FINAL REPORT

“Evaluation of the Power Line Motor Carrier Rearview Video System”

Submitted to:

Florida Department of Transportation
District Seven
11201 N McKinley Drive
Tampa, FL 33612-6403

Submitted by:
Pei-Sung Lin, Ph.D., P.E., PTOE
Chanyoung Lee, Ph.D., PTP
Achilleas Kourtellis
Center for Urban Transportation Research
University of South Florida

June 2009
DISCLAIMER

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the State of Florida Department of Transportation or the US Department of Transportation.
This project was funded by the Federal Highway Administration and managed by the Florida Department of Transportation District 7. The authors would like to sincerely thank the project manager, Mr. Peter Hsu, and project panels, Mr. Lawrence Taylor, Mr. David Skrelunas, and Mr. Larry Hagen of the Florida Department of Transportation District 7 Office and Capt. Troy Thomson and Lt. Buchanan Folsom of the Motor Carrier Compliance Office in the Florida Department of Transportation for their guidance and assistance. The authors would also like to thank Mr. Tommy Thomas from Roadmaster Drivers School in Tampa, Florida, Mr. Thomas Olitsky, Mr. Jeff Boesger and Troy Sinclair from Sysco Food Services in Palmetto, Florida for providing the facilities for the controlled driver test, Mr. James Marcus from Zone Defense, LLC for his assistance with the equipment purchase, and Mr. Ron Silc from R.G. Silc & Associates for his assistance to locate participating trucking companies. Finally the authors would like to thank the trucking companies that participated in the rearview video system deployment.
**Technical Report Documentation Page**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaluation of the Power Line Motor Carrier Rearview Video System</td>
<td>June 2009</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Pei-Sung Lin, Chanyoung Lee, Achilleas Kourtellis</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>9. Performing Organization Name and Address</th>
<th>10. Work Unit No. (TRAIS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center for Urban Transportation Research</td>
<td></td>
</tr>
<tr>
<td>4202 E. Fowler Avenue, CUT 100</td>
<td></td>
</tr>
<tr>
<td>Tampa, FL 33620-57350</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>AOJ82</td>
<td>Florida Department of Transportation, District 7</td>
<td>Draft Final Report</td>
<td></td>
</tr>
<tr>
<td></td>
<td>11201 N McKinley Drive, Mail Station 7-500</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tampa, FL 33612</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>15. Supplementary Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>16. Abstract</th>
</tr>
</thead>
<tbody>
<tr>
<td>A growing awareness is emerging regarding truck backing crash problems in the U.S. “No view” or “limited view” are commonly cited as the cause of backing crashes, which means that backing crashes occurred because the driver did not see the struck vehicle, object, or pedestrian in the rear. Unlike cars, trucks have huge areas directly behind them that cannot be seen by drivers. The size of this “no view” area in the rear becomes bigger as vehicle size increases.</td>
</tr>
<tr>
<td>Three types of rearview video systems including Power Line Carrier (PLC), wireless and cable systems currently available in the market were compared for their advantages/disadvantages as a countermeasure for truck backing crashes. The main difference of the systems is the signal transmission technology. Among these three systems there is no significant difference on time required for the system installation. All systems are easy to use. The cable system is the most reliable system and can provide clear camera images to assist truck drivers on backing maneuvers. The PLC system and wireless system could not provide reliable camera images during field deployment.</td>
</tr>
<tr>
<td>This study deployed a total of 100 Rearview Video Systems (RVS) in three different companies to evaluate the effectiveness of rearview video systems in reducing backing crashes and obtain the feedback from truck drivers participating in the study. Most drivers involved in the study showed a positive attitude towards the system, with a few exceptions. The drivers did not take much time to become comfortable with using the system in their daily activities, and they agreed that it can help in minimizing potential backing crashes.</td>
</tr>
<tr>
<td>A controlled test was designed and conducted to evaluate the effectiveness of RVS to reduce potential truck backing crashes in a controlled environment. The results showed that the presence of a rearview video system increased the stop rate (avoiding hitting an object) of drivers in the Straight Line Back maneuver by 46.7 percent, which can be interpreted as increasing the odds of avoiding potential backing crashes in the maneuver. The stop rate increased 4.4 percent and 17.8 percent for Offset Right Back and Alley Dock Back maneuvers, respectively. A benefit-cost analysis was conducted based on the collected data. The estimated B/C ratio is 1.5 or higher.</td>
</tr>
<tr>
<td>The study found that the rearview video system can be effective in reducing truck backing crashes if it can function as intended. It is important to make sure that the system performs satisfactorily before it is used by drivers.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>17. Key Word</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rearview video system, truck safety, Backup camera, rear vision system, backing crash, back over crash</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>18. Distribution Statement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Unclassified</td>
<td>Unclassified</td>
<td>107</td>
<td></td>
</tr>
</tbody>
</table>
Table of Contents

