2009

Operational evaluation of advanced safety enhancement devices: Rearview video system

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Operational Evaluation of Advanced Safety Enhancement Devices: Rearview Video System

by

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A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
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College of Engineering
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Date of Approval:
October 14, 2009

Keywords: camera, methodology, implementation, experimental, in-vehicle, driver behavior

To my parents, Panayiota and Ioannis Kourtellis and my beloved wife, Hayley.

Acknowledgments

I would like to thank Dr. Jian (John) Lu, and Dr. Pei-Sung Lin for being my co-major professors and academic supervisors, for their guidance and advice during the past few years. I would also like to thank Dr. Chanyoung Lee, Dr. Abdul Pinjari, Dr. George Yanev and Dr. Yu Zhang for serving as my graduate advisory committee and Dr. Edward Mierzejewski for serving as the defense chair. I would especially like to thank Dr. Lin and Dr. Lee for giving me the opportunity to work with them and guide me at the Center for Urban Transportation Research (CUTR) at USF in the ITS, Traffic Operations and Safety Program. The data used in this dissertation was collected during a research project sponsored by the Federal Highway Administration and managed by the Florida Department of Transportation District 7. I would also like to thank the Graduate Research Assistants at the ITS, Operations and Safety Program at CUTR for their assistance in field data collection and data reduction.

Note to Reader: The original of this document contains color that is necessary for understanding the data. The original dissertation is on file with the USF library in Tampa, Florida.

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List of Acronyms

ANPRM	Advanced Notice for Proposed Rulemaking
CAR	Florida's Crash Analysis Reporting System
CDL	Commercial Driver License
CRT	Cathode Ray Tube
CUTR	Center for Urban Transportation Research
FARS	Fatality Analysis Reporting System
FMCSA	Federal Motor Carrier Safety Administration
FMVSS	Federal Motor Vehicle Safety Standards
GES	General Estimates System
GVWR	Gross Vehicle Weight Rating
LCD	Liquid Crystal Display
LED	Light Emitting Diode
NHTSA	National Highway Traffic Safety Administration
OEM	Original Equipment Manufacturer
PDO	Property Damage Only
RVS	Rearview Video System
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users
TRIP	The Road Information Program
VMT	Vehicle Miles Traveled

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ABSTRACT

Since the creation of the automobile, there has been an effort to create and implement mechanical and electronic devices that would improve vehicle safety. In recent years, electronic technologies have become more efficient and cost effective, therefore creating a great spike in widespread implementation. These safety related devices have to be tested for their reliability and amount of help they provide the driver with. The end user (the driver) has to be involved for a successful device. This research presents the methodology used to evaluate the effectiveness of the rearview video system (RVS) used in vehicles, especially in large commercial trucks and effectively the methodology for a more complete investigation of the problem of correctly implementing a safety device. The focus of this research is backing crashes that involve large trucks. The countermeasure tested was a rearview video system which provides a rear view to the driver in real time. A traditional crash data analysis is almost impossible since there is not enough data to perform it, and no data are available for the use of this system since it is fairly new to the market. A driver experiment under controlled conditions was used to create and collect the data necessary for the analysis. The experiment yielded a total of 71 crashes out of 270 maneuvers (26.3%). When analyzed, three backing neuvers yielded different probabilities of having a backing crash with and without the RVS. The increase in stop rate ranged from 46.67 percent to 4.44 percent. This is interpreted as crash reduction due to the device. Driver behavior was observed during the experiment and measured for significant differences. The drivers needed on average 6.47 seconds more time for the maneuvers with the RVS in use. They spent less time looking at mirrors and did it less frequently in order to accommodate the additional glance location presented to them. Overall they seemed to be able to manage their time with some exceptions.

The driver acceptance of the device was also measured with a survey given to them after they completed the test. Overall in all measures the majority of drivers agreed that the system helps in reducing the rear blind spot and thus it is a helpful device in reducing backing crashes since it will help them avoid potential hazards while backing. The majority also stated that they would like to have the device in their truck for every day operations. These results show an acceptance of the device and therefore the maximization of the device's use and potential benefits. The RVS is therefore effective in reducing potential backing crashes. The results presented here are limited, and inferences are made with the experiment conditions in mind. General application of the results is possible, with certain assumptions and restrictions.

Chapter 1: Introduction

In-vehicle safety devices have been increasingly used in the industry to enhance the safety of the drivers and passengers of vehicles. Since the development of these devices is primarily driven by research, a certain amount of such safety enhancements comes in the aftermarket and not in the Original Equipment Manufacturer (OEM) industry. This however, creates the problem of additional devices being present in drivers' cabins other than original equipment, especially in the case of commercial vehicles. In addition to safety devices, infotainment telematic devices are becoming increasingly popular, thus increasing the drivers' stimulus and glance locations. In recent years more such devices have become available in the aftermarket, thus providing individual drivers or companies with fleets the opportunity to equip their vehicles with the latest technology but for a fraction of the manufacturer's price.

When a manufacturer creates a device after rigorous research and development process, the device must be tested for its reliability, and effectiveness. A problem occurs however when the device is developed and implemented without testing or feedback from the end users, in this case the drivers. It was found that against belief, a device that should be very useful to drivers is not used because it was simply not accepted. A proper methodology encompassing driver use behavior and feedback needs to be implemented to secure a more complete approach in developing or testing such devices.

1.1 Background

In general, the operation of large trucks involves many different types of maneuvers. The "backing maneuver", in particular, requires a higher level of driver attention due to the limited view. Most trucking companies have a policy that encourages drivers to visually check the rear of a vehicle before performing a backing maneuver, regardless of the backing distance, and to use a spotter who can stand outside the vehicle to ensure safety during the maneuver.

As part of the federal transportation authorization known as the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU), the U.S. Congress has identified a high-priority need for research to reduce fatalities, injuries, and property damage caused by backing crashes involving trucks. These backing crashes are often caused by the presence of large blind spots, commonly known as the “No Zone”, where the truck driver has virtually no visibility.

Blind spots or areas in the context of driving an automobile are those areas of the road that cannot be seen while looking forward or through either rearview or side mirrors. Blind spots can be eliminated by overlapping side and rearview mirrors, by the driver physically turning around to look backwards, or by adding another mirror with a larger field of view. Detection of vehicles or other objects in blind spots may also be aided by systems such as video cameras or distance sensors. Blind spots can be at any location around a vehicle, depending on the size and structure of the vehicle, or presence of vehicle features such as A-pillars. Therefore, there can be side, front, and rear blind spots.

Rear blind spots are of the most concern in large trucks or commercial vehicles. Usually, these vehicles do not have a rear window or a rearview mirror, which are the primary methods for eliminating blind spots. In addition, the large size of trucks and commercial vehicles makes the rear blind spot a dangerous area or zone. If a smaller vehicle or pedestrian is in this area while the truck is backing, there is a great potential for a crash since the truck driver cannot see them. This rear blind spot increases as the vehicle size increases.

It is believed that there is a very large potential to reduce backing crashes by reducing or eliminating the rear blind spot using rearview video technologies that make the blind spot visible to the driver through a video system. This study aims to evaluate the effectiveness of rearview video systems as a countermeasure for large trucks to reduce potential backing crashes. A large truck is defined as a truck with a gross vehicle weight rating (GVWR) greater than 10,000 pounds and includes both medium and heavy trucks. Usually, these trucks are a tractor-trailer combination, although certain categories of heavy trucks are a single unit.

1.2 Problem Statement

Since the creation of the automobile, man has strived to create and implement mechanical and electronic devices that would improve vehicle safety. Especially in more recent years, when electronic technologies have become more efficient and cost effective, therefore creating a great spike in widespread implementation. When manufacturers create devices, especially human interface devices, they have to make sure that the device will help the driver without increasing the mental or physical workload thus hindering the same safety they were meant for. It has been shown that increasing the driver workload can cause severe deterioration of the driver's attention and ability to respond fast to a dangerous situation causing a crash. The process involved in the development of such devices involves identification of a problem, and implementation of ideas to solve the problem. Often the device is made and installed on vehicles without having the direct involvement of the end user: the driver. A more holistic approach must involve identification of the problem, development of the device and test runs with a wide panel of drivers to gain insight as to the usage of the device to be able to implement it more effectively. Especially devices that require the driver's attention (passive devices), such as most telematic devices, have to be implemented in the best way possible to be used by the driver.

1.3 Research Objectives

This research involved several objectives to encompass in realizing the main objective of evaluating the operational effectiveness of the rearview video system in large trucks. The objectives are described as:

- Analyze crash data to obtain understanding on the problem size and conditions,
- Identify amount and characteristics of backing crashes the system is applicable to,

- Design driver experiment in controlled conditions to test the effectiveness of the RVS in reducing backing crashes,
- Analyze data from the experiment and infer on if, when and how the system helps the driver,
- Provide analysis on the driver behavior and usage of the system and recommendations on the device's usage.

1.4 Outline of Dissertation

This document consists of eight chapters. Chapter 1 provides an introduction to the research problem and outlines the research objectives. Chapter 2 summarizes a literature review in this area. Chapter 3 describes the research methodologies utilized to reach the objectives of the study. Chapter 4 describes the procedures followed to complete data collection in an efficient and appropriate manner. Chapter 5 includes analysis results and findings from a crash database on backing crashes. Chapter 6 summarizes the results of data analysis for driver behavior during the experiment. Chapter 7 provides a discussion implementation of the models to a more general problem or device. Finally, chapter 8 provides summary, conclusions and recommendations from this research, as well as discussion on future research.

Chapter 2: Literature Review

A backing crash occurs when a backing vehicle strikes another vehicle, stationary object, a bicyclist, a motorcyclist or a pedestrian. Considerable research has been performed by the National Highway Traffic Safety Administration (NHTSA) over the past two decades to identify how back crashes happen and evaluate available countermeasures to prevent and reduce them. The main cause of these crashes is the rear blind zone the driver exhibits directly behind the vehicle. This zone becomes larger with increasing vehicle size and length. It is especially dangerous in the case of large trucks, either single or multi-unit due to the size of the vehicle and the fact that the drivers do not have a rear field of view available.

Backing crashes are a small percentage of all types of crashes. Studies concerning backing crashes have been conducted through the last 20 years. One major characteristic of backing crashes however that does not apply to all other crashes is that they can be avoided by rational driver behavior and a rear visibility that covers the area behind any vehicle.

2.1 Backing Crash Problem Size and Description

Backing crashes occur at a small rate compared to other crashes. Obviously this is due to the small amount of exposure this particular has in comparison to all other crash types. They are not negligible nonetheless. A major problem with backing crash reporting is the fact that a large majority of these crashes happen on private property. This will be shown later in backing crashes analyzed from a Florida crash database for the years 2003-2006. Since all crash databases include only crashes that occur in public roads, the crashes that occur on private property are not reported. This way the actual percentage of backing crashes cannot be known, but estimation methods can be utilized to obtain a better understanding of the problem size. Fortunately a large number of the unreported crashes are property damage only but some injuries and fatalities are also included. The first study found to examine backing crashes [3], was published in 1994 with 1990 data. The team identified the problem of backing crashes in 1990 to be 181,500 police reported backing crashes with 185 associated fatalities. These numbers do not include off-roadway crashes such as driveway backing crashes. The study also reported:

- Approximately 22,000 associated injuries, including 1,500 serious injuries.
- Approximately 91 percent of all backing crashes were Property Damage Only (PDO).
- Backing crashes were 3 percent of all crashes but accounted for only 0.4 percent of all fatalities.
- During its lifetime a vehicle is expected to be involved in 0.01 police reported backing crashes as the backing vehicle.
- Approximately 300,000 non-police reported backing crashes were estimated for 1990.
- Backing crashes cause about 1 percent of all crash-caused delay.

Although the numbers have obviously changed this shows that the problem was big even then. Also useful analysis showed that the crashes were categorized with respect to the vehicle movements, the vehicle speeds, and the vehicle types. These categories apply today as well.

2.1.1 Backing Crash Types

From [3], backing crashes were divided into two main types:

1. Slow-closing speed "encroachment" backing crashes
   (a) Pedestrian/cyclist
   (b) Parallel path

   (c) Curved path

2. Crossing path backing crashes involving higher closing speeds

2.1.2 "Under Control" Backing Crashes

Furthermore the backing crashes were divided into "under control" and "not under control" backing crashes. The "under control" backing crashes usually occur at slow speeds, and the at-fault drivers can potentially avoid the crash if they can see the other vehicle. The "not under control" backing crashes occur when one or both drivers cannot avoid the crash because of factors they do not control. Disqualified cases for "not under control" backing crashes included: icy/snowy roadway surfaces, selected vehicle defects, driverless vehicles, grossly-intoxicated drivers and selected driver physical impairments. These cases were deemed "not under control" because the driver would potentially not be capable to respond to a collision warning given by a collision warning system (countermeasure) thus the backing crash would be unavoidable. The main reason for aggregating the crashes into these categories was to establish which crashes could be potentially avoided with a countermeasure namely backup sensors or rearview systems. As the RVS becomes more popular, there have been growing interests on various aspects of RVS including the benefit/cost of using the RVS.

2.1.3 Vehicle Types

The vehicle types involved in backing crashes are:

- Passenger vehicles: cars, light trucks, and vans,
- Medium size trucks: single-unit trucks,
- Large size trucks: single unit or combination unit trucks.

2.1.4 Backing Crash Fatalities

Fatalities that occur from a backing crash are called "backover" fatalities since the vehicle usually backs over the person being a pedestrian, a cyclist or a motorcyclist. A recent study examined the fatalities of backing crashes for all vehicles [1], and estimated that there are about 183 fatalities from backing crashes per year. Table 2.1 shows the number of fatalities occurring from backing crashes. The estimation of 183 fatalities per year was based on death certificate data, Fatality Analysis Reporting System (FARS) data, and General Estimates System (GES) data.

Table 2.1: Backover fatalities in FARS by year [1].

Year	Fatalities
1991	83
1992	80
1993	76
1994	84
1995	75
1996	79
1997	59
1998	83
1999	70
2000	89
2001	66
2002	66
2003	79
2004	72

The fatalities, however, are only a small portion of all the backing crashes. Crash data from Florida's Crash Analysis Reporting System (CAR) show that on average there are more than 14,000 police reported backing crashes per year in Florida. This accounts for about 4.61 percent of all crash types. Although this number is small, the drive behind this research is that a large number of this crashes can be avoided using technology countermeasures. As will also be shown later, large trucks have a much larger - almost double - percentage of backing crashes than passenger vehicles.
In addition to the fatalities from backing crashes, a report to U.S. Congress in 2006 showed that there are between 6,700 and 7,419 injuries from backing crashes per year [2].

2.1.5 Backover Crash Characteristics

According to [2], in analysis of death certificates, 14 percent of backover deaths were found that could be called the "Road/Street" occurrences. The specific locations of these crashes are shown in Table 2.2. This table presents categories based on the limited details provided on the death certificates and in some cases supplementary information (e.g. newspaper reports). These data suggest that cases occur predominantly away from streets and roads. A review of FARS cases from 2000 and 2001 by location also reveals that backover fatalities occur predominantly away from the roads or streets, shown in Table 2.3.

Table 2.2: Backover deaths identified in 1998 death certificates by location [2].

Location	Frequency*	Percent
Driveway	21	23
Home	21	23
Parking Lot	21	23
Road/Street	13	14
Sidewalk	2	2
Other Off Road	13	14

*Data are from 35 States and the District of Columbia.

Table 2.3: Backover deaths identified in FARS (2000-2001) [2].

Location	Frequency	Percent
Driveway	44	43
Parking Lot	5	5
Road/Street	28	27
Other Off Road	25	25

Through these studies, it was also found that backing crashes occur largely during daytime with no adverse weather conditions or other major environmental contributing factors. There was a higher involvement rate (per million Vehicle Miles Traveled (M VMT)) for younger (15-19) and older (75+) drivers, as well as males had a 7.5 per 100M VMT to females 4.3 per 100M VMT. A major cause for backing crashes was "recognition error/improper lookout." The driver of the backing vehicle either “failed to look or looked but didn’t see” [3]. Although registered vehicles increase through time, and one would expect an increase in the rate of backing crashes, it seems that the trend is relatively constant. According to [4], “Despite the above trends in the fleet with respect to vehicle registrations and increasing vehicle size, FARS backover fatalities analyzed for this report (1981-2004) do not show an increasing trend. In fact, there is a non-significant, yet decreasing trend. However, there are no accurate trend data specifically for the non-traffic incidents that may or may not follow the fatality trends seen in the traffic crash databases. A LexisNexis review of periodicals on backover incidents including non-traffic crashes from 1998 to 2002 was also not able to demonstrate a clear trend.”

2.2 Backover Crashes Including Commercial Trucks

Over 15 billion tons of goods, worth over $92 trillion, are moved annually in the U.S. - the equivalent of 310 pounds of freight being moved daily for each U.S. resident. The largest share of the nation’s freight is moved by trucks, which carry 71 percent of all tonnage and 80 percent of the value of U.S. shipments, a significant factor to the U.S. economy [5].

Data on backover crashes across various states in the nation were collected and used to assess the impact of reducing these crashes. Information on backover crashes was researched in publications, printed articles, journals, online databases, and websites of companies that provide products for reducing backover crashes. Statistics on backover crashes were available in some publications and online databases on safety and security.

Traffic accidents involving large trucks with Gross Vehicle Weight Rating (GVWR) over 10,000 pounds are responsible for a significant proportion of traffic fatalities annually, and accidents involving large trucks are more likely to result in fatalities, due to the more serious consequences of accidents involving larger vehicles. The Road Information Program (TRIP) analyzed data from the National Highway Traffic Safety Administration (NHTSA) on fatal traffic accidents involving large trucks in the U.S. from 1998 to 2002 to gain a better understanding of the characteristics of these accidents [6]. It was found that 26,065 of the 210,174 traffic fatalities that occurred from

1998 to 2002 in the U.S. - approximately one of eight - resulted from a collision that involved a large truck. Fatal traffic accidents involving large trucks from 1998 to 2002 resulted in the deaths of 3,647 persons who were drivers or occupants of large trucks, and the remaining 22,418 people killed were either drivers or occupants of other vehicles or were non-motorists, such as pedestrians or cyclists. Thus, approximately six out of seven people killed in fatal traffic accidents involving large trucks were not occupants of a large truck.

It has been reported that about 67 percent of fatal crashes due to backing of heavy trucks go unreported in crash databases because they do not usually happen on roads [2]. According to the Florida Traffic Crash Statistics Report 2005 [7], improper backing was the cause of 218 crashes of the total 5,709 crashes involving a heavy truck. The State of Michigan reported a total of 777 heavy trucks or buses involved in improper backing crashes of the total 16,238 heavy truck or buses involved in a crash in the year 2005 [8]. During 2005 in Minnesota, 4.4 percent of the total 4,150 contributing factors cited in large truck crashes were “unsafe backing” [9]. According to the 2004 Wisconsin Traffic Crash Facts, 394 driver-related circumstances were attributed to unsafe backing by the driver of a large truck in 7,898 large truck crashes [10]. In 2004, backing resulted in 639 crashes of the total 13,908 crashes involving a large truck or bus on all state-maintained roads in North Carolina [11]. Improper backing was the primary collision factor in 107 fatal or injury crashes of the total 3,762 fatal or injury crashes involving a truck [12]. The New York State Department of Motor Vehicles reported 110 crashes of the total 5,410 large truck crashes as a result of unsafe backing in 2004. As shown in Table 2.4, the ratio of fatalities of large trucks for backing per million registered vehicles and per 100 billion vehicle miles traveled is significantly larger than any other type of vehicles.

2.3 Backing Crash Countermeasures

In the last 15 years, there has been development of technological devices that address the issue of the rear blind spot in vehicles. It has been identified by research studies that the major cause of

Table 2.4: Rate of on-road fatal backing crashes.
(Cumulative FARS data from 1991-1997)

Vehicle Type	Pedestrians and Cyclists Killed by a Backing Vehicle per Million Registered Vehicles	Pedestrians and Cyclists Killed by a Backing Vehicle per 100 Billion Vehicle Miles Traveled
Passenger cars	1.05	1.26
Light trucks/vans	2.32	2.80
Combination trucks	9.94	2.21
Straight trucks	29.68	21.89

backing crashes is the limited or no rear visibility, thus devices that help the driver identify objects behind the vehicle should help in avoiding potential backing crashes.

A backing crash countermeasure should provide the driver with information on objects behind the vehicle while backing. It is reasonable to assume that if the driver knows that there is an object or person behind the vehicle while they are backing, the driver will stop the vehicle to avoid striking the object or person. In the case of large trucks, there is no rear view mirror since there is no rear window, thus the driver has to rely solely on the two side view mirrors for backing maneuvers. The countermeasures can be divided into two main categories:

1. Sensor based technologies

2. Video based technologies

Another visual countermeasure previously used was convex mirrors (cross-view mirrors) mounted in the back upper left corner of the truck. The driver was able to identify large objects behind the truck using the driver side mirror and the cross-view mirror. This countermeasure will not be discussed since it is relatively old and unreliable.

2.3.1 Sensor Based Countermeasures

These countermeasures usually involve ultrasonic or radar sensors mounted on the bumper of the vehicle. The sensors emit waves, and if an object is present in close proximity to the vehicle, the reflected waves are captured and translated to a visual or audible warning so the driver knows that there is something in the path of the backing vehicle. Different sensors have different ranges and capabilities. These systems were first developed to be used as parking aids, so that the driver can park the vehicle during slow parking maneuvers with accuracy and safety. These systems have been widely used in the past on passenger cars, vans and light trucks. They are usually called "backup sensors" and are also available for commercial vehicles.

Research studies conducted by the NHTSA have shown however that these systems, are not accurate enough to be trusted with the task of person detection, the most severe situation of a backing crash. Since the early 1990's these systems have been available to be used on vehicles for these purposes. The first studies showed a potential for the sensor systems to aid the drivers avoid backing crashes [13]. Also numerous studies have investigated the benefits and limitations of using such systems [14–17]. Further examination however, showed that these systems are not accurate, have inconsistent detection patterns and lack reliability in detecting objects and people behind the vehicles [18–20]. In reference to commercial trucks, the NHTSA showed that the systems cannot be used as object detection systems [2, 21–23]. The latest report to the U.S. Congress summarized the following:

> Findings for ultrasonic backing systems: "With respect to the functional goals of a backing system, neither of these two systems meets any of the requirements. Even for near zone detection both systems have a maximum range of about 9 ft, not the 15 ft called for. Ultrasonic backing systems were found to be extremely sensitive and prone to false alarms. Backing systems suffer from orthogonal requirements. On the one hand one does not want the system to go off all the time, while on the other hand one would like to be sensitive to small targets, such as children, in an environment with a large amount of ground return."

2.3.2 Video Based Countermeasures

In latest studies where both sensor and video systems were compared, the video systems performed better. The only difference between the video systems and the sensor systems being that they are passive systems, thus they require the driver's attention in order to provide the information. The video systems cover the whole rear area of the vehicle, leaving the driver being the only factor between detecting or not detecting the objects. From recent studies performed by the NHTSA [2, 21, 22, 24–26] the following can be summarized:

> Findings for rearview video systems: "The video systems tested appear to be quite capable of extending the drivers' field of regard. The contrast compression may obscure some targets under certain lighting conditions, but such a condition was not observed during these tests. The field of view of both systems provided adequate coverage toward the rear of the vehicle. These systems are quite capable of satisfying the target detection functional goal. Obviously, they cannot satisfy the warning requirement."

Since it has been shown that the sensor systems are not as effective, only rearview video systems were taken into consideration for this research.

Rearview video systems (RVS) consist of one or more cameras and a monitor. There are certain positions in which the cameras can be placed on a truck to provide a rear view. The main objective is to provide the driver with a rear view of the vehicle so they can use it similar to a rearview mirror in a passenger car. Figure 2.1 shows the rear "No Zone" of a truck, the location for a camera, and the camera's field of view. Usually the camera is mounted at the rear of the truck at bumper height (3 ft from ground level) or at the top of the cargo box of a truck (13 ft from ground level) to eliminate the rear blind spot. Figure 2.2 and Figure 2.3 show views from such cameras. The rear camera is used during backing maneuvers, and the view can be set up to automatically switch on when the reverse gear is engaged. The monitor is located on the dashboard of the vehicle in the line of sight of the driver. Figure 2.4 shows an example of a display mounted on the dashboard of a semi truck.

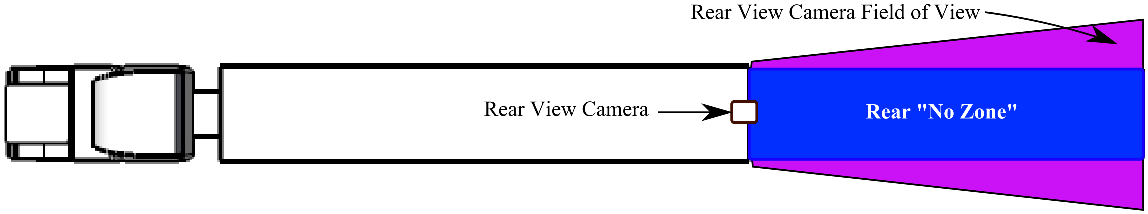

Figure 2.1: Large truck rear “No Zone”, camera location and camera field of view.

Figure 2.2: View from rearview camera located at 3 ft from ground level.

