess the fidelity of the AR systems and they should obey traffic laws and rules. In case of driving more than one scenario, participants were given at least two minutes to rest before running the next scenario.

To get a more subjective view regarding AR systems realism and the design of each scenario, a survey was handed to participants. The survey included questions regarding quality of images, scene visibility, scenario realism, driving comfort, HMD comfort, and system fidelity. Furthermore, subjects were asked question related to their driving experience; whether they felt any motion sickness while driving or not, and whether they felt safe while driving or not. Furthermore, subjects were asked about their opinion of how the AR system affected their driving comfort and its appropriateness for other use in future research. Finally, participants were asked general questions regarding the scenarios they finished, as shown in Appendix A.

CHAPTER 5: DATA OUTPUT INVESTIGATION

5.1. AR Systems Data Output

As discussed in Chapter 3, the ARV system has three main components (video camera, HMD, and GPS) connected to a powerful computer. The GPS records the vehicle's position (longitude and attitude), the speed, and the direction every 1/10 second and send these data to the computer. A sample of the GPS output data (raw data) is shown in Appendix B. Based on these data, the computer calculates the X- and Y-coordinate and save them with the speed and the direction data into an output file.

Moreover, the OARSim system has the same main components as the ARV system (video camera, GPS, HMD, and computer) besides having a driving wheel and brake and gas pedals. During the first stage (recording stage), the GPS records the vehicle's position (longitude and attitude), the speed, and the direction every 1/10 second and send these data to the computer. Then the computer calculates the X- and Y-coordinate and save them with the speed and the direction data into an output file to be used in the second stage (testing stage). During the testing stage the computer uses this output file with the brake pedal's, gas pedal's and the steering wheel's information to obtain the subject's position (X and Y-coordinate), speed and direction.

Other traffic variables, such as distance, angular velocity, and acceleration/ deceleration can be calculated using the AR systems' output data. During experiments, the number of crashes (if any) is reported by a second person.

5.2. Experimental Variables

Based on the AR systems' output data some variables were calculated for each experiment, as will be discussed in the following sections.

5.2.1. On–the-Road under AR Evaluation Experiment

In evaluating the on-the-road driving under AR, subjects were asked to drive the vehicle as close as possible to lane center while following the speed limit "25 mph" and stop the vehicle at the stop sign, with what they perceived, to be the front bumper of the vehicle over a white stop line. Form this experiment some variable were calculated based on the recorded output data as following:

Distance to stop Line "d"

The point where each driver initially stopped was recorded then the distance to the stop line was calculated using the following equation.

$$d = X_1 - X_2$$

Where,

d is distance to the stop line

X_1 is the position of the stop line

X_2 is the initial stop position of the vehicle's front bumper.

This distance is a good indication of each driver's distance judgment. Figure 5.1 shows this distance.

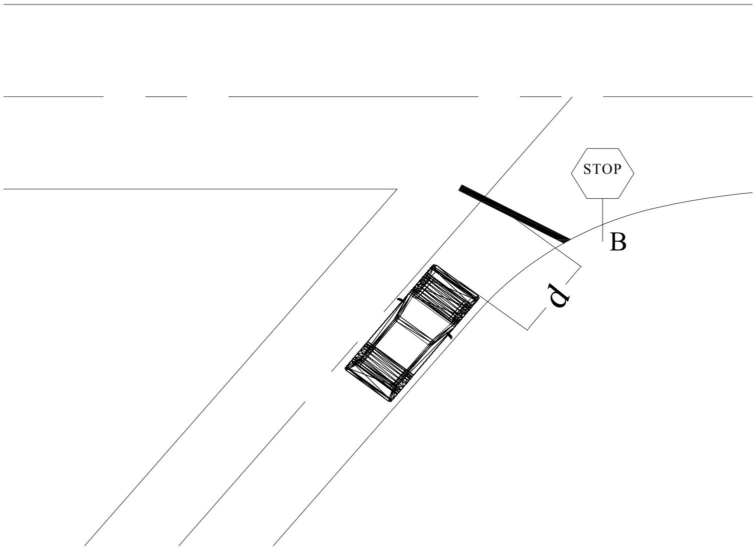


Figure 5-1: An AutoCAD drawing shows the distance to the stop line "*d*" in on-the-road evaluation experiment.

Average Cruising Velocity "AV"

The average cruising velocity refers to the average vehicle's velocity through the experiment. The average cruising velocity is a good indication of each driver's speed judgment. In the experiment, subjects drove on a straight segment and on a curved segment. Therefore two average velocities were calculated; one on the straight segment "*AVs*" and one on the curved segment "*AVc*".

Average Offset from the lane Center "AO"

Since subjects were asked to drive as close to the center of the lane while maintaining road speed limit (25mph), the average offset from the lane center is a good indication of each driver's level of comfort while driving. The average offset was calculated while driving along the straight segment "*AOs*" and while driving alone the curved segment "*AOc*".

5.2.2. Left-Turn Maneuver Experiment

In studying effects of the left-turn driver’s characteristics (age and gender) on the left turning maneuver at two-way stop-controlled intersection some variables were calculated based on the AR systems’ output data as follows:

Acceptable Gap “GAP”

The gap is the time gap between two successive vehicles in the opposing flow, measured from the instance that the front of the first vehicle passes a point to the instance that the front of the following vehicle passes the same point, in seconds, as shown in Figure 5.2. If the subject chose a gap between two vehicles, on the major road, then the distance between the leading car and the following car divided by the major road design speed is equal to the accepted gap.

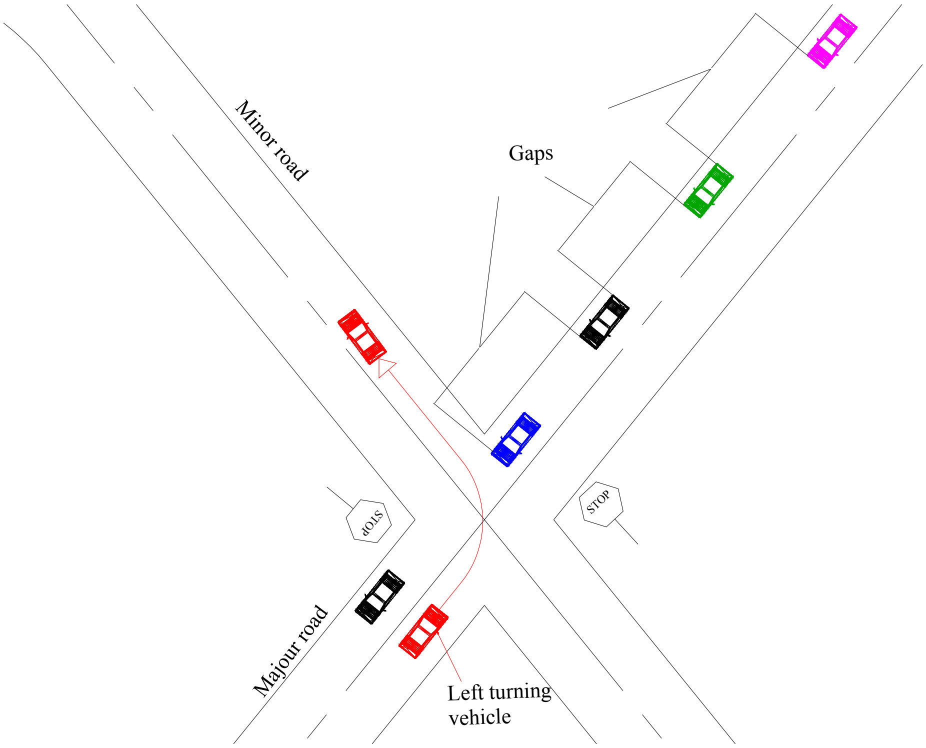


Figure 5-2: The gaps between opposing vehicles.

Left-Turn Time "LTT"

The left-turn time is the total time during which the vehicle steer turned left and turned back when subjects complete the left turn maneuver.

LTT= Tc-Ts

Where, *LTT* is the total left turning time.

Ts is the time at which the vehicle started to turn left.

Tc is the time at which the vehicle completes left turning maneuver.

Average Left-turn Acceleration "ALTA"

The average left-turn acceleration is the average vehicle's acceleration rate during the period of making left turn maneuver.

$$ALTA = \frac{(V_c - V_s)}{LTT}$$

Where, *ALTA* average left-turn acceleration

Vs is the velocity at which the vehicle started left turning.

Vc is the velocity at which the vehicle completed left turning maneuver.

LTT is the total left turning time.

Average Left-Turn Angular Velocity "ALTAV"

The average left-turn angular velocity is equal to the to the total sum of the rotation angle difference for every time unit divided by the total time during which the vehicle's steer turned left and turned back when subjects completed the left turn maneuver. The angular velocity can be calculated as following:

$$ALTAV = \frac{\sum_{i=s}^{i=c} \alpha_i}{LTT}$$

Where:

ALTAV is the average left-turn angular velocity.

α_i= the vehicle shifted angel at time *i*.

S is the point at which the vehicle started left turning

C is the point at which the vehicle finish left turning maneuver.

LTT = the total left turning time

The shifted angel at any time i can be calculated as following

$$\alpha_i = \tan^{-1}\left[\frac{(Y_{i+1} - Y_i)}{(X_{i+1} - X_i)}\right]$$

Where, X_i and Y_i are the vehicle x and y positions at time i.

X_{i+1} and Y_{i+1} are the vehicle x and y positions at time i+1.

5.2.3. Horizontal Visibility Blockage

In studying effects of following an LTV on the leading vehicle driver's performance and the contribution of rear-end crash, two scenarios were conducted; following a PC, and following an LTV using the OARSim system. For the two scenarios some important variables were calculated as follows:

Incident Headway "IHWAY"

The incident headway refers to the headway between the OARSim and the leading vehicle just before the OARSim started braking, measured from the end of the leading vehicle to the center of the following OARSim, as shown in Figure 5.3. The incident headway is one of the factors that indicate a collision threat. When it is too small the possibility of rear-end crash increases.

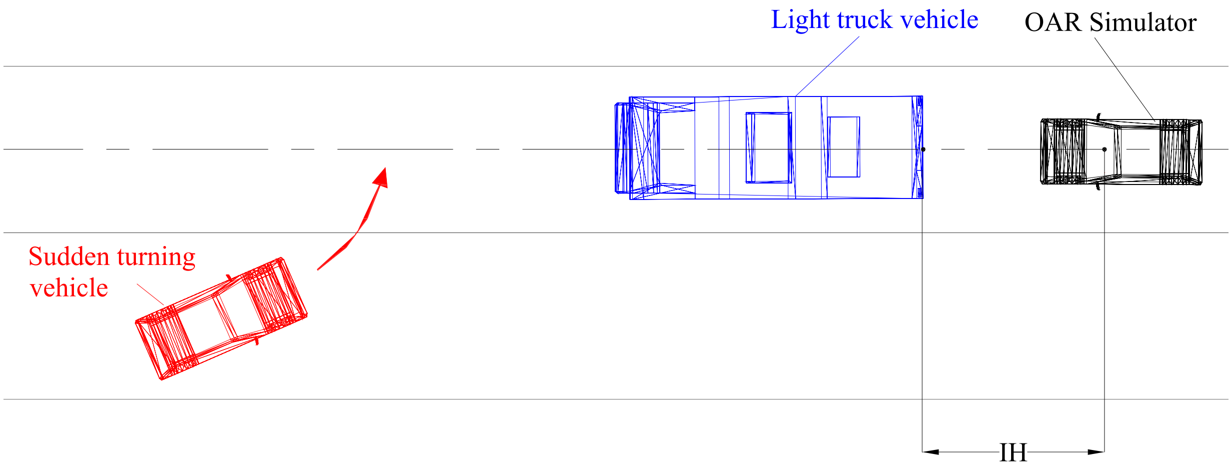


Figure 5-3: The incident headway "IH" in the Horiz. View blockage study.

The Blocked View Headway "Hb"

The blocked view headway *"Hb"* is the headway between the leading LTV and the succeeding car that define the beginning of the blocked view area caused by following an LTV, measured from the end of the leading LTV to the center of the following car , as shown in Figure 5.4. In Figure 5.4, the hatched area represents the blocked view area of the small vehicle when following the LTV. When a passenger car is following an LTV with a distance less than or equal to Hb the succeeding car will not able to see the sudden turning vehicle, i.e. the sudden turning vehicle will be in the blocked view area of the following car, as shown in Figure 5.4.

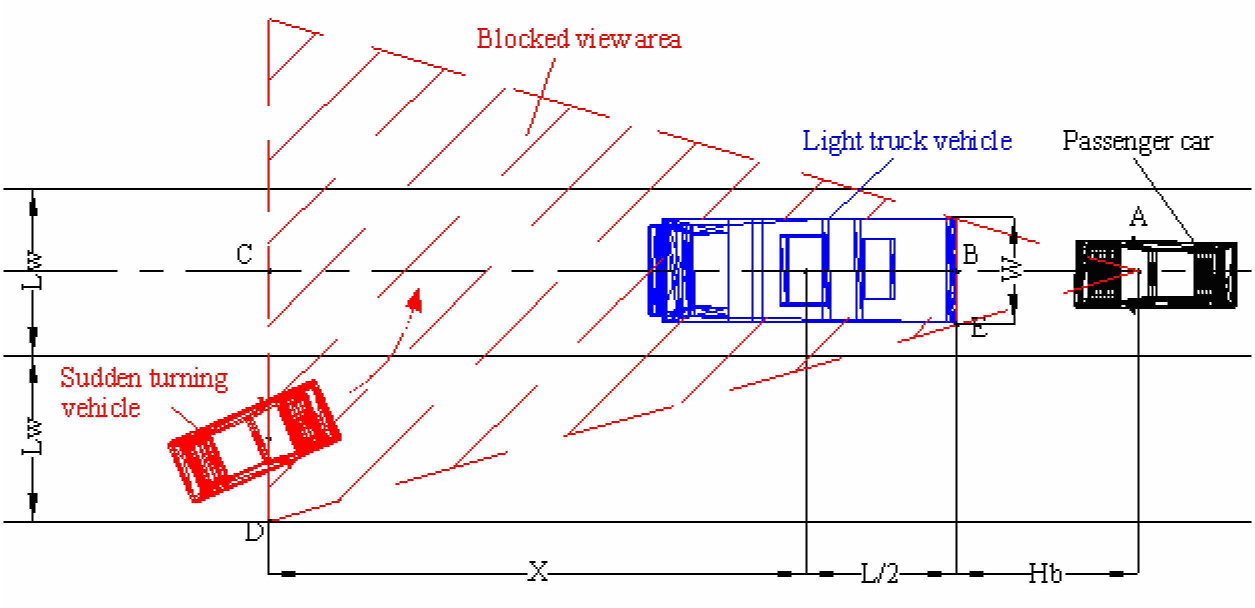


Figure 5.4: The blocked headway “Hb” when following an LTV.

From Figure 5.4, the blocked view headway “Hb” can be calculated as following,

$$\frac{AB}{AC} = \frac{BE}{CD}$$

$$\frac{H_b}{\left(H_b + L/2 + X\right)} = \frac{W/2}{1.5L_w}$$

$$H_b(1.5L_w - W/2) = W/2\left(X + L/2\right)$$

$$\therefore H_b = \frac{W/2\left(X + L/2\right)}{(1.5L_w - W/2)}$$

Where, Hb: blocked view headway,

X: the distance from the center of the leading LTV to the event (sudden turning vehicle) = 131.15ft.

W and L are the light truck vehicle dimensions, equal to 9.22ft and 27.2ft respectively.

Lw: lane width, equal to 15 ft.

$$\therefore H_b = \frac{9.22/_2\left(131.15 + 27.2/_2\right)}{(1.5 * 15 - 9.22/_2)} = 62.6\, ft$$

Therefore, the blocked view area's headway is a function of the lane width, the LTV's dimensions (width and length), and the distance from the LTV to the incident (sudden turning vehicle).

Incident Velocity "IV"

The incident velocity refers to the vehicle's velocity just before it starts braking when the vehicle from the opposing traffic makes a sudden turn and the leading vehicle brakes accordingly.

Incident Response Time "IRT"

In our experiment, the incident response time refers to the time it took the vehicle's driver to response to the incident (opposing vehicle makes a sudden turn).

$IRT = T_3 - T_1$

Where, *IRT* is the response time to the sudden left turning vehicle.

T_1 is the time at which the vehicle from the opposing traffic makes a sudden turn.

T_3 is the time at which the vehicle started to decelerate as a response to the incident.

Incident Deceleration Rate "IDR"

The incident deceleration rate is the succeeding vehicle's deceleration rate when the vehicle from the opposing traffic made a sudden turn and the leading vehicle brake suddenly which led the succeeding vehicle's driver to decelerate. The deceleration rate can be calculated as follows:

$$IDR = \frac{(V_3 - V_4)}{(T_4 - T_3)}$$

Where, IDR is the vehicle's deceleration rate

V_3 is the velocity at the instant the succeeding vehicle started to brake.

V_4 is the velocity at which the succeeding vehicle stopped.

T_3 is the time at which the succeeding vehicle started to brake.

T_4 is the time at which the succeeding vehicle reached a complete stop.

V_4 is assumed to be $\leq$ 5 mph since in some cases when the vehicles had enough time to brake and stop, they start braking when they are far away from the stop line and they roll at approximately 5 mph or less for a while before they come to a complete stop.

Incident Impact Velocity "IIV"

In case of a crash between the two vehicles (the leading and the following vehicles), the velocity of the succeeding vehicle just before the crash was recorded as the incident impact velocity "IIV".

5.3. Pilot Studies

Before starting the formal experiments, pilot studies were conducted for all the experiments. The main purposes of the pilot studies were to test the design of the experiments, and to help in calculating the sample size needed for each experiment in the formal study.

5.3.1. On-The-Road Evaluation Pilot Study

In the pilot study for on-the-road evaluation two scenarios were considered; driving without the ARV system and driving with the ARV system, designs of the scenarios were as described in Chapter 4. In both scenarios, subjects were asked to drive 25 mph (40 km/h) and as close to the center of the lane as possible along both straight and curved segments. In addition, they were asked to stop the vehicle at the stop sign in which the front pamper of the vehicle is over the stop line.

In the pilot study, eleven individuals drove the vehicle (a rented vehicle) for the two scenarios; with the ARV system and without the ARV system. Subjects were handed a survey to fill after finishing the experiment (see Appendixes A).

Data Collection

For both scenarios (without the ARV system and with the ARV system) performance measures were captured over the course of the entire drive. Measures included distance to the stop line "d", as shown in Figure 5.1, average cruising velocity on the straight segment and on the curved segment and the average offset from the center of the lane along the straight segment and along the curved segment. Measurements are summarized in Table 5.1. In Table 5.1, the positive sign of d indicates that the vehicle's front bumper stopped before the stop line. The negative sign of d indicates that the vehicle's front bumper stopped after the stop line.

Table 5.1: Data collection summary for each driver for on-the-road driving evaluation scenarios in the pilot study

WITHOUT ARV SYS Scenario					
Subject No.	**Distance to Stop Line “d” (ft.)**	**Avg. Velocity on Straight Segment “AVs” (mph)**	**Avg. Velocity on Curved Segment “AVc” (mph)**	**Avg. Offset on Straight Segment “Os” (ft)**	**Avg. Offset on Curved Segment “Oc” (ft)**
1	0.34	9.99	14.16	0.68	0.52
2	-0.17	9.41	14.98	0.34	0.26
3	-0.85	7.40	10.62	0.89	0.95
4	-1.03	7.38	13.54	1.01	1.2
5	-0.32	6.43	12.05	0.64	1.34
6	-0.90	8.36	12.36	1.20	1.08
7	-0.70	10.23	12.4	1.40	2.10
8	-1.02	9.52	14.26	1.04	1.44
9	-0.82	9.14	12.06	1.32	1.10
10	-1.16	6.60	12.32	1.25	1.05
11	-0.42	8.95	13.28	0.85	0.63
WITH ARV SYS Scenario					
Subject No.	**Distance to Stop Line “d” (ft.)**	**Avg. Velocity on Straight Segment “AVs” (mph)**	**Avg. Velocity on Curved Segment “AVc” (mph)**	**Avg. Offset on Straight Segment “Os” (ft)**	**Avg. Offset on Curved Segment “Oc” (ft)**
1	0.25	8.21	11.37	0.85	0.65
2	-0.13	10.12	10.48	0.425	0.32
3	-0.48	6.75	9.52	1.11	1.19
4	-1.17	7.96	10.52	1.26	1.50
5	-0.67	6.01	8.81	0.80	1.70
6	-0.54	7.50	11.72	1.50	1.35
7	-1.05	9.40	9.51	1.75	2.10
8	-0.72	7.51	11.52	1.3	1.80
9	-0.93	8.86	8.08	1.65	1.37
10	-0.79	6.14	9.42	1.56	1.31
11	-0.85	6.43	10.23	1.16	2.01

Data Analysis

Figure 5.5 shows one of the subjects cruising velocities through the experiment, along the straight and the curved segments, for the two scenarios (without the ARV system and with the ARV system). In which participant started the experiment at point A and drove along the straight segment till reaching the stop sign at point B and stopped. Afterward he continued driving along the curved segment and pass point C till reaching the end of the curve at point A'. Descriptions of points on the driving path are shown in Table 5.2. From Figure 5.5, the participant's maximum speed along the straight segment was 18.77 mph when driving without the ARV system and 19.95 mph when driving with the ARV system. On the other hand, the participant's maximum speed along the curved segment was 22.96 mph when driving without the ARV system and 20.89 mph when driving with the ARV system.

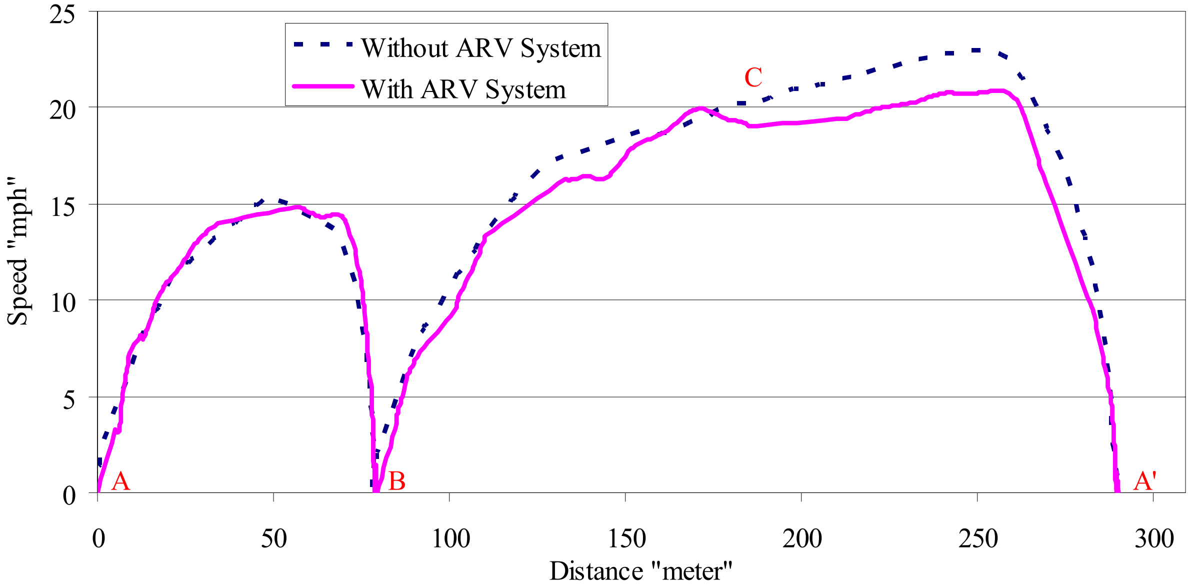


Figure 5-4: One of the participants cruising velocities with distances in on-the-road evaluation experiment.

Table 5.2: Descriptions of participant's driving path for on-the-road driving evaluation

Point	**Descriptions**
A	Beginning of the experiment (start driving on the straight segment).
B	Point where the stop sign is
C	Point on the curved segment
A'	End of the curved segment

Using the data in Table 5.1, five tests were conducted as a measure of driver's distance judgment, speed judgment, and driving comfort when driving without the ARV system versus driving with the ARV system, as following,

1. Test the statistical significance difference between the mean of the **distance to stop line** for without the ARV system and with the ARV system scenarios.
2. Test the statistical significance difference between the mean of the **average cruising velocity on the straight segment** for without the ARV system and with the ARV system scenarios.
3. Test the statistical significance difference between the mean of the **average cruising velocity on the curved segment** for without the ARV system and with the ARV system scenarios.
4. Test the statistical significance difference between the mean of **the average offset from the center of the lane along the straight segment** for without the ARV system and with the ARV system scenarios.
5. Test the statistical significance difference between the mean of **the average offset from the center of the lane along the curved segment** for without the ARV system and with the ARV system scenarios.

The statistical summary of those tests are summarized in Table 5.3.

Table 5.3: Statistical summary of Minitab outputs of paired t-tests for without the ARV system and with the ARV system scenarios in the pilot study

Parameter		**Hypothesis**	**P-VALUE**	**Conclusion***
Distance to Stop line "d"		H0: mean1 = mean 2 H1: mean1 ≠ mean 2	0.974	Don't Reject H0
Avg. Cruising Velocity	**on Straight Segment "AVs"**	H0: mean1 = mean 2 H1: mean1 ≠ mean 2	0.06	Don't Reject H0
	on Curved Segment "AVc"	H0: mean1 = mean 2 H1: mean1 ≠ mean 2	0.00	Reject H0
Avg. Offset from Lane Center	**on Straight Segment "AOs"**	H0: mean1 = mean 2 H1: mean1 ≠ mean 2	0.504	Don't Reject H0
	on Curved Segment "AOc"	H0: mean1 = mean 2 H1: mean1 ≠ mean 2	0.013	Reject H0

*Based on 95% confidence ($\alpha = 0.05$)

At a 95% level of confidence, there was no statistically significant difference in all parameters between the two scenarios (without and with the ARV system) when driving along the straight segment. On the other hand, there were significant differences in the average cruising velocity and the average offset from the lane center between the two scenarios when driving along the curved segment.

Based on those results it can be confirmed that drivers' distance judgment did not significantly change under driving with the ARV system. In addition, both drivers' speed judgment and their level of comfort did not significantly change when driving along the straight segment with the ARV system. On the other hand, drivers' speed judgment and their level of comfort significantly changed while driving along the curved segment with the ARV system. This can be explained as for driving with the ARV system, drivers base their decisions on the view that they see through the HMD, which comes from the video camera that is fixed on the vehicle's front windshield. Although the view from the video camera is wide enough to enable drivers to drive safely, driving on the curve required a wider view because of the nature of a curve and its wide width, 15 ft (4.57 m) lane-width. Therefore, when drivers turned their head to the right and to the left, to get a wider view, it did not help because the camera is permanently attached to the front windshield. That led people to slow down on the curved segment when driving with the ARV system.