2.3.2.1 Rearview Cameras

The cameras currently used in these systems are usually encased in a waterproof enclosure in a robust metal case that provides protection in extreme environmental conditions. Since all cameras require illumination of the scene to provide an image, these cameras are usually equipped with infrared Light Emitting Diodes (LEDs), which help when the ambient light is not enough for viewing, i.e., at dusk, dawn or in shade. These infrared LEDs illuminate the area with infrared waves that are not visible to the human eye, but only to the camera, thus providing an image even in complete darkness. The image however is no longer in color but in black and white when the “night vision” is used. The infrared LEDs are shown in Figure 2.5, which shows the camera type

Figure 2.3: View from rearview camera located at 13 ft from ground level.

Figure 2.4: LCD 5 inch display mounted on dashboard of large truck.

used for this study with the mounting bracket. The particular camera has a $\frac{1}{3}$ inch lens and requires zero Lux illumination since it uses the infrared LEDs for light. The lens aperture is f/2.8. The technical specifications of the camera used in this study are shown in Table A.1 located in Appendix A. Figures 2.2 and 2.3 show views using the same $\frac{1}{3}$ inch lens camera.

Figure 2.5: $\frac{1}{3}$ inch rearview camera with infrared LEDs.

2.3.2.2 Monitors

The monitors used in RVS can be either cathode-ray tube (CRT) or liquid crystal display (LCD). CRT monitors are bulky and require a larger space, are heavier and older in technology, and could be potentially more dangerous when used in vehicles because the vacuum inside the tube would implode, and glass shatter will cover the driver cabin injuring the occupants in an accident. The lightweight LCD monitors are the choice of many vehicle manufacturers for displays inside the vehicle since they have no glass parts under vacuum, are thinner and lighter than CRTs, and show detail and color better than CRTs. The technical specifications of the LCD monitors used for this study are shown in Table A.2 located in Appendix A. Figure 2.4 shows a 5 inch LCD monitor installed on the dashboard of a vehicle as a part of a rearview video system.

2.4 Previous Testing Efforts on Similar or Same Devices in a Controlled Environment

Previous efforts on similar technologies include a number of studies performed by the NHTSA, FMCSA, and other agencies for sensor-based systems as well as camera-based systems [2, 17, 21–23, 26–28]. The majority of these studies performed static tests with the system under investigation installed on the vehicle with the vehicle not moving, but objects or pedestrians moving around the vehicle to gauge if the detection of the system was adequate. More recent advanced research efforts include driver simulator tests, where the drivers were asked to drive a simulated vehicle and respond to certain stimuli. The observation of the drivers was the primary objective of these efforts. The only study that performed dynamic tests is described in [26, 28], where the drivers drove an experimental truck equipped with the systems under evaluation and were asked to perform certain maneuvers, with and without the system, in separate runs.

Table 2.5 shows the history of these studies and the findings of each. Several studies, especially in the 1990's, included mirrors in the list of technologies used for backing crash avoidance. Current studies focus more on sensor and video systems and combinations of both technologies. Unfortunately, it is still too early to determine how well these systems work on a large scale. The latest update from NHTSA is an Advance Notice of Proposed Rule Making (ANPRM) released in 2009 for Federal Motor Vehicle Safety Standard No.111: Rearview Mirrors, "to improve a driver's ability to see areas to the rear of a motor vehicle in order to mitigate fatalities and injuries associated with backover incidents"[29]. This notice asks for the industry to provide questions and comments on the proposed amendment of requiring additional systems to improve the driver's visibility in "blind areas."

Table 2.5: Studies related to rear object detection technologies.

Year	Agency	Title	Findings
1994	NHTSA	A Study of Commercial Motor Vehicle Electronics-Based Rear and Side Object Detection Systems.	This study dealt with mirror and sensor systems used for side and rear object detection on market-ready and prototype systems. Results showed that they have a potential in helping drivers avoid crashes.
1995	NHTSA	Hardware Evaluation of Heavy Truck Side and Rear Object Detection Systems.	This is the first time a video system is evaluated for its potentials in truck crash avoidance along with sensor systems. Results showed that all systems improve driver potential in avoiding crashes.
2006	NHTSA	Experimental Evaluation of the Performance of Available Back-over Prevention Technologies.	In this comprehensive study, mirror, sensor, and video systems were tested for their performance on SUV-type vehicles. Results showed that video systems help the driver detect pedestrians behind their vehicles better than other systems.
2007	NHTSA	Evaluation of Performance of Available Backover Prevention Technologies for Light Vehicles.	This study, similar to the previous, tested the same systems on light vehicles. The outcome was that the video systems perform better in helping the driver but do not warn the driver of potential danger.

Table 2.5: (continued).

Year	Agency	Title	Findings
2007	NHTSA	Experimental Evaluation of the Performance of Available Back-over Prevention Technologies for Medium Straight Trucks.	The same study was performed for medium trucks. The outcome showed that video systems are the most reliable to show objects behind a truck.
2007	NHTSA	Use of Advanced In-Vehicle Technology by Young and Older Early Adopters.	This study showed the differences in age with the use of sensor and camera systems. It also showed that drivers overestimate the effectiveness of the systems and are more likely to back faster and more carelessly when having the system.
2008	NHTSA	Development of Performance Specification for Camera-Video Imaging Systems on Heavy Vehicle.	This study, the latest of its kind, tested camera systems for different locations on the truck, to improve visibility and potentially replace mirrors. This study included dynamic testing of systems with drivers performing backing maneuvers.

Table 2.5: (continued).

Year	Agency	Title	Findings
2008	NHTSA	On-Road Study of Drivers' Use of Rearview Video Systems.	The latest naturalistic study of its kind collected driver behavior data for a month from minivan drivers. The results showed that the effectiveness of the video systems is only about 20% and the drivers use the systems but not in an efficient manner to avoid all potential crashes.

Chapter 3: Research Methodology

This chapter describes the methodology followed in various sections of this research in order to achieve the proposed results. In order to measure and evaluate the rearview video system, a good understanding of the characteristics of backing crashes must be gained in order to effectively be able to apply the countermeasure. Since this system is deemed a countermeasure for backing crashes, the reasons and causes of backing crashes have to be first investigated in order to test the system against those issues. First the Florida CAR System Database was reviewed to obtain more details for the backing crashes involving large trucks. Then an experiment was designed to test different aspects of using the system in real situations, and analysis of the results shows the important factors that influence the use of such a system.

3.1 Crash Analysis Reporting System

Florida's CAR database was used to obtain information on backing crashes involving large trucks. The data used were from years 2003-2006 and included a total of 1,280,130 crashes. Table 3.1 shows the data distribution. The passenger vehicle category includes passenger car, passenger van and light pickup truck types, whereas the large truck category includes medium and heavy trucks and truck tractors.

As shown later in chapter 5, the data were analyzed in reference to the causes of backing crashes. The database has three major variables related to backing:

1. First harmful event: backed into

2. Vehicle movement: backing

Table 3.1: Total crashes, Florida (2003-2006).

Year	Passenger Veh.		Large Truck		All Vehicle Types
	Total	%	Total	%	Total
2003	248,215	82.44	15,975	5.31	301,095
2004	265,124	81.93	18,460	5.70	323,599
2005	270,436	81.39	20,283	6.10	332,279
2006	261,767	81.00	19,213	5.95	323,157
Total	1,045,542		73,931		1,280,130

3. Contributing cause: improper backing

The first variable is the first event coded by the police officer as the first event that occurred during the crash. This variable is used as the crash type. The second variable, is the vehicles' movement when the crash occurred and it should be obviously "backing" for the at-fault vehicle. The third variable is the contributing cause as coded by the police officer after the crash. This is based on opinions, and statements of the drivers involved and witnesses. Although these variables should be consistent, as shown later there is a discrepancy in the numbers.

Based on findings from subsection 2.1.1, the countermeasure cannot be applied on all types of backing crashes. The countermeasure is applicable only to certain backing crashes. The requirements are:

- Both vehicles should travel at low speeds (<10 mph) because the vehicles have to be under the control of the drivers and give them enough time to respond to a potential danger,
- The at fault vehicle has initial point of impact the rear end, rear right and rear left corners of the vehicle since these are the zones that are covered by the rearview video system and any rear object detection system.

All other backing crash types, cannot be said to be potentially avoided since such a claim cannot be substantially supported. The crash data analysis is described in detail and results shown in chapter 5.

3.2 Experiment Design

Backing crashes are a rare event. As with all crashes there is no way to know when one will occur. That is the main reason safety analysis is performed on crash data after the events. In this case however, backing crashes do not occur frequently enough so in order to accumulate adequate sample size for statistical analysis, many years of data are needed.

A second method for safety analysis is the conflict analysis. This method is not the same as traffic conflicts since the observation is not made in the road under normal conditions, but rather in a controlled environment. An experiment can simulate real like conditions in a controlled environment and using vehicles equipped with data collection equipment it is possible to collect adequate data for analysis.

The experiment objectives were:

- To identify if the system helps the driver perform a backing maneuver safer than without the system, i.e. to help the driver avoid potential hazards,
- To observe how the drivers use the system in actual driving conditions,
- To quantify measures of effectiveness in order to evaluate the system,
- To obtain feedback from actual drivers for the system,
- To gain an understanding to the system's use, functions, potentials and limitations.

The experiment was designed to use backing maneuvers to test the effectiveness of the rearview video system in aiding the drivers with avoiding potential hazards that could lead to a crash. One of the problems related with the testing of a crash is obviously to simulate a crash without actually harming anyone in the process. As implemented in previous studies in controlled environments, pedestrian surrogates were used to simulate actual persons walking behind the vehicles. The difference with this experiment however was that the truck would be moving, thus making the test more complicate to administer. It was decided to utilize two methods of introducing pedestrian surrogates behind the backing truck:

1. Stationary Object
2. Surprise Pedestrian Surrogate

3.2.1 Stationary Object

The objective of this test was to identify if the system could help the drivers identify that a stationary object is blocking the vehicle's path and that to avoid crash they have to stop the vehicle. One of the main issues with this test was to make the object small enough so that is not very obvious, but big enough to have an importance to the driver to stop. In the experiment, an orange traffic cone was selected for its contrast with the environment, and to make it more visible to the driver. It is clear however that different color objects might not be as visible as a bright orange traffic cone. It was decided that the cone had to be positioned behind the truck after the driver entered the truck to perform the maneuvers. This would make the object an unexpected event, thus providing a more realistic scenario. If the driver was expecting the object, it would obviously not benefit the study. In this fashion, the driver was let in the truck for maneuver briefing, and during the first maneuver: Straight Line Backing, an examiner holding a stack of two cones, walked in a perpendicular path behind the backing truck and dropped one of the cones in the middle of the path, as described in detail in subsection 4.2.2.1. This was performed only for this maneuver, since an actual person carried the cones, and the truck would only have to travel at a straight line, making it easier to predict where the truck would be at all times.

3.2.2 Surprise Pedestrian Surrogate

This method was used in previous studies conducting controlled experiments. The difference however was that the apparatus in previous studies moved only at a straight line, because the pedestrian dummy used was hanging from a small crane being pulled by a weight/pulley system. The other difference was that the vehicles in previous studies were stationary. In this study it was decided that the pedestrian surrogate would have to be mobile and independent of the truck, in order to position it at required time intervals and positions in the truck's path. To achieve this, a three year old child's figure 3 ft high was mounted on a remote controlled toy-car. The figure was cut out from white foam board as shown in Figure 3.1 and was much smaller in relation to the truck as shown in Figure 3.2.

Figure 3.1: Pedestrian dummy behind truck.

Figure 3.2: Pedestrian dummy close-up.

3.2.3 Testing Procedure

1. The participating drivers were asked to read and sign a driver informed consent form that explained the procedure of the test, risks and discomforts, benefits to the driver, extent of anonymity and confidentiality, compensation, and rights, and thus they gave their permission to participate in the test. The informed consent form is shown in Appendix B. The drivers were assigned a number that would serve as an identifier for all stages and forms of the test for anonymity purposes.

2. The drivers were then given a flyer showing diagrams of the three maneuvers that were included in the test, with details for each maneuver. Each driver entered the equipped truck, and performed the maneuvers in the predefined random sequence. A second team member was inside the truck to guide the driver through the maneuvers.

3. The drivers were asked to perform two sets (with and without a rearview system) of three different maneuvers (Straight Line Backing, Offset Right Backing, and Alley Dock Backing). To minimize potential bias, the order of the six maneuvers for each driver followed a pre-generated random number table. Therefore, each driver completed the maneuvers in a different order.

4. Another two team members were stationed outside the truck to observe, record, and control the test dummies.

5. After completion of all six maneuvers, the drivers were asked to complete a survey to provide their feedback for the system. The evaluation form and data collection survey is shown in Appendix C.

3.2.4 Data Reduction

The data collected in the experiment were in the form of survey answers and video from the drivers' behavior at the time of the test. The reduction of the second, the video data, required many hours of watching video. A computer software was used that multiplexes all three cameras and sensor information stored on the Data Acquisition System unit and presents it on a single screen. A view of this screen is shown in Figure 3.3. The video was recorded with a rate of 30 frames/second. The video was watched and for every frame equivalent to 0.033 of a second, the drivers' glance location and duration was recorded.
It was decided that for the driver behavior data, the objective was to observe if distinctive patterns in the system's use appeared during the experiment. The drivers were expected to use the system like a mirror, where during the backing maneuver, the driver scanned from the driver to the passenger side mirror while trying to adjust the truck for its final destination, avoiding potential hazards. This meant that the location of the glances of the drivers and the duration of these glances should be recorded. Four distinct locations were identified and categorized:

1. The driver side mirror and over the left shoulder,

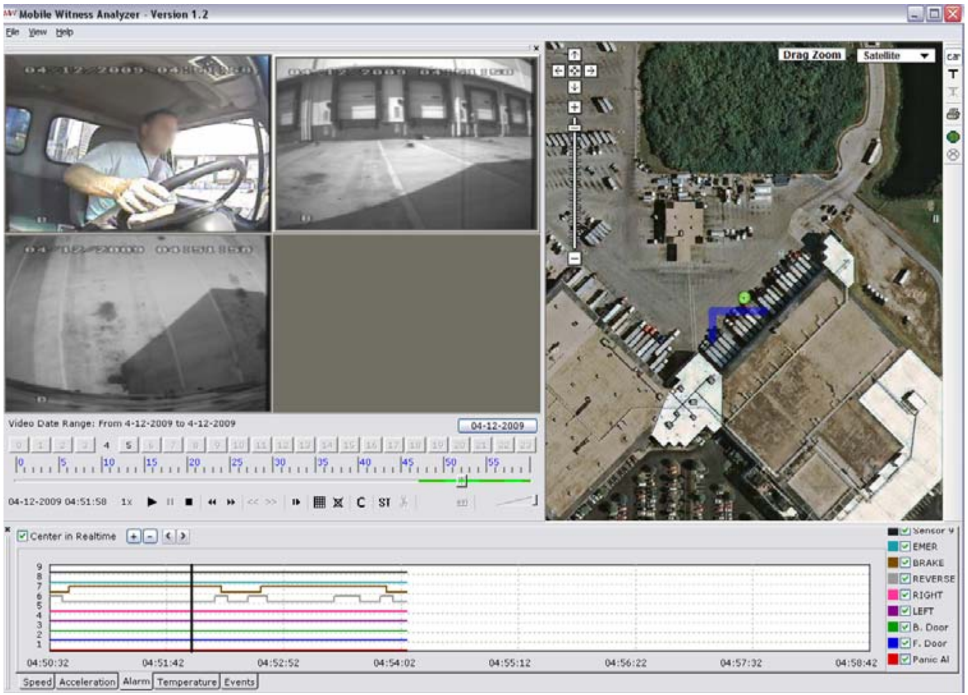

Figure 3.3: Video/Sensor analysis software screen.

2. The passenger side mirror,

3. The rearview video system monitor,

4. Any other location including forward, left and right bumper convex mirrors.

The driver and passenger side mirrors included both the flat surface (West-Coast) mirror and convex mirror together as one location because it was not possible to distinguish from the video if the driver was looking at one or the other. The four areas are shown in Figure 3.4.

3.3 Statistical Model Development

After the analysis of both behavior and acceptance data, a statistical model was fitted to estimate the probability of having a backing crash given the characteristics controlled in the experiment. This model allowed inference on the important factors measured during the experiment that influence if, how, and when a backing crash will occur. At the same time, this model was used to

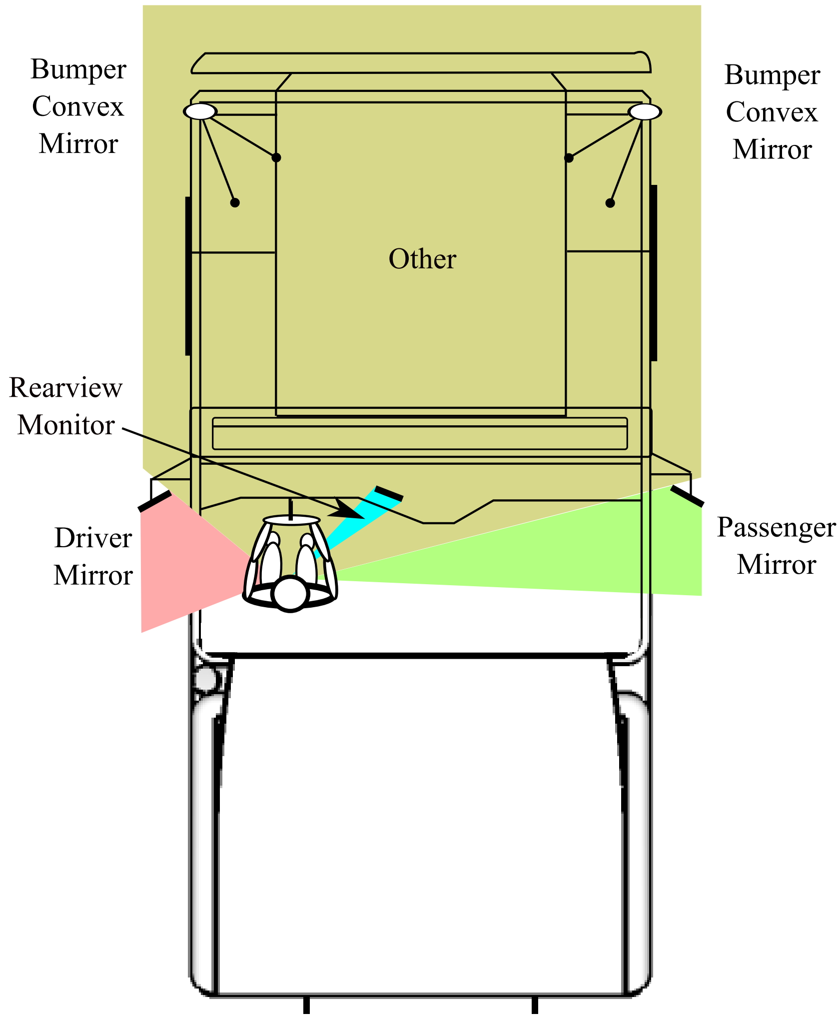

Figure 3.4: Driver four glance locations used for data analysis.

identify the levels which make a significant difference on if a crash will occur or not. Sensitivity analysis provided changes in the factors' components and provided the corresponding probability change.

The outcome of the experiment was a dichotomous variable of backing crash occurrence. This was coded as 1 for backing crash, and 0 for no backing crash. Since this dependent or response variable had two possible values, a binary regression model was used to estimate the probability of having a crash. The model effectively estimates the outcome as a number between 0 and 1. With a decision rule of cutoff value 0.5, the model then decides in which group to place each run.

This cutoff value can be changed to reduce the error of making a false positive or false negative estimation.

Chapter 4: Data Collection Methodology

This chapter describes the methodology for the required data collection. Two areas of data were defined: crash data and experiment data. Since the backing crash data with RVS are not enough, in order to identify the potential backing crashes where the RVS can be applied, crash records need to be reviewed to estimate the problem size, and description. Furthermore the designed experiment provides data pertaining to the backing crash in relation to specific characteristics of the environment and the drivers.

4.1 Crash Data from CAR System

The Florida Crash Analysis Reporting (CAR) database for years 2003 to 2006, was available for review. From the database, variables such as the vehicle types, crash date, time, location and injury severity were available. These variables however do not provide a clear description of the conditions under which the crash occurred. The only method to establish what happened was to review the police reports (long form) in order to obtain information on the vehicle speeds at the time of crash, and more importantly the narrative (explanation) given by the police officer on what happened. This narrative provides details on the conditions under which the crash occurred and also provides an opportunity to capture any errors made in the data reduction from the police forms to begin with.

The traffic crash report form (long form) is a four page form that the police officers fill every time they respond to a crash. The form has two pages of coded variables including vehicle data, time, location, crash number, vehicle types, driver information, insurance, contributing causes, vehicle movements, point of impact, first harmful event, injuries, etc. The third page includes a narrative of the investigation and the fourth page includes a schematic diagram of the crash.

4.2 Experiment Data

The second data collection was completed during the driver experiment. This experiment described in detail in section 3.2 was designed to produce behavior data during backing maneuvers from truck drivers with the use of RVS. The collection methodology for the experiment data is described in the following subsections.

4.2.1 Data Acquisition System

During the experiment the truck was equipped with a Data Acquisition System (DAS) to record and store the necessary data for the analysis. The data collected for the experiment came in two forms: (1) video, audio and sensor data recorded in the digital video recording (DVR) unit and (2) from observations and measurement from the field personnel taken during the tests. Figures 4.1 and 4.2 show the DAS unit used in the experiment. The DAS comprised of a DVR, a monitor, a Global Positioning System (GPS) Antenna, a cooling fan, power switches and relevant power and video/audio connectors. A schematic diagram of the case wiring is shown in Figure 4.3.
The truck was equipped with three cameras. As shown in Figure 4.4, one camera (Camera 1) was installed inside the cabin next to the monitor to record the driver's behavior, and two rearview cameras were mounted at the back of the truck. The second camera (Camera 2) was installed on the top of the cargo box trailer in the center, aimed down at an angle of 60° to the horizontal. The third camera (Camera 3) was installed under the position/brake lights of the trailer at an angle of 0° to the horizontal. Camera 3 was used to provide live video feed to the driver through the monitor located in the driver's cabin. The block diagram for the processing and storage of the data is shown in Figure 4.5.

Figure 4.1: DAS - Outside view.

Figure 4.2: DAS - Inside view.

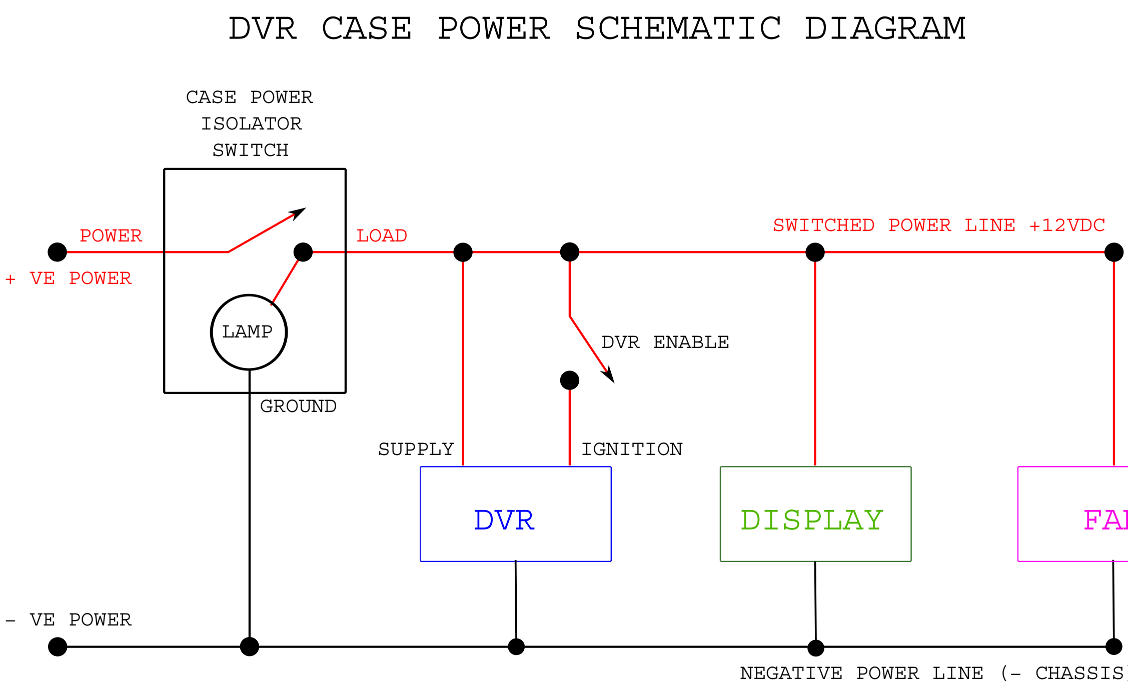

Figure 4.3: The DAS case wiring diagram.

4.2.2 Backing Maneuvers

The experiment was designed to test the effectiveness of the rearview video system, as backing crash countermeasure. Since the system was to be tested while backing, only certain backing

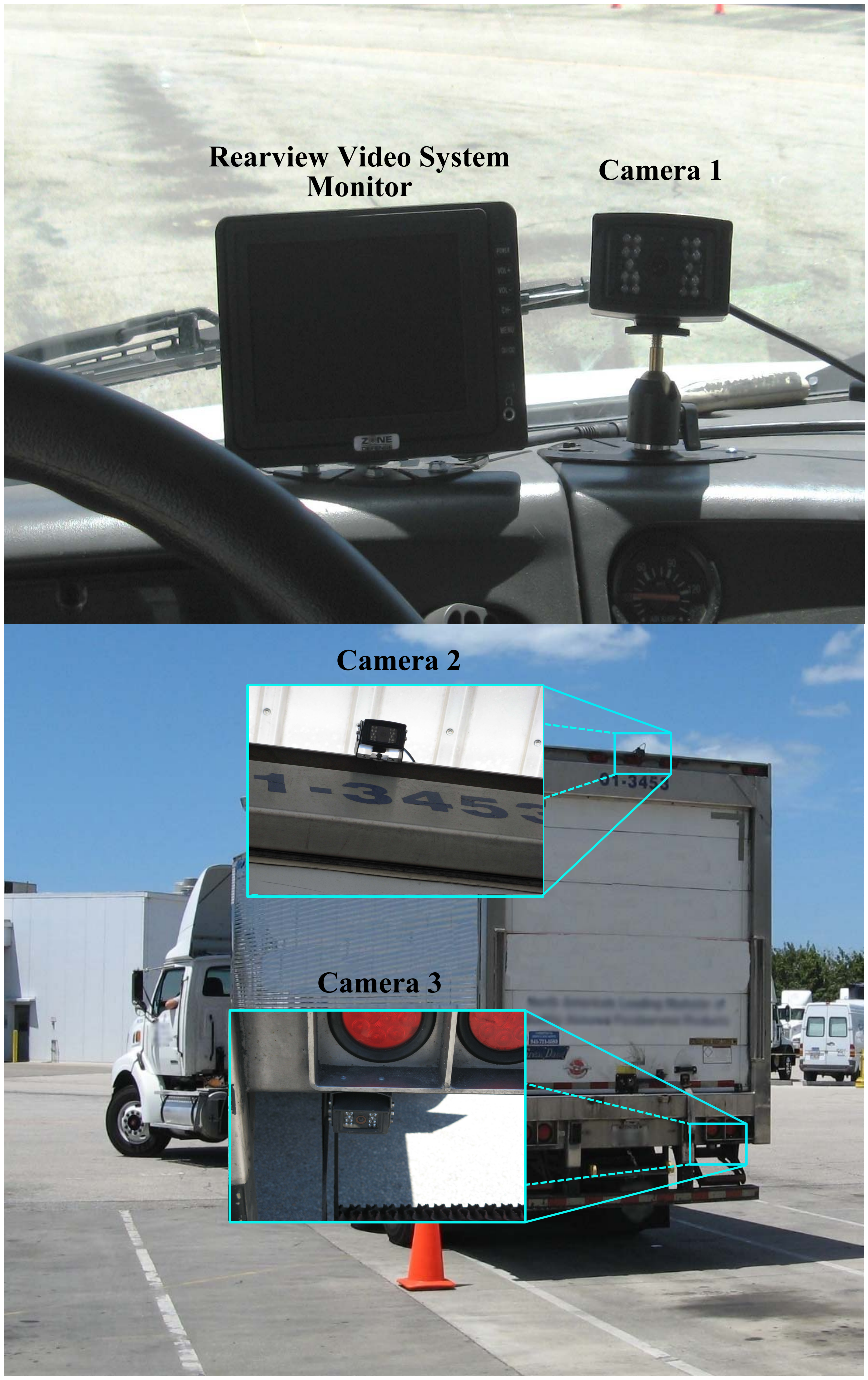

Figure 4.4: Location of the three cameras used in the experiment.

maneuvers were selected to be included in the final experiment. The following maneuvers were

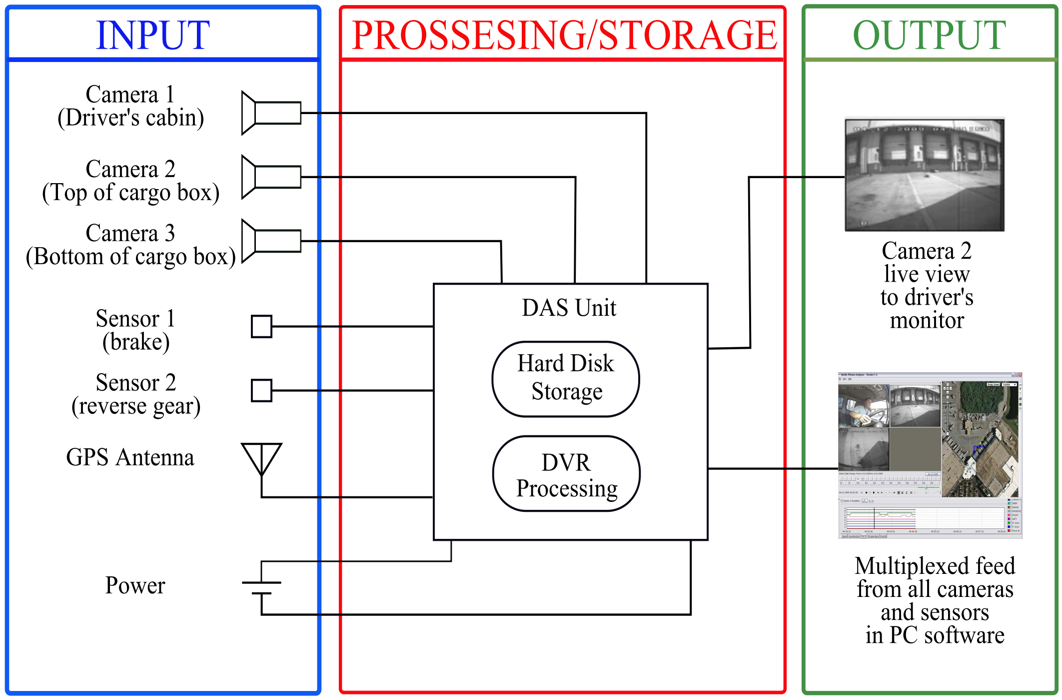

Figure 4.5: The experiment data processing/storage process.

included in the experiment after an initial pre-test. All the maneuvers were taken from the Commercial Driver License (CDL) skills test. The maneuvers are:

1. Straight Line Backing Maneuver

2. Offset Right Backing Maneuver

3. Alley Dock Backing Maneuver

4.2.2.1 Straight Line Backing Maneuver

This maneuver required the driver to back the truck in a straight line for a total of 195 ft. The driver would have to back the truck at a straight line (hence the name of the maneuver) through the cones. The schematic diagram is shown in Figure 4.6. When the back of the trailer reached about 65 ft from the end position (the line connecting the first two cones), as shown, the examiner crossed behind the trailer along the path shown. The examiner who was carrying two 3 ft high cones, passed at normal walking speed, then dropped the bottom cone in the centerline of the box in the path of the backing truck and continued walking out of the box while carrying the second cone. This procedure was adopted so that if the driver saw the examiner passing through the side mirrors, he would not be able to detect immediately that the examiner dropped a cone since it would appear that the cone was transferred all the way to the other side of the box. As one would understand, if the driver detected that a cone was missing from the hands of the examiner, the driver could easily assume that the cone was dropped behind the truck and stop for that reason. Since this was not the intention of the test, the procedure described above was used. The maneuver was performed twice, once without the use of the RVS, and once with it, in a random order for each driver.

If the driver stopped for the cone, the distance from the back of the trailer to the cone was measured and recorded. This happened on both occasions (when the driver was using the system, and when the driver was not using the system). It was expected that the driver would not stop when the system was not being used. The drivers were not aware when and if the team member would cross behind the truck to create a naturalistic reaction by the driver. The procedure had as follows (shown in Figure 4.7):

1. The examiner carries a stack of two cones.
2. The examiner walks behind the backing truck, dropping a cone and continues to walk away while still carrying the other cone. (This was done to position the unexpected object on the backing path of vehicle.)
3. A cone is located at the backing path of the truck.
4. The driver apparently does not notice the cone.
5. The driver continues to make a straight backing maneuver as instructed.
6. If the driver failed to detect the presence of the cone, the vehicle would knock it down, signifying a crash.

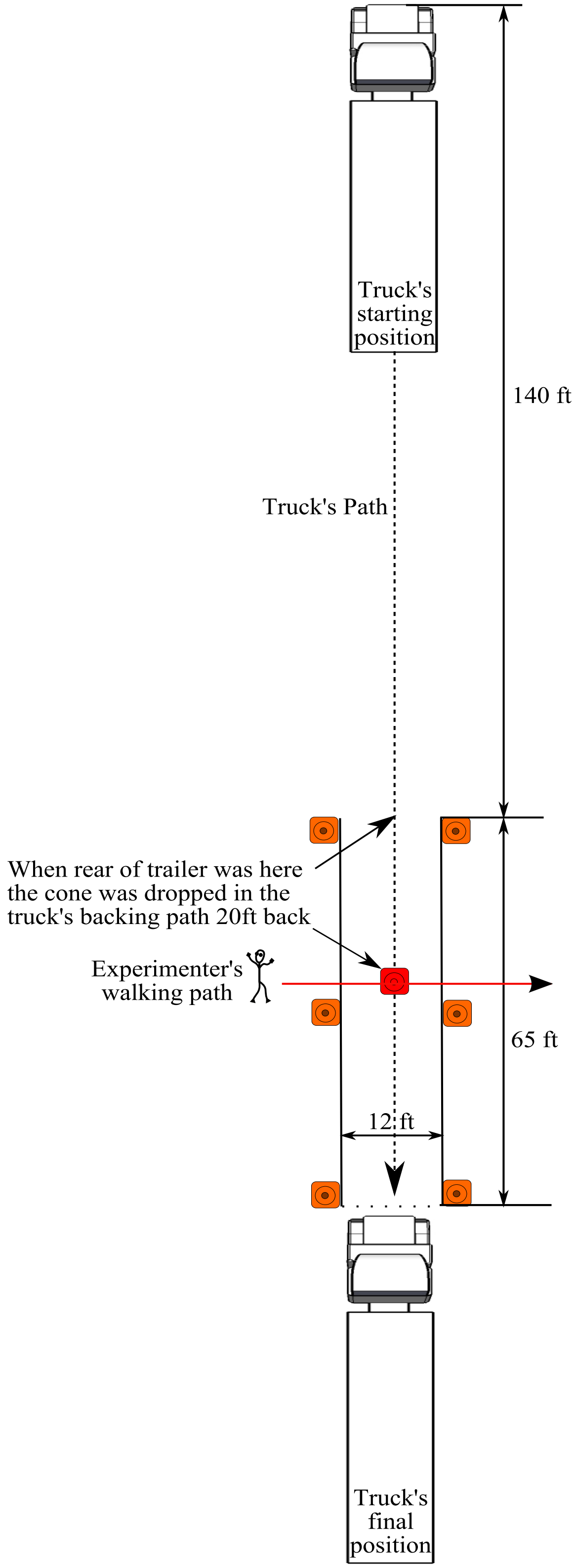

Figure 4.6: Diagram of Straight Line Backing Maneuver.

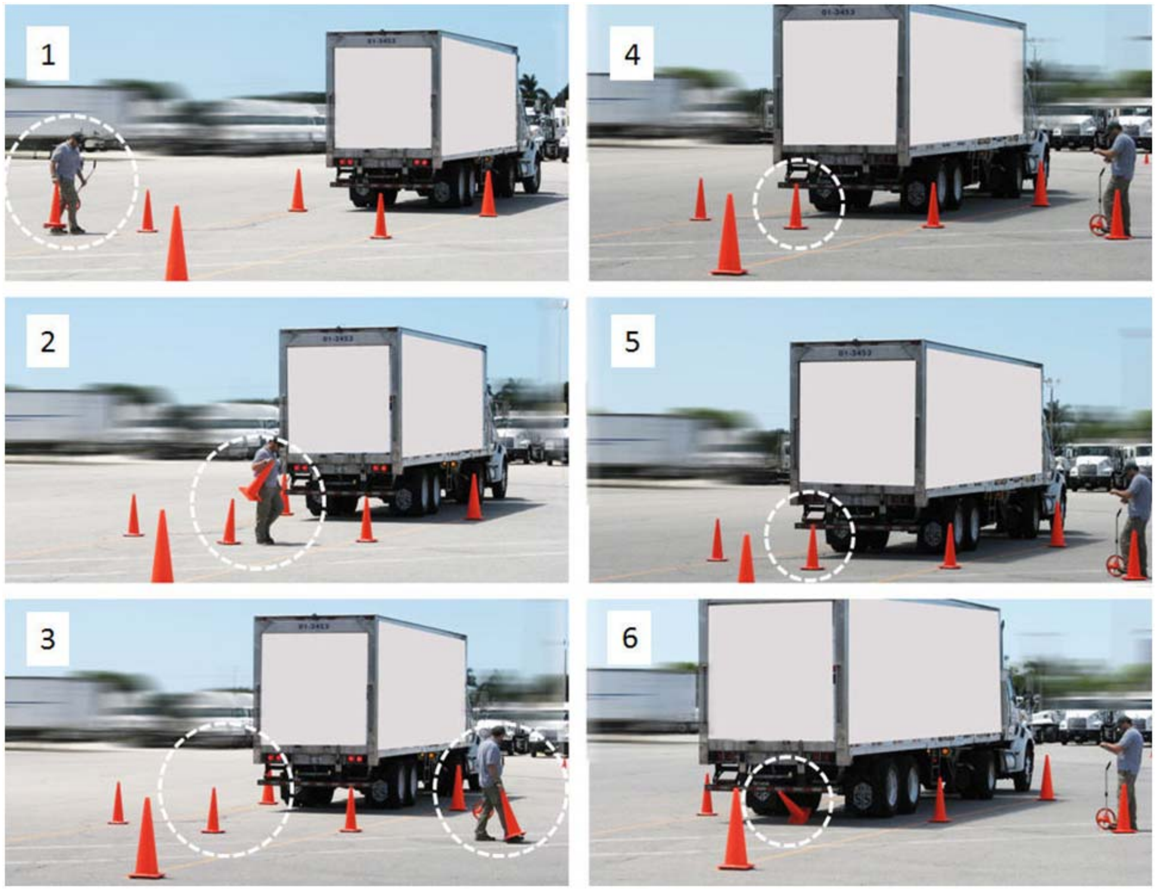

Figure 4.7: Straight Line Backing Maneuver cone sequence.

4.2.2.2 Offset Right Backing Maneuver

This maneuver required the driver to start from a position on the left of the first maneuver, backing the truck and curving to the right at a box, as shown in Figure 4.8. The end of the box was a loading dock, and the drivers were asked to stop the truck at a distance of 3 ft from the door. During this maneuver and when the back of the trailer was located approximately 55 ft from the loading dock, an examiner introduced the pedestrian surrogate described in section 3.2.2. The dummy was steered from a safe distance and it was introduced at approximately 20 ft from the back of the trailer. If the driver stopped, the distance between the dummy and the trailer was measured and recorded and the outcome was noted as a “stop.” If the driver did not stop and hit the dummy, then the outcome was recorded as a “hit.” After this, the driver continued the maneuver and the distance stopped from the loading dock was recorded. A picture of this maneuver is shown in Figure 4.9.

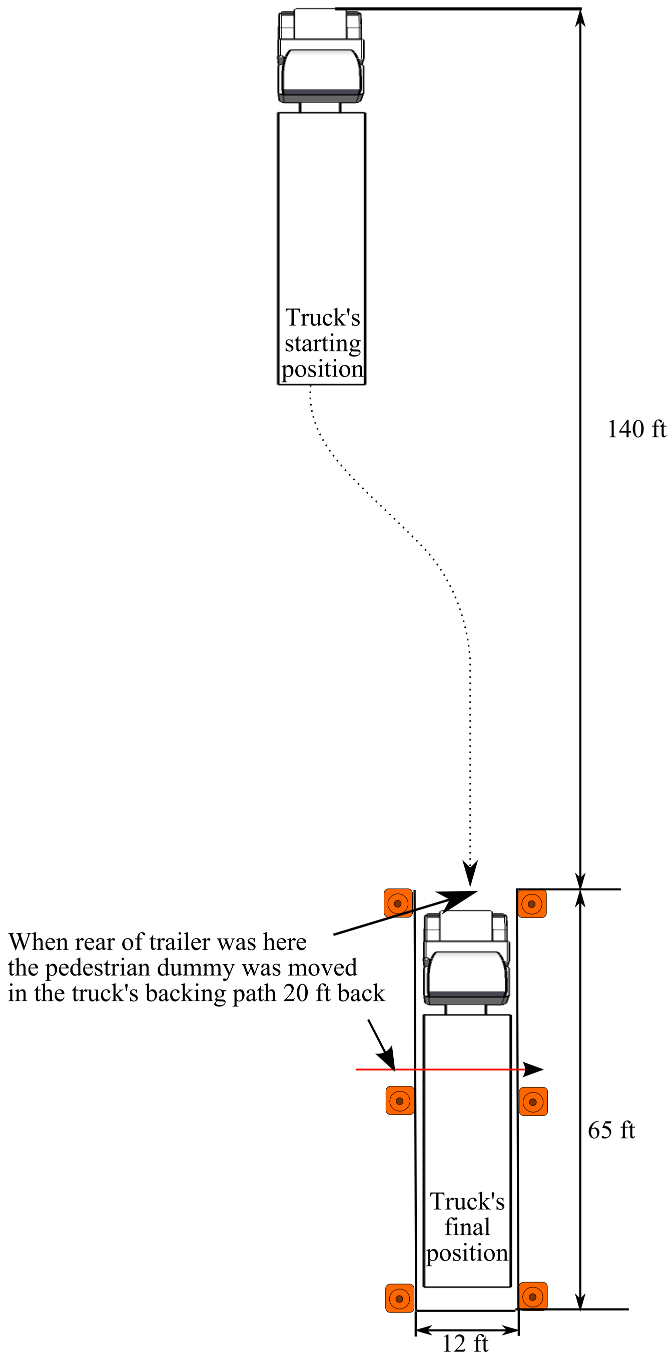

Figure 4.8: Diagram of Offset Right Backing Maneuver.

Figure 4.9: Pedestrian dummy introduction. The dummy is steered in the truck's path.

4.2.2.3 Alley Dock Backing Maneuver

This maneuver required the drivers to position the truck at a 90° angle from a box leading to a loading dock and steer the truck into the box, parking the truck 3 ft from the loading dock. A schematic diagram is shown in Figure 4.10. As with the Offset Right Backing Maneuver, when the trailer reached approximately 55 ft from the dock, the pedestrian surrogate was introduced to observe the reaction of the driver. If the driver stopped, the distance between the dummy and the trailer was measured and recorded and the outcome was noted as a "stop." If the driver did not stop and hit the dummy, then the outcome was recorded as a "hit." After this, the driver continued the maneuver and the distance stopped from the loading dock was recorded.

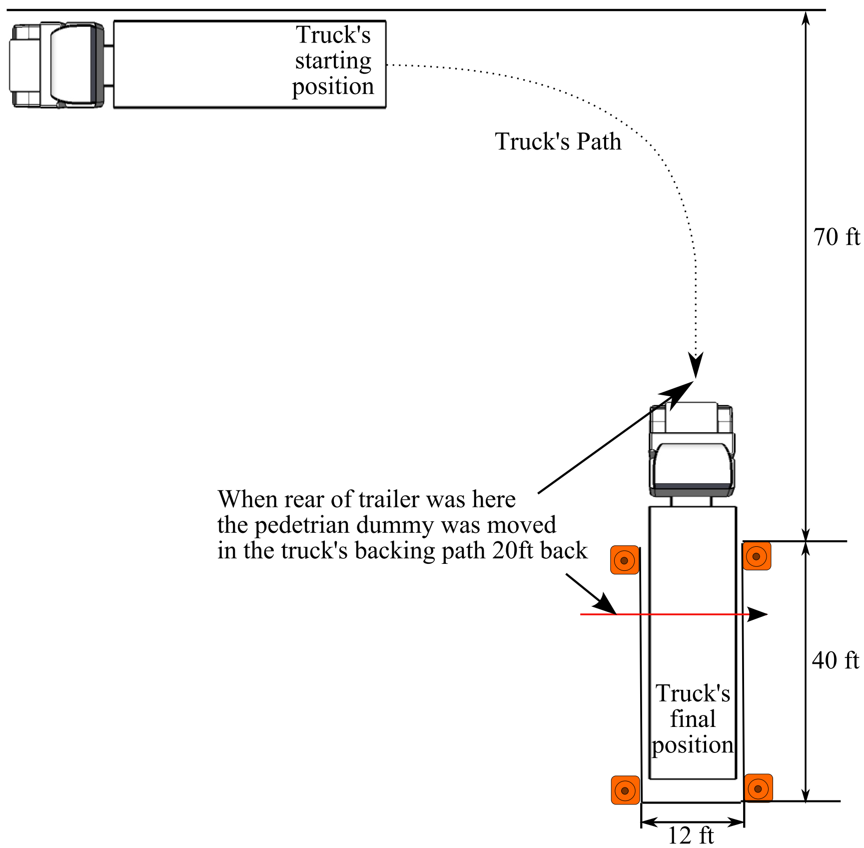

Figure 4.10: Diagram of Alley Dock Backing Maneuver.

4.2.3 Determination of Experiment Variables

As mentioned earlier, the DAS was used to record and store data during the experiment to be retrieved and analyzed at a later time. A number of variables were created for the analysis. The variables created are shown in Table 4.1.

Table 4.1: Variables created for data analysis.

Variable	Source	Type	Value
Outcome	Experiment	Nominal	1 = Crash, 0 = No Crash
Dist_obj	Experiment	Continuous	Number of Feet
Dist_dock	Experiment	Continuous	Number of Feet

Table 4.1: (continued)

Variable	Source	Type	Value
DriverAge	Survey Form	Ordinal	1 = Under 25, 2 = 26-30, 3 = 31-40
			4 = 41-50, 5 = 50+
CDL_exp	Survey Form	Continuous	Number of Years
RVS_exp	Survey Form	Nominal	1 = Yes, 0 = No
Backing_hist	Survey Form	Nominal	1 = Yes, 0 = No
Backing_no	Survey Form	Continuous	Number of crashes in previous years
Comf_RVS_M1	Survey Form	Ordinal	1 = Strongly Agree, 2 = Somewhat Agree
			3 = Agree, 4 = Disagree,
			5 = Somewhat Disagree, 6 = Strongly Disagree
Comf_help_M1	Survey Form	Ordinal	1 = Strongly Agree, 2 = Somewhat Agree
			3 = Agree, 4 = Disagree,
			5 = Somewhat Disagree, 6 = Strongly Disagree
Comf_RVS_M2	Survey Form	Ordinal	1 = Strongly Agree, 2 = Somewhat Agree
			3 = Agree, 4 = Disagree,
			5 = Somewhat Disagree, 6 = Strongly Disagree
Comf_help_M2	Survey Form	Ordinal	1 = Strongly Agree, 2 = Somewhat Agree
			3 = Agree, 4 = Disagree,
			5 = Somewhat Disagree, 6 = Strongly Disagree
Comf_RVS_M3	Survey Form	Ordinal	1 = Strongly Agree, 2 = Somewhat Agree
			3 = Agree, 4 = Disagree,
			5 = Somewhat Disagree, 6 = Strongly Disagree
Comf_help_M3	Survey Form	Ordinal	1 = Strongly Agree, 2 = Somewhat Agree
			3 = Agree, 4 = Disagree,
			5 = Somewhat Disagree, 6 = Strongly Disagree
Like_have_RVS	Survey Form	Ordinal	1 = Strongly Agree, 2 = Somewhat Agree

Table 4.1: (continued)

Variable	Source	Type	Value
			3 = Agree, 4 = Disagree,
			5 = Somewhat Disagree, 6 = Strongly Disagree
Comp_pays	Survey Form	Ordinal	1 = Strongly Agree, 2 = Somewhat Agree
			3 = Agree, 4 = Disagree,
			5 = Somewhat Disagree, 6 = Strongly Disagree
RVS_help_blind	Survey Form	Ordinal	1 = Strongly Agree, 2 = Somewhat Agree
			3 = Agree, 4 = Disagree,
			5 = Somewhat Disagree, 6 = Strongly Disagree
Man_dur	Video	Continuous	Number of Frames
React_gl_loc	Video	Nominal	m = monitor, p = passenger mirror
			d = driver mirror, o = other location
m_cnt	Video	Continuous	Number of Glances
m_dur	Video	Continuous	Number of Frames
p_cnt	Video	Continuous	Number of Glances
p_dur	Video	Continuous	Number of Frames
d_cnt	Video	Continuous	Number of Glances
d_dur	Video	Continuous	Number of Frames
o_cnt	Video	Continuous	Number of Glances
o_dur	Video	Continuous	Number of Frames
avg_trans	Video	Continuous	Number of Frames
avg_gl_dur	Video	Continuous	Number of Frames

Chapter 5: Crash Database Analysis

In this study, the Florida Crash Analysis Reporting Database (CAR) years 2003-2006 was analyzed with the purpose of understanding the contributing factors and distribution of the backing crashes involving large trucks and 1,549 actual police crash reports were reviewed to assess the potential of reducing truck backing crashes with the RVS. A large truck is defined as a truck with a Gross Vehicle Weight Rating (GVWR) greater than 10,000 pounds and includes both medium and heavy trucks.