Survey Analysis

The results for analyzing questions regarding the on-the-road evaluation study are presented in Figure 5.6. One of the survey questions asked subjects about the scene visibility, 45% answered that it was good, 27% answered that it needed improvements, 18% answered that it was satisfactory, and 10% answered that it was excellent. Also, subjects were asked about the scene realism, 37% answered that it was excellent, 27% answered that it was satisfactory, 18% answered that it was good, and 18% answered that it needed improvements. Another question was about the scenario realism, 36.5% answered that it was excellent, 36.5% answered that it was good, and 27% answered that it was satisfactory. Regarding driving comfort, 46 % answered that it was excellent, 36% answered that it was satisfactory, and 18 % answered that it was good. About the HMD comfort, 64 % answered that it was good, and 27% answered that it was satisfactory, 9% answered that it needed improvement. Regarding the level of risk of the experiment (very high-high-moderate-small-none), 45% answered that there was no risk and 45% answered that there was a small risk. Overall, about the whole system fidelity, 37% answered that it was good, 27% answered that it was excellent, 27% answered that it was satisfactory, and 9% answered that it needed improvements. None of the subject felt any kind of motion sickness. All participants indicated that the experiment had none or small level of risk.

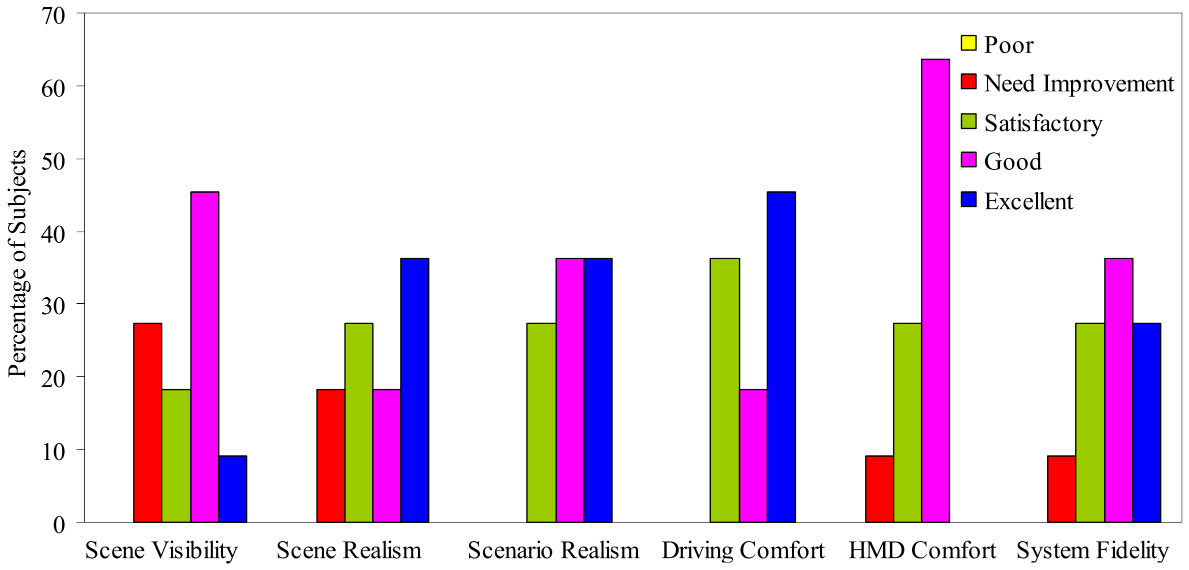


Figure 5-5: Survey analysis for on-the-road driving evaluation pilot study.

Conclusions

In evaluating the on-road driving under the AR, drivers' distance to the stop line, position from the center of the lane, and cruising velocity while driving were considered. The results indicated that drivers' distance judgment didn't significantly change when driving with the ARV system. Moreover, both drivers' speed judgment and lane offsite didn't significantly change when driving on the straight segment while driving with the ARV system. On the other hand, for driving on the curved segment, drivers' speed judgment and lane offsite significantly changed when driving under the AR. In the survey questions, participants were asked about the scene visibility, scene realism, scenario realism, driving comfort, HMD comfort, and system fidelity. Most of the answers indicated good overall system reliability. None of the participants felt any kind of motion sickness. All participants indicated that the experiment had none or small level of risk. Overall, the pilot study approved the design of the experiment.

5.3.2. Left-Turn Maneuver Pilot Studies

Two pilot studies were performed to study left-turn maneuver at un-signalized intersection under the effect of driver's age and gender. The first pilot study was conducted using the ARV system and the second pilot study was conducted using the OARSim system. In both studies one scenario was considered as described in Chapter 4. Figure 5.2 illustrate the scenario, in which drivers drove on a straight segment until reaching a two-way stop-controlled intersection and asked to select an appropriate gap between the oncoming virtual vehicles to make the left turn. During the scenario, the posted speed limit as well as the opposing virtual vehicles speed was 25 mph (40 kph). Eleven subjects were participated in each pilot study.

Data Collection

During the left-turn pilot studies, some measures were captured for each driver. Measures included the selected gap between opposing virtual vehicles (in seconds), the left-turn time (in seconds), the left-turn acceleration (in feet per second square), and the left-turn angular velocity (in degree per seconds). Those measurements are summarized in Table 5.4 below.

Table 5.4: Data collection summary for each driver for the left-turn maneuver scenario in the pilot studies

Using the ARV System						
Subject No.	**Age***	**Gender****	**Acceptable Gap “GAP” (sec)**	**Left-Turn Time “LTT” (sec)**	**Avg. Left-Turn Acceleration “ALTA” (ft/sec^2)**	**Avg. Left-Turn Ang. Velocity “ALTAV” (deg/sec)**
1	Y	M	4	3.3	4.55	2.95
2	Y	M	5	6.2	3.39	1.57
3	Y	F	6	4.6	3.51	2.12
4	O	M	5	5	2.31	1.95
5	O	M	6	6	1.71	1.63
6	Y	F	5	7.2	1.71	1.35
7	O	F	8	3.5	3.53	2.79
8	Y	M	6	7.7	1.23	1.27
9	Y	M	4	3.3	4.95	2.95
10	Y	F	3	4.7	3.12	2.07
11	Y	M	5	4	3.34	2.44
Using the OARSim System						
Subject No.	**Age***	**Gender****	**Acceptable Gap “GAP” (sec)**	**Left-Turn Time “LTT” (sec)**	**Avg. Left-Turn Acceleration “ALTA” (ft/sec^2)**	**Avg. Left-Turn Ang. Velocity “ALTAV” (deg/sec)**
1	Y	M	4	2.54	9.82	3.84
2	Y	M	5	2.3	14.6	4.24
3	Y	F	6	2.57	13.86	3.79
4	O	M	6	4.1	5.48	2.38
5	O	M	8	2.2	14.08	4.43
6	Y	F	4	2.05	15.89	4.76
7	O	F	8	5.03	3.21	2.26
8	Y	M	3	3.7	6.67	2.64
9	Y	M	3	2.16	14.85	4.51
10	Y	F	6	3.67	7.38	2.66
11	Y	M	5	3.32	10.01	2.94

*Y means young (18-45 years old) and O means old (>45 years old).

** M means male, and F means female.

Data Analysis

The results from the two experiments were compared to test if there was a significant difference between the two experiments' parameters. The Minitab software was used to conduct four statistical tests as following:

1. Test the statistical significance difference between **accepted gaps' means** for using ARV system and using the OARSim system experiments.
2. Test the statistical significance difference between **left-turn times' means** for using ARV system and using the OARSim system experiments.
3. Test the statistical significance difference between **left-turn accelerations' means** for using ARV system and using the OARSim system experiments.
4. Test the statistical significance difference between **left-turn angular velocities' means** for using ARV system and using the OARSim system experiments.

The results from Minitab software are summarized in Table 5.5, in which no adjustments were made for age and gender.

Table 5.5: Statistical summary of Minitab outputs of two-sample t-test for left-turn maneuver parameters using ARV and OARSim systems

Parameter	**Hypothesis**	**P-VALUE**	**Conclusion***
Accepted Gap	H0: mean1 = mean 2 H1: mean1 ≠ mean 2	0.892	Don't Reject H0
LT-Time	H0: mean1 = mean 2 H1: mean1 ≠ mean 2	0.000	Reject H0
Avg. LT-Acceleration	H0: mean1 = mean 2 H1: mean1 ≠ mean 2	0.000	Reject H0
Avg. LT-Angular Velocity	H0: mean1 = mean 2 H1: mean1 ≠ mean 2	0.001	Reject H0

*Based on 95% confidence ($\alpha = 0.05$)

From Table 5.5, there was no significant difference between accepted gap mean from the means for using ARV system and using OARSim system at a level of confidence 95% (P-value 0.892). This indicates that using two different AR systems (ARV and OARSim systems) did not affect the accepted gaps. The reason for that is both systems (ARV and OARSim) provided drivers with almost the same augmented view, which is a combination of real-world video and virtual vehicles. Although the video using the ARV system was on-time video and using the ORVSim was pre-recorded video, this didn't affect the drivers' accepted gap means.

On the other hand, there was a statistical significant difference in the left-turn time means, left-turn acceleration means and left-turn angular velocity means using both systems at a 95% level of confidence. Drivers had a smaller left-turn time mean, a *larger* left-turn acceleration mean, and a *larger* left-turn angular velocity mean when using the OARsim system than when using the ARV system. The reason for that is driving a non-real vehicle (when using the OARSim system) had different effects from driving a real-vehicle (when using the ARV system) on drivers' left-turn time mean, acceleration mean, and angular velocity mean.

Survey Analysis

After finishing the pilot studies, each subject was handed a survey, see Appendix A. Subjects in both studies were asked about the level of comfort of the left-turn maneuver, the visibility of the on-coming vehicles, and the realism of the on-coming vehicle speed with five choices to select from; poor, satisfactory, good, very good, and excellent. Subjects in the first study (using ARV system) indicated an overall good level of comfort of the left-turn maneuver and overall very good of the coming vehicles visibility and realism. While in the second study (using the OARSim system) subjects indicated an overall satisfactory level of comfort of the left-turn maneuver, overall very good of the coming vehicles visibility and overall good of the coming vehicle realism.

Conclusions

The two AR systems; ARV system and OARSim system were used to conduct the same scenario to study left-turn maneuver at un-signalized intersection. While there was no significant difference in the accepted gap mean between using ARV system and using OARSim system, drivers had a smaller left-turn time mean, a larger left-turn acceleration mean, and a larger left-turn angular velocity mean when using the OARsim system than when using the ARV system. This might be because both systems (ARV and OARSim) provided drivers with almost the same augmented view (a combination of real-world video and virtual vehicles) that contributed to non-significant accepted gaps' means difference. On the other hand, driving a non-real vehicle (when using the OARSim system) had different effects from driving a real-vehicle (when using the ARV system) on drivers' left-turn time mean, acceleration mean, and angular velocity mean.

5.3.3. Horizontal Visibility Blockage Pilot Study

In the pilot study for the horizontal view blockage two scenarios were considered; following a PC (PC-PC) and following an LTV (LTV-PC) using the OARSim system, designs of the scenarios were as described in Chapter 4. Figure 5.7 (a) and (b) below illustrate both scenarios, in which participants drove the OARVSim system following a leading vehicle (PC in the first scenario and an LTV in the second scenario), after driving about 100 ft an incident hindered the leading vehicle (a sudden turning vehicle in front of the leading vehicle) caused the leading vehicle to brake suddenly.

Twelve subjects participated in the pilot study in which six participants drove each scenario. The reason that all participants didn't drive both scenarios simultaneously is that the results could be biased. Subjects were handed a survey to fill out after finishing the experiment (see Appendixes A).

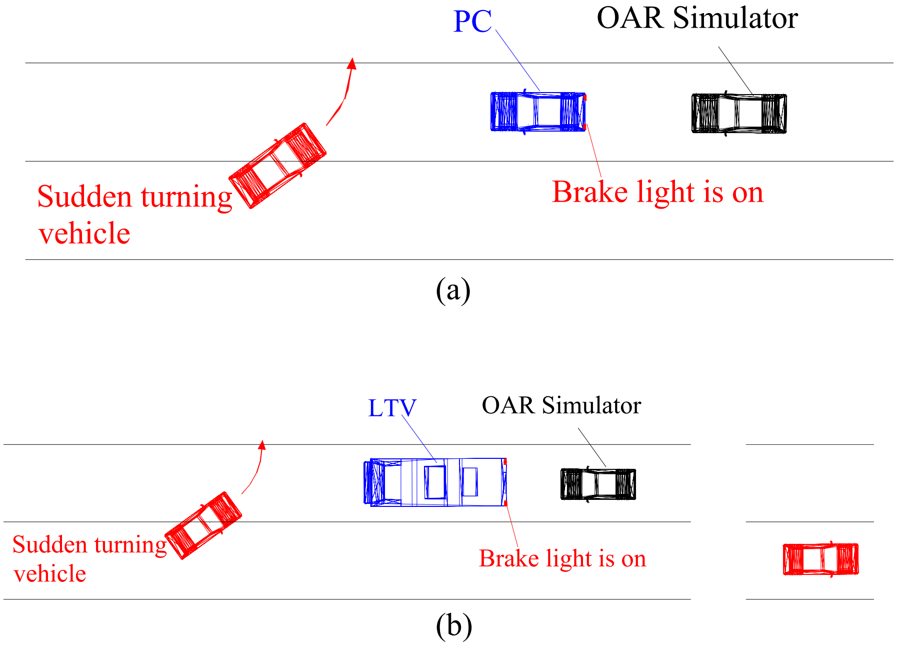


Figure 5-6: The horizontal view blockage scenarios in pilot study; (a) following a PC, and (b) following an LTV.

Data Collection

For both scenarios (PC-PC and LTV-PC) performance measures were recorded for each participant. Those measures include; whether the subject involved in a rear-end collision or not, subject's response time to the incident (sudden turning vehicle), subject's velocity at the time of the incident, the headway between the leading vehicle and the OARSim's driver at the time of the incident, and the subject's deceleration rate. Those measurements are summarized in Table 5.6 below.

Table 5.6: Data collection summary for each driver for the horizontal visibility blockage scenarios in the pilot study

PC-PC Scenario					
Subject No.	**Rear-end crash***	**Incident Response Time “IRT” (sec.)**	**Incident Velocity “IV” (mph)**	**Incident Headway “IH” (ft)**	**Incident Deceleration Rate “IDR” (ft/sec2)**
1	0	1.65	32.84	55.00	11.99
2	0	1.23	27.39	109.74	16.00
3	0	2.48	25.54	91.32	19.00
4	0	1.12	20.09	106.89	7.65
5	0	0.65	29.40	77.00	19.00
6	0	0.55	20.68	89.90	15.00
PC-LTV Scenario					
Subject No.	**Rear-end crash***	**Incident Response Time “IRT” (sec.)**	**Incident Velocity “IV” (mph)**	**Incident Headway “IH” (ft)**	**Incident Deceleration rate “IDR” (ft/sec2)**
1	0	1.17	25.84	51.18	17.00
2	1	0.86	35.73	39.73	16.77
3	1	1.15	33.90	45.00	21.91
4	1	1.91	39.97	49.82	27.43
5	0	2.14	35.71	61.52	21.56
6	1	1.64	25.55	44.35	23.00

*0 means that there was no crash, 1 means that there was a crash.

Data Analysis

The Minitab software was used to conduct five statistical tests to study the statistically significant difference between the recorded parameters for PC-PC and LTV-PC scenarios as following,

5. Test the statistical significance difference between the **number of potential rear-end crashes** for the PC-PC and LTV-PC scenarios.
6. Test the statistical significance difference between the mean of the **incident response time** for the PC-PC and LTV-PC scenarios.

7. Test the statistical significance difference between the mean of the **incident velocity** for the PC-PC and LTV-PC scenarios.
8. Test the statistical significance difference between the mean of the **incident headway** for the PC-PC and LTV-PC scenarios.
9. Test the statistical significance difference between the mean of the **incident deceleration rate** for the PC-PC and LTV-PC scenarios.

The results from Minitab software are summarized in Table 5.7.

Table 5.7: Statistical summary of Minitab outputs for PC-PC and LTV-PC scenarios in the pilot study

Parameter	**Hypothesis**	**P-Value**	**Conclusion***
Number of Rear-End Crashes	H0: P1 = P2 H1: P1 ≠ P2	0.001	Reject H0
Incident Response Time "IRT" (sec)	H0: mean1 = mean 2 H1: mean1 ≠ mean 2	0.591	Don't Reject H0
Incident Velocity "IV" (mph)	H0: mean1 = mean 2 H1: mean1 ≠ mean 2	0.058	Don't Reject H0
Incident Headway "IH" (ft)	H0: mean1 = mean 2 H1: mean1 ≠ mean 2	0.004	Reject H0
Incident Deceleration "IDR" (ft/sec2)	H0: mean1 = mean 2 H1: mean1 ≠ mean 2	0.025	Reject H0

*Based on 95% confidence ($\alpha = 0.05$)

At a 95% level of confidence, there was a significant difference between the number of rear-end crashes for following a PC and following an LTV (P-value= 0.001) with a higher number of rear-end crashes when following an LTV. In additional, there was a statistical significant difference for the incident headway for following a PC and following an LTV at a 95% level of confidence (P-value= 0.004) with a smaller headway mean when following an LTV, that might contribute to a higher chance of rear-end crashes. On the other hand, there was no significant difference in the incident velocity mean for following a PC and following an LTV at a 95% level of confidence (P-values= 0.058). For the deceleration rate, there was a statistical significant difference for following a PC and following an LTV (P-value= 0.025), with a higher deceleration rate when following an LTV. Therefore, driving closer to the LTV might cause drivers to decelerate sharply as a response to the sudden application of LTV's brake due to the incident (sudden turning vehicle). Thought the incident response time mean was higher when following an LTV than when following a PC, there was no significant difference between the incident response time mean for following an LTV and following a PC at a 95% level of confidence (P-value was 0.591).

Based on those results, it was clear that drivers drove closer to the LTV vehicle than to the PC. Accordingly, at the time of the incident (sudden turning vehicle), drivers following the LTV sharply decelerated to avoid the collision with the leading LTV. But the higher deceleration rate when following the LTV did not help, most of the drivers, to avoid the collision with the leading LTV and the number of rear-end crashes when following the LTV was significantly higher than when following the PC.

Survey Analysis

The results for analyzing questions regarding the horizontal visibility study are presented in Figure 5.8. One of the survey questions asked subjects if they drive closely behind a PC or an LTV in their real life, 33% of subjects that followed the PC (PC-PC scenario) indicated that they drive closely behind PCs in their real life and 50% of subjects that followed the LTV (PC-LTV scenario) indicted that they drive closely behind LTVs in their real life. When subjects were asked about seeing the sudden left-turn vehicle that hindered the leading vehicle, about 85% of subjects following the PC indicated that they saw it while only 17% of subjects following the LTV indicated that they saw it. The small percentage of subjects that saw the sudden turning vehicle, when following the LTV, indicates the visibility blockage caused by the leading LTV. Finally most of the subjects indicated that they face the same visibility problem in their real life when they follow LTVs.

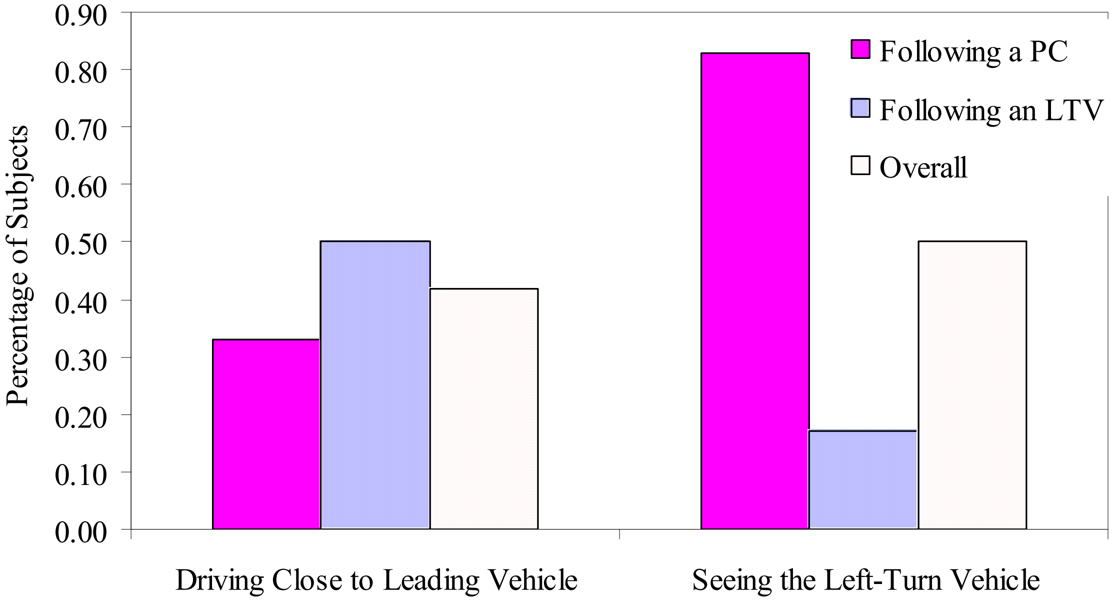


Figure 5-7: Survey analysis for the horizontal visibility pilot study.

Conclusions

In the horizontal visibility blockage pilot study, following an LTV significantly increased the number of rear-end crashes than following a PC. Drivers intended to drive closer to the LTV than to the PC while maintaining almost the same speed which caused them to sharply decelerate when an incident hindered the leading LTV. There was no significant difference in the succeeding vehicle's driver response time for following a PC and following an LTV, when an incident hindering the leading vehicle. In the survey questions, participant were asked if they sow the sudden turning vehicle, do they drive close to PCs or LTVs in their real life, and do they face a visibility problem when they follow an LTV in their life. While most of participants followed the PC sow the sudden turning vehicle, only one participant followed the LTV indicated seeing the sudden turning vehicle which might be due to the visibility blockage caused by following the LTV. The majority of participants indicated facing visibility problems when following LTVs in their real life. Overall, the pilot study approved the design of the experiment.

CHAPTER 6: AR SYSTEMS EVALUATION'S RESULTS AND DATA ANALYSIS

In evaluating the AR systems, two stages were performed; evaluate AR systems' outcomes, and evaluate on on-the-road driving under the AR. The results from those steps are discussed in this chapter.

6.1. Evaluate AR Systems' Outcomes

Although the ARV system used on-time videos and the ORVSim used pre-recorded videos, the outcome from both systems (augmented view) was almost the same, which is a combination of real-world video and virtual vehicles.

In evaluating AR systems' outcomes, the systems' abilities to duplicate real scenes as well as generate new scenes were assessed. Since in augmented images virtual objects are added to the real view, it is very important that the real and virtual objects are well aligned, in position, orientation, and scale, with each other in the final view. Small errors in this alignment generate visual inconsistencies, which can easily be detected by the user. When comparing real-world's images with their corresponding augmented images "final view", we were able to verify that both systems are compatible, as will be discussed in the following sections.

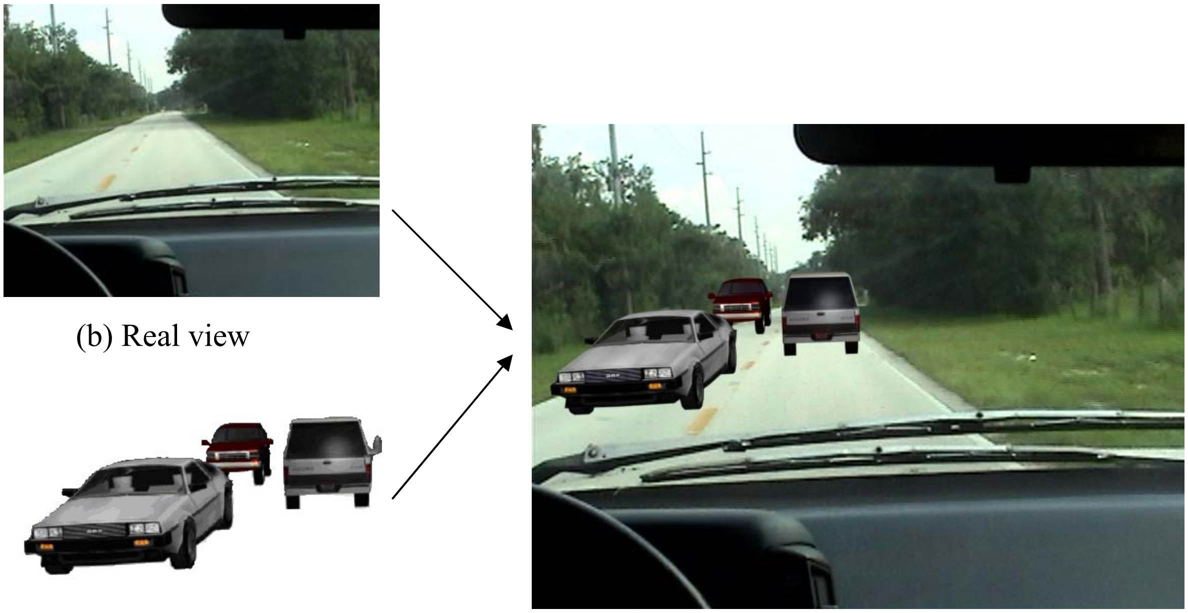
6.1.1. Duplicate Real Scenes

The systems' ability to generate augmented images that fairly duplicate real world images is very important. A real photo of three vehicles on a real road is shown in Figure 6.1 (a). Generating the same view by combining a real world image of the road with images of virtual vehicles can be done using the computer as shown in Figure 6.1 (b), (c), and (d). In the augmented view "final view”, virtual vehicles were well aligned in scale, position, and orientation to the real objects in the scene as shown in Figure 6.1 (d).

6.1.2. Generate New Scenes

In addition, the systems’ capability to generate new images, based on the desired scenario need to be evaluated. Actually this is one of the advantages of using the AR technology; to generate new desired scenarios that is hard to conduct in real world. For example, if a scenario requires driving in foggy weather, it would be risky and dangerous to carry out a field experiment under this inclement weather condition. An AR technology utilized to generate a driving scene, which is a combination of a real-world scene and virtual objects (vehicles and fog) would be of great value. An example of this scene is shown Figure 6.2 (a), (b), and (c). The augmentation in Figure 6.2 (c) appears visually very good without any visual inconsistency; virtual objects (vehicles and fog) and real objects (road and trees) are well aligned.

(a) Real-world view



(b) Real view

(c) Virtual vehicles

(d) Augmented view

Figure 6-1: Evaluating the system's ability to duplicate real scenes.

(a) Real-world view

(b) Virtual vehicles

(c) Augmented view

Figure 6-2: Evaluating the system’s ability to generate a fogy scene.

6.2. Evaluate ARV System’s Effects on on-the-Road Driving

The main purpose from this experiment is to evaluate the on-the-road driving performance under only the effect of the AR, this can only be achieved using the ARV system which allows drivers to drive a real vehicle on a real road under the AR. Therefore, two scenarios (driving without the

ARV system, and driving with the ARV system) were built using the ARV system. In both scenarios, subjects were asked to drive 25 mph (40 kph) and as close to the center of the lane as possible along both a straight and a curved segments. In addition, they were asked to stop the vehicle at a stop sign in which the front bumper of the vehicle is over the stop line.

Two photos taken during the two scenarios are shown in Figure 6.3 (a), and (b). These photos show one of the participants driving the vehicle along the straight segment; (a) without the ARV system, (b) with the ARV system. A small photo of what the subject sees, through the HMD, during the second scenario, is shown in the top left corner of Figure 6.3 (b). Two small photos taken from outside the vehicle during the two scenarios are shown in the bottom left corners of Figures 6.3 (a) and (b). Another two photos taken during the two scenarios while driving along the curved segment are shown in Figure 6.4 (a), and (b).

(a) (b)

Figure 6-3: Evaluate on-the-road driving on the straight segment; (a) driving without the ARV system, (b) driving with the ARV system.

(a) (b)

Figure 6-4: Evaluate on-the-road driving on the curved segment; (a) driving without the ARV system, (b) driving with the ARV system.

In both scenarios, the following measures were recorded for each driver; the distance to stop line, the average cruising velocity on the straight and on the curved segments, the average offset from the center of the lane along the straight and the curved segments. Those data are shown in Appendix C. Descriptive statistics for on-the-road evaluation's parameters are shown in Table 6.1. While distances to stop line gave us an indication of the drivers' distance judgment, average cruising velocities indicated drivers' speed judgment on both straight and curved segments. Offsets from lanes' centers provided good feedback about how smoothly subjects maneuvered along the straight and curved segments. As a measure of drivers' distance judgment, speed judgment, and driving comfort statistical tests using Minitab software were conducted on the measured parameters for without the ARV system versus with the ARV system.

Table 6.1: Descriptive statistics for left-turn maneuver’s parameters

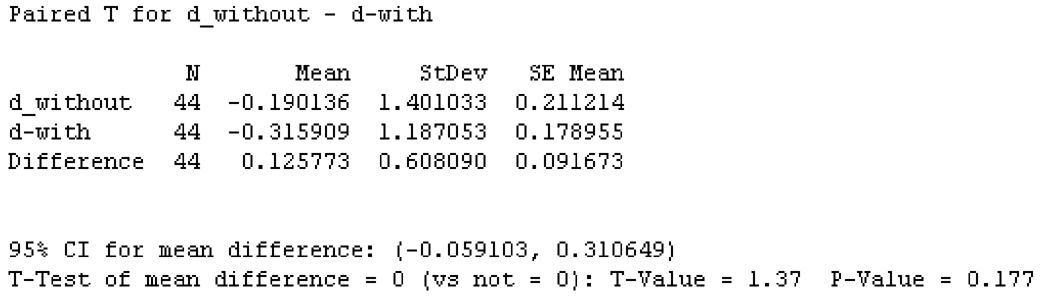
Driving without ARV System Scenario					
	Distance to stop line “d” (ft)*	**Avg. Cruising Speed along**		**Avg. Offset from the Lane Center for**	
		Straight Segment “Vs” (mph)	**Curved Segment “Vc” (mph)**	**Straight Segment “Os” (ft)**	**Curved Segment “Oc” (ft)**
N	44	44	44	44	44
Mean	-0.19	8.48	12.56	1.03	1.285
Median	-0.59	8.62	12.34	1.05	1.3
Std. Deviation	1.40	1.45	1.76	0.37	0.41
Variance	1.965	2.12	3.08	0.136	0.17
Minimum	-1.84	5.87	8.05	0.07	0.4
Maximum	5.38	12.41	15.65	1.55	1.95
Driving with ARV System Scenario					
	Distance to stop line “d” (ft)*	**Avg. Cruising Speed along**		**Avg. Offset from the Lane Center for**	
		Straight Segment “Vs” (mph)	**Curved Segment “Vc” (mph)**	**Straight Segment “Os” (ft)**	**Curved Segment “Oc” (ft)**
N	44	44	44	44	44
Mean	-0.32	8.127	10.63	1.04	1.56
Median	-0.53	8.16	10.50	1.05	1.69
Std. Deviation	1.19	1.20	1.57	0.42	0.49
Variance	1.41	1.44	2.48	0.17	0.24
Minimum	-1.54	6.02	8.09	0.26	0.32
Maximum	4.66	10.59	13.91	2.1	2.43

*Positive sign indicates that the vehicle’s front bumper stopped before the stop line, and negative sign indicates that the vehicle’s front bumper stopped after the stop line.

6.2.1. Distance Judgment

As a measure of drivers’ distance judgment, the distance to the white stop line was recorded for each subject in the normal driving (without the ARV system) and in driving with the ARV system. A paired t-test was conducted using Minitab software on the distance to stop line between the two scenarios. Table 6.1 shows the Minitab output. In which, the resulted P-value is equal to 0.177 which is larger than α/2=0.025. As a conclusion, there is no significant statistical difference in the distance to stop line between driving without the ARV system and driving with the ARV system. It means that driving under the ARV system didn't affect drivers' distance judgment.

Table 6.2: Minitab output for paired t-test, distance to stop line for without ARV System and with ARV system scenarios

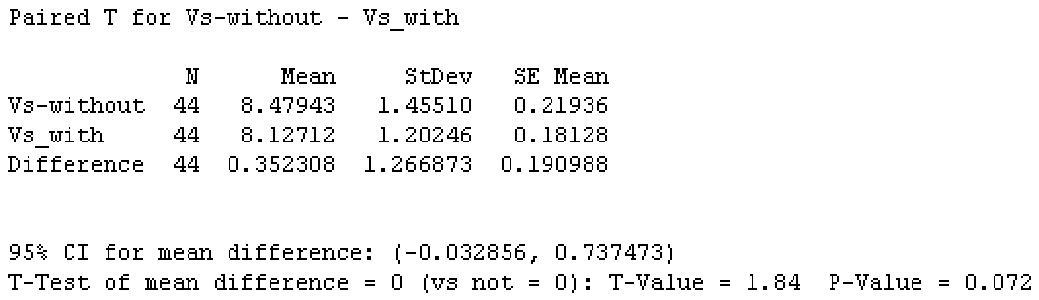


```
Paired T for d_without - d-with

             N       Mean     StDev   SE Mean
d_without   44  -0.190136  1.401033  0.211214
d-with      44  -0.315909  1.187053  0.178955
Difference  44   0.125773  0.608090  0.091673


95% CI for mean difference: (-0.059103, 0.310649)
T-Test of mean difference = 0 (vs not = 0): T-Value = 1.37  P-Value = 0.177
```

6.2.2. Speed Judgment

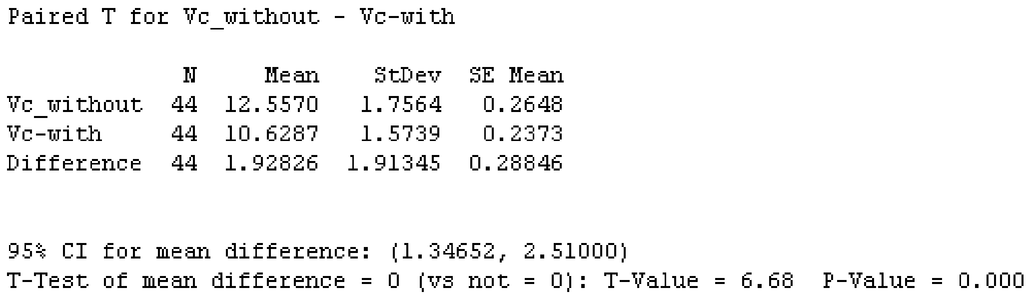
As a measure of speed judgment, each driver's average cruising velocity along both the straight and the curved segments was calculated for the two scenarios. Two paired t-tests were conducted on the average cruising velocity along the straight segment and along the curved segment for the two scenarios (without the ARV system and with the ARV system). Table 6.2 and 6.3 show the MINITAB outputs for the two tests. In Table 6.2, at a level of confidence 95%, there was no significant difference in the average cruising velocity along the straight segment between the two scenarios. In which the resulted P-value was 0.072 which is larger than α/2=0.025. On the other hand, from Table 6.3, at a level of confidence 95%, there was a significant difference in the average cruising speed along the curved segment between the two scenarios (P-value was 0.0). As a conclusion, driving under the ARV system didn't affect drivers' speed judgment when driving along a straight segment but it did affect drivers' speed judgment when driving along a curved segment. This can be explained that in the case of driving with the ARV system, drivers base their decisions on the view that they see through the HMD, which comes from the video camera that is fixed on the vehicle's front windshield. Although the view from the video camera is wide enough to enable drivers to drive safely, driving on the curve required a wider view because of the nature of a curve and its wide width, 15 ft (4.57 m) lane-width. Therefore, when drivers turned their head to the right and to the left, to get a wider view, it did not help because the camera is permanently attached to the front windshield. That led people to slow down on the curved segment when driving with the ARV system.

Table 6.3: Minitab output for paired t-test, average speed on the straight segment of without ARV system and with ARV system scenarios



```
Paired T for Vs-without - Vs_with

              N      Mean     StDev   SE Mean
Vs-without   44   8.47943   1.45510   0.21936
Vs_with      44   8.12712   1.20246   0.18128
Difference   44  0.352308  1.266873  0.190988


95% CI for mean difference: (-0.032856, 0.737473)
T-Test of mean difference = 0 (vs not = 0): T-Value = 1.84  P-Value = 0.072
```

Table 6.4: Minitab output for paired t-test, average speed on the curved segment of without ARV system and with ARV system scenarios

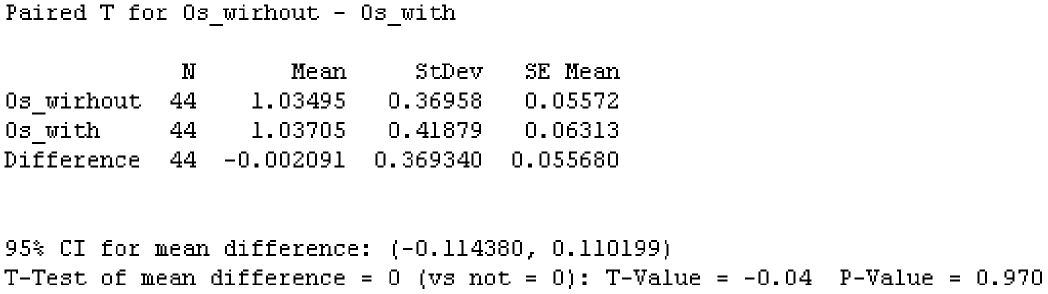


```
Paired T for Vc_without - Vc-with

              N     Mean    StDev  SE Mean
Vc_without   44  12.5570   1.7564   0.2648
Vc-with      44  10.6287   1.5739   0.2373
Difference   44  1.92826  1.91345  0.28846


95% CI for mean difference: (1.34652, 2.51000)
T-Test of mean difference = 0 (vs not = 0): T-Value = 6.68  P-Value = 0.000
```

6.2.3. Driving Comfort

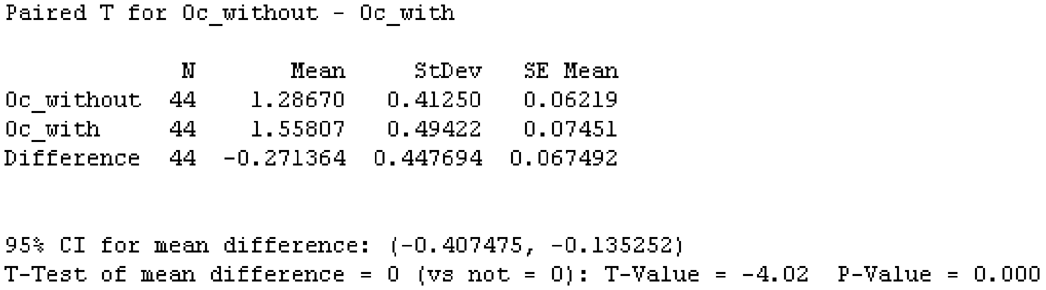
As a measure of driving comfort, average offsets form the center of the lane along both the straight and the curved segment for each driver were calculated for the two scenarios. Offsets from the lane's center line reflect drivers' lane keeping therefore represent their level of comfort while driving. Two paired t-tests were performed using Minitab software to test if there is a significant difference in the mean average offsets along the straight segment and along the curved segment between driving without the ARV system and driving with the ARV system. Tables 6.4 and 6.5 show the Minitab outputs. For driving along the straight segment, there was no significant difference in lane offsets between driving without the ARV system (normal driving) and driving under the ARV system (P-value was 0.97) as shown in Table 6.4. On the other hand, there was a significant difference when driving along the curved segment (P-value was 0.0), as shown in Table 6.5. It indicates that, driving under the ARV system didn't affect drivers' level of comfort when driving along a straight segment but it did affect drivers' level of comfort when driving along a curved segment. That can be explained as driving along a wide curve required a wider view than what the fixed camera provided. That caused people to deviate around the center of the lane when driving along the curved segment with the ARV system.

Table 6.5: Minitab output for paired t-test, average offset from lane center along the straight segment of without ARV system and with ARV system scenarios



```
Paired T for Os_wirhout - Os_with

              N       Mean     StDev   SE Mean
Os_wirhout   44    1.03495   0.36958   0.05572
Os_with      44    1.03705   0.41879   0.06313
Difference   44  -0.002091  0.369340  0.055680


95% CI for mean difference: (-0.114380, 0.110199)
T-Test of mean difference = 0 (vs not = 0): T-Value = -0.04  P-Value = 0.970
```

Table 6.6: Minitab output for paired t-test, average offset from lane center along the straight segment of without ARV system and with ARV system scenarios



```
Paired T for Oc_without - Oc_with

              N       Mean     StDev   SE Mean
Oc_without   44    1.28670   0.41250   0.06219
Oc_with      44    1.55807   0.49422   0.07451
Difference   44  -0.271364  0.447694  0.067492


95% CI for mean difference: (-0.407475, -0.135252)
T-Test of mean difference = 0 (vs not = 0): T-Value = -4.02  P-Value = 0.000
```

6.3. Survey Analysis

The results from analyzing the survey questions regarding system evaluation are presented in Figure 6.5. The survey questions are shown in Appendix A. One of the survey questions asked subjects about the scene visibility, 44% answered that it was good, 22% answered that it was satisfactory, 17% answered that it was excellent, and 17% answered that it needed improvements. Also, subjects were asked about the scene realism, 34% answered that it was good, 32% answered that it was satisfactory, 27% answered that it was excellent, and 7% answered that it needed improvements. Another question was about the scenario realism, 46% answered that it was good, 27% answered that it was satisfactory, 22% answered that it was excellent, and 5% answered that it need improvements. Regarding driving comfort, 37% answered that it was excellent, 34% answered that it was good, 27% answered that it was satisfactory, and 2% answered that it needed improvements. About the HMD comfort, 49 % answered that it was good, and 29% answered that it was satisfactory, 12 % answered that it was excellent, and 10% answered that it needed improvement. Regarding the level of risk of the experiment (very high-high-moderate-small-none), 45% answered that there was no risk and 45% answered that there was a small risk. Overall, about the whole system fidelity, 41% answered that it was good, 29% answered that it was excellent, 20% answered that it was satisfactory, and 10% answered that it needed improvements. None of the subject felt any kind of motion sickness.

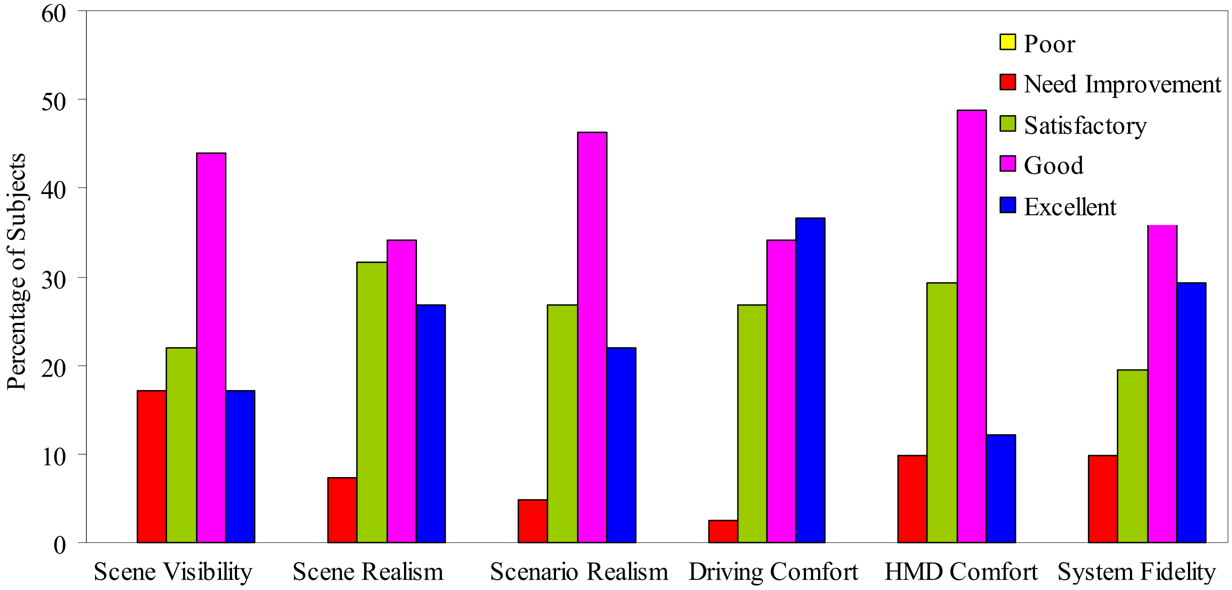


Figure 6-5: Survey analysis for system evaluation experiment.

6.4. Conclusions

In evaluating the proposed ARV system's outcomes, the system was successfully able to duplicate real scenes and generate new scenes. Inside augmented views (final views), virtual objects were well aligned with real objects in position, orientation, and scale without any visual inconsistency.

In evaluating the ARV system's effects on on-road driving, drivers' distance judgment, speed judgment, and level of comfort while driving were considered. The results indicated that drivers' distance judgments while driving were not affected by the ARV system. Moreover, both drivers' speed judgments and level of comforts did not significantly change under driving with the ARV system on a straight segment. Drivers' speed judgments and levels of comfort were affected when driving with the ARV system along a curved segment. The main reason for that was using a video camera that is fixed to the front windshield. The fixed video camera gave a wide view, which was enough to help drivers to drive easily on a straight segment but driving along a wide lane curved segment needed a wider view.

In the survey questions regarding the system fidelity, participants were asked about the scene visibility, scene realism, scenario realism, driving comfort, HMD comfort, and system fidelity. Most of the answers indicated good overall system reliability. None of the participants felt any kind of motion sickness. All participants indicated that the experiment had none or small level of risk.

CHAPTER 7: LEFT-TURN MANEUVER EXPERIMENT'S RESULTS AND DATA ANALYSIS

In studying left-turn maneuver, the ARV system and the OARSim system were used. Two experiments were performed; first using the ARV system and, second using the OARSim system. In both experiments, one scenario was conducted, during which drivers drove on a straight segment until reaching a two-way stop-controlled intersection and asked to select an appropriate gap between the oncoming virtual vehicles to make the left turn. During the scenario, the posted speed limit as well as the opposing virtual vehicles speed was 25 mph (40 kph).

During the left-turn experiments, some measures were captured for each driver. Measures included the selected gap between opposing virtual vehicles (in seconds), the left-turn time (in seconds), the left-turn acceleration (in feet per second square), and the left-turn angular velocity (in degree per seconds). Those data are shown in Appendix D. The results from both experiments are discussed and analyzed in this chapter.

7.1. Studying Left-Turn Maneuver using ARV System

Our ARV system installed in a rented vehicle was used to study effects of left-turn drivers' characteristics (age and gender) on the left-turn maneuver at two-way stop-controlled intersection. Figure 7.1 shows a photo of one of the participants during the left-turn experiment, in which, the participant is driving the vehicle on a paved racetrack while seeing through the HMD. A small photo of what the subject sees during the experiment is shown in the top left corner of Figure 7.1. Another photo taken from out of the vehicle during the experiment is shown in the bottom left of Figure 7.1.

Descriptive statistics for left-turn maneuver's measurements are shown in Table 7.1.

Statistical analyses were conducted using Minitab software to test if there were significant age and/or gender effects on those measurements.

Figure 7-1: Left turning maneuver at two-way stop-controlled intersection experiment using the ARV system.

Table 7.1: Descriptive statistics for left-turn maneuver's parameters

	Gap (sec)	**LT-Time (sec)**	**LT-Acceleration (ft/sec2)**	**LT-Angular Velocity (deg/sec)**
N	44	44	44	44
Mean	5.58	4.69	3.36	2.32
Median	6.00	5.00	3.32	1.95
Std. Deviation	1.22	1.45	1.50	0.86
Variance	1.49	2.09	2.24	0.74
Minimum	3.00	2.10	1.23	1.27
Maximum	8.00	7.70	7.33	4.64

7.1.1. Acceptable Left Turning Gap

The gap is the time gap between two successive vehicles in the opposing flow, measured from the instance that the front of the first vehicle passes a point to the instance that the front of the following vehicle passes the same point, in seconds. Each left-turn driver accepted a gap between opposing through traffic for making the left-turn maneuver. From Table 7.1, the average acceptable gap for all participants was 5.58 with a minimum of 3 seconds and a maximum of 8 seconds. The average acceptable gaps for each age and gender group are shown in Figure 7.2. The average acceptable gap for males was 5.50 seconds, for females group was 5.67 seconds, for young group was 5.20 second, and for old group was 6.36 seconds.

Statistical analyses were conducted to test if there were significant age's and gender's effects on acceptable gaps. The results from the analyses are summarized in Table 7.2 and Table 7.3. There was a significant **age** difference in the acceptable gap for male and female groups under a 95% confidence level, as highlighted in Table 7.3. There was no significant **gender** effect for both age groups (young and old) at the 95% level of confidence. It indicates that, both old males and old females need bigger gaps than what younger drivers need, with no significant difference in gaps between males and females. Therefore, there is an **age** effect but there is no **gender** effect in the acceptable gaps.

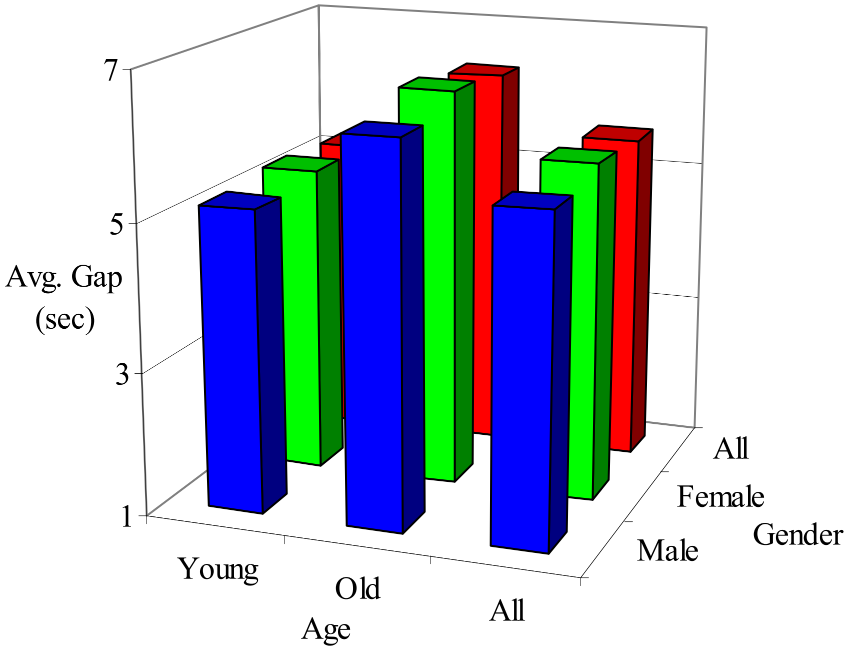


Figure 7-2: Average acceptable gap by age and gender.

Table 7.2: One-Sample Test for average acceptable gap between male and female groups

	Male				**Female**				**Mean Difference**		
			95% CI				95% CI			95% CI	
	N	Mean	Lower	Upper	N	Mean	Lower	Upper	Mean	Lower	Upper
Young	18	5.17	4.65	5.69	12	5.25	4.48	6.02	-0.08	-0.97	0.81
Old	8	6.25	5.28	7.22	6	6.50	5.40	7.60	-0.25	-1.56	1.06
Total	26	5.50	5.03	5.97	16	5.67	5.03	6.30	-0.17	-0.95	0.61

Table 7.3: One-Sample Test for average acceptable gap between young and old groups

	Young				**Old**				**Mean Difference**		
			95% CI				95% CI			95% CI	
	N	Mean	Lower	Upper	N	Mean	Lower	Upper	Mean	Lower	Upper
Male	18	5.17	4.65	5.69	8	6.25	5.28	7.22	-1.08	-2.14	-0.03
Female	12	5.25	4.48	6.02	6	6.50	5.40	7.60	-1.25	-2.47	-0.03
Total	30	5.20	4.80	5.60	14	6.36	5.73	6.98	-1.16	-1.88	-0.43

A wide variety of models for estimating the accepted gap have been used (Miller 1972 and Brilon et al. 1999). Harwood et al. (1999) indicated that statistical tests on the same data set showed that different models can give up to 2 second difference in the estimate of the mean accepted gap. The model adopted in this dissertation for estimating the accepted gap was the logistic regression. The Logistic regression is a statistical technique for developing predictive model for the probability that an event (in our case is accepting a gap) will or will not happen. The probability that a driver will accept a gap *X* is modeled as logistic distribution as in the following Equation:

$$\pi(x) = \frac{e^{g(x)}}{1 + e^{g(x)}} \quad \text{..........(7.1)}$$

Then when applying the logistic regression model the following predictive equation is obtained:

$$g(x) = \ln\left[\frac{\pi(x)}{1 - \pi(x)}\right] = \beta_0 + \beta_1 x \quad \text{..........(7.2)}$$

In which, $\pi(x)$ is the probability that a gap of size *X* will be accepted,

β_0, *and* β_1 are constants.