5.1 Backing Crashes

The Florida Crash Analysis Reporting Database (CAR) maintained by the Florida Department of Transportation (FDOT) Safety Office was used to retrieve the crash data for 2003-2006 to understand the contributing factors and distribution of the backing crashes involving trucks. First, the CAR database was reviewed for relevant variables for backing crash. Three variables were identified that can be used to estimate truck backing crashes: the variable coded as the (1) “first harmful event: backed into” which is used as the crash type, (2) the vehicle movement coded as “backing”, and (3) the contributing cause for the crash coded as “improper backing.” It is expected that a crash coded as a backing crash, with first harmful event “backed into” will have a “backing” movement and the contributing cause as “improper backing”. However, it was found that 5,718 crashes were coded as “backed into”, but 9,092 were coded as “backing” movement and 7,567 were coded with “improper backing” as the contributing cause.

This discrepancy prompted a more thorough investigation of the database, and it was found that the police officers were responsible for coding these variables, thus introducing an error in the data. Some backing crashes were also coded to have "careless driving, failure to use due care, unsafe backing, violation of right of way, etc" as their cause. After the review of the CAR database, it was found that it is appropriate to use both "backing" as the at-fault vehicle movement and "improper backing" as the contributing cause of the crash to select backing crashes.

As shown in Table 5.1, backing crash rates in Florida have remained relatively constant over the years. It is noted that trucks have a higher percentage of backing crashes as compared to passenger cars. There were a total of 7,356 backing crashes that involved trucks for four years.

Table 5.1: Percent of backing crashes to total crashes, Florida (2003-2006).

Year	2003	2004	2005	2006	Total
Passenger Car					
Total	248,215	265,124	270,436	261,767	1,045,542
Backing	10,293	11,162	11,168	11,217	43,840
Percent	4.15	4.21	4.13	4.29	4.19
Truck					
Total	15,975	18,460	20,283	19,213	73,931
Backing	1,601	1,800	1,994	1,961	7,356
Percent	10.02	9.75	9.83	10.21	9.95
All Vehicle Types					
Total	301,095	323,599	332,279	323,157	1,208,130
Backing	13,709	14,933	15,189	15,238	59,069
Percent	4.55	4.61	4.57	4.72	4.61

After review it seems that "improper backing" is a major contributing factor for truck backing crashes. According to Florida Statutes 316.1985(1), a driver is prohibited from doing a backing maneuver unless such movement can be made with safety and without interfering with other traffic. If this is violated, the driver can be cited for "improper backing."

Considering that the purpose of this study is to understand truck backing crashes and potential reduction with the RVS, it is needed to investigate the details of backing crashes including the crash speed and the cause of "improper backing." However, no further information can be drawn about the cause of "improper backing" from CAR. Specifically, there was no information regarding if

"improper backing" crashes occurred due to the lack of a clear rear view of the vehicle or whether the "improper backing" could have been avoided by providing a rear view.
To find "improper backing" under common circumstances and whether it could be eliminated by providing a rear view of the vehicle, actual police crash reports (long forms) were reviewed. A total of 1,549 individual crash reports were stratified by crash severity and randomly selected. The conditions under which the backing crashes occurred were summarized into the following cases/scenarios:

1. The truck driver misses a turn, stops in the road, and backs to be able to make the turn, striking a vehicle that managed to stop behind the truck without the driver seeing the vehicle. The second vehicle is usually either stopped or coming to a stop. (Note here that many truck drivers say that they did check their mirrors prior to backing and could not see the vehicle behind the truck due to a blind spot. Also, tractor-trailer trucks, when backing, give no warning because the trailers usually have no backup lights or alarms. Straight medium or heavy trucks usually have an audible alarm when backing). This crash occurs on roadways, intersections with side streets, driveway access, and highway entrance or exit ramps, etc.

2. The truck driver realizes is in the wrong lane at a signal and backs to change lanes, striking the vehicle stopped behind it.

3. The truck driver is negotiating a turn at an intersection, but due to the length of the trailer and not having adequate space, the driver needs to backup to complete turn and strikes the vehicle that follows too closely behind the truck (within a blind spot).

4. The truck driver is stopped at a signal or stop sign intersection, and to make room for another large vehicle turning perpendicularly with the truck's direction, backs into the vehicle behind it.

5. The truck driver stops too far, passing the stop bar at a traffic signal or stop sign, and backs to correct this mistake, striking the vehicle stopped behind the truck.

6. The truck driver is backing in a parking lot to deliver goods, striking parked vehicles around it (usually behind).

7. The truck driver is backing at any location and strikes a second vehicle backing as well.

8. The truck driver is backing out of a driveway or side street into the main street, striking an oncoming vehicle that did not see the truck until it was too late or the driver could not stop in time.

9. The truck driver is performing a backing maneuver, and the driver cannot see around the vehicle, thus striking a vehicle that is parked next to it. This happens when the driver is turning the tractor to adjust the trailer.

The review of police crash reports provided a mixed lesson. It was found that more than 50 percent of crash reports actually have a driver's statement regarding no view/missed view. However it was found that the point of impact for backing crash is not always the rear end of the at-fault vehicle as it can be commonly expected. As shown in Figure 5.1, it was found that the point of impact for at-fault vehicle is the front end of vehicle in more than 10 percent of truck backing crash.

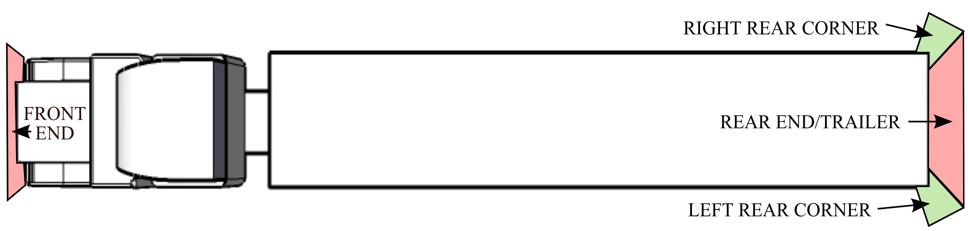

Figure 5.1: Point of impact of at-fault vehicle in backing crashes.

Table 5.2 shows the site location of truck backing crashes. More than 35 percent of backing crashes occurred in parking lots. However, it is noted that 14 percent of backing crashes are also reported at intersection where usually backing maneuver is not expected. Also, it was found that many crashes occur in locations that they should not be occurring, i.e. backing crashes in a road section or at intersections. The distribution of location of the crashes is shown in Table 5.2. As shown, 26.4 percent of backing crashes occurred at a road section, and another 14 percent occurred at an intersection. It also implies that not all backing crashes are low-speed crashes.

Table 5.2: Site location of backing crashes, Florida (2003-2006).

Site Location	Medium Truck (4 rear tires)	Heavy Truck (2 or more rear axles)	Truck Tractor (Cab)	Total	%
Road Section	647	786	527	1,960	26.40
At Intersection	361	388	284	1,033	14.04
Infl.by Intersection	113	158	132	403	5.48
Driveway Access	193	193	187	573	7.79
Parking Lot (Public)	520	331	412	1,263	17.17
Parking Lot (Private)	432	336	419	1,187	16.14
Private Property	176	185	180	541	7.35
*All Other	138	145	113	396	5.38
Total	2,580	2,522	2,254	7,356	100

*All Other includes RRXing, Bridge, Entrance/Exit Ramps, Toll Booth, Public Bus Stop.

Table 5.3 shows the injury severity of backing crashes by truck type. As shown, 87-92 percent of backing crashes are property damage only (PDO) crashes and very few fatality involved crashes were found.

Table 5.3: Backing crash injury severity, Florida (2003-2006).

		Vehicle Type		
Injury Severity	Medium Truck (4 rear tires)	Heavy Truck (>2 rear axles)	Truck Tractor (Cab)	Total
None (PDO)	2,245	2,234	2,081	6,560
Possible Injury	149	135	90	374
Non-Incapacitating Injury	61	53	30	144
Incapacitating Injury	19	30	11	60
Fatal (Within 90 Days)	2	2	3	7
Non-Traffic Fatality	2	2	1	5
Total	2,580	2,522	2,254	7,356

5.2 Crash Reports Analysis Results

Some severe backing crashes occur mainly due to irrational driving maneuvers instead of limited rear view or no rear visibility. Also, it is noted that there is limited potential of using a rearview video system to prevent certain type of high speed backing crashes, including crashes that occur at a 90° angle where one vehicle is entering the path of another vehicle and thus cannot be avoided because the situation leaves little or no warning to the driver to react.

As mentioned earlier, a total of 1,549 Florida traffic crash police reports (Long Form) between 2003 and 2006 were randomly selected and reviewed to assess if the cause of the backing crash was closely related to the lack of view or limited view. The review of these crash reports included backing crashes involving medium and large trucks as well as tractor-trailers. The backing crashes were classified by injury severity, which can be used as a measure of crash severity. In general, the injury severity is highly correlated with the speed of the vehicles involved in the crash. The injury severity index has five categories:

1. No injury
2. Possible injury
3. Non-incapacitating injury
4. Incapacitating injury
5. Fatality

The review process began with the most severe crashes that involved incapacitating and fatal injuries. About fifty percent of these crashes involved at least one vehicle that was traveling at higher than 10 mph, and the cause of crash was random, primarily due to irrational driving maneuvers instead of limited or no rear visibility. The effort was then extended to lower injury severity. The remainder of the backing crashes reviewed included 104 non-incapacitating injury, 323 possible injury, and 1,035 no injury crashes.

5.2.1 "No Injury" Backing Crashes

For the "No injury" category, coded as 01, the reports showed that a total of 1,080 crashes involved trucks (including vehicle type 04 = medium truck, type 05 = heavy truck, and type 06 = tractor trailer). Of those, 45 were eliminated because the at-fault vehicle did not back up but rather rolled back and struck the vehicle behind it.

For the purpose of this study being the use of the rearview video system as backing crash countermeasure, the crashes were analyzed for their major causes and useful information for the intended research. First the crash location was found as shown in Table 5.4.

Table 5.4: Crash location for "No Injury" backing crashes.

Location	Frequency	Percent
Access road	1	0.10
Alley	3	0.29
Check point gate	3	0.29
Construction site	2	0.19
Construction zone	1	0.10
Dirt road	2	0.19
Driveway access	79	7.63
Dump site	1	0.10
Emergency lane	1	0.10
Entrance ramp	5	0.48
Exit ramp	3	0.29
Intersection	273	26.38
Parking lot	331	31.98
Private property	25	2.42
Railroad	3	0.29
Shoulder	2	0.19
Street	288	27.83
Toll booth	7	0.68
Unknown	5	0.48
Total	1,035	100

Since the crash location has quite a few categories, the most common (highest in percentage) categories were chosen to be represented in Figure 5.2. The "parking lot" category includes both public and private parking lots. The “other” category includes all other locations shown in Table 5.4.

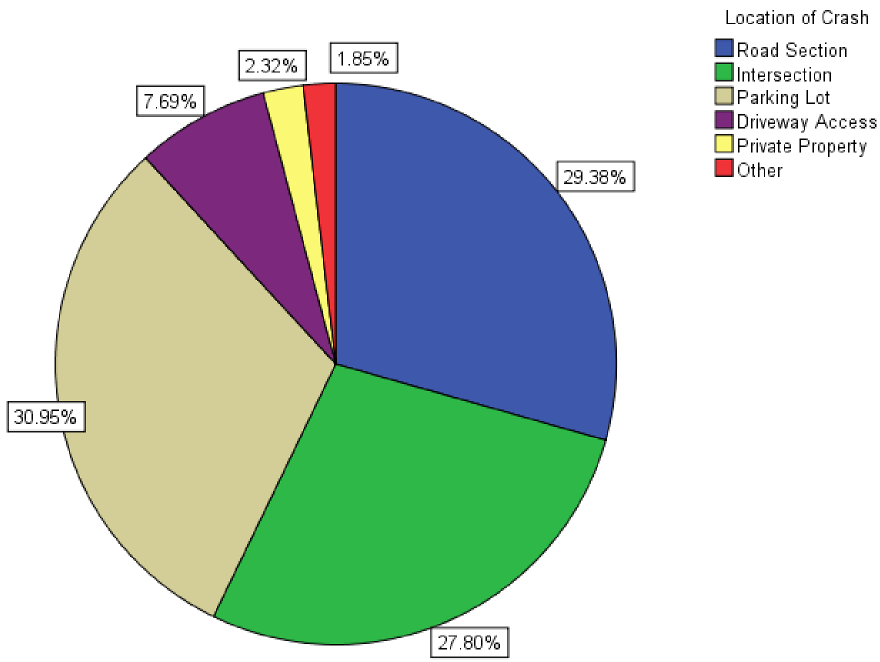

Figure 5.2: The most common crash locations for “No Injury” backing crashes.

Next analysis of the speed of vehicle 1 (the at-fault vehicle) and vehicle 2 (the second vehicle) was performed. The speed of the vehicle is the “estimated speed” reported by the police officer; it is not an observed value but provides the best estimate for the vehicle speed at the time of the crash. The mean of both speeds was below 1.5 mph, which indicates that the vehicles were traveling at very low speeds. As shown in Table 5.5, 74 percent of the crashes with reported speeds occurred when both the at-fault vehicle and the second vehicle were traveling at speeds less than 10 mph. This includes the crashes when the second vehicle was stopped, and the speed was zero mph. Due to the nature of these crashes, the location and estimated speed of the vehicles, most could have been avoided if a rear view was provided and the driver could see that there was a vehicle

Table 5.5: Estimated speed of vehicles for "No Injury" backing crashes.

		Next vehicle speed					
	Speed (mph)	0-5	5-10	10-15	15-20	20+	Total
At-fault veh.speed	0-5	577	17	8	4	18	619
	5-10	110	10	3	2	2	127
	10-15	17	1	5	1	2	26
	15-20	1	1	1	2	1	6
	20+	2	1	0	0	2	5
	Total	707	30	17	9	20	783*

*Discrepancy in totals due to missing data.

behind the truck when backing. Since no driver deliberately wants to hit another vehicle, the lack of rear view or limited rear view can be named as the cause of the crash.

Table 5.6 shows that in the majority of backing crashes (60%) the at-fault vehicle is a truck, but the second vehicle is an automobile. This supports the evidence that small vehicles such as the passenger vehicles tend to "disappear" in the rear blind spot of larger vehicles so that the driver cannot see them prior to backing. This was reported in 133 cases (12.9%) where the at-fault drivers reported that they checked their mirrors before backing and did not see the vehicle behind them.

Table 5.6: Vehicle types involved in "No Injury" backing crashes.

	At-Fault Vehicle Type			
Other Vehicle Type	Medium Truck (4 rear tires)	Heavy Truck (>2 rear axles)	Truck Tractor (Cab)	Total
Automobile	214	182	164	560
Van	20	23	18	61
Light Truck	57	59	54	170
Medium Truck	11	12	15	38
Heavy Truck	5	34	5	44
Truck Tractor	5	2	51	58
Total	312	312	307	931*

*Discrepancy in totals due to missing data.

5.2.2 "Possible Injury" Backing Crashes

For the "Possible Injury" category coded as 02, the Florida Crash Database had a total of 334 crashes involving trucks (vehicle codes 04, 05, and 06). Of those, 11 cases were eliminated because the at-fault vehicle did not back up but rather rolled back and struck the vehicle behind it. In these cases the at-fault driver didn't realize that the vehicle was rolling back and thus could not avoid the crash even with a countermeasure in place. For the purpose of our study, the crashes were analyzed for their major causes and useful information for the countermeasure research. First the crash location was found as shown in Table 5.7.

Table 5.7: Crash location for "Possible Injury" backing crashes.

Location	Frequency	Percent
Airport tarmac	1	0.31
Bridge	2	0.62
Cul de sac	2	0.62
Driveway access	29	8.98
Exit ramp	5	1.55
Intersection	110	34.06
Loading dock	1	0.31
Median opening	1	0.31
Parking lot	57	17.65
Private property	8	2.48
Street	102	31.58
Toll booth	4	1.24
Total	323	100

Since the crash location has quite a few categories, the most common categories are presented in Figure 5.3. The "parking lot" category includes both public and private parking lots. The "other" category includes all other locations shown in Table 5.7.

Next, an analysis of the speed of vehicle 1 (at fault vehicle) and vehicle 2 (the second vehicle) was performed. The speed of the vehicle is the "estimated speed" and is reported by the police officer by estimation and/or reported by witnesses. It is not a fact, or measured in any way but it gives a feel to the vehicle speed at the time of the crash. The missing values were not reported in the crash

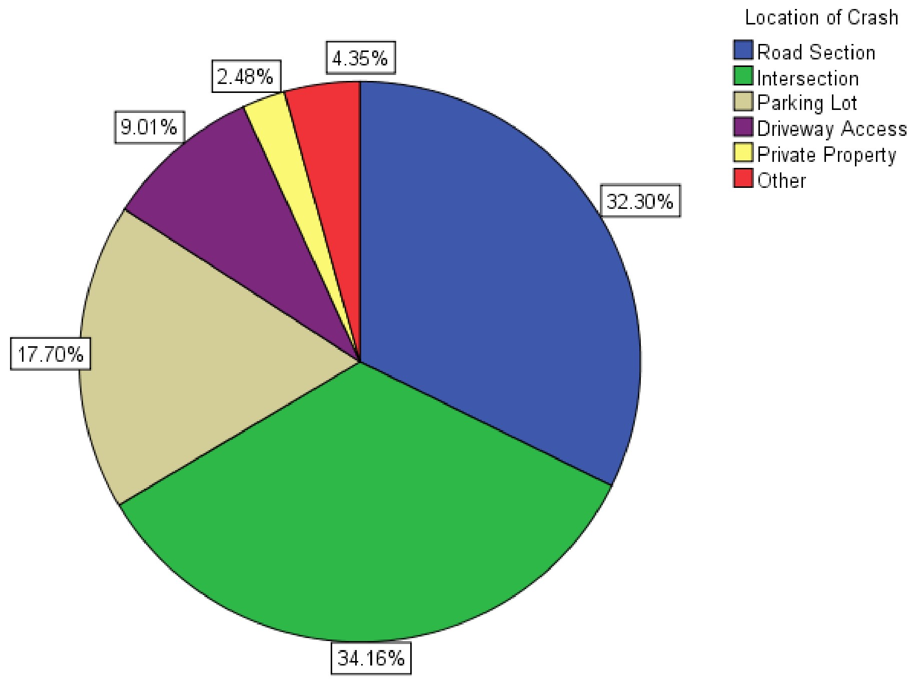

Figure 5.3: The most common crash locations for “Possible Injury” backing crashes.

reports. The mean of both speeds is below 1.5 mph which shows the vehicles were traveling at very low speeds. As expected the at-fault vehicle, is traveling at lower than 10 mph and the second vehicle most of the time is also traveling at lower than 10 mph. Table 5.8 shows that 53 percent of the crashes with reported speeds occurred when both vehicles were traveling with less than 5 mph. This includes the crashes when the second vehicle was stopped and the speed was zero mph. Table 5.9 shows that in the majority of backing crashes (68%) the at-fault vehicle is a truck, but the second vehicle is an automobile. This supports the evidence that small vehicles such as the passenger vehicles tend to “disappear” in the rear blind spot of larger vehicles so that the driver cannot see them prior to backing. This was reported in 62 cases (20%) where the at-fault driver reported that they checked their mirrors before backing and did not see the vehicle behind them.

Table 5.8: Estimated speed of vehicles for “Possible Injury” backing crashes.

		Next vehicle speed					
	Speed (mph)	0-5	5-10	10-15	15-20	20+	Total
At-fault veh.speed	0-5	140	10	3	2	18	173
	5-10	47	4	5	2	9	67
	10-15	10	0	2	0	1	13
	15-20	5	1	0	0	0	6
	20+	0	1	1	0	1	3
	Total	202	16	11	4	29	262*

*Discrepancy in totals due to missing data.

Table 5.9: Vehicle types involved in “Possible Injury” backing crashes.

	At-Fault Vehicle Type			
Other Vehicle Type	Medium Truck (4 rear tires)	Heavy Truck (>2 rear axles)	Truck Tractor (Cab)	Total
Automobile	87	81	43	211
Van	6	7	7	20
Light Truck	25	11	11	47
Medium Truck	2	2	1	5
Heavy Truck	1	3	0	4
Truck Tractor	1	1	11	13
Bus	1	3	0	4
Motorcycle	1	1	2	4
Other	0	2	0	2
Total	124	111	75	310*

*Discrepancy in totals due to missing data.

5.2.3 “Non-Incapacitating Injury” Backing Crashes

For the “Non-Incapacitating Injury” category coded as 03, the Florida Crash Database had a total of 104 crashes involving trucks (vehicle codes 04, 05, and 06). Similar to the two previous injury severity crashes, the “Non-Incapacitating Injury” crashes occurred in the locations shown in Table 5.10.

The most common location categories are presented in Figure 5.4.

Table 5.10: Crash location for "Non Incapacitating Injury" backing crashes.

Location	Frequency	Percent
Bridge	1	0.96
Driveway access	11	10.58
Entrance ramp	1	0.96
Exit ramp	3	2.88
Influenced by ramp	1	0.96
Intersection	43	41.35
Median opening	1	0.96
On Road	25	24.04
Private parking lot	6	5.77
Private property	2	1.92
Public parking lot	10	9.62
Total	104	100

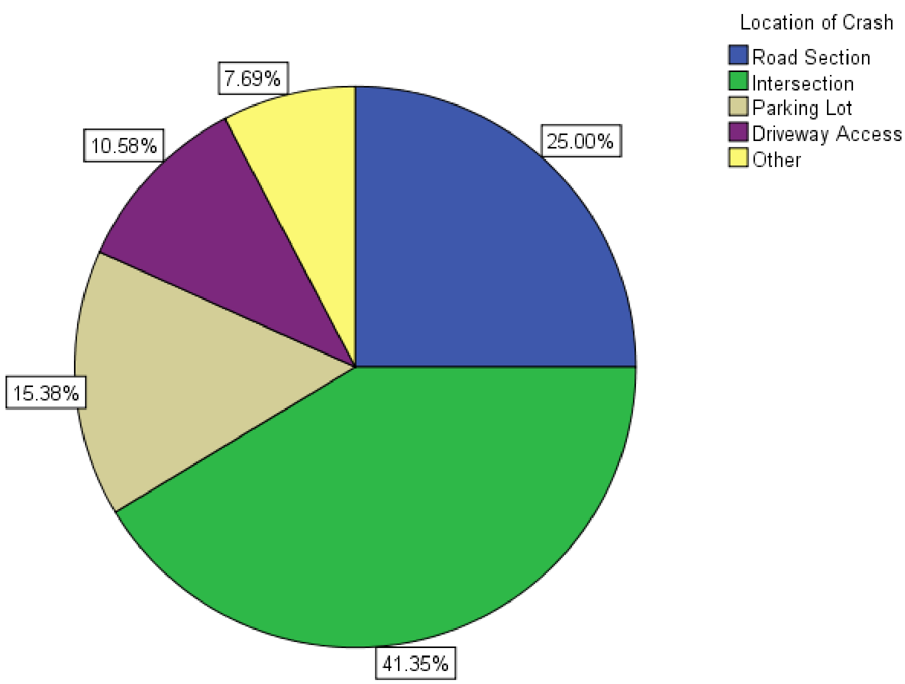

Figure 5.4: The most common crash locations for "Non-Incapacitating Injury" backing crashes.

Next, an analysis of the speed of v1 (at fault vehicle) and v2 (the second vehicle) was performed. The speed of the vehicle is the "estimated speed" and is reported by the police officer by estimation and/or reported by witnesses. As shown in Table 5.11, 58 percent of the crashes occurred while the vehicle speed was less than 10 mph. Due to the nature of these crashes, the location and estimated speed of the vehicles, most crashes above could be avoided if the driver could see that there was a vehicle behind the truck when backing.

Table 5.11: Estimated speed of vehicles for "Non-Incapacitating Injury" backing crashes.

		Next vehicle speed					
	Speed (mph)	0-5	5-10	10-15	15-20	20+	Total
At-fault veh.speed	0-5	40	3	2	0	13	58
	5-10	7	1	1	1	5	15
	10-15	3	0	1	0	3	7
	15-20	2	1	0	0	0	3
	20+	2	0	0	0	27	4
	Total	54	5	4	1	23	87*

*Discrepancy in totals due to missing data.

Table 5.12 shows that in the majority of backing crashes (59%) the at-fault vehicle is a truck, but the second vehicle is an automobile. The difference in size is more important in cases where the second vehicle is much smaller than the at-fault vehicle such as automobiles or motorcycles.

Table 5.12: Vehicle types involved in "Non-Incapacitating Injury" backing crashes.

	At-Fault Vehicle Type			
Other Vehicle Type	Medium Truck (4 rear tires)	Heavy Truck (>2 rear axles)	Truck Tractor (Cab)	Total
Automobile	18	19	20	57
Van	5	5	1	11
Light Truck	4	4	2	10
Medium Truck	0	0	0	0
Heavy Truck	1	0	0	1
Truck Tractor	0	3	0	3
Bus	2	1	0	3
Motorcycle	4	3	2	9
Other	2	1	0	3
Total	36	36	25	97*

*Discrepancy in totals due to missing data.

5.2.4 "Incapacitating Injury" Backing Crashes

For the "Incapacitating Injury" category coded as 04, the Florida Crash Database had a total of 60 crashes involving trucks (vehicle codes 04, 05, and 06). Of those, 22 cases were eliminated because the at-fault vehicle did not back up but rather rolled back and struck the vehicle behind it. Another 15 crashes were removed because of wrong coding. The crash location was found as shown in Figure 5.5.