Therefore the logistic regression model of the probability of accepting a gap can be presented by the following equation.

$$\therefore g(x) = \ln\left[\frac{\pi(x)}{1 - \pi(x)}\right] = 1.49 * X - 7.67 \qquad (R^2 = 98.1\%)$$

Based on the Logistic model, the critical gap which is the median of accepted gaps, i.e. the gap which is accepted by 50% of the subjects is approximately 5.15 seconds.

Plotting the **logistic regression model** of the probability of accepting a gap with the corresponding gap and the **cumulative probability** of accepting a gap with the corresponding gap shows that the logistic regression model is well representing the data, as shown in Figure 7.3. The critical gaps (the gap corresponds to the 50% probability of gap acceptance) from both curves are very close, approximately 5.15 seconds (from the logistic regression curve) and 5 seconds (from the cumulative probability curve).

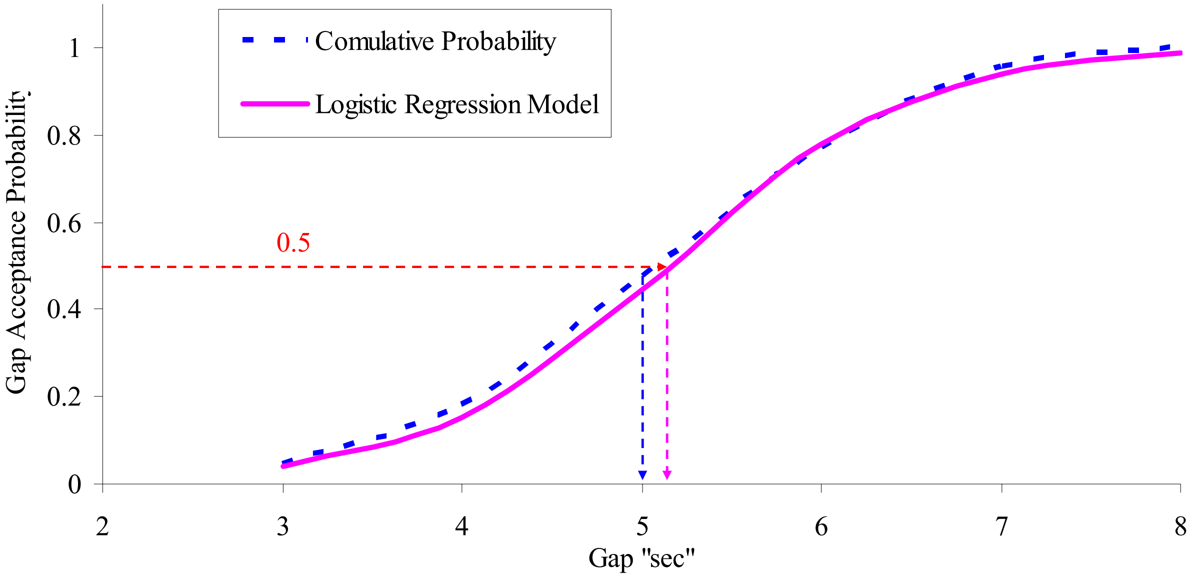


Figure 7-3: Gap acceptance probability.

7.1.2. Left Turning Time

The left-turn time is the total time during which the left turning vehicle's steer turned left and turned back when subjects complete the left-turn maneuver. The left-turn time is one of the variables that reflect the driver's steer control. From Table 7.1, the average left-turn time is 4.69 second with a minimum of 2.1 seconds and a maximum of 7.7 seconds. The average left-turn time for each age and gender group are shown in Figure 7.4. In which, the average left-turn time for males is 4.63 seconds, for females group is 4.74 seconds, for young group is 4.61 second, and for old group is 4.81 seconds.

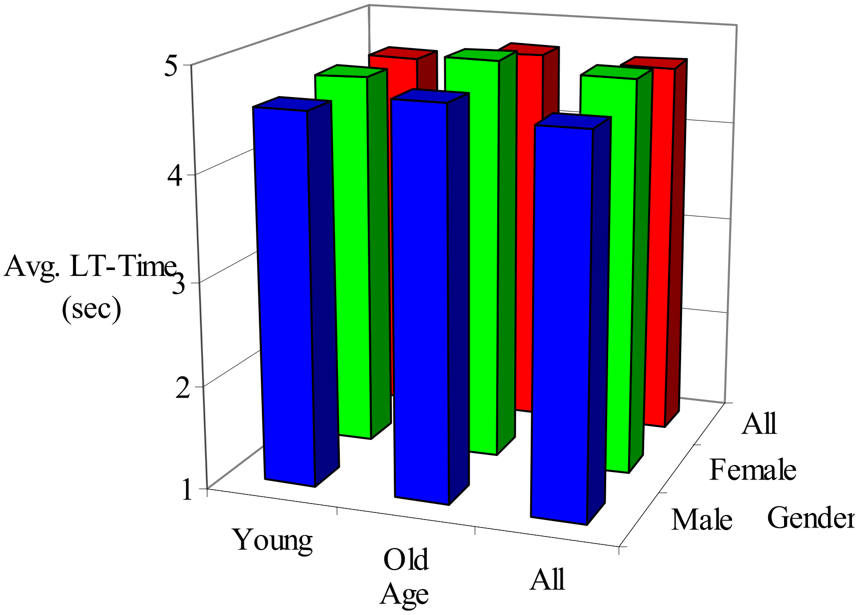


Figure 7-4: Average left-turn time by age and gender.

Statistical analyses were conducted to test if there were significant age and gender effects on the left-turn time. The results from the analyses are summarized in Table 7.4 and 7.5. There were no significant **age** or **gender** differences under a 95% confidence level for the left-turn time. It means that left-turn time was not significantly affected by drivers' characteristics (age and gender).

Table 7.4: One-Sample Test for average left-turn time between male and female groups

	Male				Female				Mean Difference		
			95% CI				95% CI			95% CI	
	N	Mean	Lower	Upper	N	Mean	Lower	Upper	Mean	Lower	Upper
Young	18	4.58	3.81	5.35	12	4.66	3.63	5.69	-0.08	-1.31	1.15
Old	8	4.74	3.63	5.84	6	4.9	3.76	6.04	-0.16	-1.58	1.26
Total	26	4.63	4.04	5.21	16	4.74	3.98	5.49	-0.11	-1.04	0.82

Table 7.5: One-Sample Test for average left-turn time between young and old groups

	Young				Old				Mean Difference		
			95% CI				95% CI			95% CI	
	N	Mean	Lower	Upper	N	Mean	Lower	Upper	Mean	Lower	Upper
Male	18	4.58	3.81	5.34	8	4.74	3.63	5.84	-0.16	-1.48	1.16
Female	12	4.66	3.63	5.69	6	4.9	3.76	6.04	-0.24	-1.65	1.16
Total	30	4.61	4.04	5.18	14	4.81	4.12	5.49	-0.20	-1.08	0.69

7.1.3. Average Left-turn Acceleration

The average left-turn acceleration is the average vehicle's acceleration rate during the period of making the left-turn maneuver. As shown in Table 7.1, the average left-turn acceleration rate during the period of left turn time is 3.36 ft/sec^2 with a minimum of 1.23 ft/sec^2 and a maximum of 7.33 ft/sec^2. The average left-turn accelerations for each age and gender group are shown in Figure 7.5. In which, the average left-turn acceleration for males is 3.50 ft/sec^2, for females is 3.11 ft/sec^2, for young group is 3.63 ft/sec^2, and for old group is 2.73 ft/sec^2. Statistical analyses were conducted to test if there were significant age and gender effects on the left-turn acceleration. The results from the analyses are summarized in Table 7.6 and 7.7.

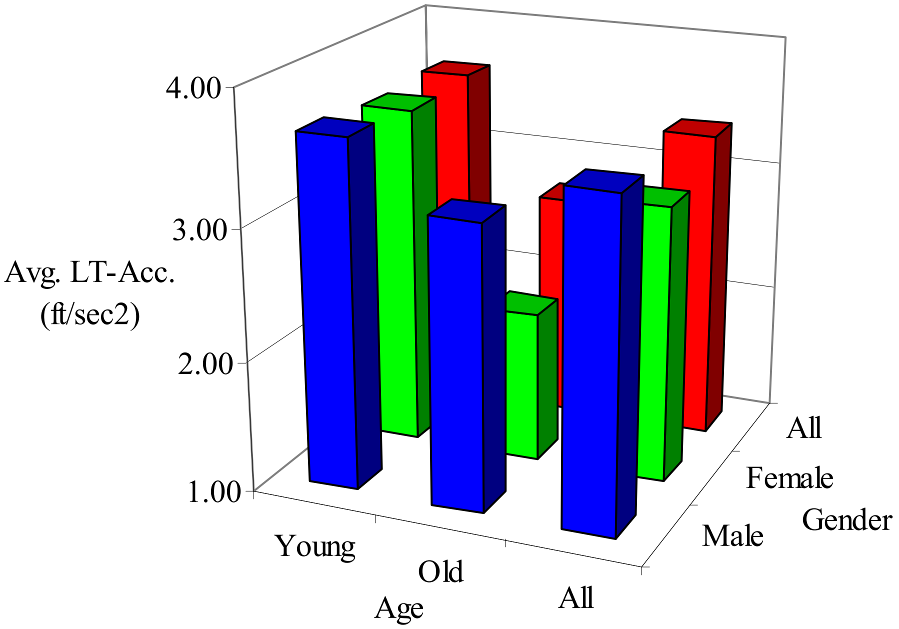


Figure 7-5: Average left-turn acceleration by age and gender.

Based on the mean analysis produced by the MINITAB software, Table 7.6 shows that there is no **gender** difference in left turn acceleration. However, there is significant **age** difference in left turn acceleration especially in female groups as highlighted in Table7.7. Younger females had significant higher left-turn accelerations then older females under a 95% level of confidence. Furthermore, there was no significant age difference in the left-turn acceleration between male groups, which contributed to the non-significant age difference between males and females. It means that older subjects like to use lower acceleration rates during the left-turn maneuver than younger group, especially for the older female drivers.

Table 7.6: One-Sample Test for average left-turn acceleration between male and female groups

	Male				**Female**				**Mean Difference**		
			95% CI				95% CI			95% CI	
	N	Mean	Lower	Upper	N	Mean	Lower	Upper	Mean	Lower	Upper
Young	18	3.65	3.02	4.27	12	3.60	2.41	4.78	0.05	-1.24	1.35
Old	8	3.17	1.93	4.42	6	2.15	1.28	3.01	1.03	-0.34	2.40
Total	26	3.50	2.97	4.03	16	3.11	2.26	3.96	0.39	-0.59	1.37

Table 7.7: One-Sample Test for average left-turn acceleration between young and old groups

	Young				**Old**				**Mean Difference**		
			95% CI				95% CI			95% CI	
	N	Mean	Lower	Upper	N	Mean	Lower	Upper	Mean	Lower	Upper
Male	18	3.65	3.02	4.27	8	3.17	1.93	4.42	0.47	-0.87	1.82
Female	12	3.60	2.41	4.78	6	2.15	1.28	3.01	1.45	0.04	2.86
Total	30	3.63	3.08	4.18	14	2.73	1.97	3.49	0.89	-0.02	1.81

7.1.4. Average Left-turn Angular Velocity

The average left-turn angular velocity is equal to the total sum of the rotation angle difference for every time unit divided by the total time during which the vehicle's steer turned left and turned back when subjects complete the left turn maneuver. As shown in Table 7.1, the average left-turn angular velocity during the period of left turn time is 2.32 deg/sec with a minimum of 1.27 deg./sec. and a maximum of 4.64 deg./sec. The average left-turn angular velocities for each age and gender group are shown in Figure 7.6. In which, the average left-turn angular velocities for males is 2.35 deg/sec, for females group is 2.29 deg/sec, for young group is 2.39 deg/sec, and for old group is 2.19 deg/seconds.

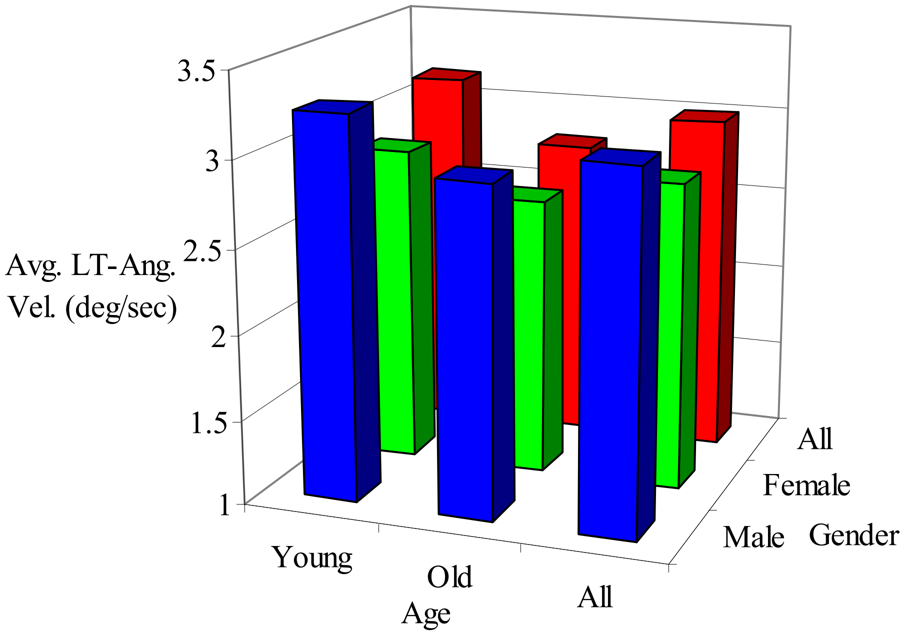


Figure 7-6: Average left-turn angular velocity by age and gender.

Statistical analyses were conducted to test if there were significant age's and gender's effects on the left-turn angular velocity. The results from the analyses are summarized in Table 7.8 and 7.9. There were no significant **age** or **gender** differences under a 95% confidence level, as shown in Table 7.8 and 7.9. It means that the drivers' characteristics (age and gender) had no significant impact on the left-turn angular velocity.

Table 7.8: One-Sample Test for average left-turn angular velocity between male and female groups

	Male				**Female**				**Mean Difference**		
			95% CI				95% CI			95% CI	
	N	Mean	Lower	Upper	N	Mean	Lower	Upper	Mean	Lower	Upper
Young	18	2.39	1.96	2.81	12	2.39	1.74	3.04	-0.01	-0.75	0.74
Old	8	2.27	1.51	3.04	6	2.08	1.58	2.56	0.2	-0.64	1.04
Total	26	2.35	2.01	2.69	16	2.29	1.83	2.75	0.06	-0.50	0.63

Table 7.9: One-Sample Test for average left-turn angular velocity between young and old groups

	Young				**Old**				**Mean Difference**		
			95% CI				95% CI			95% CI	
	N	Mean	Lower	Upper	N	Mean	Lower	Upper	Mean	Lower	Upper
Male	18	2.39	1.96	2.81	8	2.27	1.51	3.04	0.11	-0.72	0.95
Female	12	2.39	1.74	3.04	6	2.08	1.58	2.57	0.32	-0.45	1.09
Total	30	2.39	2.06	2.72	14	2.19	1.76	2.62	0.20	-0.33	0.73

7.1.5. Survey Analysis

After finishing the left-turn maneuver experiment, participants were handed a survey, see Appendix A. The results from analyzing questions related to the left-turn maneuver are presented in Figure 7.7. One of the survey questions asked subjects about the comfort of the left-turn maneuver, 44% answered that it was good, 34% answered that it was satisfactory, 12% answered that it needed improvements, 8% answered that it was excellent, and 2% answered that it was poor. Also, subjects were asked about the visibility of the coming vehicles, 36% answered that it was good, 27% answered that it was satisfactory, 22% answered that it needed improvements, and 15% answered that it was excellent. Regarding the realism of the coming vehicle, 42% answered that it was good, 32% answered that it was satisfactory, 14% answered that it was excellent, and 12% answered that it needed improvements.

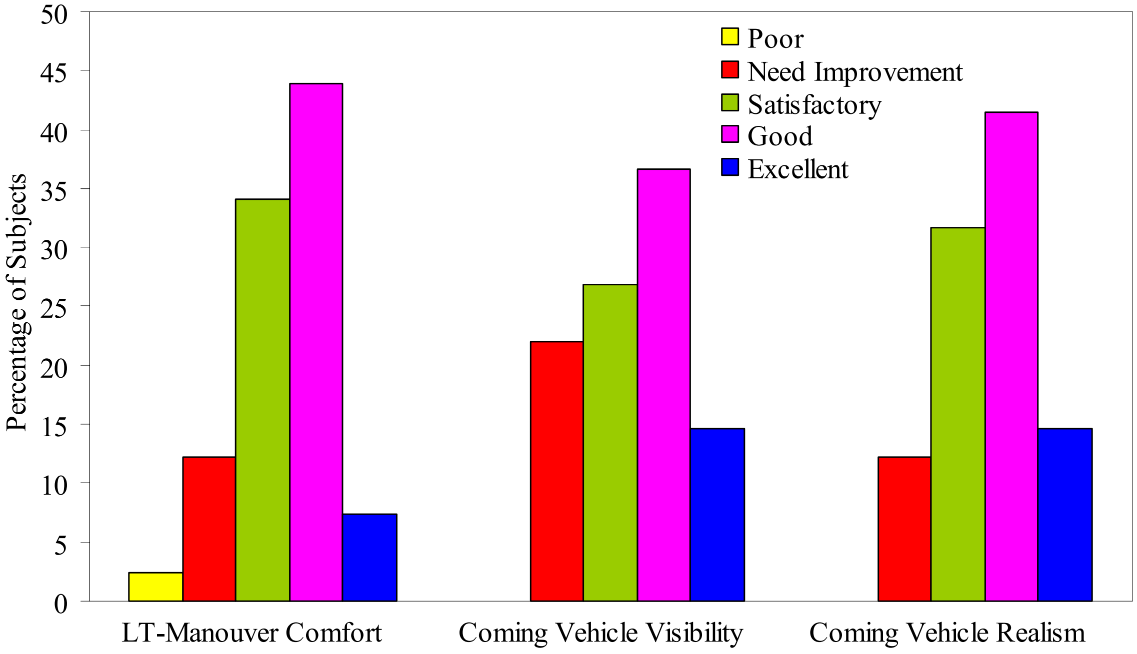


Figure 7-7: Survey analyses for left-turn maneuver experiment.

7.2. Studying Left-Turn Maneuver using OARSim System

Our OARSim system was used to study effects of left-turn drivers' characteristics (age and gender) on the left-turn maneuver at two-way stop-controlled intersection. Figure 7.8 shows a photo of one of the participants during the left-turn experiment, in which, the participant is driving the OARSim system while wearing the HMD. A small photo of what the subject sees during the experiment is shown in the top left corner of Figure 7.8.

Descriptive statistics for left-turn maneuver's measurements are shown in Table 7.10. Statistical analyses were conducted using Minitab software to test if there were significant age and/or gender effects on those measurements.

Figure 7-8: Left turning maneuver at two-way stop-controlled intersection experiment using the OARSim system.

Table 7.10: Descriptive statistics for left-turn maneuver's parameters

	Acceptable Gap (sec)	**LT-Time (sec)**	**LT-Acceleration (ft/sec2)**	**LT-Angular Velocity (deg/sec)**
N	44	44	44	44
Mean	5.36	3.82	8.26	3.00
Median	5.00	3.58	7.77	2.88
Std. Deviation	1.33	1.35	3.85	0.88
Variance	1.77	1.81	14.82	0.77
Minimum	3.00	2.03	2.27	1.55
Maximum	8.00	7.10	16.74	4.80

7.2.1. Acceptable Left Turning Gap

As mentioned early, the gap is the time gap between two successive vehicles in the opposing flow, measured from the instance that the front of the first vehicle passes a point to the instance that the front of the following vehicle passes the same point, in seconds. In the experiment, each left-turn driver accepted a gap between opposing through traffic for making the left-turn maneuver. From Table 7.10, the average acceptable gap for all drivers was 5.36 with a minimum of 3 seconds and a maximum of 8 seconds. The average acceptable gaps for each age and gender group are shown in Figure 7.9. The average acceptable gap for males was 5.27 seconds, for females group was 5.50 seconds, for young group was 5 second, and for old group was 6.5 seconds.

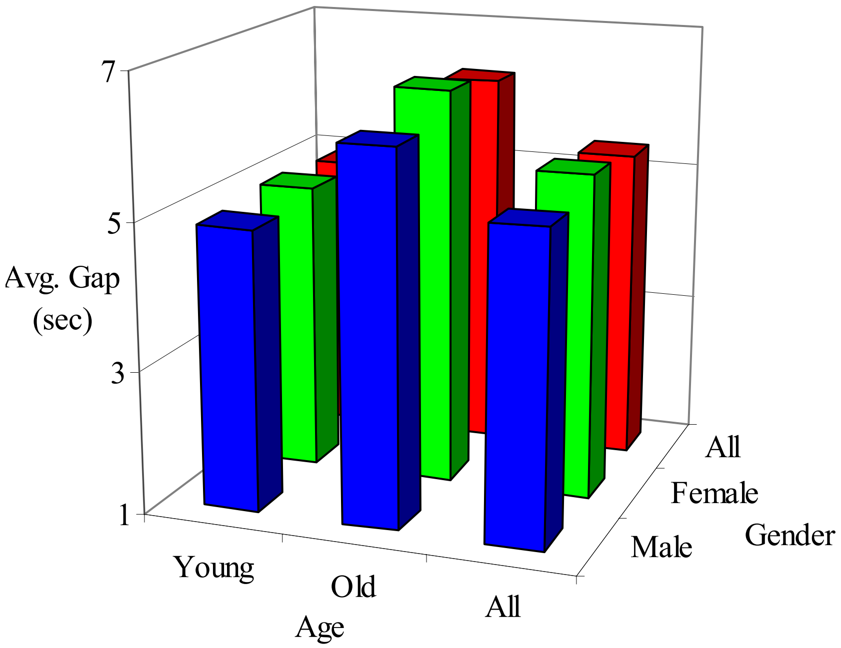


Figure 7-9: Average acceptable gap by age and gender.

Statistical analyses were conducted to test if there were significant age's and gender's effects on acceptable gaps. The results from the analyses are summarized in Table 7.11 and Table 7.12. There was a significant **age** difference in the acceptable gap for male and female groups under a 95% confidence level, as highlighted in Table 7.12. On the other hand, there was no significant **gender** effect for both age groups (young and old) at the 95% level of confidence. It indicates that, both old males and old females need bigger gaps than what younger drivers need, with no significant difference in gaps between males and females. Therefore, there is an **age** effect but there is no **gender** effect in the acceptable gaps.

Table 7.11: One-Sample Test for average acceptable gap between male and female groups

	Male				**Female**				**Mean Difference**		
			95% CI				95% CI			95% CI	
	N	Mean	Lower	Upper	N	Mean	Lower	Upper	Mean	Lower	Upper
Young	18	4.89	4.25	5.52	12	5.00	4.23	5.77	-0.11	-1.07	0.85
Old	8	6.13	5.30	6.95	6	6.50	5.21	7.79	-0.38	-1.72	0.97
Total	26	5.27	4.74	5.80	16	5.50	4.81	6.19	-0.23	-1.07	0.61

Table 7.12: One-Sample Test for average acceptable gap between young and old groups

	Young				**Old**				**Mean Difference**		
			95% CI				95% CI			95% CI	
	N	Mean	Lower	Upper	N	Mean	Lower	Upper	Mean	Lower	Upper
Male	18	4.89	4.25	5.52	8	6.13	5.30	6.95	-1.24	-2.25	-0.22
Female	12	5.00	4.23	5.77	6	6.50	5.21	7.79	-1.50	-2.84	-0.16
Total	30	4.93	4.48	5.38	14	6.29	5.67	6.90	-1.35	-2.10	-0.60

In order to calculate the critical acceptable gap, the logistic regression model was used as in the previous experiment. Therefore the logistic regression model of the probability of accepting a gap of size X can be presented by the following equation.

$$g(x) = 1.30 * X - 6.27 \qquad (R^2 = 99.4\%)$$

Based on the Logistic model, the critical gap which is the median of accepted gaps, i.e. the gap which is accepted by 50% of the subjects is about 4.80 seconds.

Plotting the **logistic regression model** of the probability of accepting a gap with the corresponding gap and the **cumulative probability** of accepting a gap with the corresponding gap shows that the logistic regression model is well representing the data, as shown in Figure 7.10. The critical gaps (the gap corresponds to the 50% probability of gap acceptance) from both curves were very close, approximately 4.80 seconds (from the logistic regression curve) and 4.90 seconds (from the cumulative probability curve).

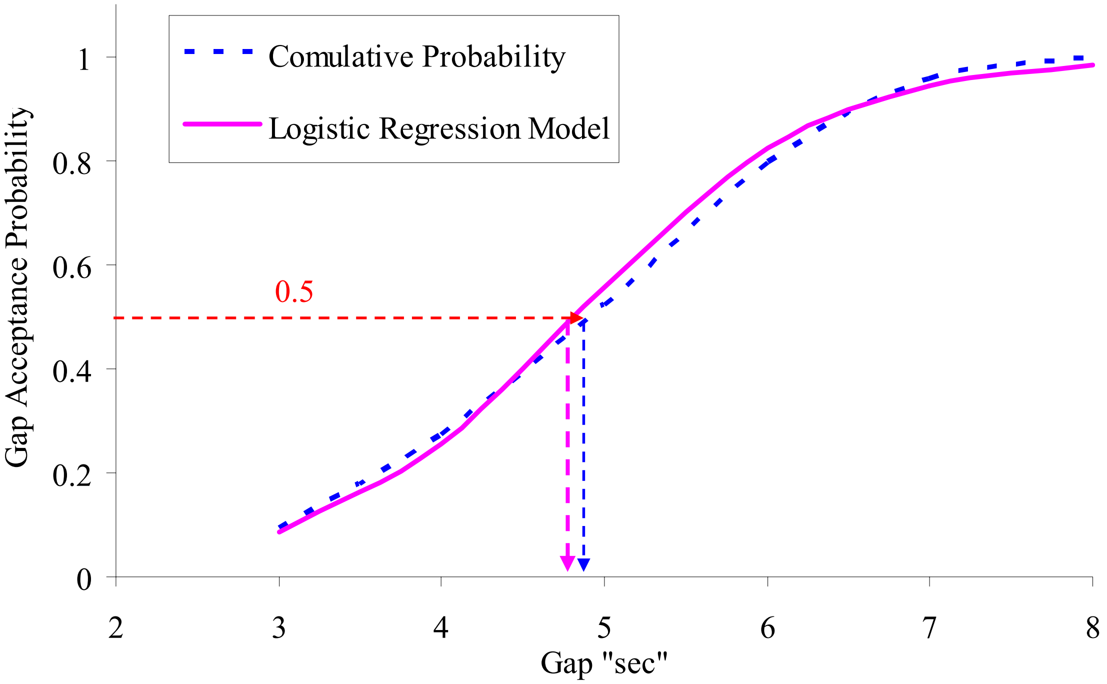


Figure 7-10: Gap acceptance probability.