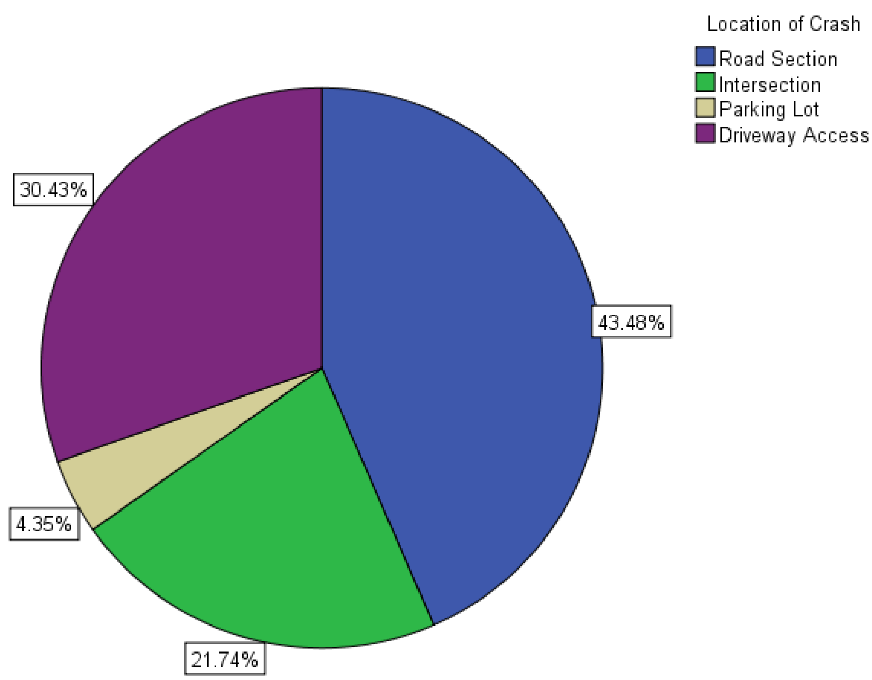

Figure 5.5: The location categories for "Incapacitating Injury" backing crashes.

Next, an analysis of the speed of v1 (at fault vehicle) and v2 (the second vehicle) was performed. As shown in Table 5.13, only 38 percent of the crashes occurred while the vehicle speed was less than 10 mph. The majority of backing crashes in this category occurred when both vehicles were traveling with more than 10 mph, even more than 20 mph, thus the high injury severity.

Table 5.13: Estimated speed of vehicles for “Incapacitating Injury” backing crashes.

		Next vehicle speed					
	Speed (mph)	0-5	5-10	10-15	15-20	20+	Total
At-fault veh.speed	0-5	5	1	0	0	11	17
	5-10	2	0	0	0	0	2
	10-15	0	2	0	0	0	2
	15-20	0	0	0	0	0	0
	20+	2	0	0	0	0	0
	Total	7	3	0	0	11	21*

*Discrepancy in totals due to missing data.

Due to the nature of these crashes, the location and estimated speed of the vehicles, most crashes above could not be avoided even if the driver could see that there was a vehicle behind the truck when backing.

Table 5.14 shows that in the majority of backing crashes (61%) the at-fault vehicle is a truck, but the second vehicle is an automobile. The difference in size is more important in cases where the second vehicle is much smaller than the at-fault vehicle such as automobiles, and vans.

Table 5.14: Vehicle types involved in “Incapacitating Injury” backing crashes.

	At-Fault Vehicle Type			
Other Vehicle Type	Medium Truck (4 rear tires)	Heavy Truck (>2 rear axles)	Truck Tractor (Cab)	Total
Automobile	3	8	2	13
Van	1	0	0	1
Light Truck	1	2	0	3
Medium Truck	1	0	1	2
Other	0	4	0	4
Total	6	14	3	23*

*Discrepancy in totals due to missing data.

5.2.5 “Fatal” Backing Crashes

The fatal backing crashes coded as 05 and 06 in the database, were much less frequent than other injury severities. From a total of 12 fatal backing crashes, only 8 did not have missing data. The most common locations of these backing crashes, are shown in Figure 5.6. The speed of the two vehicles involved in these crashes is shown in Table 5.15.

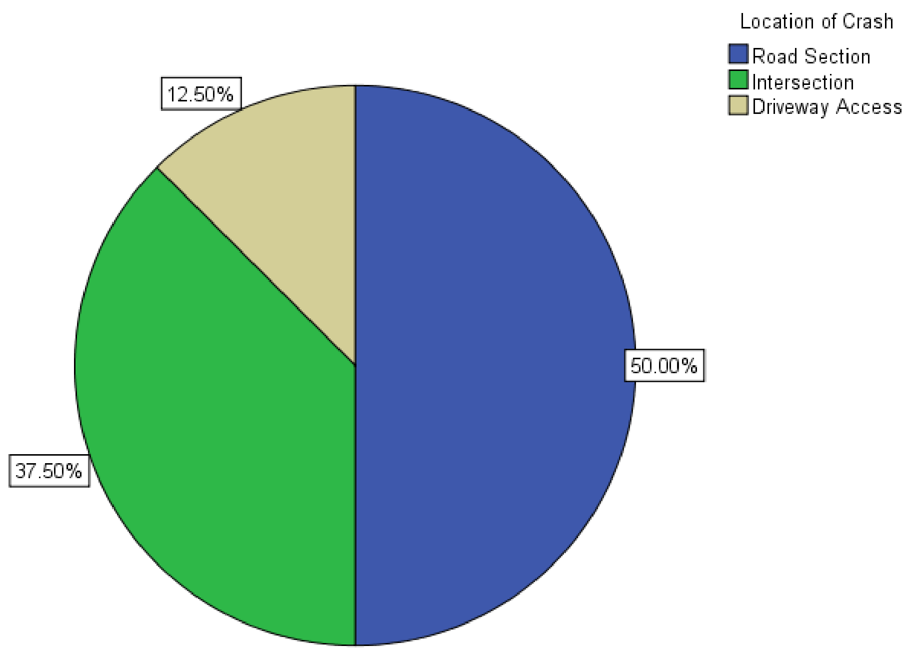

Figure 5.6: The location categories of “Fatal” backing crashes.

Due to the nature of these crashes, the location and estimated speed of the vehicles, most crashes above could not be avoided even if the driver could see that there was a vehicle behind the truck when backing. The vehicle types involved in fatal backing crashes for the years 2003-2006 in Florida are shown in Table 5.16. For all fatal crashes the at-fault vehicle was much larger in size than the second vehicle.

Table 5.15: Estimated speed of vehicles for "Fatal" backing crashes.

		Next vehicle speed				
	Speed (mph)	0-5	5-10	10-45	45+	Total
At-fault veh.speed	0-5	2	0	2	0	4
	5-10	0	1	0	0	1
	10-20	0	0	0	0	0
	20+	0	0	1	2	3
	Total	2	1	3	2	8*

*Discrepancy in totals due to missing data.

Table 5.16: Vehicle types involved in "Fatal" backing crashes.

	At-Fault Vehicle Type			
Other Vehicle Type	Medium Truck (4 rear tires)	Heavy Truck (>2 rear axles)	Truck Tractor (Cab)	Total
Automobile	2	1	0	2
Light Truck	3	0	0	3
Motorcycle	0	0	1	1
Other	1	0	0	1
Total	6	1	1	8*

*Discrepancy in totals due to missing data.

5.3 Identification of Applicable Backing Crashes

To prevent backing crashes with the RVS, the crash needs to meet certain conditions such as "point of impact" and "crash speed." Since the rearview camera is located at the rear of the vehicle, it would be difficult to assume that the RVS can help to prevent backing crashes when the point of impact of the at-fault vehicle is the front side of the vehicle. Based on each type of vehicle point of impact, the backing crash amount was estimated. Results indicated that for the at-fault vehicles, the point of impact usually was the rear part of the vehicle, while for the second vehicle it was the front part of the vehicle. However, as shown in Table 5.17, a total of 17.1 percent of backing crashes involved vehicle damage to the front side of the vehicles (impossible for the backing vehicle).

Table 5.17: Point of impact of at-fault vehicle during all backing crashes.

Point of Impact	Frequency	Percent
Front End	962	13.08
Right Front Corner	141	1.92
Right Front Quarter Panel	79	1.07
Right Rear Quarter Panel	206	2.80
Right Rear Corner	1,064	14.46
Rear End	2,177	29.59
Left Rear Corner	724	9.84
Left Rear Quarter Panel	74	1.01
Left Front Corner	78	1.06
Trailer	1,421	19.32
Other*	262	3.64
Total	7,188	100

*Note: Other includes hood, roof, trunk, undercarriage, windshield, overturn, etc.

Also, the RVS can be effective to prevent backing crashes when the vehicle speed is relatively low. Table 5.18 shows the speed of the vehicles at the time of the crash. As shown, 84 percent of backing crashes occurred when both vehicles are stopping or moving with less than 10 mph.

Table 5.18: Speed of vehicles at time of all backing crashes.

		Next vehicle speed					
	Speed (mph)	0-5	5-10	10-15	15-20	20+	Total
At-fault veh.speed	0-5	789	35	15	6	55	900
	5-10	164	16	10	4	16	210
	10-15	28	2	8	0	5	43
	15-20	8	3	2	2	2	17
	20+	5	2	2	0	6	15
	Total	994	58	37	12	84	1,185*

*Discrepancy in totals due to missing data.

Based on the analysis with the point of impact and speed of vehicles at the time of crash, it seems that 84 percent of low speed (both vehicles travel with less than 10 mph) backing crashes among 83 percent of all backing crashes which damages the rear side of the backing vehicle can be potentially eliminated or reduced by adopting RVS as a countermeasure.

Chapter 6: Driver Behavior Analysis

According to the research methodology described in chapter 3, the data collected from the experiment were twofold: driver behavior or usage of the system, and driver acceptance of the system. The analysis of this data provides important factors needed to be included in the statistical model for the system evaluation.

A total of 45 drivers participated in the experiment. Their ages ranged from under 25 years old to above 50 years old. They were all male. Figure 6.1 shows the 45 drivers' age distribution.

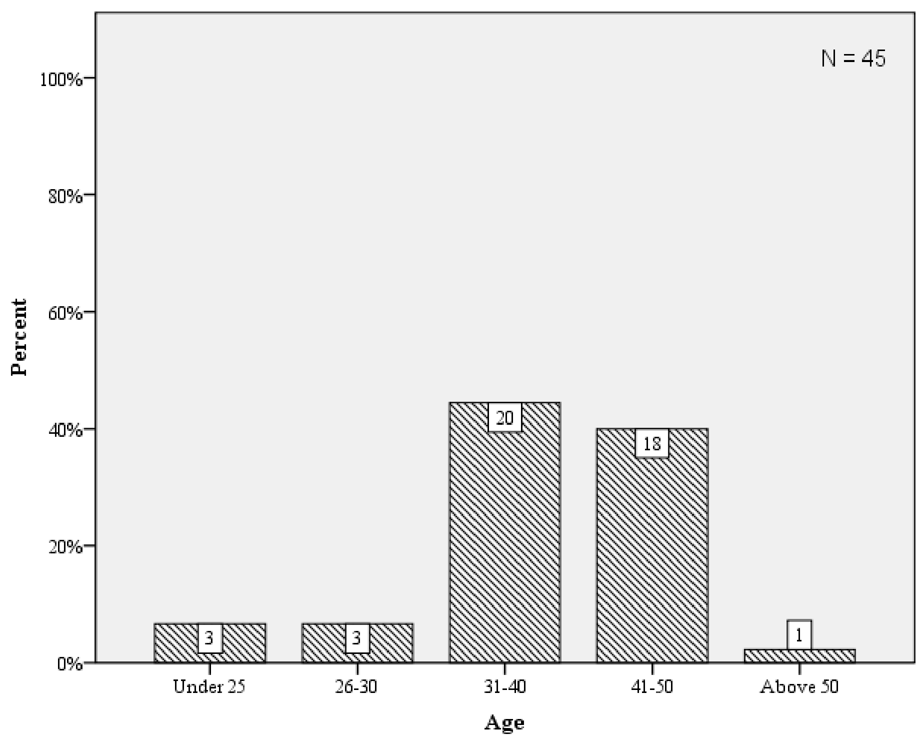

Figure 6.1: The driver age distribution.

The drivers had commercial driving experience from 1 year to 34 years with a mean of 10.91 years as shown in Figure 6.2. Their driving experience does not follow their age distribution precisely as expected, but as a driver gets older it has more experience. This is due to some drivers starting to work at this profession at an older age. Out of 45 drivers 15 had previous experience with the RVS whereas for 30 drivers it was the first time they used the RVS.

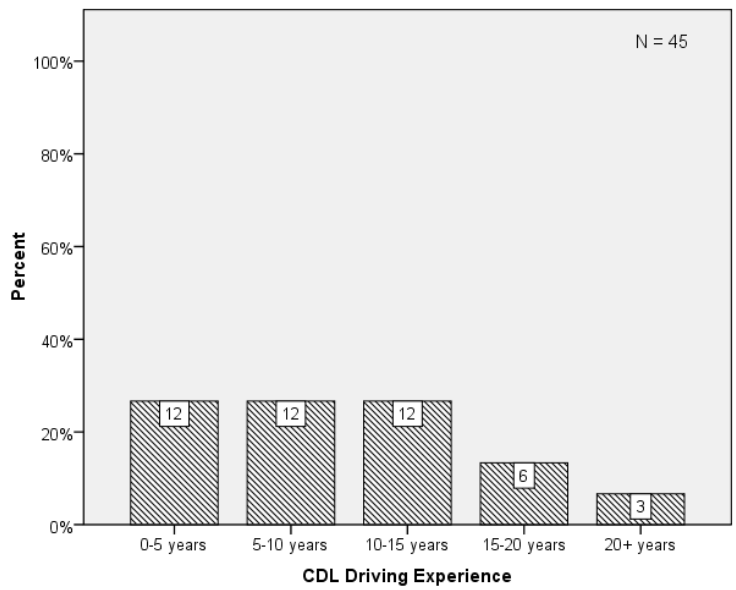

Figure 6.2: Drivers' CDL driving experience distribution.

In addition, 15 drivers had at least one backing crash in their career, with one having up to 4 backing crashes. Figure 6.3 shows that according to their own testimonials, 30 drivers had no backing crashes.

The driver behavior was divided into two aspects: driver visual attention and driver acceptance. The following sections present the driver's attention in relation to the usage of the system and if the drivers accept the device as a useful addition to their vehicles.

Figure 6.3: The backing crash history of the sample in number of crashes.

6.1 Driver Visual Attention

The drivers were expected to use the system in a specific manner, but in order to collect realistic data, the drivers were observed during the experiment, and inferences could be made on the usage of the system. It was found that the drivers used the RVS just like another mirror. They glanced at the monitor while scanning from the driver side mirror to the passenger side mirror. As mentioned earlier, it was decided that four locations were used for the driver glance location analysis:

1. Driver side mirror
2. Passenger side mirror
3. Rearview video system monitor
4. All others

These four locations were distinguished by looking at the driver's head direction during the maneuver. Figure 6.4 shows a driver looking at the driver side mirror location, Figure 6.5 shows the driver looking at the passenger side mirror location, Figure 6.6 shows the driver looking at the monitor, and Figure 6.7 shows the driver looking straight forward which is considered as "other" location.

Figure 6.4: "Driver" side location.

Figure 6.5: "Passenger" side location.

Figure 6.6: "Monitor" location.

Figure 6.7: "Other" location.

When investigating the driver's glance locations, a pattern becomes clear. When the drivers did not have the system, they spent their backing time glancing at the three areas: driver and passenger mirror and any other location. At these times the rear of the vehicle is completely blind to the driver. When they have the system, however, they have to divide their time in four locations: the three mentioned before as well as the monitor. In fact, the average maneuver time increased for the maneuvers with the system as shown in Table 6.1.

The maneuver duration was measured from the time the truck started moving backwards, until the time the truck stopped at the end of the maneuver position. During this time there were three possible cases shown in Figure 6.8:

Table 6.1: Average maneuver times.

Maneuver Type	Without RVS (sec)	With RVS (sec)
Straight Line Backing	65.5	72.2
Offset Right Backing	60.3	66.0
Alley Dock Backing	70.5	77.5
Total	65.4	71.9

- Case 1: The driver started backing, but needed to adjust the truck, and stopped, moved forward, stopped again and then continued backing until the end. If the driver saw the object, he stopped again, similar to case 2.
- Case 2: The driver started backing, and when the pedestrian dummy was introduced the driver stopped for a certain time, until the measurements were made, and continued to finish the maneuver.
- Case 3: The driver started backing, and not seeing the dummy or cone, thus having a crash continuing to back until the end point. In this case the driver did not know he had a crash.

For all maneuver durations to be comparable, the stopped and forward time was subtracted from the total elapsed time for all drivers. The reported maneuver times are only backing times.

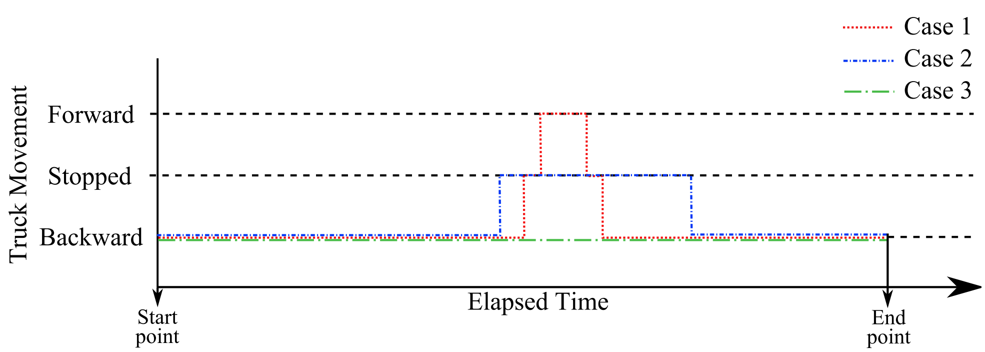

Figure 6.8: The maneuver timeline.

The drivers had to divide their backing time looking at all locations. Figure 6.9 shows an example of the same driver performing the Straight Line Backing Maneuver with and without the RVS. As expected, the time with the RVS was longer, since the addition of the monitor location demanded their attention. Different drivers however had different patterns in the frequency and duration of the glance locations.

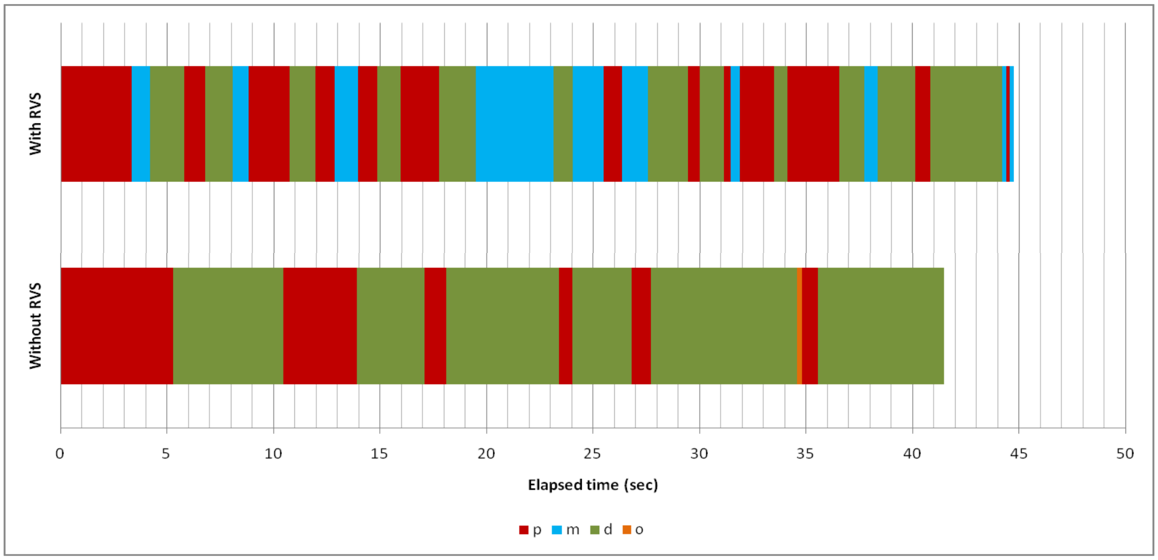

Figure 6.9: The glance pattern of a driver performing the Straight Line Backing Maneuver. Legend: p = "passenger" location, m = "monitor" location, d = "driver" location, o = "other" location.

The drivers' outcome was coded as a crash if they struck the cone or pedestrian surrogate, and no crash if they stopped before striking the two objects. First, differences in the stopping rates (not hitting cone or dummy object) were tested with and without a rearview system. Table 6.2 shows the summarized raw data. To test the null hypothesis is the same as testing the difference of the probabilities of stopping with and without a RVS:

$$H_0 : P_{1+} = P_{+1}$$

$$H_1 : P_{1+} > P_{+1}$$

$$P_{1+} = P_{11} + P_{12} = Pr(\text{Stop} \mid \text{With Camera})$$

$$P_{+1} = P_{11} + P_{21} = Pr(\text{Stop} \mid \text{Without Camera})$$

The dataset includes three types of maneuvers (tests):

Table 6.2: Summarized outcomes.

		Without RVS Stop	Without RVS Crash
With RVS	Stop	P_{11}	P_{12}
	Crash	P_{21}	P_{22}

1. Straight Line Backing Maneuver

2. Offset Right Backing Maneuver

3. Alley Dock Backing Maneuver

These were analyzed using only the outcome information, i.e., crash or stop. Table 6.3 shows the summarized 2X2 contingency tables.

Table 6.3: 2X2 Contingency tables for the three tests.

		Straight Line Back Without RVS		Offset Right Back Without RVS		Alley Dock Back Without RVS		Total Without RVS	
		Stop	Crash	Stop	Crash	Stop	Crash	Stop	Crash
With RVS	Stop	11	21	30	7	35	9	76	37
	Crash	0	13	5	3	1	0	6	16

$$\text{Estimations: } d = P_{1+} - P_{+1},\ \hat{\sigma}^2(d) = \frac{P_{12} + P_{21} - (P_{12} - P_{21})^2}{n}$$

A McNemar test was adopted for matched paired data and to report the p-values from the null binomial probability distribution and the asymptotic calculations.

$$\text{McNemar Test Statistics} = \frac{(P_{12} - P_{21})^2}{P_{12} + P_{21}} \sim X^2_{df=1} \text{ under null probability distribution.}$$

The value in parentheses is the asymptotic calculation, and the rates and variances are calculated from the above equations. As an example the stop rate and variance of the Straight Line Backing

Maneuver are calculated:

$$\text{Straight Line Backing Increase Stop Rate} = \frac{(P_{11}+P_{12})}{n} - \frac{(P_{11}+P_{21})}{n} = \frac{32}{45} - \frac{11}{45} = 0.4666$$

$$\text{Straight Line Backing Variance} = \frac{P_{12}+P_{21}-(P_{12}-P_{21})^2}{n} = \frac{\frac{21}{45}+\frac{0}{45}-(\frac{21}{45}-\frac{0}{45})^2}{45} = 0.00553$$

The calculations of the increased stop rate for all maneuvers are shown in Table 6.4. The presence of an RVS increased the stop rate of the drivers in Straight Line Backing Maneuver by 46.7 percent, which can be interpreted as the increase of odds to avoid potential backing crash in the maneuver. Respectively, the stop rate is increased 4.4 and 17.8 percent for the Offset Right Backing Maneuver and Alley Dock Backing Maneuver.

Table 6.4: Result of McNemar test.

Maneuver	P-value	Increased Stop Rate	Variance
Straight Line Backing	4.593e-06	46.7%	0.55%
Offset Right Backing	0.5637	4.4%	0.59%
Alley Dock Backing	0.0114	17.8%	0.42%
Total (45) Back Test	2.274e-06	23.0%	0.20%

To test variables having a significant effect on the increase of the stop rate, variables such as Type (Maneuver Type), Cam (RVS), Age (Driver Age), Yr (CDL Experience), and ExpRVS (RVS Experience) were evaluated. The model was refined for the important variables. Also, two interaction terms were introduced and the final mathematical model is shown in Table 6.5.

Table 6.5: Coefficients for first model.