7.2.2. Left Turning Time

The left-turn time for each driver (the time it took him/her to complete the left turning maneuver) was recorded. From Table 7.10, the average left-turn time was 3.82 second with a minimum of 2.03 seconds and a maximum of 7.10 seconds. The average left-turn times for each age and gender group are shown in Figure 7.11. In which, the average left-turn time for males is 3.56

seconds, for females group is 3.56 seconds, for young group is 3.45 second, and for old group is 4.61 seconds.

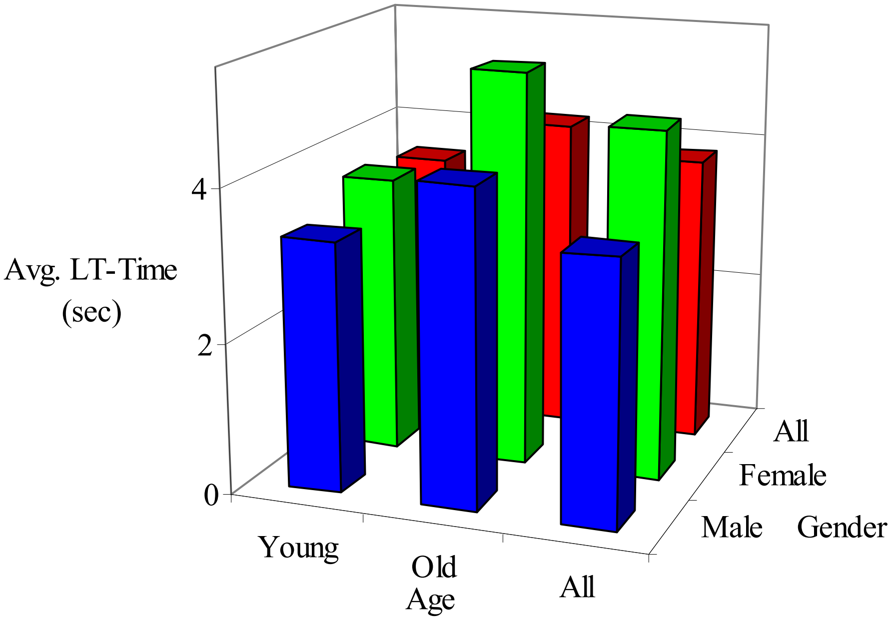


Figure 7-11: Average left-turn time by age and gender.

Statistical analyses were conducted to test if there were significant age and gender effects on the left-turn time. The results from the analyses are summarized in Table 7.13 and 7.14. While there was no significant **gender** effect on the left-turn time, there was a significant **age** effect especially between female groups under a 95% confidence level as highlighted in Table 7.14. It was found that older drivers took longer left turning time to complete the maneuver than younger drivers especially in female groups.

Table 7.13: One-Sample Test for average left-turn time between male and female groups

	Male				**Female**				**Mean Difference**		
			95% CI				95% CI			95% CI	
	N	Mean	Lower	Upper	N	Mean	Lower	Upper	Mean	Lower	Upper
Young	18	3.30	2.74	3.86	12	3.68	3.02	4.35	-0.39	-1.21	0.44
Old	8	4.16	2.89	5.43	6	5.22	3.71	6.73	-1.06	-2.81	0.70
Total	26	3.56	3.04	4.08	16	3.56	3.04	4.08	-0.63	-1.47	0.20

Table 7.14: One-Sample Test for average left-turn time between young and old groups

	Young				**Old**				**Mean Difference**		
			95% CI				95% CI			95% CI	
	N	Mean	Lower	Upper	N	Mean	Lower	Upper	Mean	Lower	Upper
Male	18	3.30	2.74	3.86	8	4.16	2.89	5.43	-0.86	-2.18	0.46
Female	12	3.68	3.02	4.35	6	5.22	3.71	6.73	-1.54	-2.99	-0.08
Total	30	3.45	3.05	3.85	14	4.61	3.73	5.50	-1.16	-2.11	-0.22

7.2.3. Average Left-turn Acceleration

As shown in Table 7.10, the average left-turn acceleration rate during the period of left turn time is 8.26 ft/sec^2 with a minimum of 2.27 ft/sec^2 and a maximum of 16.74 ft/sec^2. The average left-turn accelerations for each age and gender group are shown in Figure 7.12. In which, the average left-turn acceleration for males is 9.06 ft/sec^2, for females is 7.10 ft/sec^2, for young group is 9.14 ft/sec^2, and for old group is 6.36 ft/sec^2. Statistical analyses were conducted to test if there were significant age and gender effects on the left-turn acceleration. The results from the analyses are summarized in Table 7.6 and 7.7.

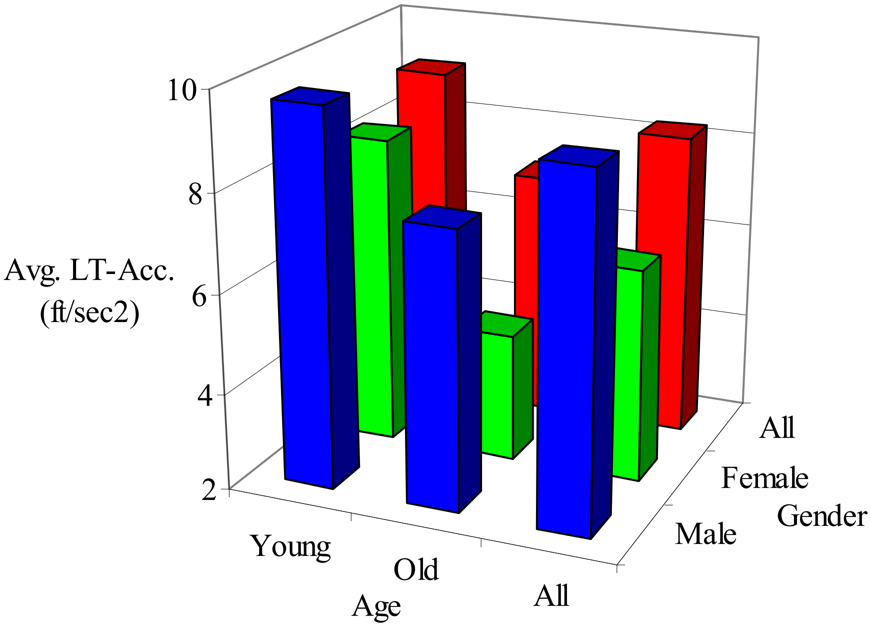


Figure 7-12: Average left-turn acceleration by age and gender.

Based on the mean analysis produced by the MINITAB software, Table 7.15 shows that there is no **gender** difference in the left-turn acceleration. However, there is significant **age** difference in the left-turn acceleration especially in female groups as highlighted in Table 7.16. Furthermore, there was no significant age difference in the left-turn acceleration between male groups, under a 95% level of confidence. However, younger females had significant higher left-turn accelerations then older females which contributed to the significant age difference between males and females. It means that older subjects have lower acceleration rates during the left-turn maneuver than younger group, especially for the older female drivers.

Table 7.15: One-Sample Test for average left-turn acceleration between male and female groups

	Male				**Female**				**Mean Difference**		
			95% CI				95% CI			95% CI	
	N	Mean	Lower	Upper	N	Mean	Lower	Upper	Mean	Lower	Upper
Young	18	9.68	7.82	11.55	12	8.33	5.90	10.76	1.35	-1.56	4.26
Old	8	7.66	4.68	10.64	6	4.63	2.05	7.21	3.03	-0.51	6.57
Total	26	9.06	7.55	10.57	16	7.10	5.21	8.99	1.96	-0.39	4.32

Table 7.16: One-Sample Test for average left-turn acceleration between young and old groups

	Young				**Old**				**Mean Difference**		
			95% CI				95% CI			95% CI	
	N	Mean	Lower	Upper	N	Mean	Lower	Upper	Mean	Lower	Upper
Male	18	9.68	7.82	11.55	8	7.66	4.68	10.64	2.03	-1.36	5.41
Female	12	8.33	5.90	10.76	6	4.63	2.05	7.21	3.70	0.42	6.98
Total	30	9.14	7.76	10.53	14	6.36	4.39	8.32	2.78	0.44	5.12

7.2.4. Average Left-turn Angular Velocity

The average left-turn angular velocity is equal to the total sum of the rotation angle difference for every time unit divided by the total time during which the vehicle's steer turned left and turned back when subjects complete the left turn maneuver. As shown in Table 7.10, the average left-turn angular velocity during the period of left turn time is 3 deg/sec with a minimum of 1.55 deg/sec. and a maximum of 4.80 deg/sec. The average left-turn angular velocities for each age and gender group are shown in Figure 7.13. In which, the average left-turn angular velocity for males is 3.15 deg/sec, for females group is 2.79 deg/sec, for young group is 3.09 deg/sec, and for old group is 2.81 deg/seconds.

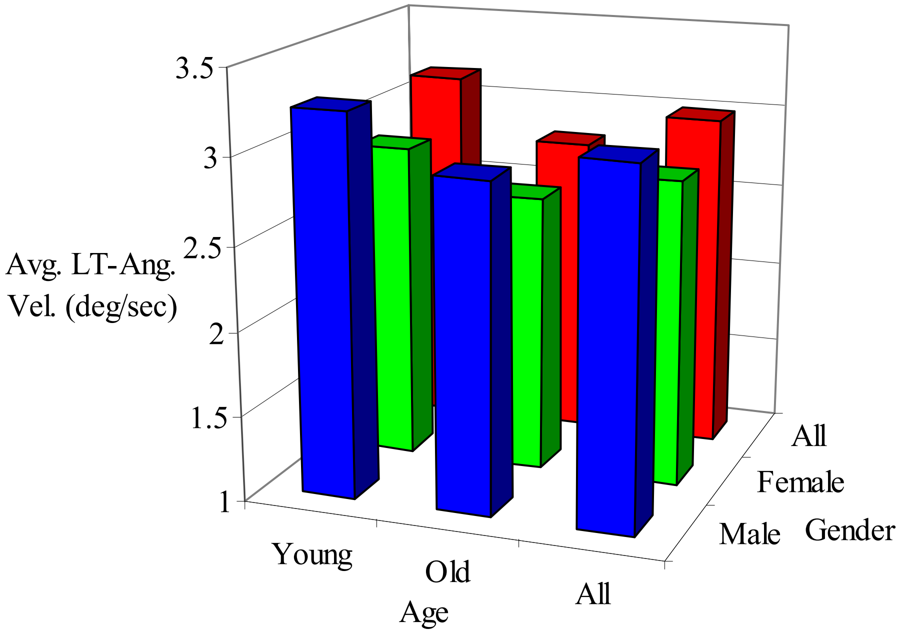


Figure 7-13: Average left-turn angular velocity by age and gender.

Statistical analyses were conducted to test if there were significant age's and gender's effects on the left-turn angular velocity. The results from the analyses are summarized in Table 7.17 and 7.18. For the average steering angle velocity during left turn time, there were no significant **age** or **gender** differences under a 95% confidence level, as shown in Table 7.17 and 7.18. It means that the drivers' characteristics (age and gender) had no significant impact on the left-turn angular velocity.

Table 7.17: One-Sample Test for average left-turn angular velocity between male and female groups

	Male				**Female**				**Mean Difference**		
			95% CI				95% CI			95% CI	
	N	Mean	Lower	Upper	N	Mean	Lower	Upper	Mean	Lower	Upper
Young	18	3.25	2.77	3.72	12	2.87	2.31	3.43	0.38	-0.32	1.08
Old	8	2.93	2.23	3.64	6	2.64	1.91	3.36	0.30	-0.61	1.20
Total	26	3.15	2.78	3.52	16	2.79	2.39	3.19	0.36	-0.17	0.89

Table 7.18: One-Sample Test for average left-turn angular velocity between young and old groups

	Young				**Old**				**Mean Difference**		
			95% CI				95% CI			95% CI	
	N	Mean	Lower	Upper	N	Mean	Lower	Upper	Mean	Lower	Upper
Male	18	3.25	2.77	3.72	8	2.93	2.23	3.64	0.31	-0.51	1.13
Female	12	2.87	2.31	3.43	6	2.64	1.91	3.36	0.23	-0.60	1.07
Total	30	3.09	2.76	3.43	14	2.81	2.36	3.25	0.29	-0.26	0.83

7.2.5. Survey Analysis

Participants were handed a survey after finishing the experiment with the same questions as in previous experiment using ARV system, see Appendix A. The results from analyzing questions are presented in Figure 7.14. When subjects were asked about the comfort of the left-turn maneuver, 25% answered that it was good, 36% answered that it was satisfactory, 27% answered that it needed improvements, 8% answered that it was excellent, and 4% answered that it was poor. Also, subjects were asked about the visibility of the coming vehicles, 34% answered that it was good, 39% answered that it was satisfactory, 18% answered that it was excellent, and 9% answered that it needed improvements. Regarding the realism of the coming vehicle, 34%

answered that it was good, 32% answered that it was satisfactory, 16% answered that it was excellent, and 18% answered that it needed improvements.

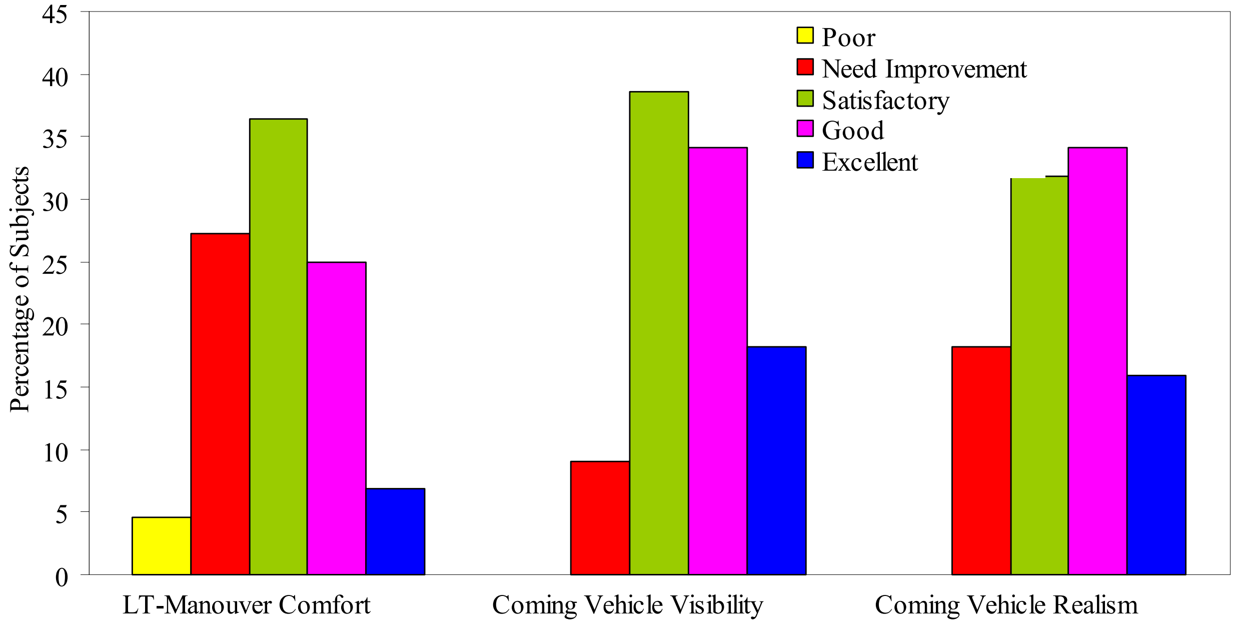


Figure 7-14: Survey analyses for left-turn maneuver experiment.

7.3. Interpreting the Results

7.3.1 ARV vs. OARSim in Studying the Left-Turn Maneuver

The purpose of this statistical comparison is to study left-turner driver's characteristics on the left-turn maneuver at un-signalized intersection using ARV system and OARSim system. During experiments, the following parameters were recorded for each driver; the acceptable gap (in second), the left-turn time (in second), the left-turn acceleration (in feet per second square), and the left-turn angular velocity (in degree per second. Those data are shown in Appendix D.

Descriptive statistics for those parameters using the two systems are shown in Table 7.1 and Table 7.10 respectively.

Statistical analyses were conducted using Minitab software to test if there was a statistical difference of those parameters between the two experiments. The results from Minitab software are summarized in Table 7.19.

Table 7.19: Statistical summary of Minitab outputs of two-sample t-tests for left-turn maneuver parameters using ARV and OARSim systems

Left-Turn Maneuver's Parameter	Hypothesis	P-VALUE	Conclusion*
Acceptable Gap	H0: mean1 = mean 2 H1: mean1 ≠ mean 2	0.453	Don't Reject H0
LT-Time	H0: mean1 = mean 2 H1: mean1 ≠ mean 2	0.002	Reject H0
Avg. LT-Acceleration	H0: mean1 = mean 2 H1: mean1 ≠ mean 2	0.000	Reject H0
Avg. LT-Angular Velocity	H0: mean1 = mean 2 H1: mean1 ≠ mean 2	0.001	Reject H0

*Based on 95% confidence ($\alpha = 0.05$)

At a 95% level of confidence, there was no significant difference for acceptable gap means for using ARV system and using OARSim system. The reason is that both systems (ARV and OARSim) provided drivers with almost the same augmented view, which is a combination of real-world video and virtual vehicles. Although the video using the ARV system was on-line video and using the ORVSim was pre-recorded video, this didn't affect the drivers' accepted gap means.

On the other hand, there was a statistical significant difference between the left-turn time means using both systems at a 95% level of confidence with a *smaller* left-turn time mean when using the OARSim system than when using the ARV system. In addition, there was a statistical significant difference in the left-turn acceleration means and left-turn angular velocity using both systems at a 95% level of confidence. Drivers had a *larger* left-turn acceleration mean and *larger* left-turn angular velocity mean when using the OARsim system than when using the ARV system. Left-turn time, left-turn acceleration, and left-turn angular velocity are all attributed to the drivers' ability to push the gas pedal and steer the vehicle fast enough to turn. It appears that the subjects had much better feel and handling of both the gas pedal and the steering system of the OAR system more so than the ARV system. Furthermore, the nature of the portable simulator of the OAR system make subjects believes that they are in game and they tend to drive more aggressive.

7.3.2 Age and Gender Effects on the Left-Turn Maneuver

Two experiments were conducted to study left-turner driver's age and gender effects on the left-turn maneuver at un-signalized intersection; using the ARV system and the OARSim system. The accepted gap, the left-turn time, the left-turn acceleration, and the left-turn angular velocity were recorded for each subject in both experiments.

In both experiments (using ARV and OARSim systems), there was no significant gender effect on all left-turn parameters (acceptable gap, left-turn time, left-turn acceleration, and left-turn angular velocity) in the two experiments. This conclusion is supported by Kroemer et. al (1994) and Koppa (1992) findings.

On the other hand there was a significant age effect on the accepted gap in both experiments. In which, both old males and old females needed bigger gaps than what younger drivers needed. This agrees with Yan's (2003), Alexander's (2002), Tarawneh's (1996), and

Lerner's (1995) findings.

Although, experiments' results, using both the ARV and the OARSim systems, showed that there is an age effect on left-turn gap acceptances, the AASHTO (2001) criteria for left-turn gap acceptances did not consider left-turn drivers' characteristics (gender, age). While the critical accepted gap from our logistic regression models were 5.15 seconds (using the ARV system) and 4.80 seconds (using the OARSim system), the AASHTO (2001) indicated a 5.50 seconds as a critical gap for this type of maneuver (left-turn from a major road) which is a little conservative. Moreover, due to the significant difference between old and young drivers in accepted gaps during both experiments, it is recommended to increase the critical accepted gap by 1.0 seconds for all design criteria at un-signalized intersections in areas with high-density old age population.

In the experiment using the OARSim system, older drivers took significantly longer time to complete the left-turn maneuver than what the younger driver took, especially in female groups. However there was no age effect on the left turning time in the left-turn experiment using the ARV system.

Furthermore, in both experiments, there was a significant age effect on the left-turn acceleration rate, especially among female groups at a 95% level of confidence. Older females had a smaller acceleration rate when performing the left-turn maneuver than younger females. This result agrees with Yan's (2003) findings.

Regarding the left-turn angular velocity, there was no significant age effect under a 95% confidence level.

CHAPTER 8: HORIZONTAL VISIBILITY RESULTS AND DATA ANALYSIS

Our Offline Augmented Reality Simulator “OARSim” system was used to study the effects of following an LTV on the succeeding car driver’s performance and the contribution of rear-end crash. Two scenarios were conducted; following a passenger car “PC-PC” and following a large truck vehicle “PC-LTV”. During the two scenarios, the posted speed limit as well as the leading virtual vehicle speed was 35 mph (56 kph). Two groups of participants (A and B) rode the OARSim system for about 5 minutes, while seeing through the HMD a real offline video of a two-way road with virtual vehicles and asked to drive as in the real life. Group “A” completed PC-PC scenario while group “B” completed PC-LTV scenario. In both scenarios participants were forced to follow a leading vehicle (PC for the first scenario and LTV in the second scenario). The posted speed limit as well as the leading vehicle speed was 35 mph (56 kph).

Figure 8.1 (a) and (b) show two photos of two participants during PC-PC and PC-LTV scenarios, in which, participants are driving the OARSim system while wearing the HMD. Two small photos of what each subject sees during the experiment are shown in the top left corner of Figure 8.1 (a) and (b).

(a) (b)

Figure 8-1: Horizontal visibility blockage experiment; (a) following an LTV, and (b) following a PC.

8.1. Driver's Performance Analysis for Following a PC and LTV

During both scenarios (PC-PC and PC-LTV), the following parameters were recorded for each driver; the velocity (in mph), the headway (in feet), the response time (in seconds), the deceleration (in feet per second square), and the impact velocity (in mph) (in case of a rear-end crash with the leading vehicle). Those data are shown in Appendix E. Descriptive statistics for the horizontal visibility blockage's parameters are shown in Table 8.1. Statistical analyses were conducted using Minitab software to test if the leading vehicle's type (PC/LTV) had significant effects on those parameters. There were one and fourteen (14) rear-end crashes observed for the PC-PC and PC-LTV experiments, respectively.

Table 8.1: Descriptive statistics for horizontal visibility blockage's parameters

Following a PC Scenario					
	Incident Headway (ft)	**Incident Velocity (mph)**	**Incident Response Time (sec)**	**Incident Deceleration (ft/sec2)**	**Impact Velocity (mph)**
N	22	22	22	22	1
Mean	82.08	26.93	12.52	1.64	17.35
Median	77.09	27.58	11.66	1.64	17.35
Std. Deviation	21.98	4.03	4.43	0.64	---
Variance	483.30	16.21	19.66	0.41	---
Min.	51.28	20.09	6.52	0.55	17.35
Max.	127.23	33.10	21.57	2.98	17.35
Following an LTV Scenario					
	Incident Headway (ft)	**Incident Velocity (mph)**	**Incident Response Time (sec)**	**Incident Deceleration (ft/sec2)**	**Impact Velocity (mph)**
N	22	22	22	22	14
Mean	51.34	31.15	17.05	1.85	22.46
Median	46.81	30.40	16.77	1.78	22.92
Std. Deviation	16.60	4.68	7.12	0.64	5.10
Variance	275.45	21.94	50.63	0.41	26.05
Min.	25.42	24.22	5.24	0.59	14.50
Max.	95.00	22	27.47	3.09	32.64

8.1.1. Incident Headway "IH"

The incident headway refers to the distance between the two vehicles (the leading and the succeeding vehicles), measured from the end of the leading vehicle to the center of the following vehicle in feet, just before the participant starts braking due to the sudden turning vehicle. The incident headway is one of the factors that indicate the collision threat. When the headway is too small, the succeeding vehicle is more likely to result in a rear-end accident.

From Table 8.1, the average incident headway was 82ft when following a PC and 51ft when following an LTV. The incident headway for each driver in both scenarios is shown in

Figure 8.2. The trend of the data in Figure 8.2 indicates that the headway tends to be larger when following a PC than when following an LTV.

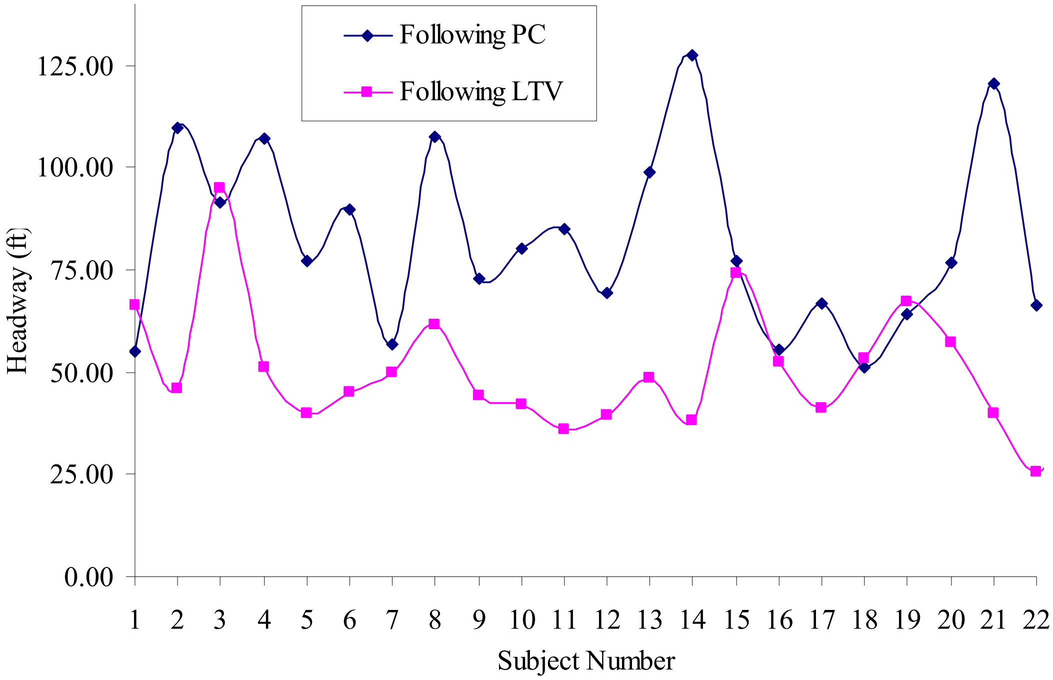
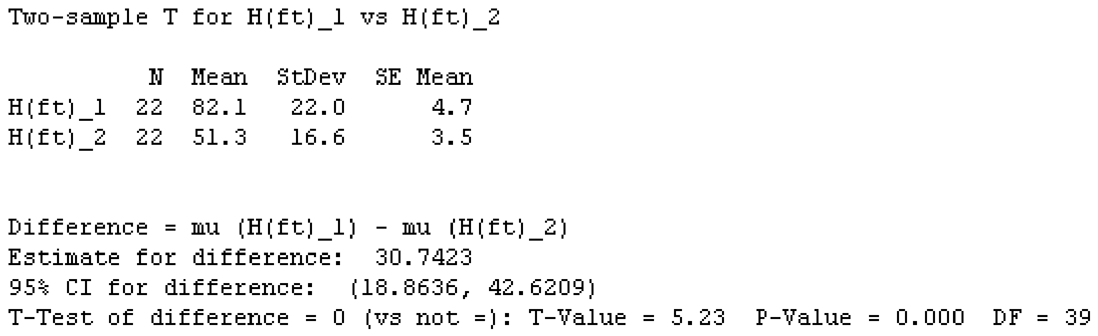


Figure 8-2: Headway for following a PC and following LTV.

A two sample t-test was conducted using Minitab software on the headway between the two scenarios (following a PC and following an LTV). Table 8.2 shows the Minitab output, in which the resulted P-value was 0.00. Therefore, there was a statistical significant difference between the following headway means of both scenarios at a 95% level of confidence. It indicates that subjects following LTVs left significantly smaller headways than what other subjects left when following PCs. The subjects drove closer to LTVs than to PCs because when they drive behind LTVs they feel uncomfortable and anxious to pass it due to the view blockage caused by LTVs, which is supported by the findings from Sayer (2003), and Harb (2005).

Table 8.2: Minitab output for 2 sample t-test, incident headway of following an LTV and PC



```
Two-sample T for H(ft)_1 vs H(ft)_2

          N  Mean  StDev  SE Mean
H(ft)_1  22  82.1   22.0      4.7
H(ft)_2  22  51.3   16.6      3.5


Difference = mu (H(ft)_1) - mu (H(ft)_2)
Estimate for difference:  30.7423
95% CI for difference:  (18.8636, 42.6209)
T-Test of difference = 0 (vs not =): T-Value = 5.23  P-Value = 0.000  DF = 39
```

8.1.2. Incident Velocity “IV”

The incident velocity refers to the subject’s driving velocity just before braking when the vehicle from the opposing traffic made a sudden turn and the leading vehicle braked accordingly. The velocity is an important factor when following LTV, in case of a sudden stop of the LTV, the speedy succeeding vehicle might not have the time to stop causing a higher potential of rear-end collision with the LTV.

The incident velocity of each subject (in the two groups) is shown in Figure 8.3; the trend of the data indicates higher velocity when following an LTV. From Table 8.1 the mean velocity was 26.9mph (with a minimum of 20mph and a maximum of 33mph) when following a PC and 31mph (with a minimum of 24mph and a maximum of 40 mph) when following an LTV.

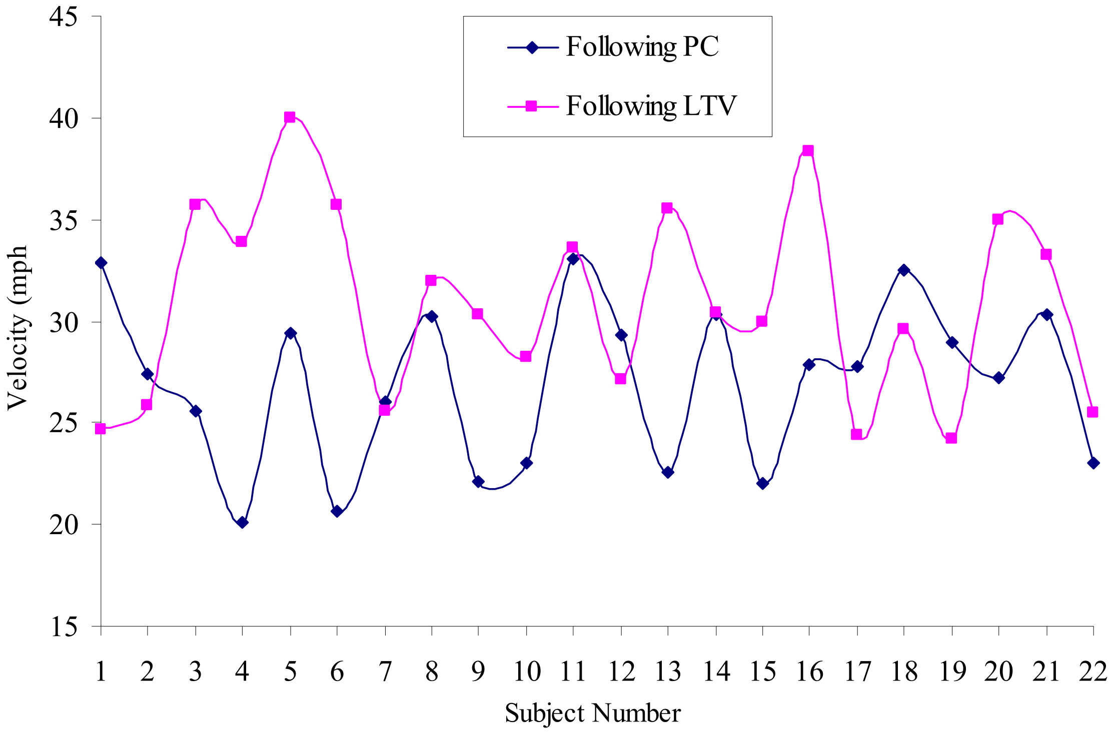
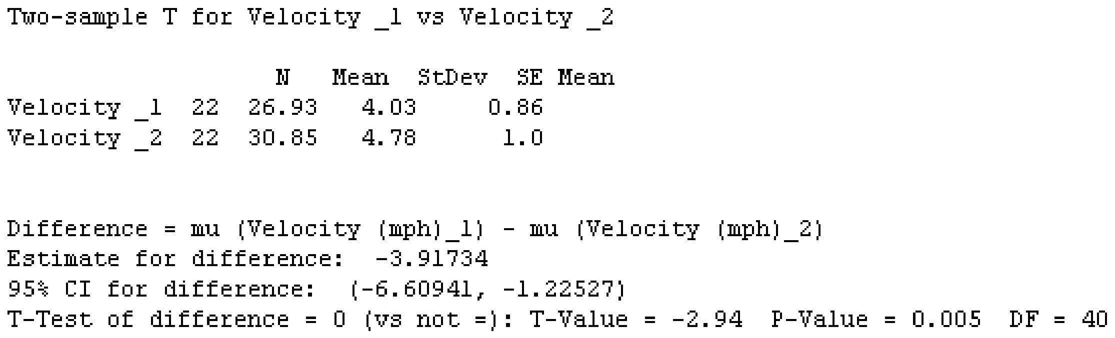


Figure 8-3: Velocity for following a PC and following LTV.

A two sample t-test to compare the velocity means of the two samples at a 95 % confidence interval was performed using Minitab software. The output from the statistical test is shown in Table 8.3, in which there was a significant difference between the two velocity means (P-value =0.005). The higher velocity mean for following the LTV can be explained by the fact that subjects driving behind the LTV cannot see beyond it causing uncomfortable feeling and anxious desires to pass it, which agrees with the findings from Harb (2005).

Table 8.3: Minitab output for 2 sample t-test, incident velocity of following an LTV and PC



```
Two-sample T for Velocity _1 vs Velocity _2

                  N   Mean  StDev  SE Mean
Velocity _1  22  26.93   4.03     0.86
Velocity _2  22  30.85   4.78      1.0


Difference = mu (Velocity (mph)_1) - mu (Velocity (mph)_2)
Estimate for difference:  -3.91734
95% CI for difference:  (-6.60941, -1.22527)
T-Test of difference = 0 (vs not =): T-Value = -2.94  P-Value = 0.005  DF = 40
```

8.1.3. Incident Response Time “IRT”

The incident response time refers to the time it took the participant (succeeding car’s driver) to respond to the incident (opposing vehicle sudden turn). Although the response time is a good parameter that reflects the view blockage caused by following the LTV, it is also a very sensitive parameter that can be affected by many other factors such as the driver’s age and gender, and the headway between the LTV and the succeeding vehicle.

Figure 8.4 shows the response times for both following the PC and following the LTV scenarios. The data does not have a certain trend. From Table 8.1, the average incident response time was 12.5 sec when following a PC and 17.5 sec when following an LTV.

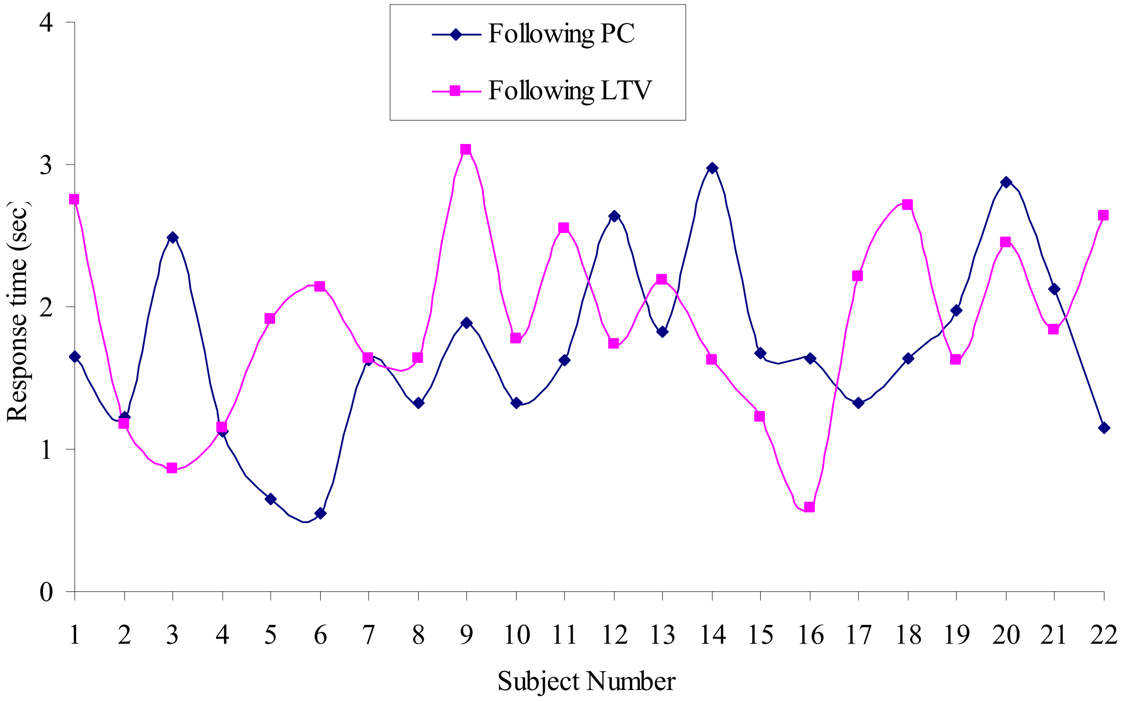
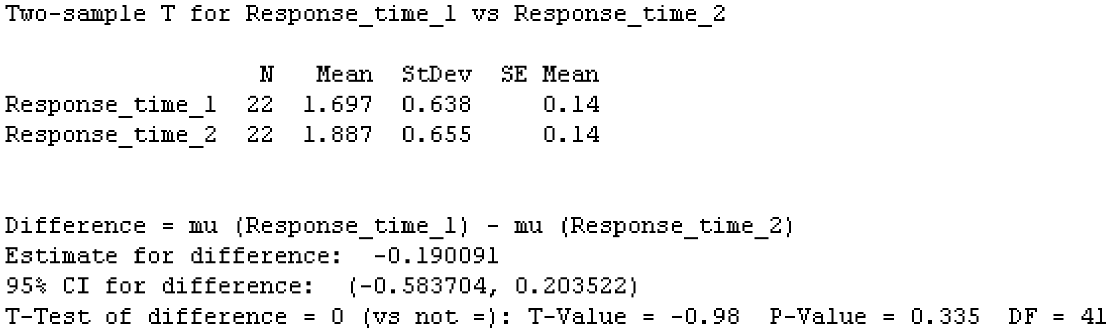


Figure 8-4: Response time for following a PC and following LTV.

A two sample t-test was conducted using Minitab software to compare the means of response delay time of both scenarios. From Table 8.4 the resulted P-value was 0.335 which means that there is no significant statistical difference between the response delay time means of the two samples at a 95% level of confidence.

Table 8.4: Minitab output for 2 sample t-test, incident response time of following an LTV and PC



```
Two-sample T for Response_time_1 vs Response_time_2

                  N   Mean  StDev  SE Mean
Response_time_1  22  1.697  0.638     0.14
Response_time_2  22  1.887  0.655     0.14


Difference = mu (Response_time_1) - mu (Response_time_2)
Estimate for difference:  -0.190091
95% CI for difference:  (-0.583704, 0.203522)
T-Test of difference = 0 (vs not =): T-Value = -0.98  P-Value = 0.335  DF = 41
```

8.1.4. Incident Deceleration Rate "IDR"

The incident deceleration rate refers to the succeeding car's deceleration rate when the vehicle from the opposing traffic made a sudden turn and the leading vehicle braked accordingly which led the succeeding car's driver to decelerate. The deceleration rate is an important factor that can reflect the accident risk. If the succeeding car's deceleration rate is high it indicates that there is a high potential for rear-end collision with the leading vehicle.

Figure 8.5 shows the deceleration rates of each participant for both scenarios (following a PC and following an LTV). The deceleration rate for following an LTV seems higher than the deceleration rate for following a PC. From Table 8.1, the average incident deceleration rate was 1.64ft/sec2 when following a PC and 1.85ft/sec2 when following an LTV.

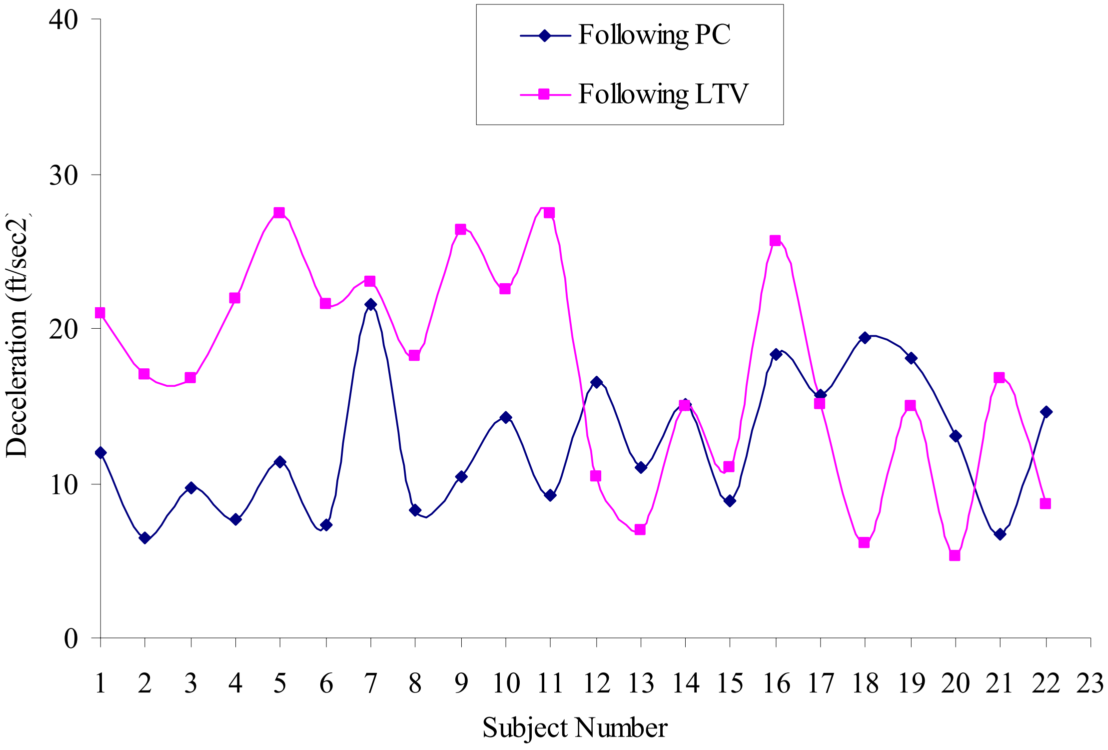
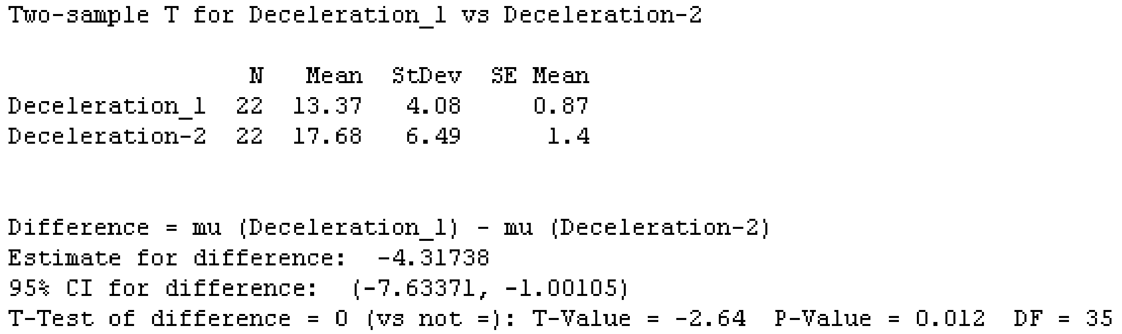


Figure 8-5: Deceleration rate for following a PC and following LTV.

A two sample t-test was performed using Minitab software to check for a statistical significant difference between the deceleration means of both samples. From the MINITAB output below the P-value is equal to 0.012 which means that there is a statistical significant difference between the deceleration means of following a PC and following an LTV at a 95%level of confidence.

Table 8.5: Minitab output for 2 sample t-test, incident deceleration of following an LTV and PC



```
Two-sample T for Deceleration_1 vs Deceleration-2

                 N   Mean  StDev  SE Mean
Deceleration_1  22  13.37   4.08     0.87
Deceleration-2  22  17.68   6.49      1.4


Difference = mu (Deceleration_1) - mu (Deceleration-2)
Estimate for difference:  -4.31738
95% CI for difference:  (-7.63371, -1.00105)
T-Test of difference = 0 (vs not =): T-Value = -2.64  P-Value = 0.012  DF = 35
```

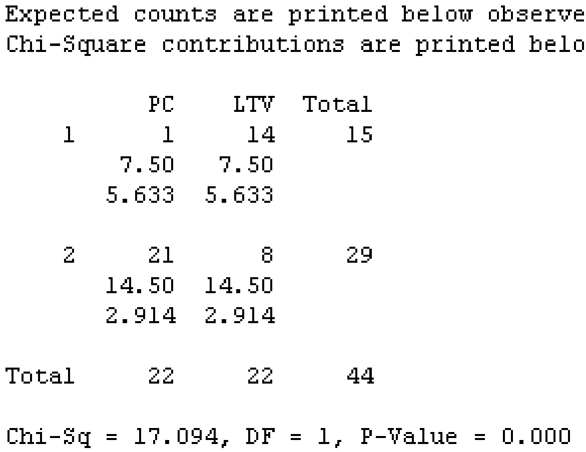
8.1.5. Incident Impact Velocity "IIV"

The incident impact velocity refers to the velocity at which the succeeding vehicle hit the PC or the LTV (in case of a crash). The impact velocity is a good parameter that can reflect the severity of the crash; the higher the impact velocity the greater the severity of the crash. From Table 8.1, the numbers of crashes (one for following a PC and 13 for following an LTV) were not comparable and it was hard to perform a statistical analysis. However, the trend of the data in Table 8.1 indicates 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.

8.2. Rear-End Collision Analysis

While one subject out of 22 subjects following the PC got involved in a rear-end collision with the PC, 14 subjects out of the 22 subjects following the LTV were involved in rear-end collisions with the LTV, see Appendix E. Therefore, the probabilities of being involved in an accident following PC and following LTV are 4.5%, and 63.6% respectively. It is clear from the data that following LTVs caused more rear-end crashes than following PCs. Minitab software was used to conduct Chi-square test for the two accidents' ratios. There was a significant difference between the accident ratios for following an LTV (P-value= 0.00), as shown in Table 8.6. Without a doubt, following LTVs contributed to more rear-end crashes than following PCs.

Table 8.6: Minitab output for Chi-square test for accident ratios when following PC and LTV



```
Expected counts are printed below observed counts
Chi-Square contributions are printed below expected counts

           PC     LTV  Total
    1       1      14     15
         7.50    7.50
        5.633   5.633

    2      21       8     29
        14.50   14.50
        2.914   2.914

Total      22      22     44

Chi-Sq = 17.094, DF = 1, P-Value = 0.000
```

In order to study factors that contribute to rear-end crashes when following LTV, binary logistic regression was used. The binary logistic regression is a statistical technique for developing predictive model for the probability that an event (in our case is involving in a rear-end crash) will or will not happen. Minitab software was used to build a model for the probability of rear-end crashes when following LTVs using the logistic regression. The probability that a driver will involve in a rear-end crash is modeled as logistic distribution in the following equation,

$$\pi(x) = \frac{e^{g(x)}}{1+e^{g(x)}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(8.1)$$

The Logit of the multiple logistic regression model is presented in the following equation;

$$g(x) = \ln\left[\frac{\pi(x)}{1-\pi(x)}\right] = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots \beta_n x_n \quad \text{(8.2)}$$

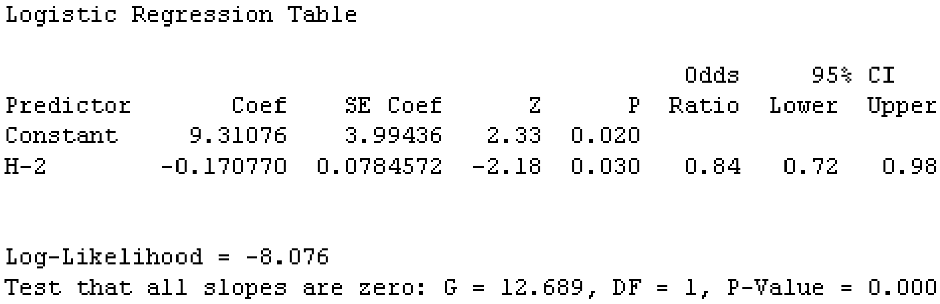
In which, $\pi(x)$ is the probability that the driver will involve in a rear-end crash,

β_0, $\beta_1, \beta_2, \ldots, \beta_n$ are constants.

$x_1, x_2, \ldots, x_n$ are independent variables

Four potential independent variables; Velocity (mph), headway (ft), response time (sec), and the deceleration rate (ft/sec2) suspected to be related to the rear-end collision probability when following an LTV. The four variables were used to construct the logistic model in Minitab software. After several trials and eliminations, the final model is shown in Table 8.7 where the P-values< 0.05. The final model consists of one factor which is the headway between the succeeding and the leading vehicles.

Table 8.7: Minitab output for Logistic regression model of rear-end accident



```
Logistic Regression Table

                                                   Odds     95% CI
Predictor       Coef    SE Coef       Z       P  Ratio  Lower  Upper
Constant     9.31076    3.99436    2.33  0.020
H-2        -0.170770  0.0784572   -2.18  0.030   0.84   0.72   0.98


Log-Likelihood = -8.076
Test that all slopes are zero: G = 12.689, DF = 1, P-Value = 0.000
```

Therefore, the logistic regression model of the probability of involving in a rear-end crash when following an LTV can be presented by the following equation.

$$g(x) = \ln\left[\frac{\pi(x)}{1-\pi(x)}\right] = 9.311\text{-}0.171\text{*Headway} \quad \text{(8.3)}$$

Based on the Logistic model, the probability of rear-end collision with the corresponding headway, when following an LTV, is shown in Figure 8.6. From Figure 8.6, the critical headway “Hc” between the succeeding car and the leading LTV can be obtained (approximately 54.5ft), as the headway corresponds to the 50% probability of rear-end collisions. This indicates that cars’ drivers who leave headways equal or smaller than 54.5ft from the leading LTV have 50% or higher chance of being involved in a rear-end crashes with the LTV.

Based on the theoretical calculation of the blocked view area of the small car when following an LTV, the blocked headway “Hb” was 62.6 ft, see Chapter 5. Hb is the calculated headway at which the succeeding car is not able to see the sudden turning vehicle, i.e. the sudden turning vehicle is in the blocked view area of the following car. In Figure 8.6, the hatched area represents the blocked view area of the small vehicle when following the LTV. From Figure 8.6, the probability of rear-end crashes that corresponds to “Hb” was approximately 20%. Therefore, about 80% of the rear-end crashes occurred when driving in the blocked view area. This indicates that following LTVs may prevent drivers in cars behind them from being aware of the traffic situation ahead that increased the chance of involving in rear-end crashes with LTVs in case of sudden application of the breaks. This agrees with Graham’s (2000), Abdel-Aty’s (2004), and Rami (2005) findings.

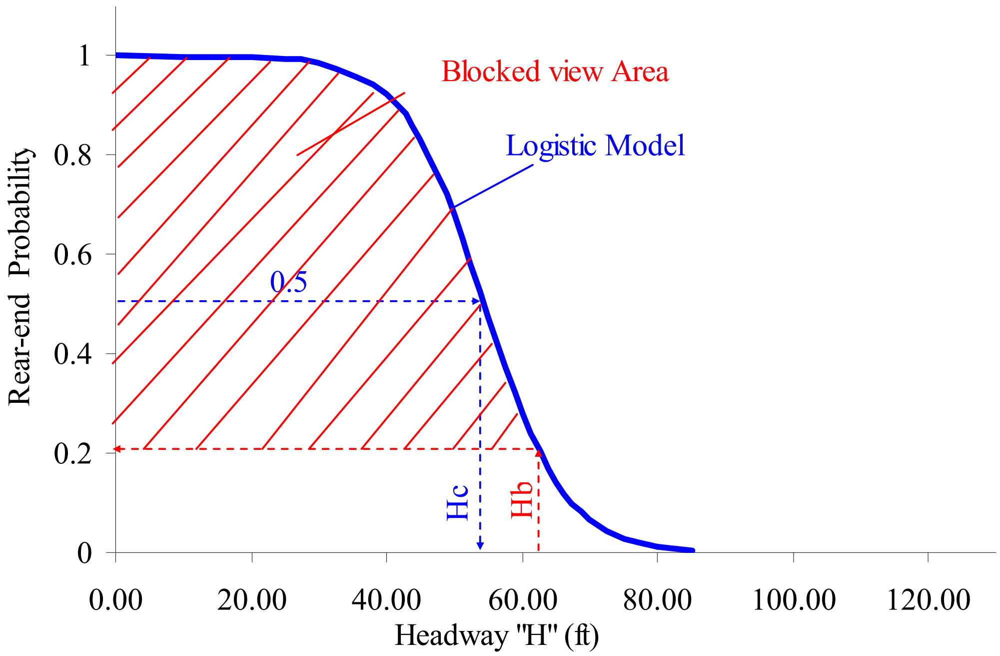


Figure 8-6: Rear-end crashes probability for following LTVs.