Coefficients	Estimate	Std. Error	Z value	Pr(>|z|)	
Intercept	1.1285	0.3469	3.253	0.00114	**
Type 2	-2.3812	0.4989	-4.773	1.81e-06	***
Type 3	-2.5148	0.5091	-4.939	7.84e-07	***
RVS	-2.0293	0.4780	-4.245	2.18e-05	***
Type 2:RVS	1.7505	0.7135	2.453	0.01415	*
Type 3:RVS	-0.3686	1.1790	-0.313	0.75453	

Significant Codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

The mathematical model can represent the probability of backing crash based on the controlled test data as follows:

$$log\frac{Pr(Y=1)}{Pr(Y=0)} = \alpha_0 + \alpha_1 X_1 + \alpha_2 X_2 + \alpha_3 X_3 + i_1 X_1 X_3 + i_2 X_2 X_3$$

By entering the coefficients, the probability of having a crash becomes:

$$Pr(Y=1) = \frac{e^{1.1285-2.3812X_1-2.5148X_2-2.0293X_3}}{1+e^{1.1285-2.3812X_1-2.5148X_2-2.0293X_3}}$$

Where,

$$X_1 = \begin{cases} 1, & \text{Man 2} \\ 0, & \text{otherwise} \end{cases}$$

$$X_2 = \begin{cases} 1, & \text{Man 3} \\ 0, & \text{otherwise} \end{cases}$$

$$X_3 = \begin{cases} 1, & \text{with RVS} \\ 0, & \text{without RVS} \end{cases}$$

The probability of having a crash (hitting the object) as described in the experiment can be estimated by using the mathematical model for each maneuver as follows:

- Maneuver 1 (Straight Line Backing):

$$Pr(\text{Crash | M1 With RVS}) = \frac{e^{1.1285-2.0293}}{1+e^{1.1285-2.0293}} = 28.89\%$$

$$Pr(\text{Crash | M1 Without RVS}) = \frac{e^{1.1285}}{1+e^{1.1285}} = 75.56\%$$

The difference of crash rate for M1 with/without RVS = 75.56% - 28.89% = 46.67%

- Maneuver 2 (Offset Right Backing):

$$Pr(\text{Crash} \mid \text{M2 With RVS}) = \frac{e^{1.1285-2.3812+1.7505-2.0293}}{1+e^{1.1285-2.3812+1.7505-2.0293}} = 17.78\%$$

$$Pr(\text{Crash} \mid \text{M2 Without RVS}) = \frac{e^{1.1285-2.3812}}{1+e^{1.1285-2.3812}} = 22.22\%$$

The difference of crash rate for M2 with/without RVS = 22.22% - 17.78% = 4.44%

- Maneuver 3 (Alley Dock Backing):

$$Pr(\text{Crash} \mid \text{M3 With RVS}) = \frac{e^{1.1285-2.5148-2.2093-0.3686}}{1+e^{1.1285-2.5148-2.2093-0.3686}} = 2.22\%$$

$$Pr(\text{Crash} \mid \text{M3 Without RVS}) = \frac{e^{1.1285-2.5148}}{1+e^{1.1285-2.5148}} = 20.00\%$$

The difference of crash rate for M3 with/without RVS = 20.00% - 2.22% = 17.78%

Further testing was performed to evaluate if the increase in the stop rate was related to the actual frequency or duration of watching the monitor during the backing maneuvers by the drivers. Since the duration of backing maneuvers was different by the individuals in the test, the updated frequency (F*) was used for further analysis as follows:

$$F(k)^*_{Driver_i} = F_{Driver_i} * \frac{\text{Duration of Maneuver } k_{Driver_i}(t)}{\text{Average Duration of Maneuver } k(\bar{t})\forall \text{ Drivers}}$$

$F(k)_{Driver_i}$ = Frequency of Driver *i* of monitor glances during maneuver *k*.

The likelihood of having a crash with the frequency of monitor glancing was tested and shown in Table 6.6. The ODDS ratio is decreased by the factor $e^{-0.05694} = 0.94465$.

Table 6.6: Monitor glance frequency ANOVA testing.

Coefficients	Estimate	Std. Error	Z-Value	Pr (>|z|)	
Intercept	-1.18961	0.35382	-3.362	0.000773	***
M_cnt	-0.05694	0.03827	-1.488	0.136806	

Significant Codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

$M\_cnt = F(k)*_{Driver_i}$

Example:

$Pr(H_{11})$= Probability of crash when driver looks at monitor 11 times during backing maneuver.

$Pr(H_{10})$= Probability of crash when driver looks at monitor 10 times during backing maneuver.

$$\frac{Pr(H_{11})}{1-Pr(H_{11})} = 0.94465\frac{Pr(H_{10})}{1-Pr(H_{10})}$$

It appears that the likelihood of a crash is more closely associated with the ratio of time spent watching the monitor during backing maneuver. The probability of a crash is reduced as the duration of looking at the monitor is increased. Similarly to the frequency, the duration of the monitor glance was updated to (M*) for analysis as follows:

$$M^* = \frac{\text{Monitor Glance Duration}}{\text{Duration of Backing Maneuver}}$$

The likelihood of having a crash with the monitor glance duration was tested and shown in Table 6.7. The ODDS ratio is decreased by the factor $e^{-0.1801} = 0.83519$.

Table 6.7: Monitor glance duration ANOVA testing.

Coefficients	Estimate	Std. Error	Z-Value	Pr (>|z|)	
Intercept	-1.0905	0.3496	-3.119	0.00182	
M_t	-0.1801	0.1006	-1.791	0.07326	.

Significant Codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
M_t = Monitor glance duration.

Example:

$Pr(H_{11})$= Probability of crash when driver looks at monitor for 11 seconds.

$Pr(H_{10})$= Probability of crash when driver looks at monitor for 10 seconds.

$$\frac{Pr(H_{11})}{1-Pr(H_{11})} = 0.83519\frac{Pr(H_{10})}{1-Pr(H_{10})}$$

Although the two measures (monitor glance frequency and duration) were tested individually, they are not statistically significant to the traditional 0.05 level of significance.

From a simple analysis it looks like the three maneuvers did not yield to the same reduction of crash probabilities. Maneuver 2 (Offset Right Backing) yielded to the minimum of 4.44 percent reduction, whereas maneuver 3 (Alley Dock Backing) had 17.78 percent. The highest reduction was experienced in maneuver 1 (Straight Line Backing) with a 46.67 percent reduction of the probability of having a crash. A positive outcome is that a reduction of the probability of having a crash or increase in stop rate was experienced in all maneuvers.

It it important to note that the size of the rear blind spot and the required maneuver effort for both Straight Line Backing Maneuver and Offset Right Backing Maneuver are nearly same in general, but this test introduced a dummy object with different methods. For the Straight Line Backing Maneuver, the dummy object was positioned directly behind the vehicle while a dummy object was moved from the either side of the vehicle to the rear for the Offset Right Backing Maneuver. When the object was approached from the side, the driver had a chance to spot it with one of the two side view mirrors, but the object would be relatively difficult to detect when positioned from the right rear of the truck. Therefore, the difference in the results should not be interpreted as a difference in maneuvers. Rather, it represents a different level of effectiveness of the rearview video system to detect objects from different sides of the vehicle.

Also, it is noted that there is a difference in the increase of the stop rate for Offset Right Backing Maneuver and Alley Dock Backing Maneuver, although the same method was used to introduce a dummy object into the test. It appears that the Alley Dock Backing Maneuver requires more attention and effort by the driver to control the vehicle compared to the Offset Right Backing Maneuver, and it can result in more opportunities for the driver to miss the approaching object with the traditional side view mirrors.

This analysis however has its main objective to include the driver behavior and usage of the system while backing. To continue the driver behavior analysis, the variables shown in Table 6.8 were tabulated in a correlation matrix to obtain correlations between them.

Since a regression model was to be utilized to calculate the probability of having a crash, the variables needed to be uncorrelated. Many of the above variables were highly correlated so they could

Table 6.8: Variables used for behavior analysis.

Variable	Source	Type	Value
Outcome	Experiment	Nominal	1 = Crash, 0 = No Crash
DriverAge	Survey Form	Ordinal	1 = Under 25, 2 = 26-30, 3 = 31-40 4 = 41-50, 5 = 50+
CDL_exp	Survey Form	Continuous	No. of Years
RVS_exp	Survey Form	Nominal	1 = Yes, 0 = No
Backing_hist	Survey Form	Nominal	1 = Yes, 0 = No
Backing_no	Survey Form	Continuous	Number of Crashes
Man_dur	Video	Continuous	Number of Frames
m_cnt	Video	Continuous	Number of Glances
m_dur	Video	Continuous	Number of Frames
p_cnt	Video	Continuous	Number of Glances
p_dur	Video	Continuous	Number of Frames
d_cnt	Video	Continuous	Number of Glances
d_dur	Video	Continuous	Number of Frames
o_cnt	Video	Continuous	Number of Glances
o_dur	Video	Continuous	Number of Frames
avg_trans	Video	Continuous	Number of Frames
avg_gl_dur	Video	Continuous	Number of Frames

not be used in a regression model. A principal component analysis was then utilized to solve this problem. According to [30]:

> "Principal Component Analysis (PCA) involves a mathematical procedure that transforms a set of correlated variables into a smaller set of uncorrelated variables called principal components."

In addition, the variables related to the drivers' glances can be grouped into a category describing the driver's visual attention. The statistical package SPSS ® v17.0 was used to perform the principal component analysis and regression.

Kaiser's Measure of Adequacy (MSA) for a variable X_i is the ratio of the sum of the squared simple r's between X_i and each other X. Thus,

$$MSA = \frac{\Sigma r_{ij}^2}{\Sigma r_{ij}^2 + \Sigma pr_{ij}^2}$$

The overall MSA for these variables is 0.567 which is adequate.

Table 6.9: Correlation matrix for the 8 driver attention variables.

Variables	m_cnt	m_t	d_cnt	d_t	p_cnt	p_t	o_cnt	o_t
m_cnt	1.000	0.907	0.437	-0.195	0.135	-0.201	-0.020	-0.056
m_t	0.907	1.000	0.331	-0.170	0.023	-0.241	-0.015	-0.052
d_cnt	0.437	0.331	1.000	-0.071	0.8007	0.307	0.378	0.253
d_t	-0.195	-0.170	-0.071	1.000	-0.235	-0.233	0.088	0.061
p_cnt	0.135	0.023	0.800	-0.235	1.000	0.628	0.267	0.186
p_t	-0.201	-0.241	0.307	-0.233	0.628	1.000	0.169	0.190
o_cnt	-0.020	-0.015	0.378	0.088	0.267	0.169	1.000	0.780
o_t	-0.056	-0.052	0.253	0.061	0.186	0.190	0.780	1.000

*Note: Shaded cells represent high correlations.

Next the principal components were extracted. The principal components are uncorrelated components that explain the variance of the correlated variables. Table 6.10 shows the eigenvalues and proportions of variance for the eight components.

Table 6.10: Total variance explained.

	Initial Eigenvalues		
Component	Total	% of Variance	Cumulative %
1	2.697	33.715	33.715
2	2.152	26.900	60.615
3	1.484	18.554	79.169
4	0.876	10.951	90.120
5	0.415	5.185	95.305
6	0.205	2.560	97.865
7	0.089	1.110	98.975
8	0.082	1.025	100.000

Extraction Method: Principal Component Analysis.

In order to decide how many components to retain, a rule of thumb is to retain only components with eigenvalues of one or more. That is, drop any component that accounts for less variance than does a single variable. A test however to help with this decision, the SCREE test is a plot that visually aids deciding at what point including additional components no longer increases the amount of variance accounted for by a nontrivial amount. Figure 6.10 shows the SCREE plot provided by SPSS.

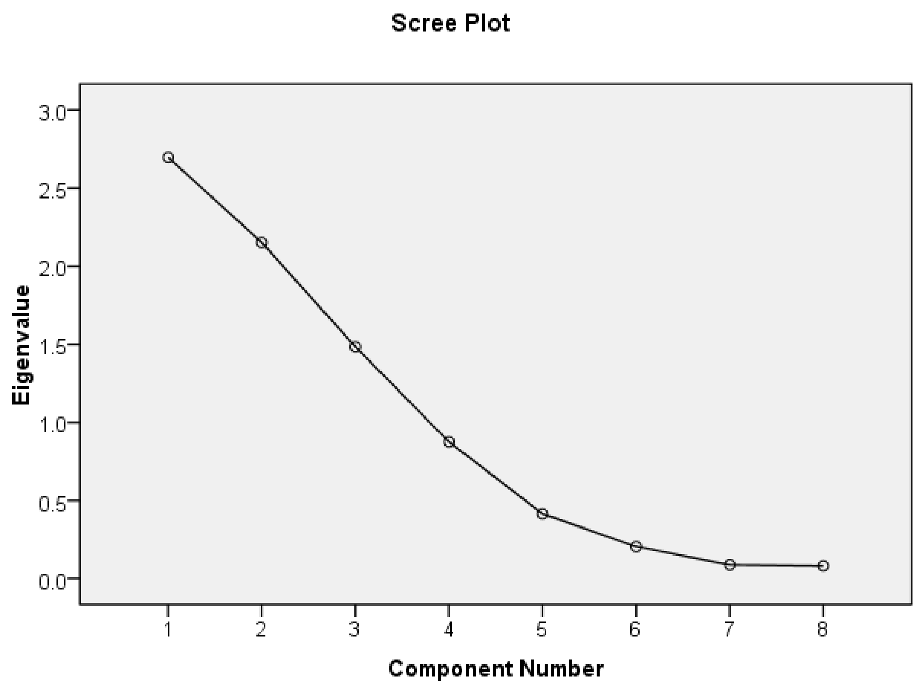

Figure 6.10: The SCREE plot provided by SPSS.

For these data, it was decided that only the first three components would be retained. Component four could be included, but since there were only eight variables, and with three components explaining almost 80 percent of the variance, it was decided to be dropped. After a Varimax rotation, the rotated component matrix is shown in Table 6.11. The coefficients can be used to create the three chosen components.

The three components were named based on their magnitude:

- Component 1: monitor location component
- Component 2: driver and passenger location component
- Component 3: other location component

Table 6.11: Rotated component matrix.*

Variable	Component 1	Component 2	Component 3
Monitor glance frequency	0.966	0.079	-0.039
Monitor glance duration	0.954	-0.024	-0.037
Passenger glance frequency	0.093	0.909	0.208
Passenger glance duration	-0.332	0.805	0.086
Driver glance frequency	0.455	0.665	0.375
Driver glance duration	-0.172	-0.487	0.332
Other glance frequency	0.016	0.129	0.918
Other glance duration	-0.047	0.078	0.895

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
*Note: Rotation converged in 4 iterations.

As mentioned earlier the three new components account for 79.17 percent of the variance of the eight initial variables.

To ensure that the three components are not correlated, the correlation matrix was calculated and shown in Table 6.12. The high correlations experienced before are significantly reduced after the Principal Component Analysis and extraction of the first three principal components.

Table 6.12: Principal components correlation matrix.

Component	Monitor Location	Driver and Passenger Location	Other Location
Monitor Location	1.000	0.161	-0.119
Driver and Passenger Location	0.161	1.000	0.162
Other Location	-0.119	0.162	1.000

A binary logistic regression model was estimated with the three new components grouped for drivers' attention, the driver age, previous experience with the RVS, backing crash history, the maneuver type, if the RVS was ON or OFF and two interaction terms with RVS and maneuver type. Dummy variables were created for all categorical variables and one of the levels was kept as their base. For driver age, the age level above 50 was the control. For maneuver type, maneuver

3 was the control since maneuvers 2 and 3 had a similar pedestrian dummy introduction, whereas maneuver 1 was different. The regression model is predicting the logit, that is, the natural log of the odds of having one or the other outcome (crash, not-crash). That is,

$$ln(ODDS) = ln\left(\frac{\hat{Y}}{1-\hat{Y}}\right) = \alpha_0 + \alpha_1 X_1 + \alpha_2 X_2 + \ldots + \alpha_i X_i$$

Where, $\hat{Y}$ is the predicted probability of the event which is coded with 1 (crash) rather than with 0 (no-crash), $(1-\hat{Y})$ is the predicted probability of the other outcome, X_i is the predictor variable with i variables and α are the coefficients in the model. The -2 Log Likelihood statistic of the model is 202.670. The variables in the equation output shown in Table 6.13, show the regression equation to be:

$$\begin{aligned} ln(ODDS) &= 4.585 - 7.051Age(<25) - 8.171Age(26-30) - 7.081Age(30-40) \\ &\quad -7.869Age(40-50) - 0.787RVS\_Exp(Yes) - 1.671RVS(ON) \\ &\quad -0.292Crash\_history + 3.887Man(1) + 1.292Man(2) \\ &\quad -0.076PC1 - 0.053PC2 + 0.040PC3 + 1.322RVS(ON)*Man(1) \\ &\quad +2.446RVS(ON)*Man(2) \end{aligned}$$

The model's decision rule is used to determine into which group to classify each run given the tests estimated probability of crash. The most obvious decision rule would be to classify the run into the crash group if $\rho > 0.5$ and into the no crash group if $\rho < 0.5$. Since we do not want to make the error of not predicting a crash when it occurred, the decision rule was changed to 0.4 cut-off value. This increased the overall correct percentage to 81.5 percent and significantly increased the percent correct for crash probability estimation. Table 6.14 shows the specification for the two models. The second with cutoff value 0.4 is predicting correctly more crash occurrences.

We can now use this model to predict the ODDS that a driver with given characteristics will have a backing crash. The ODDS prediction equation is $ODDS = e^{\alpha_0+\alpha_1 X_1+\alpha_2 X_2+\ldots+\alpha_i X_i}$. If we have a driver that is 25 years old, with no previous RVS experience, with one previous backing crash,

Table 6.13: Variables in the model.

Variable	B	S.E.	Wald	Sig.
Constant	4.585	2.754	2.771	0.096
Age1	-7.051	2.673	6.960	0.008
Age2	-8.171	2.804	8.494	0.004
Age3	-7.081	2.657	7.101	0.008
Age4	-7.869	2.682	8.606	0.003
RVS Exp (Yes)	-0.787	0.420	3.514	0.061
RVS (ON)	-1.671	1.195	1.954	0.162
Crash history	0.292	0.266	1.205	0.272
Man1	3.887	0.703	30.557	0.000
Man2	1.292	0.699	3.420	0.064
PC1	-0.076	0.027	7.664	0.006
PC2	-0.053	0.015	12.557	0.000
PC3	0.040	0.029	1.891	0.169
RVS(ON) by Man1	1.322	1.318	1.006	0.316
RVS(ON) by Man2	2.446	1.351	3.275	0.070

Table 6.14: Classification statistics for different decision rules.

Cutoff Value	0.5	0.4
Sensitivity	0.493	0.634
Specificity	0.920	0.879
False Positive Rate	0.314	0.651
False Negative Rate	0.164	0.129

Sensitivity = percentage of occurrences predicted correctly, Specificity = percentage of non occurrences predicted correctly, False positive rate = percentage of predicted occurrences which are incorrect, False negative rate = percentage of predicted non occurrences which are incorrect.

with the RVS OFF performing maneuver 1, we would have the first equation, whereas the same driver with all variables constant except the RVS is ON we would have the second equation:

$$ODDS = e^{4.585-7.051+0.292+3.887-0.076-0.053+0.040} = 5.073$$

$$ODDS = e^{4.585-7.051-1.671+0.292+3.887-0.076-0.053+0.040+1.322} = 3.579$$

The ODDS can be converted to probabilities using:

$$\hat{Y} = \frac{ODDS}{1 + ODDS}$$

Using the above equation the probability of having a crash for the driver described above during the experiment, with the RVS OFF is 83.53 percent, whereas the same driver with the RVS ON has a probability of 78.16 percent. Observing the signs of the coefficients one can also infer on the different perspectives of the model. As expected, a driver with previous RVS experience will have a smaller probability, a driver with more backing crashes will have an increased probability, and in this particular test, the maneuver 1 has a higher probability and magnitude than the other two maneuvers. Certain variables did not come as significant as others but were kept in the model for control purposes.

The second model shown in Table 6.13 is meant to help with the identification of important factors that influence the use of the system. Although it calculates the probability of having a backing crash as described in the experiment, this model is not meant to be used for the estimation of crash probability in general. The probabilities calculated are rather high. It must be kept in mind that this model describes the data collected during this experiment. It is far from complete and the probability estimates describe the conditions under which the particular drivers participating in the experiment, performed the requested maneuvers. The data collected during this experiment are certainly limited. Although a general estimation of the effectiveness of the RVS can be explained, the relationships between the factors included in the model are not investigated since the data are not substantial. One can also note that some variables included in the regression modeling are not statistically as significant as others. The approach of including sensible and questionable variables was followed instead of the pure optimization of the best model fit.

6.2 Driver Acceptance

The driver acceptance of any in-vehicle system is as important as the usage, because unless the device is accepted by the driver, it will never reach its full potential unless it is fully automatic. In the case of the RVS and this study, it was found that truck drivers were not convinced of the usefulness of the system from the beginning but rather wanted to test the system first. As mentioned earlier, after the test was completed, a questionnaire was given to the participating drivers shown in Appendix C. The drivers were asked a series of questions about how they felt backing with the system in relation to having no system. The replies could not be incorporated into the statistical model shown in the previous section so they are presented separately here.

First the drivers were asked to say if they felt more comfortable performing the backing maneuver with the RVS than without. The replies from this question for the three maneuvers are presented in Figures 6.11, 6.12, and 6.13 respectively.

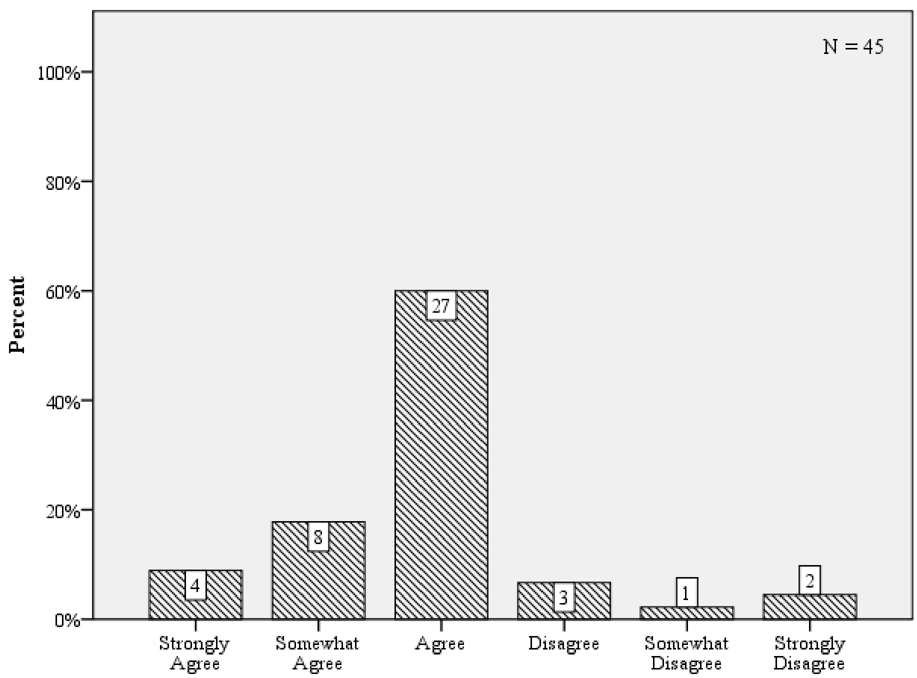

Figure 6.11: Graph showing replies to question: With the RVS I feel more comfortable performing the Straight Line Backing Maneuver. If the 6 levels are grouped into two (Agreement, Disagreement) then 87% of the drivers agree with the statement.

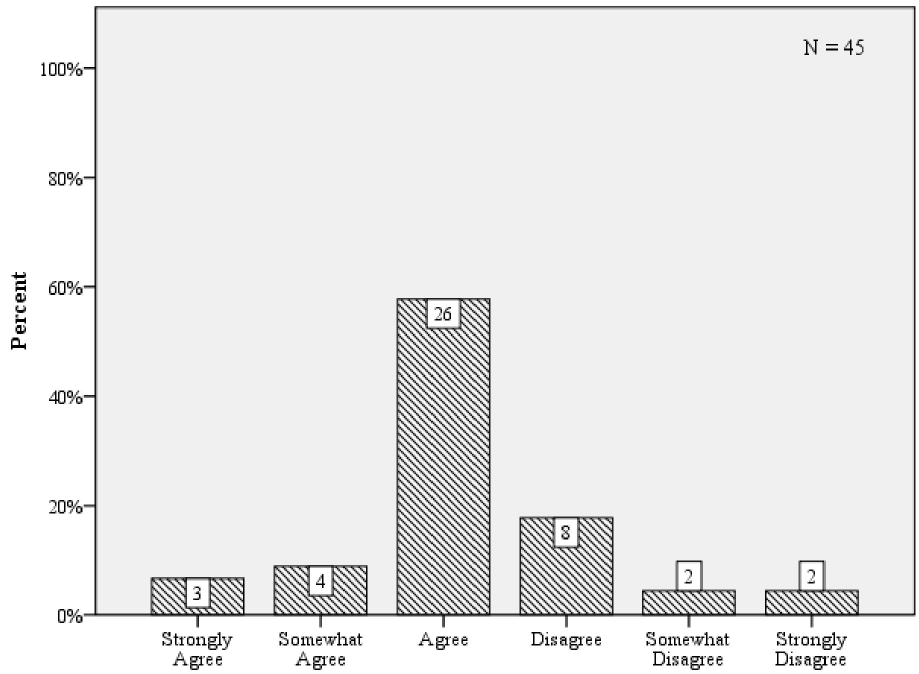

Figure 6.12: Graph showing replies to question: With the RVS I feel more comfortable performing the Offset Right Backing Maneuver. If the 6 levels are grouped into two (Agreement, Disagreement) then 73% of the drivers agree with the statement.

In addition, the drivers were asked if the system helps them avoid potential hazards while performing the maneuvers. The replies to these questions for the three maneuvers are shown in Figures 6.14, 6.15, and 6.16.

The drivers were also asked if they would like to have this system on the truck for their everyday driving operations. As shown in Figure 6.17, 78 percent of them replied “Yes” in general. The drivers were also asked if the RVS helps in reducing the rear blind spot of their vehicle, which is the main purpose of the RVS. In Figure 6.18 93 percent of the drivers - the highest percentage - agreed with this statement after the controlled test.

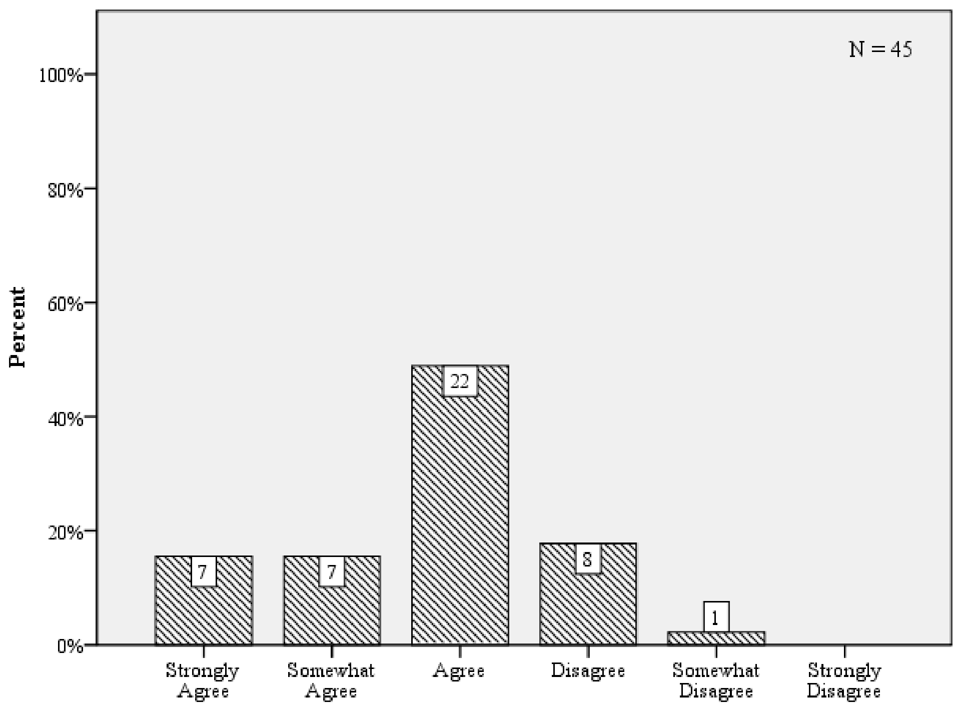

Figure 6.13: Graph showing replies to question: With the RVS I feel more comfortable performing the Alley Dock Backing Maneuver. If the 6 levels are grouped into two (Agreement, Disagreement) then 80% of the drivers agree with the statement.

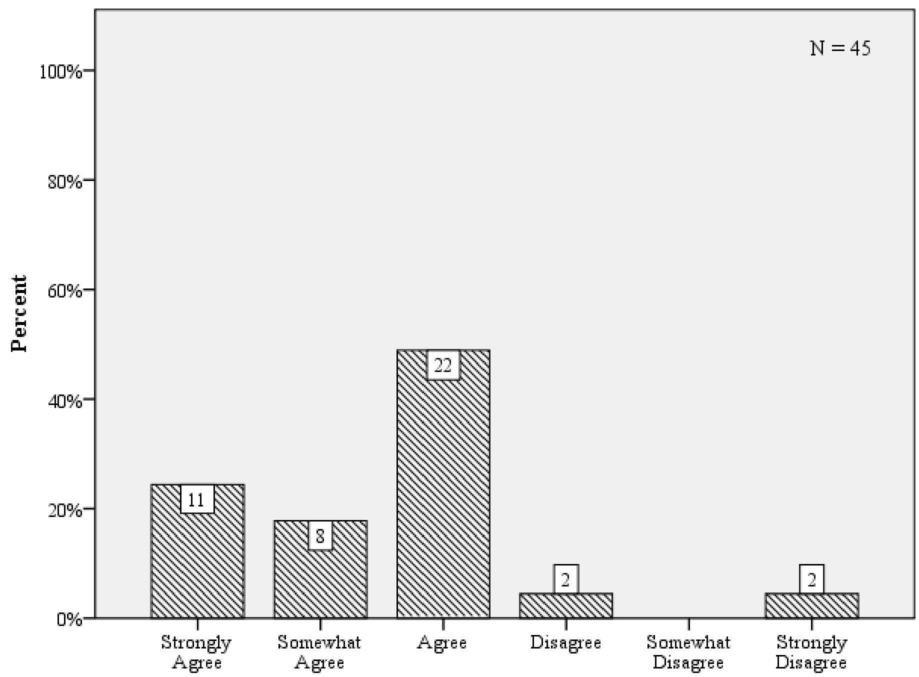

Figure 6.14: Graph showing replies to question: The RVS helps to reduce potential crashes during the Straight Line Backing Maneuver. If the 6 levels are grouped into two (Agreement, Disagreement) then 91% of the drivers agree with the statement.

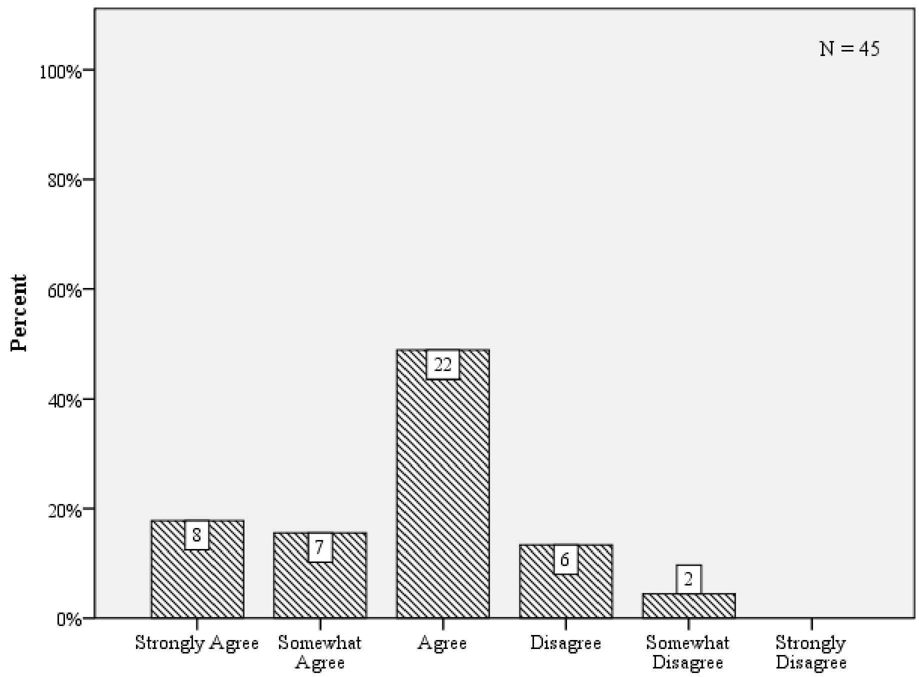

Figure 6.15: Graph showing replies to question: The RVS helps to reduce potential crashes during the Offset Right Backing Maneuver. If the 6 levels are grouped into two (Agreement, Disagreement) then 82% of the drivers agree with the statement.

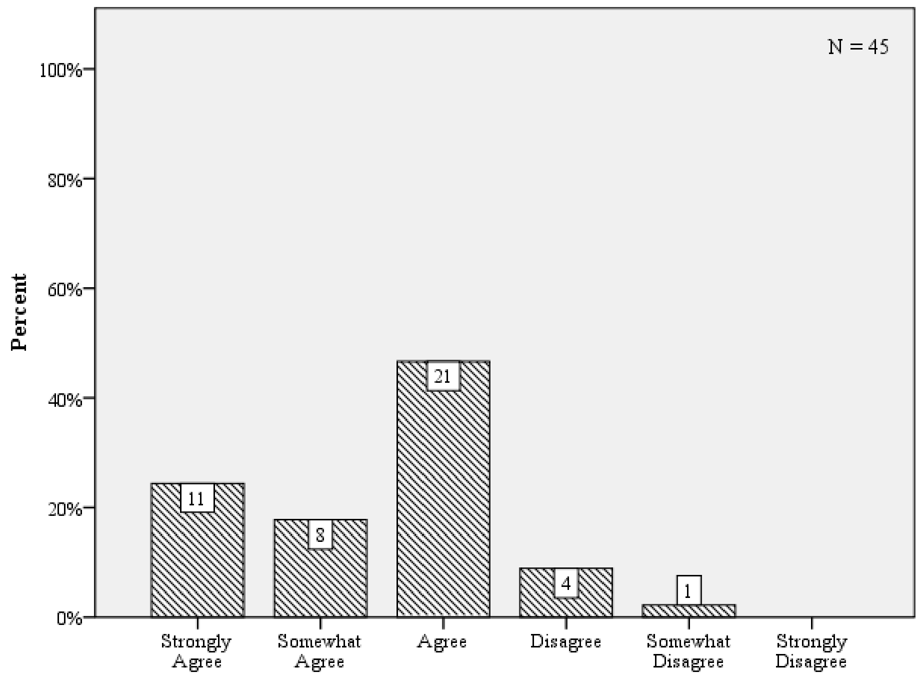

Figure 6.16: Graph showing replies to question: The RVS helps to reduce potential crashes during the Alley Dock Backing Maneuver. If the 6 levels are grouped into two (Agreement, Disagreement) then 89% of the drivers agree with the statement.

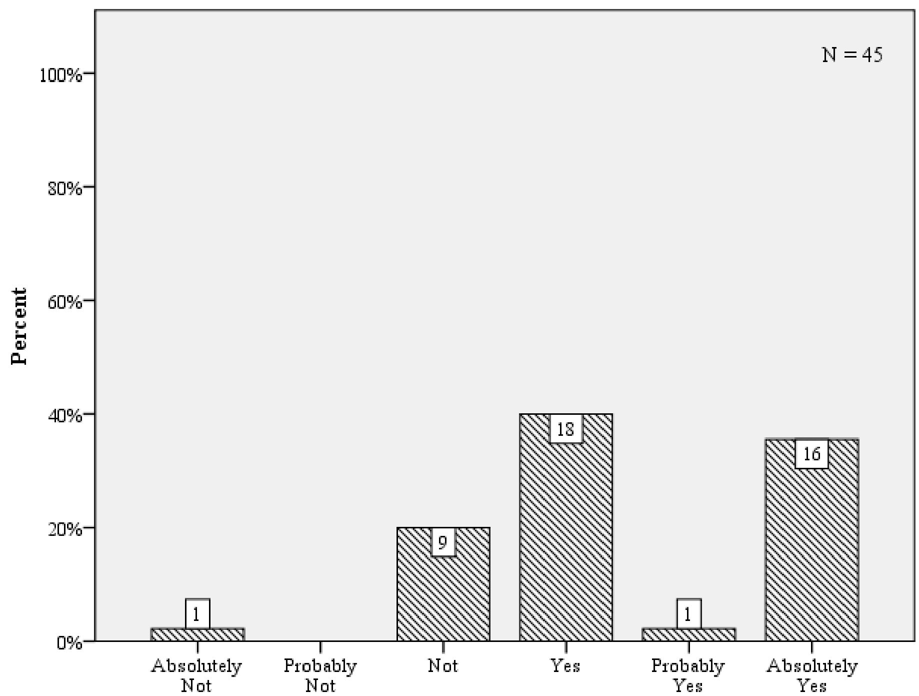

Figure 6.17: Graph showing replies to question: Would you like to have the RVS on the truck you drive every day. If the 6 levels are grouped into two (Yes, No) then 78% of the drivers said “Yes” to the question.

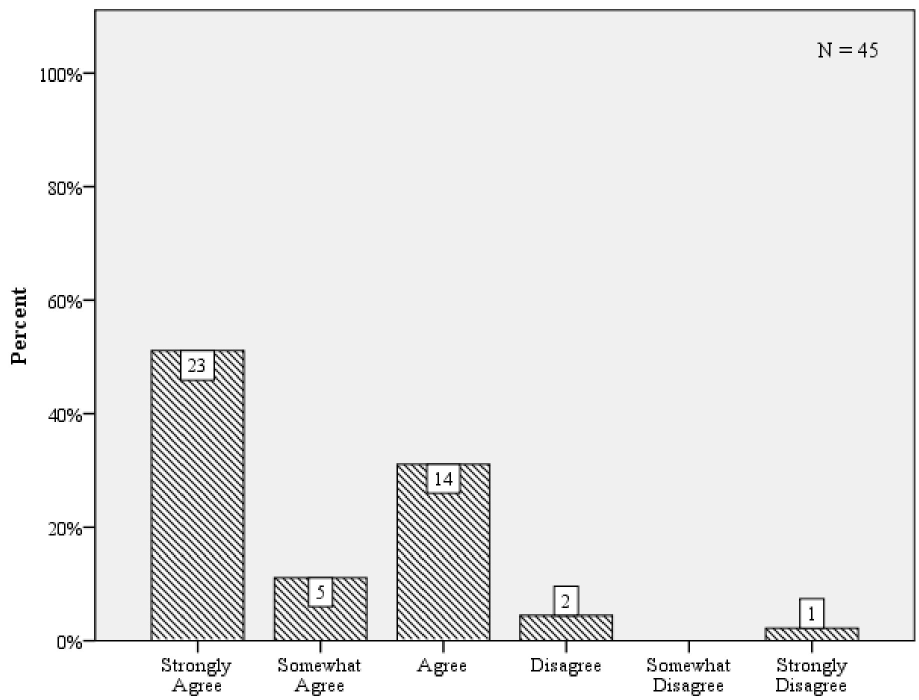

Figure 6.18: Graph showing replies to question: The RVS helps to reduce the rear blind spot of the vehicle. If the 6 levels are grouped into two (Agreement, Disagreement) then 93% of the drivers agree with the statement.

6.3 Analysis Results

The results of the analysis shown in the previous section will be summarized and discussed in this section.

6.3.1 Driver Visual Attention Results

The visual attention analysis showed that the drivers required more time to perform the maneuvers with the RVS. When the RVS was OFF, the drivers divided their attention unevenly with the highest time spent on the driver side view mirror, less on the passenger mirror as expected, and the rest of the time on the other (bumper-convex) mirrors. When the RVS was ON, the drivers divided their attention similarly to the driver, passenger and monitor locations, increasing slightly their attention to the driver and passenger mirrors, and decreasing their time on the "other" locations. This increased demand on the monitor, accounted for the increase in maneuver time. Figure 6.19 shows the mean glances per second for the two groups.

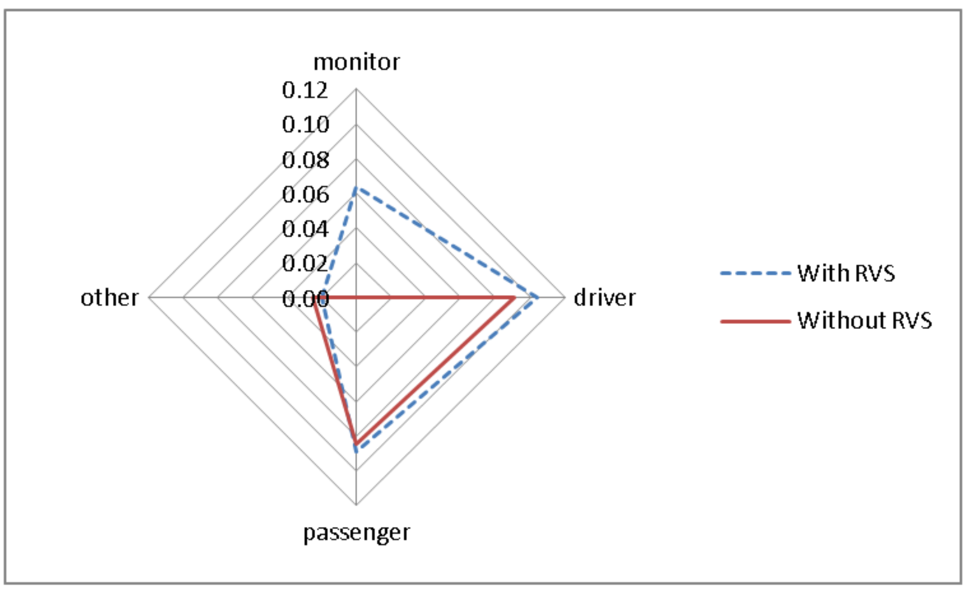

Figure 6.19: Driver mean glance per second during experiment.

In addition, the “driver” glances required more time than any other glance location, mainly due to the drivers looking over the shoulder or outside the driver window captured in this location. The passenger location is second, with the transition time (the time between glances) shared almost equally with the monitor location. It seems that the drivers are able to adjust their glancing time with an additional location. Figure 6.20 shows the distribution of the mean time spent during glances.

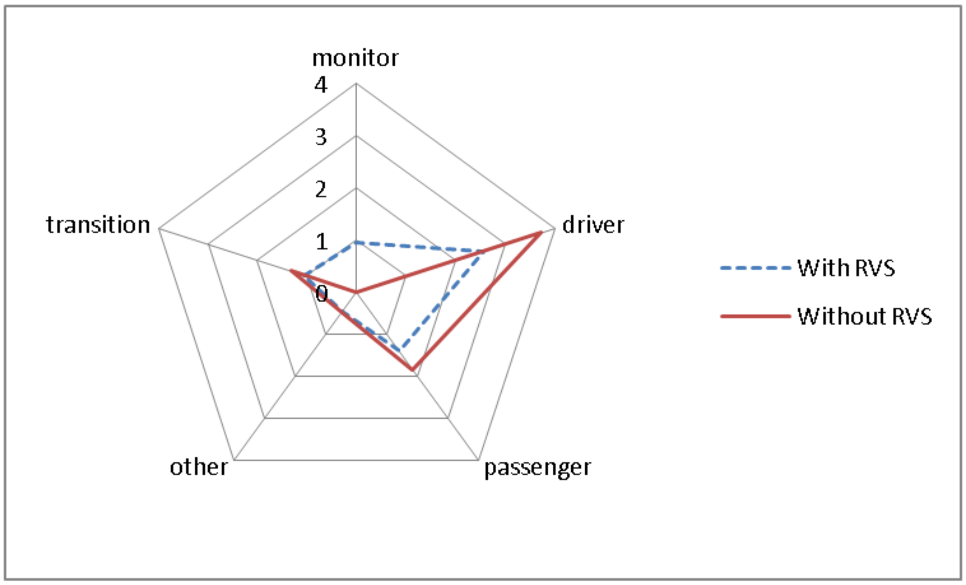

Figure 6.20: Driver mean time per glance. The time is measured in seconds. Transition is the time required for the driver to turn its head from one location to the other, i.e. between glance locations.

The statistical model presented in the previous section shows that the probability of having a crash as captured in the experiment, was decreased when the RVS was used. Different ranges of reduction were recorded with the different maneuvers utilized as tests. In general, there is a minimum of 4.44 percent and a maximum of 46.67 percent reduction of probability of a backing crash.

6.3.2 Driver Acceptance Results

The analysis performed for the device acceptance of the device is qualitative since no statistical inference can be drawn from the sample. Overall the drivers seem to agree that they felt more comfortable performing the backing maneuver with the RVS than without. The questions were asked for each maneuver separately to capture any bias towards a given maneuver. About 87 percent of drivers agreed that they felt more comfortable performing the Straight Line Backing Maneuver, whereas 73 percent agreed for the Offset Right Backing Maneuver and 80 percent for the Alley Dock Backing Maneuver. Furthermore when the drivers were asked if the RVS helps reduce potential backing crashes, 91 percent, 82 percent and 89 percent agreed for the Straight Line Backing, Offset Right Backing and Alley Dock Backing maneuvers respectively. Also, the majority of drivers, about 78 percent, said that they would want to have the RVS on the truck they drive every day and 93 percent agreed that the RVS helps in reducing the rear blind spot of the vehicle. These percentages show that the drivers overall accept the device, except the few cases who did not like the device, and used it very little or did not use it when it was ON. Figure 6.21 shows that during the experiment, 17.8 percent of drivers did not have a crash, whereas 35.6 percent experienced one crash, 24.4 percent had two crashes, 17.8 percent had three crashes, and 2.22 percent had both four and five crashes each.

6.3.3 Accuracy Test Results

As mentioned in section 4.2, during the test and when the drivers stopped at the introduction of the pedestrian surrogate, the distance between the dummy and the trailer was measured. Also for accuracy determination, for maneuvers 2 and 3, the drivers were asked to stop the truck when the rear of the trailer was located at 3 ft from the loading dock. The measurements were also recorded and the distances were tested for significant differences. One would expect that the distance between the dummy and the trailer would be similar or greater when the RVS was used, whereas the distance from the dock should be shorter for the maneuvers performed with the RVS. A paired t-test was performed on the data and the results are shown in Table 6.17. Table 6.15 shows the descriptive statistics and Table 6.16 shows the correlations between the pairs.

It seems that only pairs 3 and 5 experience somewhat a high and significant correlation between them. The t-test however shows that only for pair 2: O2dist.&W2dist. exists evidence that the

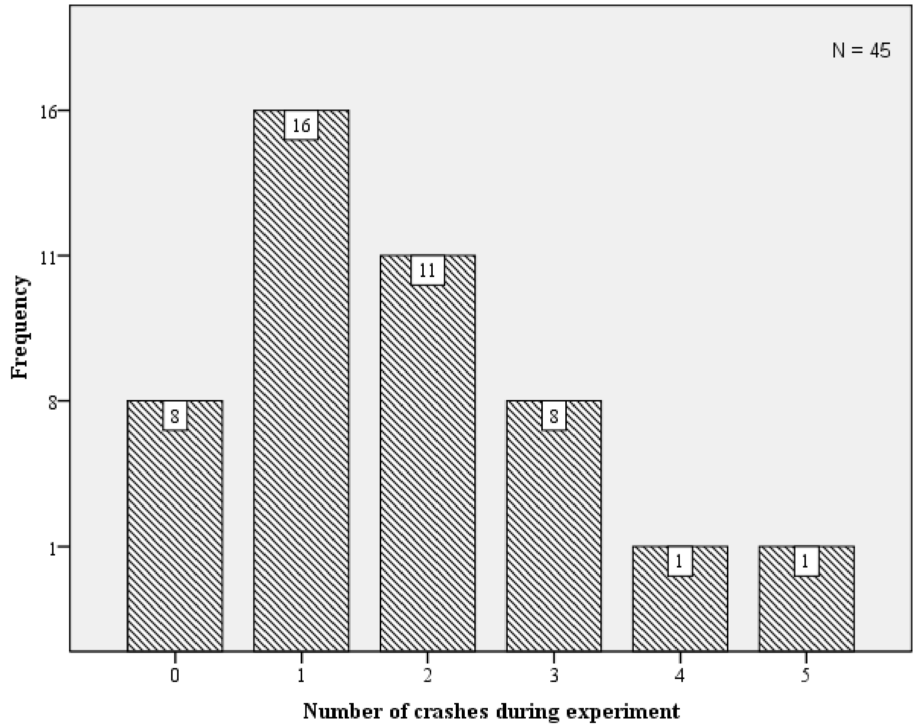

Figure 6.21: Backing crashes experienced during experiment.

Table 6.15: Paired samples descriptive statistics.

Variable Pairs		Mean	N	Std. Deviation	Std. Error Mean
Pair 1:	O1dist.	17.5155	11	7.74224	2.33437
	W1dist.	14.2882	11	7.88750	2.37817
Pair 2:	O2dist.	11.0360	30	3.25121	0.59359
	W2dist.	9.3977	30	3.11812	0.56929
Pair 3:	O2dock	6.5236	45	2.11872	0.31584
	W2dock	6.2653	45	2.28518	0.34065
Pair 4:	O3dist.	10.0591	35	3.47571	0.58750
	W3dist.	10.3049	35	3.80773	0.64362
Pair 5:	O3dock	6.6051	45	2.34143	0.34904
	W3dock	6.1033	45	2.45028	0.36527

O1 = Maneuver 1 without RVS, W1 = Maneuver 1 with RVS, dist. = distance from dummy to trailer, dock = distance from dock to trailer, etc.

means are significantly different and can be attributed to the use of the RVS. For all other pairs there is not strong evidence to suggest that the difference in means is attributed to the RVS.

Table 6.16: Paired samples correlations.

Pairs	N	Correlation	Sig.
Pair 1:O1dist. & W1dist.	11	0.438	0.178
Pair 2:O2dist. & W2dist.	30	0.145	0.443
Pair 3:O2dock & W2dock	45	0.582	0.000
Pair 4:O3dist. & W3dist.	35	0.337	0.048
Pair 5:O3dock & W3dock	45	0.591	0.000

Table 6.17: Paired samples test.

Pairs	Mean	Std. Deviation	Std.Error Mean	t	df	Sig.(2-tailed)
Pair 1:O1dist. & W1dist.	3.22727	8.28394	2.49770	1.292	10	0.225
Pair 2:O2dist. & W2dist.	1.63833	4.16449	0.76033	2.155	29	0.040
Pair 3:O2dock & W2dock	0.25822	2.01920	0.30101	0.858	44	0.396
Pair 4:O3dist. & W3dist.	-0.24571	4.20207	0.71028	-0.346	34	0.732
Pair 5:O3dock & W3dock	0.50178	2.16949	0.32341	1.552	44	0.128

As a result of the accuracy test there is evidence that the RVS helps drivers back the truck to a shorter distance to the target than without the RVS in only one of the maneuvers. However, if one observes the overall average distance, the drivers with the RVS stopped the truck at shorter distances than without RVS as shown in Table 6.18.

Table 6.18: Distance to dummy and dock for maneuvers.