8.3. Survey Analysis

After finishing the horizontal visibility blockage experiment, participants in both groups (A for following PC and B for following LTV) were handed a survey, see Appendix A. One of the survey questions asked subjects if they drive closely behind a PC or LTV in real life. Figure 8.7 shows the ratios of participants answers, in which from group A, which consisted of 22 subjects driving behind a PC, 32 % answered that they drive closely behind PCs in real life and the 68% answered that they do not drive closely to PCs in real life. On the other hand, from group B, which consisted of 22 subjects driving behind an LTV, 41 % answered that they drive closely behind LTVs in real life and the 59% answered that they do not drive closely to LTVs in real life.

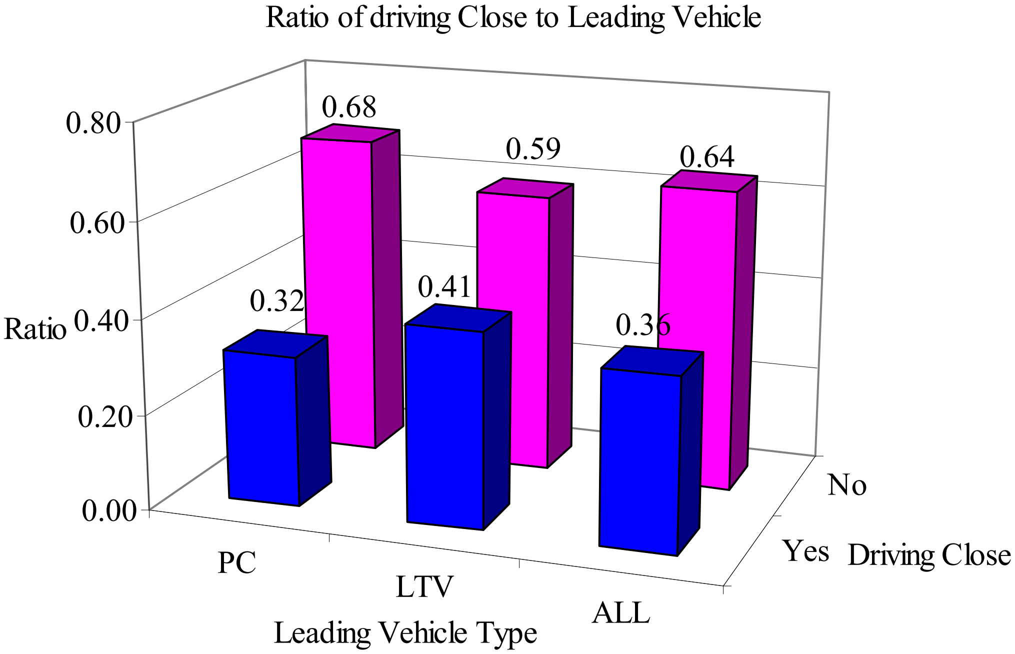


Figure 8-7: Driving close to leading vehicle (LTV and PC) in real life.

In addition, subjects from both groups (A and B) were asked if they saw the sudden turning vehicle. The ratios of subjects' answers are shown in Figure 8.8, in which 32% of subjects following a PC answered that they did not see the sudden turning vehicle from the opposite direction and 68 % of the subjects following the LTV did not see the vehicle from the opposite direction making a left turn.

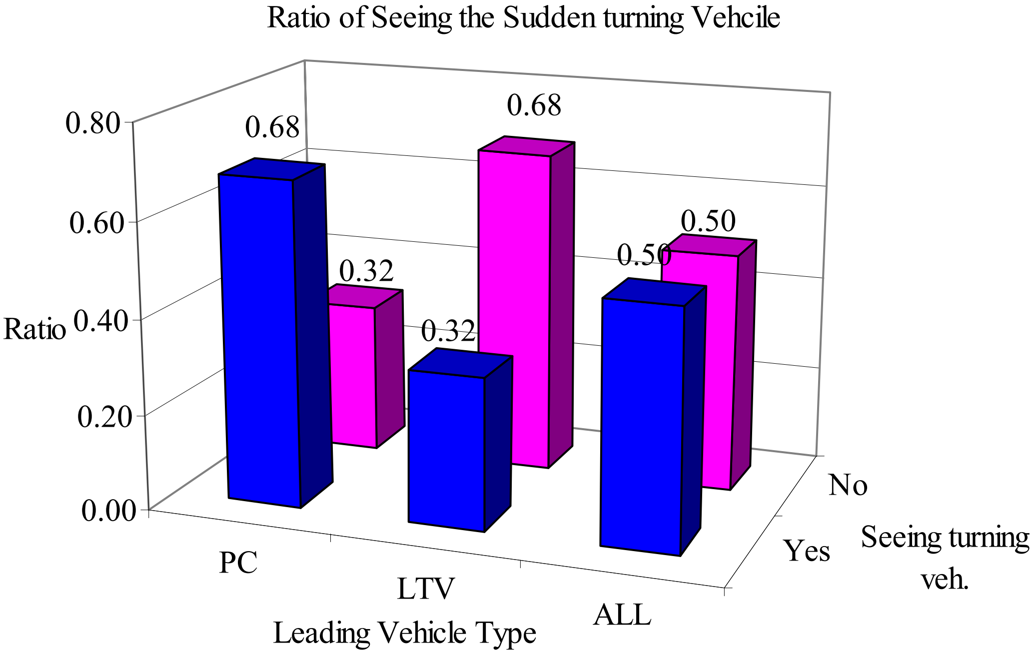


Figure 8-8: Seeing the sudden turning vehicle from the opposing direction.

Finally all subjects were asked if they face the same visibility problem when following LTVs in real life. About 70% of the subjects answered that they face the same problem and 30% answered that they do not.

8.4. Interpreting Results

In the horizontal visibility blockage experiment we focused on studying effects of driving behind LTV on the succeeding car driver's performance and the contribution of rear-end crash. Two scenarios were conducted; following a passenger car "PC-PC" and following a large truck vehicle "PC-LTV" using the OARSim system.

In studying succeeding car driver's performance when following LTV vs. following PC, statistical analysis were performed using Minitab software. Based on the results drivers intended to drive faster and closer to the leading vehicle when following LTVs than when following PCs.

This behavior can be explained by the fact that subjects drive uncomfortably behind LTVs because they cannot see beyond it with an urge feeling to pass it. Consequently, subjects speeded and stayed close behind LTVs waiting for a chance to pass them.

On the other hand, there was no significant difference in the subjects' response times to the sudden turning vehicle when following LTVs and following PCs. This can be explained as the response time is very delicate parameter and is affected by many other factors (such as driver's age and gender, and the head way between the leading and the succeeding vehicles).

Based on the statistical analysis, it was confirmed that there was a statistically significant difference between the rear-end crashes when following an LTV and following a PC with a higher percentage of rear-end crashes for following LTVs. Moreover, the trend of the impact velocities (in case of rear-end crash) showed a higher impact velocities in case of following LTVs. Therefore rear-end crashes with LTVs were more severe than rear-end crashes with regular PCs.

From the regression model of the rear-end crashes when following LTVs, the distance between the leading LTV and the following passenger car was the most significant factor. About 80% of the rear-end crashes occurred when driving in the blocked view area. That driving a passenger car closer behind an LTV produced higher probability of rear-end crashes due to the visibility blockage caused by the LTV. This visibility blockage prevented succeeding car driver from being aware of traffic situation ahead, and therefore more prone to collide with the leading LTV in case of sudden braking. This indicates that the horizontal visibility blockage is a serious problem and should be taken into consideration for the safety of the passenger car drivers who might follow LTVs.

From the survey analysis, while most of subjects following the PC (about 70%) saw the sudden turning vehicle in front of the leading vehicle, only few of subjects (about 30%) following the LTV indicated seeing it. In addition, the majority of subjects (about 70%) indicated facing the same visibility problem in their real life when following LTVs.

CHAPTER 9: CONCLUSIONS AND FUTURE WORKS

9.1. Conclusion

Augmented reality “AR” is a paradigm that combines real-world video with virtual objects (computer-generated) in a real-time. Our main goal from this research was to investigate the feasibility of adapting the AR technology into traffic engineering research. In order to achieve this goal, two systems based on the AR technology were built; Augmented Reality Vehicle “ARV” system, and Offline Augmented Reality Simulator “OARSim” system. While the first system uses an online real world video the second system relies on a pre-recorded real world video.

The ARV system can be installed in any vehicle in which the driver can wear the HMD while driving the vehicle. Through the HMD, he/she is able to see a combination of an online real video and virtual objects. While using the OARSim system, the driver wears the HMD while taking control over a gas and brake pedals, and a steering wheel. Through the HMD, the driver is able to see a combination of pre-recorded real world video and virtual objects. In both systems the combination is done through the computer so that the driver can not tell the difference between real and virtual objects in the scene.

The outcomes from the two AR systems (augmented views) were tested to be free of any inconsistency, virtual and real objects were aligned in position, orientation, and scale without any visual problems. In addition, on-the-road driving under the AR was evaluated using the ARV system installed in a rented vehicle while driving on a paved race track. Drivers’ distance judgment, speed judgment, and driving comfort under AR (drive with ARV system) and under normal driving condition (driving without ARV system) were compared. While driving under the

AR didn’t affect drivers’ distance judgment, speed judgment, and driving comfort when driving along the straight segment it significantly affected drivers’ speed judgment and driving comfort when driving along the curved segment. It is believed that the reason for the difference between driving on straight segment and driving on a curved segment may be attributed to the way the camera was fixed to the front windshield. The fixed video camera gave a view wide enough to help drivers to drive easily along the straight segment but driving along a curved segment needed a wider view. The wider view can be achieved by using a wider view camera (a camera with a wide lens), using a movable camera that can accommodate driver’s head movements, or using two or more cameras.

The two AR systems; ARV system and OARSim system were used to study left-turn maneuver at un-signalized intersection. While there was no significant difference in the accepted gap mean between using ARV system and using OARSim system, drivers had a smaller left-turn time mean, a larger left-turn acceleration mean, and a larger left-turn angular velocity mean when using the OARsim system than when using the ARV system. This might be because both systems (ARV and OARSim) provided drivers with almost the same augmented view (a combination of real-world video and virtual vehicles) that contributed to non-significant accepted gaps’ means difference. On the other hand, driving a non-real vehicle (when using the OARSim system) had different effects from driving a real-vehicle (when using the ARV system) on drivers’ left-turn time mean, acceleration mean, and angular velocity mean.

There was no significant gender effect on all left-turn parameters (acceptable gap, left-turn time, left-turn acceleration, and left-turn angular velocity) in the two experiments. On the other hand there was a significant age effect on the accepted gap in both experiments. In which, both old males and old females needed bigger gaps than what younger drivers needed.

Although, experiments' results, using both the ARV and the OARSim systems, showed that there is an age effect on left-turn gap acceptances, the AASHTO (2001) criteria for left-turn gap acceptances did not consider left-turn drivers' characteristics (gender, age). While the critical accepted gap from our logistic regression models were 5.15 seconds (using the ARV system) and 4.80 seconds (using the OARSim system), the AASHTO (2001) indicated a 5.50 seconds as a critical gap for this type of maneuver (left-turn from a major road) which is a little conservative. Moreover, due to the significant difference between old and young drivers in accepted gaps during both experiments, it is recommended to increase the critical accepted gap by 1.0 seconds for all design criteria at un-signalized intersections in areas with high-density old age population.

In the left-turn experiment using the OARSim system, older drivers took significantly longer time to complete the left-turn maneuver than what the younger driver took, especially in female groups. However there was no age effect on the left turning time in the left-turn experiment using the ARV system. Furthermore, in both experiments, older females had a smaller acceleration rate when performing the left-turn maneuver than younger females.

In addition, our OARSim system was used to study effects of following an LTV on the succeeding car driver's performance and the contribution of rear-end crash. Two scenarios were conducted; following a passenger car "PC-PC" and following a large truck vehicle "PC-LTV". Based on the results drivers intended to drive faster and closer to the leading vehicle when following LTVs than when following PCs. This behavior can be explained by the fact that subjects drive uncomfortably behind LTVs because they cannot see beyond it with an urge feeling to pass it. Consequently, subjects sped and stayed close behind LTVs waiting for a chance to pass them.

Furthermore, there was no significant difference in the subjects' response times to the sudden turning vehicle when following LTVs and following PCs. This can be explained as the response time is very delicate parameter and is affected by many other factors (such as driver's age and gender, and the head way between the leading and the succeeding vehicles). Based on the statistical analysis, it was confirmed that there was a statistically significant difference between the rear-end crashes when following an LTV and following a PC with a higher percentage of rear-end crashes for following LTVs. Moreover, about 80% of the rear-end crashes, in case off following LTVs, occurred when driving in the blocked view area. This indicates that following LTV may prevent driver in car behind them from being aware of the traffic situation ahead that increased the chance of involving in rear-end crash in case of sudden stop of the leading LTV. Furthermore, the trend of the impact velocities (in case of rear-end crash) showed a higher impact velocities in case of following LTVs.

Results from this study highly supported using the new AR systems; ARV system and OARSim system for a wide range of applications in transportation research and possible training.

9.2. Future Works

The realism of the AR system is mainly based on the realism of the final view that the driver sees. The final view is a combination of computer-generated (virtual) objects and a video of the real scene, which can help drivers to execute their tasks safely and with minimum costs. To improve the realism of the final view, some issues need to be considered as following,

9.2.1. Driver's View

Currently, the video camera is fixed on the front wind shield. The fixed video camera gives a wide view which is enough to help drivers to drive easily on a straight segment but for other applications a wider view might be needed. The wider view can be achieved by using a wider view camera (a camera with a wide lens), or using a movable camera that can accommodate driver's head movements, or using two or more cameras.

9.2.2. Sunlight Effect

An important factor that affects the final view's realism is the sunlight effect. This effect can be considered by using the sun lighting model for casting shadows and indirect light on the objects in the image, as shown in Figure 9-1 (a) , (b), and (c). Using the sun lighting model, some parameters need to be set; the geographic location (Latitude, and Longitude), the time, the date, and the orientation of the vehicle. For the geographic location for Orlando, FL, (for example) the Latitude = 28.545 and the Longitude = 81.377. Time and date parameters can be obtained from the computer's clock automatically. The vehicle's orientation can be obtained via the GPS (the difference between two GPS readings). In this case, to reduce the rendering time the rendering algorism need to be optimized.

9.2.3. Virtual Objects' Quality

The quality of the final view that the driver sees is influenced by the quality of the virtual images. In order to get more illusion 3-D virtual object, high quality 2-D images of virtual object, from different viewpoints can be recorded. Then the morphing technique can be applied to get 2-D images from any viewpoint. Afterward, these images can be augmented to the real scene to create the illusion of the 3-D as shown in Figure 9-2 (a), (b) and (c). Also, fast movements of virtual objects can be more realistic by adding motion blur to the animation.

(a) real-world view

(b) sun light effect at 7:00am

(c) sun light effect at 4:00pm

Figure 9-1: Sun Light effect, (a) normal view, (b) and (c) includes sun light effect with virtual vehicles added on July 5, 2005, Latitude = 28.545 and Longitude = 81.377.

(a)real-world view

(b) two 2D high quality vehicles (c) augmented view with 2D high quality virtual vehicles

Figure 9-2: Sun Light effect, (a) normal view, (b) two high quality 2D virtual vehicles augmented in real view as in (c).

9.2.4. A Powerful Computer

Currently, a powerful laptop is being used in the two AR systems, but for future applications with complicated scenarios and large number of virtual objects, a powerful desktop will be needed. There is always a gap between the performance of laptops and desktops. Installing a laptop in a vehicle is much easier than installing a desktop, but desktop is powerful than laptop in executing image processing and computer graphic algorithms. Installing a desktop in a vehicle requires connecting the desktop with a source of power. In this case, a recharged battery, a generator, or a DC-to-AC inverter connected to the vehicle's battery needs to be used. Both recharged battery and generator might be expensive, and most of the generators are noisy.

APPENDIX A: SURVEY QUESTIONS

System Fidelity

1. **How do you evaluate the visibility of the scene?**

1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
Poor	Needs Improvement	Satisfactory	Good	Excellent

2. **How do you evaluate the realism of the scene?**

1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
Poor	Needs Improvement	Satisfactory	Good	Excellent

3. **How do you evaluate the fidelity of the traffic scenario?**

1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
Poor	Needs Improvement	Satisfactory	Good	Excellent

4. **How do you evaluate the comfort of the flipable glasses?**

1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
Poor	Needs Improvement	Satisfactory	Good	Excellent

5. **Did you feel any kind of motion sickness (nausea, lighted head) during the experiment?**

1 ☐	2 ☐
Yes	No

6. **How long have you had a valid driver's license?**

__________________ years

7. **Overall, how do you evaluate the fidelity of the whole system?**

1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
Poor	Needs Improvement	Satisfactory	Good	Excellent

Left Turn Gap Acceptance Experiment

1. **Was the visibility of on-coming vehicles realistic?**
   1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
   Not at all Needs Improvement Satisfactory Good Excellent

2. **Was your judgment of on-coming vehicle's speed realistic?**
   1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
   Not at all Needs Improvement Satisfactory Good Excellent

3. **Was the left-turn maneuver while wearing the flipable glasses comfortable?**
   1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
   Not at all Needs Improvement Satisfactory Good Excellent

Horizontal Visibility Blockage Experiment

1. **Do you usually drive closely behind a passenger car in similar circumstances?**
   1 ☐ 2 ☐
   Yes No

2. **Do you usually drive closely behind a Van or SUV in similar circumstances?**
   1 ☐ 2 ☐
   Yes No

3. **Was the visibility of other vehicles realistic?**
   1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
   Not at all Needs Improvement Satisfactory Good Excellent

4. **Did you see the car making a left turn before the leading car started braking?**
   1 ☐ 2 ☐
   Yes No

5. **Do you encounter similar visibility problems in real life?**
   1 ☐ 2 ☐
   Yes No

Thank you for participating in this survey!

APPENDIX B: SAMPLE OF THE GPS’S OUTPUT DATA

Date	Time in sec	Record Validation*	Speed in mph	Direction	Latitude	North/ South	Longitude	East/ West
60706	165840	A	0.02	0	2832.262881	N	8105.565246	W
60706	165840.1	A	0.02	0	2832.262881	N	8105.565247	W
60706	165840.2	A	0.02	0	2832.262882	N	8105.565247	W
60706	165840.3	A	0.01	0	2832.262881	N	8105.565246	W
60706	165840.4	A	0.01	0	2832.262878	N	8105.565243	W
60706	165840.5	A	0.01	0	2832.262878	N	8105.565242	W
60706	165840.6	A	0.01	0	2832.262877	N	8105.565242	W
60706	165840.7	A	0.02	0	2832.262878	N	8105.565243	W
60706	165840.9	A	0.03	0	2832.26288	N	8105.565241	W
60706	165841	A	0.05	0	2832.262883	N	8105.565236	W
60706	165841.1	A	0.09	0	2832.262889	N	8105.56523	W
60706	165841.2	A	0.17	0	2832.262898	N	8105.565221	W
60706	165841.4	A	0.4	41.8	2832.26292	N	8105.565199	W
60706	165841.5	A	0.53	40.9	2832.262933	N	8105.565187	W
60706	165841.6	A	0.67	40.5	2832.262948	N	8105.565172	W
60706	165841.8	A	0.94	39.9	2832.262984	N	8105.565138	W
60706	165841.9	A	1.05	39.7	2832.263003	N	8105.56512	W
60706	165842	A	1.14	39.4	2832.263024	N	8105.565101	W
60706	165842.1	A	1.22	39.4	2832.263046	N	8105.56508	W
60706	165842.2	A	1.28	39.5	2832.263071	N	8105.565055	W
60706	165842.4	A	1.35	39.7	2832.263122	N	8105.56501	W
60706	165842.5	A	1.38	39.9	2832.263151	N	8105.564981	W
60706	165842.6	A	1.42	40.1	2832.263181	N	8105.564951	W
60706	165842.7	A	1.47	40.1	2832.263216	N	8105.56492	W
60706	165842.9	A	1.65	39.7	2832.263296	N	8105.564846	W
60706	165843	A	1.79	39.6	2832.263341	N	8105.564804	W
60706	165843.1	A	1.96	39.8	2832.263387	N	8105.564757	W
60706	165846.3	A	7.82	40.3	2832.266973	N	8105.561332	W
60706	165846.4	A	8	40.3	2832.267123	N	8105.561176	W
60706	165846.5	A	8.18	40.3	2832.267297	N	8105.561009	W
60706	165846.6	A	8.36	40.4	2832.267473	N	8105.560837	W
60706	165846.7	A	8.54	40.5	2832.267653	N	8105.560662	W
60706	165846.8	A	8.71	40.6	2832.267836	N	8105.560485	W
60706	165847	A	9.02	40.7	2832.268211	N	8105.560121	W
60706	165847.1	A	9.15	40.8	2832.2684	N	8105.559937	W
60706	165847.2	A	9.26	40.8	2832.268592	N	8105.55975	W
60706	165847.3	A	9.36	40.8	2832.268787	N	8105.559559	W
60706	165847.4	A	9.46	40.9	2832.268979	N	8105.559371	W
60706	165847.5	A	9.56	40.9	2832.269182	N	8105.559174	W
60706	165847.6	A	9.67	40.8	2832.269388	N	8105.558975	W
60706	165847.7	A	9.79	40.7	2832.269599	N	8105.558771	W
60706	165847.9	A	10.11	40.5	2832.270033	N	8105.558353	W

60706	165848	A	10.29	40.4	2832.270254	N	8105.55814	W
60706	165848.1	A	10.48	40.3	2832.270478	N	8105.557926	W
60706	165848.3	A	10.85	40.1	2832.270935	N	8105.55749	W
60706	165848.4	A	11.02	40	2832.271168	N	8105.557267	W
60706	165848.6	A	11.31	39.9	2832.271642	N	8105.556814	W
60706	165848.7	A	11.44	39.8	2832.271883	N	8105.556587	W
60706	165848.9	A	11.64	39.7	2832.272376	N	8105.556126	W
60706	165849	A	11.74	39.7	2832.272625	N	8105.555889	W
60706	165849.1	A	11.82	39.7	2832.272876	N	8105.555652	W
60706	165849.2	A	11.89	39.7	2832.273129	N	8105.555413	W
60706	165849.3	A	11.96	39.7	2832.273382	N	8105.555172	W
60706	165849.5	A	12.09	39.8	2832.27396	N	8105.554682	W
60706	165849.7	A	12.25	40.1	2832.27443	N	8105.554182	W
60706	165849.9	A	12.45	40.2	2832.274963	N	8105.553677	W
60706	165850	A	12.56	40.2	2832.275232	N	8105.553421	W
60706	165850.2	A	12.77	40.2	2832.275773	N	8105.552906	W
60706	165850.3	A	12.86	40.2	2832.276045	N	8105.552647	W
60706	165850.4	A	12.95	40.2	2832.27632	N	8105.552378	W
60706	165850.6	A	13.12	40.1	2832.276859	N	8105.551846	W
60706	165850.7	A	13.21	40.1	2832.277139	N	8105.551576	W
60706	165850.8	A	13.29	40.1	2832.277421	N	8105.551307	W
60706	165850.9	A	13.37	40.2	2832.27776	N	8105.551035	W
60706	165851	A	13.45	40.1	2832.277993	N	8105.550763	W
60706	165851.1	A	13.54	40.1	2832.278283	N	8105.550488	W
60706	165851.3	A	13.7	40	2832.278866	N	8105.549935	W
60706	165851.5	A	13.88	39.9	2832.279447	N	8105.549367	W
60706	165851.6	A	13.97	39.8	2832.279745	N	8105.549083	W
60706	165851.7	A	14.07	39.8	2832.280046	N	8105.548799	W
60706	165851.8	A	14.16	39.8	2832.28035	N	8105.548512	W
60706	165851.9	A	14.27	39.7	2832.280657	N	8105.548222	W
60706	165852.1	A	14.5	39.8	2832.281275	N	8105.547634	W
60706	165852.2	A	14.63	39.8	2832.281589	N	8105.547338	W
60706	165852.3	A	14.74	39.9	2832.28191	N	8105.54704	W
60706	165852.4	A	14.84	40	2832.282229	N	8105.54673	W
60706	165852.5	A	14.92	40.1	2832.282543	N	8105.546428	W
60706	165852.7	A	15.08	40.4	2832.283181	N	8105.545814	W
60706	165852.9	A	15.31	40.6	2832.283834	N	8105.545181	W
60706	165853	A	15.44	40.7	2832.284163	N	8105.544865	W

* A means the record is valid

APPENDIX C: ON-THE-ROAD EVALUATION EXPERIMENT'S DERIVED DATA

WITHOUT ARV SYS Scenario					
Subject No.	**Distance to Stop Line (ft.)**	**Avg. Velocity on Straight Segment (mph)**	**Avg. Velocity on Curved Segment (mph)**	**Avg. Offset on Straight Segment (ft)**	**Avg. Offset on Curved Segment (ft)**
1	0.34	9.9925	14.1634	0.68	0.85
2	-0.17	9.4138	14.9848	0.34	0.425
3	-0.86	7.4027	10.6278	0.89	1.11
4	-1.03	7.3787	13.5444	1.01	1.26
5	-0.32	6.4309	12.0519	0.64	0.8
6	-0.9	8.358	12.3649	1.2	1.5
7	-0.7	10.2307	12.3978	1.4	1.75
8	-1.02	9.5212	14.264	1.04	1.3
9	-0.82	9.1423	12.0649	1.32	1.65
10	-1.16	6.6031	12.3201	1.25	1.56
11	-0.42	8.946	13.2785	0.85	1.16
12	-0.96	8.0491	9.9523	0.92	1.15
13	-0.84	8.6625	12.2291	0.86	1.08
14	0.43	9.0312	13.3693	1.4	1.75
15	0.07	8.5788	11.9832	1.12	1.4
16	-0.75	8.8819	12.0541	1.5	1.88
17	-1.05	12.4087	15.1102	0.87	1.09
18	-0.46	6.8817	11.3968	0.92	1.15
19	1.05	10.4981	14.9283	1.49	1.89
20	-0.62	7.4308	11.7474	1.24	1.55
21	-1.41	8.8088	11.05	1.48	1.85
22	-0.75	8.8566	11.472	1.5	1.55
23	0.2	8.3839	14.3513	0.4	0.5
24	-1.08	7.7848	11.3108	1.16	1.45
25	0.49	7.3911	8.0548	0.98	1.22
26	-1.02	9.8544	15.654	1.04	1.3
27	5.02	9.34	12.83	1.55	1.95
28	5.38	9.87	14.77	1.44	1.8
29	-0.56	10.98	14.56	1.12	1.4
30	-0.3	7.56	11.73	0.96	1.2
31	-1.21	9.4391	12.4697	1.42	1.55