	O1 dist.	W1 dist.	O2 dist.	W2 dist.	O2 dock	W2 dock	O3 dist.	W3 dist.	O3 dock	W3 dock
n	11	32	35	37	45	45	36	44	45	45
min	3.83	2.25	3.83	2.67	0.83	1.25	5.00	1.00	1.17	0.83
max	26.92	32.00	35.00	37.00	45.00	45.00	36.00	44.00	45.00	45.00
avg	15.96	15.00	11.37	10.43	7.29	7.08	10.51	10.89	7.34	6.90

Chapter 7: General Implementation for Camera/Video-Based Devices

All camera/video imaging systems, either infontainment or safety oriented provide information to the driver in real time and most require the driver's attention. Especially in the case of safety devices, the driver needs to pay attention to the device, and respond accordingly. This should not however happen in expense to the visual or mental attention required to perform the main task: driving. Any device should adhere to certain rules and specifications which follow common sense and in this case follow recommendations from the study described in this paper. Three key elements were identified and are briefly covered:

- Scientific/Engineering Guidelines
- User Acceptance
- Usage from Drivers

These are explained in more detail below.

7.1 Scientific/Engineering Guidelines

As described in [31], some general guidelines should be followed.

- The device should perform what it is intended to, operationally (e.g., present driver a rear view of the vehicle) and conceptually (e.g., cover blind rear spot).
- The device should present the image in real time.
- The device should be consistent in its representation of the rear scene over time.

- The device should be able to operate accurately and reliably in both daytime and nighttime illumination conditions.
- For devices that produce audible warnings, it should be possible to hear the auditory output under all driving conditions at a level that is not startling to the user. The volume of auditory output should be adjustable over a reasonable range, approximately 50dB to 90dB.
- The device should be able to operate accurately and reliably over the expected range of truck cab temperature, humidity, and vibration conditions.
- The device should be able to operate continually and robustly over time with only normal maintenance and replacement costs.

In addition, common specification related to video systems, are described in detail in [26] and include:

- System operating Temperature Range, Exposure Temperature Range
- Exterior Illumination Operating Range
- Cab Interior Illumination Operating Range
- Monitor Luminance/Contrast Adjustment
- Monitor Luminance Fluctuation
- System Minimum Image Resolution
- System Refresh Rate
- System Maximum Image Delay
- System Persistence
- System Reliability
- Vibration and Shock Immunity

- Response to Activation
- Image Aspect Ratio

The reader is referred to the above publication for details on these specifications.

7.2 User Acceptance Assessment Methodology

Regardless of the projected safety benefit for any given camera/video imaging device, successful deployment is unlikely if users do not deem the device acceptable. Past work and more recent work in the area, has specified a number of criteria that should be considered when evaluating the user acceptance of such technologies. According to [32] surveys from motor carriers, drivers, manufacturers, and insurance companies showed that important factors in decisions to make, purchase and use on-board safety technologies included return on investment for purchaser, demonstrated effectiveness to improve safety, reliability and maintainability, liability, market demand, initial cost, market image, driver acceptance and in-cab interface technology integration. In many cases for heavy commercial applications, in owner-operator carriers the driver is the same person deciding to purchase the device. One of the factors usually not considered, is the driver acceptance. Even if all others are proven, the device will not be utilized unless the driver wants to. In the case of video systems which require the driver's attention, the driver can easily not use the device thus gaining nothing from having it on the vehicle.

According to [31] building on and encompassing these efforts where practical, the Department of Transportation (DOT) has conceptualized a methodology to systematically assess user acceptance for the purposes of the evaluation of various new and emerging vehicle technologies. This methodology is largely based on the NHTSA ITS Strategic Plan for 1997-2002 [33] and has evolved and been expanded iteratively for DOT projects involving field operational tests. In this approach, acceptance is dependent upon the degree to which a driver perceives the benefits derived from a system as greater than the costs. If a system's potential for safety is not perceived to outweigh its costs, it is likely that the system will not be purchased, or purchased but not utilized. On the other hand, if safety potential and driving skill enhancement as related to device use are perceived, then there is a chance that users will feel comfortable engaging in riskier driving behavior. It is important that each of these outcomes be assessed for a complete evaluation of the safety and user acceptance of such technologies. This may be accomplished conceptually by deconstructing user acceptance into five broad elements: ease of use, ease of learning, perceived value, advocacy, and driver behavior. Systematic evaluation of these areas includes the assessment of multiple criteria, each of which is based on human factors principles as applied to vehicle technologies.

Ease of use is one component of user acceptance for a vehicle safety device. This encompasses the degree to which drivers find a technology understandable, usable, and intuitive in its operation and maintenance. Full consideration should be given to the human factors, design, usability, and maintenance of a device. Testing may initially take place in a laboratory setting to ensure the accommodation of inherent variability in driver anthropometry, cognitive and physical capabilities, as well as proper operation within various driving environments. Further design and usability evaluation in the field and longitudinally will aid in refining the functionality of such technologies and assessing driver device use patterns over time.

Additionally, given various device states, it is critical to determine the degree to which drivers understand the capabilities and limitations of a system, its operational parameters, and what driver actions are expected in assorted situations. The degree to which devices accommodate individual drivers by promoting correct interpretation of their output, assuming individual differences in perception, information processing, physical, and cognitive skills, must also be evaluated. Moreover, it is necessary to assess the demands of attending to the output of an in-vehicle device, as a safety technology should never contribute to driver stress or workload. As device feedback typically takes the form of an auditory warning or alert, it is vital that various outputs are easily comprehended, discriminated, and do not conflict with those provided by other safety technologies. Finally, in order to facilitate trust in the safety benefit of such devices, it is crucial that false and/or nuisance alarms are minimized, in addition to maximizing “hits” (i.e., correct detection of objects in the rear of the vehicle).

Ease of learning as a part of evaluating user acceptance seeks information regarding how well a device is utilized in its intended manner, as well as what is done with such acquired knowledge over time. Basic testing of such parameters may be conducted in a simulated setting for the evaluation of short-term outcomes. However, only a longitudinal study in field conditions allows for the assessment of learning over time. User understanding of the applications of device feedback, both reactively and proactively, is critical for the success of such technologies. The perceived value element of user acceptance assesses the degree to which drivers perceive a safer and/or more alert driving environment as a function of device use. Ideally, the driver is able to utilize such safety-enhancing technologies to facilitate alert vehicle operation, in conjunction with successfully integrating device feedback. An additional aspect of perceived value is the degree to which drivers report that these innovations enhance driving performance and safety in their every day operations. When assessing these criteria, it is important to also consider the undesirable outcome of drivers' inadvertent or purposeful over-reliance on such technologies to detect objects in blind areas. Perceived value may also be impacted as a result of the degree to which drivers understand and are informed about device functioning and what aspects of driver behavior the device helps. For example, if real or perceived health risks are associated with the technology, drivers will weigh such costs against other perceived benefits. Additionally, users may be concerned about data confidentiality to the extent that devices are used to monitor, store, and possibly transmit information regarding their driving behavior.

Advocacy is measured in terms of the extent to which drivers consider endorsing or purchasing a safety device, and it is a critical component of user acceptance. Ultimately, regardless of a potential safety benefit, and even in spite of perceived benefits on the part of the driver, if a technology is not attainable by the intended users, it will not succeed in the marketplace. Therefore, the willingness of drivers both to purchase a safety device (whether on an individual or commercial basis) and to endorse it to others is a vital aspect of successful deployment.

7.3 Device Usage Patterns

As shown subsection 6.3.1, a device that demands the visual attention of the driver has to be tested thoroughly to ensure that the attention of the driver from the main task of driving or keeping the vehicle under control is not hindered or decreased dramatically because of the device. Alterations in driver behavior may occur as a function of device usage over time. Ideally, these changes are intended, positive, and have a permanent impact on safe vehicle operation and driver lifestyle. Evaluating a driver's allocation of cognitive and temporal resources to maintain safe driving serves to ensure that driving behavior is not negatively affected by devices requiring excessive time and cognitive resources to monitor and react to. Of additional importance is assessing the degree to which driver awareness of and exposure to device feedback over time yields behavioral adaptation. Examples include the extent to which device output is integrated into driving behavior and the potential benefits and/or risks of using a technology in an unintended manner. Further, user acceptance should focus on alterations in driving style (i.e., habits, patterns) that are brought about by modifications to glance patterns as a result of responding to device output. More broadly, it is important to assess whether extended exposure to such safety devices leads to overall lifestyle changes.

Chapter 8: Conclusions and Future Research

8.1 Summary

Camera/video-based systems have been used for several years as surrogates for mirrors or as enhancements in applications including commercial large trucks. Particularly successful has been the use of these systems where a large blind area or “No zone” exists around the vehicle. These blind areas are larger and more important in large vehicles such as tractor-trailer trucks. Specifically the use of such systems as rearview video systems has been increasingly seen in all vehicle types in recent years. This dissertation examined how such a device can help the driver in avoiding potential hazards behind the vehicle that could lead to backing crashes. The main difference with previous research efforts was to capture the drivers’ behavior as they use the system, and gain an understanding on the important factors influencing its use and maximum benefit gain. In the case of large vehicles, a rearview of the direct area behind the vehicle is not possible since they have no rear window, rearview mirror or their view is blocked by the trailer. Providing the driver with an additional rear view of the vehicle proves to be beneficial especially in certain maneuvers.
The Florida CAR system was used to analyzed backing crash data for 2003-2006, to gain insight into the characteristics of backing crashes involving large trucks. The problem is not as severe as other types of crashes but for large trucks there is a consistent trend of about ten percent of truck crashes being backing crashes. The motive behind this research is to eliminate a great percentage of these crashes since it is theoretically possible. The crash analysis was also done for two main reasons. First, to understand the locations and conditions under which the crashes happen, and secondly to estimate the potential crashes which the device is applicable. It was found that the crashes coded as “backing” crashes in the database might not necessarily be backing crashes,

or not all backing crashes are coded as backing related crashes. This created the need to review the actual police reports (long form) to understand better what happened and obtain information missing from the database. Surprisingly, backing crashes occur in locations where backing is not allowed. About 20 percent of backing crashes involving trucks occurred at intersections or near intersections, another 7 percent occurred at driveways and about 26 percent occurred on a road section. Only about 40 percent occurred at parking lots and private property where one would expect them to happen. A total of 1,549 police reports were reviewed to find that 0.17 percent were fatal, 7.85 percent involved injuries (incapacitating, non-incapacitating and possible injury) and 89.2 percent were property damage only. For the majority of these backing crashes, more than 70 percent, the at-fault vehicle was a truck and the second vehicle was an automobile. The difference in vehicle size is what makes crashes more severe since even at low speeds, the mass of the truck can inflict great damage and injuries.

Furthermore, the analysis was performed to estimate the number of backing crashes that the RVS is applicable to, thus can be claimed to be potentially avoided or eliminated. Two issues were investigated. The point of impact of the at-fault vehicle since the RVS cannot help with any other location on the vehicle, and vehicle speeds. It was identified by previous research that for the system to work, both vehicles need to be traveling at low speeds (below 10 mph) and be under the control of the driver. This way when the drivers perceive the danger using the RVS, they have enough time to react and stop the vehicle before striking the object or person. Based on the analysis with point of impact and speed of vehicles at the time of crash, it seems that 84 percent of low speed (both vehicles below or at 10 mph) backing crashes among 83 percent of all backing crashes with rear side point of impact can be potentially eliminated or avoided by adopting the RVS as a countermeasure.

After the crash analysis, the driver behavior when using the RVS was analyzed through data collected at a controlled driver experiment. The experiment was designed to test the effectiveness of the RVS in helping the drivers detect and avoid potential hazards behind the vehicle during backing maneuvers. A series of backing maneuvers were used to obtain simulated conflict and crash data. A total of 45 local truck drivers participated in the experiment. The drivers worked for a food delivery company. A day-cab tractor and a 35 ft box type trailer were used for the experiment. Three backing maneuvers found in the CDL skill driving test were utilized for the experiment. The drivers performed all maneuvers with the RVS and without the RVS in a random order. A remote controlled pedestrian dummy and traffic cone were used as surrogates to create the conflicts. All the drivers were males with average age range 31-40 years old. The drivers had an average 10.91 years of driving experience, and 15 had some previous experience with the RVS. Also 15 drivers had at least one backing crash in their history. The experiment yielded a total of 71 crashes out of 270 maneuvers (26.3%). When analyzed, the three maneuvers yielded different probabilities of having a backing crash with and without the RVS. For the Straight Line Backing Maneuver there was a decrease of 46.67 percent in probability of having a backing crash, for the Offset Right Backing Maneuver there was a 4.44 percent decrease in probability, and for the Alley Dock Backing Maneuver there was a decrease of 17.78 percent. This shows that the system helps, but in varying amount from maneuver to maneuver. Also the first maneuver had a different introduction of object than the other two.

Driver behavior was observed during the experiment and measured for significant differences. The driver behavior was separated into two aspects: first was the visual attention and second the driver acceptance of the system. The visual attention metrics included measuring where and how long the driver was glancing at different locations. These locations were identified as driver side mirror, passenger side mirror, RVS monitor location and everywhere else. The drivers needed on average 6.47 seconds more time for the maneuvers with the RVS in use. They spent less time looking at other locations and did it less frequently in order to accommodate the additional glance location presented to them. Overall they seemed to be able to manage their time with some exceptions. These exceptions included some drivers that did not use the monitor as much or at all when it was available to them and focused on their usual routine.

The driver acceptance of the device was measured with a survey given to them after they completed the test. Overall in all measures the majority of drivers agreed that the system helps in reducing the rear blind spot and thus it is a helpful device in reducing backing crashes since it will help them avoid potential hazards while backing. The majority also stated that they would like to have the device in their truck for every day operations. These results show an acceptance of the device and therefore the maximization of the device's use and potential benefits.

The methodology used for this study can be implemented in a more general approach for all in-vehicle device evaluations. Although procedures have been used from NHTSA for the evaluation of these devices, addition of the driver usage aspect seems to be important in order to encompass a more realistic picture in implementation of such devices.

8.2 Conclusions and Recommendations

Obviously with the driver still the most important factor in driving, the RVS can only provide information and help the driver avoid hazards. This device is passive and provides no warning to the driver, rather it presents a rear view much like a rearview mirror in a passenger car and the drivers needs to observe, detect and react using the information. From this analysis, the RVS is successful in reducing the rear blind spot and provides the drivers with an additional rear view they did not have before. During the experiment the RVS increased the stopping rate of the drivers, and reduced the probability of having a backing crash under the conditions of the experiment. The participating drivers although skeptical in the beginning, did show some change in their perception of the system after they experienced the potential benefits.

This method of evaluating a safety device provides great benefits for researchers, especially in the human factors area, where the exact movement, usage and ergonomics of a device are analyzed to obtain optimum benefits. Using cameras and live video feed while driving is a complicated task and the drivers need to get used to it to obtain better results. Some drivers in this experiment did not have any prior experienced with the system, whereas some did use the system before although not for long periods of time. As seen in driver behavior studies, drivers can adapt their driving habits and patterns to encompass new technologies available in vehicles every year. Several issues have to be addressed before a driver or company can purchase and use such devices on their fleet. With the increase in aftermarket systems, customization is more flexible and can produce even better results than OEM device interfaces. The only issue is regulation of such systems because without testing and inspection, faulty, inappropriate and unsafe systems might emerge and with time become part of the automobile industry safety standards.

8.3 Future Research

Future research on this subject includes testing with additional cameras in other areas of the vehicles in order to identify solutions for other types of crashes. Also testing of different location of the camera might yield different results. As an example the experiment could be performed with the camera located at the top of the cargo box. Since the view is different, it might yield different results than the ones presented here. Also a different type of truck might be used to evaluate the device under a different scenario.

In addition, the testing performed for this study was possible in a short period of time and with limited resources. The evaluation of such devices in a naturalistic driving study such as the one conducted in [25] can provide better and more robust results in determining the true benefits of using these devices on the road. Since every driver's habits are different, observing in real time over a longer period of time could present with additional issues that need to be addressed to ensure a safe operation.

Also, the perception-reaction time of the drivers with the RVS and without, could be analyzed to identify potential differences.

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Appendices

Appendix A: Rearview System Component Technical Specifications

Table A.1: $\frac{1}{3}$inch CCD rearview camera specifications.

Feature	Specifications
TV System	EIA
Effective Pixels	512 x 492 pixels
Sensing Area	4.9 mm x 3. 7 mm
Scanning System	2:1 Interlace
Sync. System	Internal
Resolution	420 TV lines
Minimum Illumination	0 Lux
Horizontal Sync. Resolution	15,734 KHz
Vertical Sync. Resolution	60 Hz
Video Output	1.0 vp-p, 75 Ohm
Microphone	Yes
Gamma Consumption	0.45
AGC	Auto
S/N Ratio	Better than 48 dB
White Balance	Auto
Electronic Shutter	$1/60 \sim 1/10,000$
BLC	Auto
Current Consumption	Max. 300 mA
Power Supply	12 VDC
Operating Temperature	$-20°C \sim 70°C$, RH95% MAX
Storage Temperature	$-40°C \sim 85°C$, RH95% MAX
Lens Aperture	f = 2.8

Appendix A: (continued)

Table A.2: LCD 5 inch monitor specifications.

Feature	Specifications
Display Device	Color TFT-LCD
Screen Size	5 inches
Audio Output	200 mW
Loudspeaker	One 4.0 cm round loudspeaker
Connecting Terminal	Earphone jack, audio/video (AV) input jack, external power supply input jack, rearview connector
Application Power Supply	12 VDC
Power Consumption	$\sim 8\ W$
Outer Dimensions	163 mm (W), 125 mm (H), 30.5 mm (T)
Weight	430 g
Resolution	960 (H), 234 (V)
Contrast Ratio	150:1
Brightness	300 cd/m^2

Appendix B: Informed Consent Form

Title of Project: Yard Tests for Rearview Video System

Experimenters: Dr. Chanyoung Lee, Achilleas Kourtellis

The Purpose of this Research

Fatalities, injuries and property damage caused by backing crash have received more and more attention from the public, trucking industry and management authorities. Backing crashes are usually caused by the "No- Zone" where the driver has virtually no visibility. The "No-Zone" is especially severe for heavy trucks. Currently, the Center for Urban Transportation Research (CUTR) at the University of South Florida (USF) is conducting research with the Florida Department of Transportation District 7 to evaluate the effectiveness of Rearview/Backup camera systems in reducing potential backing crashes among commercial vehicles.
As a part of the study, you are being asked to serve as a participant. If you agree to participate, you will drive a heavy vehicle (tractor trailer) in the company's yard. We will give you detailed instructions on what to do later, but basically you will perform several standard backing maneuvers. You will participate by performing the maneuvers in baseline, that is, with the video turned off, and also with the video turned on so you can use it. The order in which these will be presented is different for different participants. You will participate in the evaluation of a camera rear view system and corresponding baseline runs. Your participation is expected to take no more than one hour, but may be a bit longer or shorter.

Procedures

Here in the building you will first decide if you want to participate. If so, you will sign your name at the end of this form, so indicating. You should only sign after you have read and understood this form and had your questions answered. Next, we will go over the tests to be performed and the order in which they will be presented to you. For each type of run, you will perform what we call delivery driving tasks. During most of the time, you will maintain the normal backing speed. You will be asked to perform a total of six backing maneuver. Each of these will be explained in detail prior to having you perform the maneuvers. If your video is turned on during these tests, you should try to use it (them) to improve your performance. Of course, we don't know how well they will work, so your job is to just do the best you can. We will take measurements, but there is no grading, so you won't pass or fail. Also, results will be kept confidential, as will be explained.

Risks and Discomforts

The risks you will face in this experiment are probably slightly less than you would face in driving a rig for your everyday job. Speeds should be low, and you should drive as safely as possible or as you drive every day. Consequently, we believe this is a minimum risk experiment. We don't know of any discomforts associated with the experiment, except possibly your working with equipment you haven't used before. This might cause a little stress, but we think the stress should be mild.

Benefits of this Project

There are no direct benefits to you for participating in this research (other than normal participant payment). No promise or guarantee of benefits has been made to encourage you to participate. You may find the experiment interesting, and your participation may help in the evaluation of this camera system on heavy vehicles.

Appendix B: (continued)

Extent of Anonymity and Confidentiality

The result of test will remain anonymous and the raw data will not be shared beyond research team at CUTR. Also, while you are driving, equipment will record vehicle position and similar data. In addition, we will make some measurements of vehicle final position and similar aspects for the backing tasks. In all cases, your name will be kept separate from your data. Data analysis will be based on the pooled responses of those who complete participation. At this time, it is anticipated that a total of 60+ drivers will participate. It will be impossible in reporting the results of the experiment to identify any particular participant.

While you drive in this experiment, your glance position may be recorded by video. This is done by aiming a small video-camera at your face. After completion of your participation, the recordings will be used for research purposes only and will be analyzed to extract your glance positions. The recordings will be kept secure until they are no longer needed. They will then be erased.

Compensation

You will receive payment in the amount of $$ per hour for your time and participation. This payment will be made through the company (please note that expected processing time is 8-12 weeks).

Freedom to Withdraw

You should know that you are free to withdraw from the experiment at any time and for any reason without penalty. No one will try to make you continue. If you do not want to continue, you will be paid for the actual amount of time you participated. You are not required to answer any questions or to respond to any research situations, and you will not be penalized for not responding. The experimenter also has the right to end the experiment, if in his opinion it is best to do so.

Appendix B: (continued)

Participant's Permission

I have read and understand the Informed Consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project. If I participate, I understand that I may withdraw at any time without penalty.

Name	Driver Number for Test (Assigned by CUTR)
Participant's Signature	Date

Appendix C: After Experiment Evaluation Form

Driver Number:______________

1. Driver Age:

   A) Under 25 B)26-30 C) 31 to 40 D) 41 to 50 E) 50+

2. Years of CDL driving experience: ______________ yrs.

3. Previous experience with Rearview Video System: A)YES B) NO

   If YES above: Duration of experience with RVS:

   A) 1 week B) 1-2 weeks C) 3-4 weeks D) 1-2 months E) 3-4 months F) Never

4. Ever had backing crashes during CDL driving? A) YES B) NO

   If YES above: How many backing crashes? ______________

5. Based on your experience with trucking company, can you guess what is the percentage of backing crashes relative to all crashes?

   A) Less than 10% B) 10%-20% C) 20%-30% D) 30%-40% E) 40%-50% F) More than 50%

6. With the rear view camera system I feel more comfortable to perform the straight backing maneuver.

   1 Strongly Agree 2 Somewhat Agree 3 Agree 4 Disagree 5 Somewhat Disagree 6 Strongly Disagree

7. The rear view camera system helps me to reduce potential crashes during straight backing maneuver.

   1 Strongly Agree 2 Somewhat Agree 3 Agree 4 Disagree 5 Somewhat Disagree 6 Strongly Disagree

8. With the rear view camera system I feel more comfortable to perform the offset right backing maneuver.

Appendix C: (continued)

1 Strongly Agree 2 Somewhat Agree 3 Agree 4 Disagree 5 Somewhat Disagree 6 Strongly Disagree

9. The rear view camera system helps me to reduce potential crashes during offset right backing maneuver.

   1 Strongly Agree 2 Somewhat Agree 3 Agree 4 Disagree 5 Somewhat Disagree 6 Strongly Disagree

10. With the rear view camera system I feel more comfortable to perform the alley dock backing maneuver.

    1 Strongly Agree 2 Somewhat Agree 3 Agree 4 Disagree 5 Somewhat Disagree 6 Strongly Disagree

11. The rear view camera system helps me to reduce potential crashes during alley dock backing maneuver.

    1 Strongly Agree 2 Somewhat Agree 3 Agree 4 Disagree 5 Somewhat Disagree 6 Strongly Disagree

12. Would you like to have this rear view camera system in the truck you drive every day?

    1 Absolutely Not 2 Probably Not 3 Not 4 Yes 5 Probably Yes 6 Absolutely Yes

    **If you answered NO above why not?

    ____

13. If the company you work for is considering equipping the fleet with the rear view camera system to minimize backing crashes for the price of $300-$400 per system. Would you support this decision?

    1 Strongly Agree 2 Somewhat Agree 3 Agree 4 Disagree 5 Somewhat Disagree 6 Strongly Disagree

Appendix C: (continued)

14. Do you feel that the rear view camera system helps to reduce the rear blind spot of your vehicle?

    1 Strongly Agree 2 Somewhat Agree 3 Agree 4 Disagree 5 Somewhat Disagree 6 Strongly Disagree

15. Are there any additional comments you would like to make regarding the rear view camera system?

    ____

    ____

    ____

About the Author

Mr. Achilleas Kourtellis was born in Cyprus. He received his Civil Engineering Technician Diploma at the Higher Technical Institute in Nicosia, Cyprus in 2000. His thesis was on mix design methods of bituminous mixtures. Following that he served a mandatory term of 24 months in the Cyprus National Guard as a second lieutenant in the division of Civil Corps of Engineers. In 2002 he transferred to the Civil and Environmental Engineering Department at the University of South Florida where in 2004 he graduated with his B.Sc. in Civil Engineering with concentration in Transportation. He was immediately admitted to the graduate program and in 2006 he graduated with a Masters in Civil Engineering with concentration in Transportation. He then continued to the Ph.D. program. He worked at the Center for Urban Transportation Research at USF as a graduate research assistant since 2004 where the first two years he was working in the Mobility Policy Program, and the latter 3 years in the ITS, Traffic Operations and Safety Program. He is co-author of 3 papers and first author of 3 conference papers in the subject presented in this document. He has also reviewed papers, and prepared several technical reports, presentations and other documents.