32	-1.84	10.5731	14.6583	1.23	1.55
33	-0.39	6.1057	11.5949	0.78	0.98
34	2.4	6.3591	9.5569	0.85	1.06
35	-0.16	5.8691	8.6611	0.32	0.4
36	0.56	7.2731	11.9493	1.12	1.4
37	0.49	7.068	11.6228	0.98	1.44
38	-0.75	8.7585	13.6399	1.5	1.88
39	0.034	9.9925	14.1634	0.068	0.86
40	-0.17	9.4138	14.9848	0.34	0.43
41	-0.86	7.4027	10.6278	1.22	1.53
42	-1.03	7.3787	13.5444	1.06	1.07
43	-0.32	6.4309	12.0519	0.64	0.8
44	-0.9	8.358	12.3649	1.44	1.14

WITH ARV SYS Scenario

Subject No.	Distance to Stop Line (ft.)	Avg. Velocity on Straight Segment (mph)	Avg. Velocity on Curved Segment (mph)	Avg. Offset on Straight Segment (ft)	Avg. Offset on Curved Segment (ft)
1	0.26	8.2116	11.3747	0.52	0.65
2	-0.13	10.1205	10.4855	0.26	0.325
3	-0.49	6.7556	9.5166	0.95	1.19
4	-1.17	7.9599	10.5156	1.2	1.5
5	-0.67	8.0171	8.8091	1.34	1.7
6	-0.54	7.5003	11.7253	1.08	1.35
7	-1.05	9.3987	9.5073	2.1	2.1
8	-0.72	7.5142	11.5211	1.44	1.8
9	-0.93	8.8607	8.0874	1.1	1.375
10	-0.79	6.1409	9.424	1.05	1.31
11	-0.85	8.4289	10.2356	0.63	2.01
12	-0.91	6.5648	9.09	0.88	1.1
13	-0.94	8.7213	12.1628	0.98	1.3
14	0.13	8.9966	12.4076	1.55	2.03
15	-0.09	8.4927	9.517	0.91	1.89
16	-0.49	6.9071	12.4947	0.98	1.32
17	-1.34	10.5892	13.0053	1.15	1.73
18	-0.23	8.9252	8.881	0.46	1.76

19	0.69	8.7367	9.0579	1.38	2.01
20	-1.11	9.3818	9.049	1.45	1.82
21	-0.49	7.1649	10.9114	0.98	1.78
22	-1.11	6.915	9.2629	1.22	2.2
23	0.3	9.4886	13.9006	0.6	1.03
24	-0.82	7.3714	10.1335	1.64	2.05
25	-1.08	10.2357	12.5095	0.55	1.77
26	-1.48	8.1043	10.9442	1.11	1.4
27	4.66	8.34	12.87	1.6	2
28	4.17	7.52	10.54	0.95	1.19
29	-0.85	10.44	13.34	1.7	2.43
30	-0.13	8.24	9.43	0.26	0.325
31	-1.33	8.4992	13.0442	1.66	2.21
32	-1.54	8.0819	9.2258	1.08	1.99
33	-0.2	6.5054	8.8269	0.4	1.6
34	-0.42	6.5054	8.8269	0.84	1.76
35	0.49	6.1899	8.2414	0.98	1.23
36	-0.1	8.1673	11.7745	0.9	1.33
37	0.66	8.1581	11.9445	1.32	1.65
38	-0.52	8.8769	12.6422	1.04	1.98
39	0.26	8.2116	11.3747	0.52	0.65
40	-0.13	10.1205	10.4855	0.26	0.86
41	-0.49	6.7556	9.5166	0.98	1.67
42	-1.17	7.9599	10.5156	1.21	1.85
43	-0.67	6.0171	8.8091	1.34	1.98
44	-0.54	7.5003	11.7253	1.08	1.35

APPENDIX D: LEFT-TURN MANOUVER DERIVED DATA

1. Using ARV System

Subject No.	Gender	Age	Gap (sec)	LT-Time (sec)	LT-Acceleration (ft/sec2)	LT-Angular Velocity (deg/sec)
1	male	young	4.00	3.30	4.55	2.95
2	male	young	5.00	6.20	3.39	1.57
3	male	young	6.00	7.70	1.23	1.27
4	male	young	4.00	3.30	4.95	2.95
5	male	young	5.00	4.00	3.34	2.44
6	male	young	6.00	7.00	2.93	1.39
7	male	young	4.00	5.40	2.99	1.81
8	male	young	4.00	2.40	4.28	4.06
9	male	young	5.00	4.20	3.38	2.32
10	male	young	6.00	3.30	4.89	2.95
11	male	young	5.00	2.90	6.07	3.36
12	male	young	6.00	4.90	2.58	1.99
13	male	young	6.00	5.20	1.85	1.88
14	male	young	6.00	5.20	2.26	1.88
15	male	young	7.00	3.90	4.49	2.50
16	male	young	5.00	5.00	3.81	1.95
17	male	young	3.00	2.40	5.16	4.06
18	male	young	6.00	6.10	3.52	1.60
19	male	Old	5.00	5.00	2.31	1.95
20	male	Old	6.00	6.00	1.71	1.63
21	male	Old	8.00	5.00	2.64	1.95
22	male	Old	7.00	6.10	2.67	1.60
23	male	Old	7.00	5.30	3.32	1.84
24	male	Old	7.00	5.00	2.25	1.95
25	male	Old	5.00	3.20	4.13	3.05
26	male	Old	5.00	2.30	6.38	4.24
27	female	young	6.00	4.60	3.51	2.12
28	female	young	5.00	7.20	1.71	1.35
29	female	young	4.00	4.70	3.12	2.07
30	female	young	3.00	4.00	4.03	2.44
31	female	young	7.00	4.00	4.06	2.44
32	female	young	5.00	2.40	7.33	4.06
33	female	young	5.00	5.10	2.59	1.91
34	female	young	7.00	3.50	3.54	2.79
35	female	young	4.00	6.20	1.66	1.57
36	female	young	6.00	5.00	2.74	1.95

37	female	young	5.00	7.10	1.87	1.37
38	female	young	6.00	2.10	6.98	4.64
39	female	Old	8.00	3.50	3.53	2.79
40	female	Old	6.00	6.20	1.42	1.57
41	female	Old	6.00	4.50	1.63	2.17
42	female	Old	7.00	5.00	2.35	1.95
43	female	Old	7.00	6.10	1.44	1.60
44	female	Old	5.00	4.10	2.50	2.38

2. Using OARSim System

Subject No.	Gender	Age	Gap (sec)	LT-Time (sec)	LT-Acceleration (ft/sec2)	LT-Angular Velocity (deg/sec)
1	male	young	4	2.54	9.82	3.84
2	male	young	5	2.30	14.60	4.24
3	male	young	4	3.70	6.67	2.64
4	male	young	3	2.16	14.85	4.51
5	male	young	5	3.32	10.01	2.94
6	male	young	6	3.10	7.91	3.15
7	male	young	7	4.96	4.52	1.97
8	male	young	5	2.03	13.01	4.80
9	male	young	5	6.30	3.80	1.55
10	male	young	4	3.48	8.00	2.80
11	male	young	3	3.23	9.45	3.02
12	male	young	6	2.11	16.74	4.62
13	male	young	6	4.47	5.56	2.18
14	male	young	7	4.34	5.41	2.25
15	male	young	4	2.59	13.46	3.76
16	male	young	3	2.99	9.73	3.26
17	male	young	6	3.16	10.21	3.09
18	male	young	5	2.55	10.56	3.82
19	male	Old	6	4.10	5.48	2.38
20	male	Old	8	2.20	14.08	4.43
21	male	Old	5	3.40	9.49	2.87
22	male	Old	7	4.92	5.37	1.98
23	male	Old	6	6.87	3.91	2.24
24	male	Old	6	2.57	10.84	3.79
25	male	Old	5	3.92	7.62	2.49
26	male	Old	6	5.30	4.46	3.28
27	female	young	6	2.57	13.86	3.79
28	female	young	4	2.05	15.89	4.76
29	female	young	6	3.67	7.38	2.66
30	female	young	3	4.70	6.09	2.07
31	female	young	7	2.68	12.18	3.64
32	female	young	4	2.85	10.20	3.42
33	female	young	5	4.13	4.81	2.36
34	female	young	5	5.16	5.62	1.89
35	female	young	6	3.85	4.97	2.53
36	female	young	4	3.32	8.23	2.94

37	female	young	4	5.38	5.62	1.81
38	female	young	6	3.83	5.11	2.55
39	female	Old	8	5.03	3.21	2.26
40	female	Old	5	4.74	5.57	2.06
41	female	Old	7	7.10	2.27	3.92
42	female	Old	5	3.37	8.55	2.89
43	female	Old	7	4.32	5.77	2.26
44	female	Old	7	6.75	2.39	2.43

APPENDIX E: HORIZONTAL VISIBILITY BLOCKAGE'S DERIVED DATA

No.	Vehicle Type	Rear-end crash*	Incident Response Time (sec)	Incident Velocity (mph)	Incident Headway (ft)	Incident Deceleration Rate (ft/sec^2)
1	PC	0	1.65	32.84	55.00	11.99
2	PC	0	1.23	27.39	109.74	16.00
3	PC	0	2.48	25.54	91.32	19.00
4	PC	0	1.12	20.09	106.89	7.65
5	PC	0	0.65	29.40	77.00	19.00
6	PC	0	0.55	20.68	89.90	15.00
7	PC	0	1.63	26.03	56.99	9.00
8	PC	0	1.33	30.26	107.33	13.00
9	PC	0	1.89	22.12	73.00	10.43
10	PC	0	1.33	23.04	80.00	15.00
11	PC	0	1.63	33.10	85.00	9.19
12	PC	0	2.64	29.36	69.36	14.00
13	PC	0	1.82	22.60	99.00	11.01
14	PC	0	2.98	30.34	127.23	15.05
15	PC	0	1.67	22.06	77.18	8.85
16	PC	0	1.64	27.86	55.37	8.72
17	PC	0	1.33	27.76	66.76	18.00
18	PC	1	1.64	32.51	51.28	21.00
19	PC	0	1.98	28.94	64.04	18.11
20	PC	0	2.88	27.26	76.68	13.06
21	PC	0	2.12	30.29	120.61	7.00
22	PC	0	1.15	23.04	66.14	14.00
23	PC	0	3.75	23.04	46.14	18.60
24	LTV	0	2.75	24.63	95.00	21.00
25	LTV	0	1.17	25.84	51.18	17.00
26	LTV	1	0.86	35.73	39.73	16.77
27	LTV	1	1.15	33.90	45.00	21.91
28	LTV	1	1.91	39.97	49.82	27.43
29	LTV	0	2.14	35.71	61.52	21.56
30	LTV	1	1.64	25.55	44.35	23.00
31	LTV	1	1.64	31.99	42.12	18.22
32	LTV	1	3.09	30.31	35.83	26.40
33	LTV	1	1.78	28.26	39.56	22.47
34	LTV	1	2.55	33.63	48.61	27.47
35	LTV	1	1.73	27.12	38.30	10.43
36	LTV	0	2.19	35.50	73.95	6.98
37	LTV	0	1.63	30.40	52.56	15.00
38	LTV	1	1.22	30.00	41.24	11.07
39	LTV	1	0.59	38.31	53.41	25.63
40	LTV	0	2.21	24.39	67.02	15.04
41	LTV	1	2.71	29.56	57.11	6.05

42	LTV	0	1.63	24.22	39.76	15.00
43	LTV	1	2.45	34.98	25.42	5.24
44	LTV	1	1.84	33.24	43.00	16.77
45	LTV	0	2.64	25.45	85.00	8.61

*0 means that there was no crash, 1 means that there was a crash.

LIST OF REFERENCES

Abdelwahab, H., and Abdel-Aty, M., “Investigating the Effect of Light Truck Vehicle Percentages on Rear-End Fatal Traffic Crashes”, *Journal of Transportation Engineering*, Vol. 130, No. 4, pp. 419-428, 2004.

Abdel-Aty, M., and Abdelwahab, H., “Modeling Rear-End Collisions Including the Role of Driver’s Visibility and Light Truck Vehicles Using a Nested Logit Structure”, *Accident Analysis and Prevention*, Vol. 36, pp. 447-456, 2004.

Abdel-Aty M., Chen C. and Radwan E., “Using Conditional Probability to find the Driver Age Effect in Crashes”, *Journal of Transportation Engineering*, 1999, ASCE, Vol. 125, No. 6, 1999.

Acierno, S., Kaufman, and Rivara, F.P., Grossman, D.C., Mock, C., “Vehicle Mismatch: Injury Patterns and Severity, Accident Analysis and Prevention, vol. 36, pp. 761-772, 2004.

Adams, L., Gilsbach, J. M., Krybus, W. D. M.-E., Mosges, R., and Schlondorff, G., “CAS – A Navigation Support for Surgery”, *3D Imaging in Medicine*, vol. 60, pp. 411–423, 1990.

Azuma, R. A Survey of Augmented Reality. *Teleoperators and Virtual Environments*, Vol. 6, No. 4, 1997, pp. 355-385.

Azuma, R., and Bishop, G., “Improving Static and Dynamic Registration in a See- Through HMD”, *Proceedings of SIGGRAPH 37 ‘94. In Computer Graphics, Annual Conference Series*, Orlando, FL., pp. 197-204, 1994.

Bonanni, L., Lee, C. H., and Selker, T., “A Framework for Designing Intelligent Task-Oriented Augmented Reality User Interfaces”, *International Conference on Intelligent User Interfaces*, pp.317 – 319, 2005.

Bonsor, K., How Will Augmented Reality Work? (2001), How stuff works, http://www.howstuffworks.com/augmented-reality.htm, Accessed May, 2006.

Breen, B., "Applications and Demonstrators", ECRC Today, Dec. 1994.

Brilon, W., Koenig, R., Troutbeck, R.J., 1999. Useful estimation procedures for critical gaps. Transportation Research 33A, 161–186.

Caird, JK, & Hancock, PA (2002). Left-turn and gap acceptance crashes. In R.E. Dewar and R. Olson (Eds.). Human factors in traffic safety, (pp. 613-652), Lawyers & Judges Publishing: Tucson, Az.

Cavallaro, R., “The FoxTrax Hockey Puck Tracking System,” *IEEE Computer Graphics and Applications*, vol. 17, no. 2, pp. 6-12, 1997.

Chovan, J. D., Tijerian, L., Everson, J. H., Pierowicz, J. A., and Hendricks, D. L., 1994. Examination of intersection left turn across path crashes and IVHS countermeasures (DOT HS 808 154). Cambridge, MA: National Highway Traffic Safety Administration.

Cooper, P.J. and Zheng Y., 2002. Turning gap acceptance decision-making: the impact of driver distraction, *Journal of Safety Research*, Volume 33, Issue 3, 2002, pp. 321-335.

David, N.A. and Norman, J.R., *Motor Vehicle Accidents in Relation to Geometric and Traffic Features of Highway Intersections: Volume II-Research Report*, Publication No. FHWA-RD-76-129, Federal Highway Administration, Washington, DC, 1979.

Darzentas, M. R., McDowell, C., and Cooper, D., "Minimum Acceptable Gaps and Conflict Involvement in a Simple Crossing Maneuver", Traffic Engineering and Control vol. 21, pp. 58-61, 1980.

Drascic, D., "Stereoscopic Vision Augmented Reality", *Scientific Computing & Automation*, vol. 9, pp.31-34, 1993.

DTI augmented reality project: http://www.nottingham.ac.uk/aims/ar-seminar/imain.htm, accessed March 2005.

Feiner, S., Webster, A., MacIntyre, B. Höllerer, T. A Touring Machine: Prototyping 3D Mobile Augmented Reality Systems for Exploring the Urban Environment. In Proc ISWC '97 (Int. Symp. on Wearable Computing), Cambridge, MA, October 13–14 1997, pp. 74–81.

Fischer, J., Neff, M., Freudenstein, D., and Bartz, D., "Medical Augmented Reality based on Commercial Image Guided Surgery", *Eurographics Symposium on Virtual Environments*, 2004.

Gattis, J. L. And Low, S. T., "Gap Acceptance At Nonstandard Stop-Controlled Intersections", 1989

Gelenbe, E., Hussain, K. F., and Kaptan, V., "Simulating Autonomous Agents in Augmented Reality", *The Journal of Systems & Software*, vol. 74, no. 3, pp. 255-268, February 2005.

Graham, J., 2000. *Civilizing the sport utility vehicle*. Issues Sci. Technol. 17 (2), 57–62.

Grimson, W.E.L., Ettinger, G.J., Kapur, T., Leventon, M.E., Wells III, W.M., Kikinis, R., "Utilizing Segmented MRI Data in Image-Guided Surgery" In IJPRAI, 1996. http://www.ai.mit.edu/people/leventon/Research/9607-IJPRAI/paper.pdf, accessed April 2005.

Hanna, J.T., Flynn, T.E. and Tyler, W.K, "Characteristics of Intersection Accidents in Rural Municipalities", *Transportation Research Record*, 601, 1976.

Harb, R., “The Use of the UCF Driving Simulator to Test the Contribution of Larger Size Vehicles (LSVs) In Rear-End Collisions and Red Light Running On Intersections”, A Master Thesis, University of Central Florida, Orlando, Florida, 2005.

Harwood, D.W., Masonb, J. M., Brydia R. E., “Design Policies For Sight Distance At Stop-Controlled Intersections Based On Gap Acceptance”, *Transportation Research Part A: Policy and Practice*, 33 3-4, pp. 199-216, 1999.

Hussain, K. F. and Kaptan, V., Modeling and Simulation with Augmented Reality. *International Journal on Operations Research*, Vol. 38, No. 2, 2004, pp.89-103.

Jebara, T., et al., “Stochasticks: Augmenting the Billiards Experience with Probabilistic Vision and Wearable Computers”, *Proc. 1st Int’l Symp. Wearable Computers (ISWC 97), IEEE CS Press*, Los Alamitos, Calif., pp. 138-145, 1997.

Johansson, M. and, Nordin, J. *A Survey of Driving Simulators and their Suitability for Testing Volvo Cars*. Department of Machine and Vehicle Systems, Chalmers University of Technology, Göteborg, Sweden, 2002.

Juan, M.C., Botella, C., Alcañiz, M., Baños, R., Carrion, C., Melero, M., and Lozano, J.A., “An Augmented Reality System for Treating Psychological Disorders: Application to Phobia to Cockroaches”, *Third IEEE and ACM International Symposium on Mixed and Augmented Reality (ISMAR 2004)*, Arlington, VA, USA , November 02 - 05, 2004.

Kettelson, W. K., and Vandehey, M. A. Delay Effects on Driver Gap Acceptance Characteristics at Two-Way Stop-Controlled Intersections. Transportation Research Record 1320, TRB, National Research Council, Washington, D. C. 1991. pp. 154-9.

Koeda, M., Matsumoto, Y., and Ogasawara, T. Annotation-Based Assistance System for Unmanned Helicopter with Wearable Augmented Reality Environment. *Proceedings of the Third IEEE and ACM International Symposium on Mixed and Augmented Reality* (ISMAR 2004).

Koppa, 1992, Human Factors, http://www-ta.ornl.gov/cta/research/trb/tft.html, accessed on August 2006.

Kroemer, K. H. E., H. B. Kroemer, and K. E. Kroemer-Ebert, 1994. Ergonomics: How to Design for Ease and Efficiency Englewood Cliffs, NJ: Prentice-Hall.
Laberge-Nadeau, C., Maag, U., Bellavance, F., Lapierre, S. D., Desjardins, D., Messier S., and Saïdi, A., 2003. Wireless telephones and the risk of road crashes, *Accident Analysis & Prevention*, Volume 35, Issue 5, 2003, pp. 649-660.

Lerner, N.D., Huey, R.W., McGee, H.W., and Sullivan, A., Older Driver Perception-Reaction Time for Intersection Sight Distance and Object Detection: Report No. FHWA-RD-93-168. Federal Highway Administration: Washington, D.C., 1995.

Lyles, R.W., Staplin, L., “Age Differences In Motion Perception And Specific Traffic Maneuver Problems”. *Transportation Research Record*, issue 1325, 23–33, 1991.

McCoy, P.T., Bonneson, J.A. and Kollbaum, J.A., “Speed Reduction Effects of Speed Monitoring Displays with Radar in Work Zones on Interstate Highways”, *In Transportation Research Record 1509, TRB, National Research Council*, Washington D.C., pp. 65-72, 1995.

Miller, A.J., 1972. Nine estimators for gap-acceptance parameters. In: Newell, G (Ed.), Proceedings of the International Symposium on the Theory of Traffic flow and Transportation, Berkeley, California, June 1971. Elsevier, Amsterdam.

Mitchell, M., 1972 "Identifying and Improving High Accident Locations", Public Works National Highway Traffic Safety Administration Addressing the Safety Issues Related to Younger and Older Drivers. DOT HS 807 957 NTS-31, U.S. Department of Transportation, 1993. http://www.nhtsa.dot.gov/people/injury/olddrive/pub/yorept.pdf. Accessed April 2005.

National Association of Broadcasters, Princeton Electronic Billboard Develops, “Virtual Arena” Technology for Television, 1994.

National Highway Traffic Safety Administration (2000). Traffic Safety Facts 1999: A Compilation of Motor Vehicle Crash Data from the Fatality Analysis Reporting Systems (FZRS) and the General Estimates System (GES). Washington, DC.

NASCAR website: http://www.nascar.com/, accessed March 2005.

Neumann, U. and Cho, Y., "A Self-Tracking Augmented Reality System," *In Proceedings of ACM Symposium on Virtual Reality Software and Technology*, pp. 109-115, July 1996.

NHTSA VEHICLE SAFETY RULEMAKING and SUPPORTING RESEARCH PRIORITIES: 2005-2009, http://www.nhtsa.gov/cars/rules/rulings/PriorityPlan-2005.html, accessed May, 2006.

Open Source Computer Vision Library. http://www.intel.com/research/mrl/research/opencv/index.htm, accessed March 2005.

Romão, T., Correia, N., Dias, E., Trabuco, A., Santos, C., Santos, R., Nobre, E., Câmara, A., Danado, J.,and Romero, L., “Augmenting Reality with Geo-Referenced Information for Environmental Management”, *ACM GIS Conference*, McLean, VA, USA, 2002.

Rose, E., Breen, D., Ahlers, K., Crampton, C., Tuceryan, M., Whitaker, R. and Greer, D., “Annotating Real-World Objects Using Augmented Reality”, *Proceedings of Computer Graphics International '95*, Leeds, UK, pp. 357-370, 25-30 June 1995.

Sayer, J., Mefford , M., Huang, R., "The effect of Lead-Vehicle Size on Driver Following Behavior", Human Factors Division, Transportation Research Institute, Michigan University, Ann Arbor, Report No. UMTRI-2000-15. UMTRI-93805, 2000.

Scott-Young, S., Kealy, A. N., Collier, P. A., Bishop, I. D., "An augmented reality intelligent navigation aid for land application", *The 6th International Conference on Satellite Navigation Technology Including Mobile Positioning & Location Services*, Melbourne, Australia, 2003.

SporTVision website: http://www.sportvision.com/, accessed March 2005.

Staedter, T., Car Navigation Map Overlaid on Reality, Discovery Channel News, October, 31, 2005. http://dsc.discovery.com/news/briefs/20051031/tech_carnavigate.html , Accessed May, 2006.

State, A., Chen, D. T., Tector, C., Brandt, A., Chen, H., Ohbuchi, R., Bajura, M., and Fuchs, H., "Case Study: Observing a Volume-Rendered Fetus within a Pregnant Patient", *In Proceedings of IEEE Visualization '94*, pp. 364–368. 1994.

Suthau, T., Vetter, M., Hassenpflug, P., Meinzer, H. P., Hellwich, O. A Concept Work for Augmented Reality Visualisation Based on a Medical Application in Liver Surgery. *ISPRS Commission V Symposium, Close-Range Vision Techniques*, Corfu, Greece, 2002.

Tarawneh, M. S., and McCoy, P. T., "Effect of Offset between Opposing Left-turn Lanes on Driver Behavior", *Transportation Research Record 1523, TRB, National Research Council*, Washington D.C., pp. 61-72, 1996.

Tepley, S., Abou-Henaidy, M. I., and Hunt, J. D.,"Gap Acceptance Behavior; Aggregate and Logit Perspectives-Part1", Traffic Engineering Control, Vol.38, No. 9, 1997.

Uenohara, M., Kanade, T., "Vision-Based Object Registration for Real-Time Image Overlay", Computer Vision, Virtual Reality and Robotics in Medicine: CVRMed '95, N. Ayache., Berlin, Springer-Verlag, pp. 14-22, 1995.

Wang, Y., and Cartmell, M., P., "New Model for Passing Sight Distance on Two-Lane Highways", Journal of Transportation Engineering, ASCE, Vol. 124, No. 6, pp. 536-545, 1998.

Wagner, D., Pintaric, T., Ledermann, F., and Schmalstieg, D., "Towards Massively Multi-User Augmented Reality on Handheld Devices", *Published at the Third International Conference on Prvasive Computing (Pervasive 2005)*, Munich, Germany, May 9-10 2005.

Vallino, J. R., *Interactive Augmented Reality*, Ph.D. Dissertation, University of Rochester, New York, USA, 1998.

Yan, X., *Analysis of Minimum Acceptable Gap for Left Turn Maneuver Using a Driving Simulator*, Master Thesis, University of Central Florida, Orlando, Florida, USA, Feb. 2003.

Yan, X., and Radwan, E., "Characteristics of Unprotected Left-turn Accidents at Signalized Intersections", *Journal of Safety Research*, in press, 2005.