Executive Summary .........................................................................................................................1

1.0 Introduction ............................................................................................................................3
  1.1 Background ..................................................................................................................3
  1.2 Related Research .........................................................................................................3
  1.3 Study Objectives ..........................................................................................................5
  1.4 Summary .......................................................................................................................8

2.0 Backing Crashes ......................................................................................................................10
  2.1 Backing Crash Data ..................................................................................................10
  2.2 Florida Crash Database ............................................................................................11
  2.3 Florida Traffic Crash Reports ..................................................................................13
  2.4 Trucking Company Crash Database and Summary ..................................................17

3.0 Rearview Video Systems .......................................................................................................19
  3.1 Cameras .......................................................................................................................20
  3.2 Monitors .......................................................................................................................22
  3.3 Transmission Technologies .......................................................................................22
  3.4 Lab Tests .......................................................................................................................25
  3.5 Results from Initial Installation ................................................................................25
  3.6 System Configuration .................................................................................................32
  3.7 Installation of Equipment ...........................................................................................39
  3.8 Summary .......................................................................................................................39

4.0 Deployment Study ...................................................................................................................41
  4.1 Company Recruitment ...............................................................................................41
  4.2 System Installation ......................................................................................................41
  4.3 Power Line Carrier (PLC) System .............................................................................44
  4.4 Interference with Wireless Systems .........................................................................50
  4.5 Driver Surveys .............................................................................................................50
  4.6 Camera Location .........................................................................................................67
  4.7 Backing Crashes ...........................................................................................................68
  4.8 Deployment Study Results ........................................................................................70

5.0 Controlled Driver Test .............................................................................................................71
  5.1 Literature Review of Previous Testing Efforts on Similar or Same Products in a Controlled Environment ..................................................................................................................71
  5.2 Performance Measures for Controlled Driver Test .....................................................73
  5.3 Test Design ....................................................................................................................75
  5.4 Pre-Test ........................................................................................................................79
  5.5 Test Procedure .............................................................................................................83
  5.6 Analysis of Test Results ..............................................................................................92
  5.7 Summary .......................................................................................................................98
List of Figures

Figure 2-1  Vehicle Point of Impact Classification ................................................................. 13
Figure 3-1  Rear No Zone, Camera Location, and Field of View ................................................ 19
Figure 3-2  View from Rearview Camera Located at 3 ft Height ................................................ 19
Figure 3-3  View from Rearview Camera Located at 13.5 ft Height .......................................... 20
Figure 3-4  LCD 5” Display Mounted on Dashboard of Semi Truck ......................................... 20
Figure 3-5  1/3in. Rearview Camera ......................................................................................... 21
Figure 3-6  5” LCD Monitor on Dashboard ............................................................................... 23
Figure 3-7  Cable System Installed on a Semi Truck .................................................................. 23
Figure 3-8  Wireless Rearview Video System Set ...................................................................... 24
Figure 3-9  Wireless System Installed on a Semi Truck .............................................................. 24
Figure 3-10 Power Line Carrier System Installed on a Semi Truck ............................................ 25
Figure 3-11 Image from Camera during Testing ....................................................................... 26
Figure 3-12 Initial Installation of Rearview Video System .......................................................... 27
Figure 3-13 Volley Ball (7in.) .................................................................................................... 28
Figure 3-14 Box (9x7x5in.) ....................................................................................................... 28
Figure 3-15 Coffee Cup (4in.) ................................................................................................... 28
Figure 3-16 Traffic Cone (3ft) .................................................................................................. 28
Figure 3-17 Radio Controlled Car ............................................................................................. 28
Figure 3-18 Four Objects Used in Test ..................................................................................... 29
Figure 3-19 Walking Path of Person .......................................................................................... 30
Figure 3-20 Child Figure (3 ft) ................................................................................................ 31
Figure 3-21 Adult Figure (6 ft) ................................................................................................ 31
Figure 3-22 Black & White Monitor’s View of the Figure ......................................................... 32
Figure 3-23 Field of View Peripheral Limits ............................................................................. 33
Figure 3-24 Camera Angle θ and Height D .............................................................................. 34
Figure 3-25 Field of View of Camera at an Angle (top view) .................................................... 35
Figure 3-26 Field of View of Camera at 90° Angle (top view) .................................................... 35
Figure 3-27 Field of View of Camera: 3 ft – 11 ft and 60° (top view) ......................................... 36
Figure 3-28 Camera FOV Detail ............................................................................................... 36
Figure 3-29 Camera Height 3 ft ............................................................................................... 37
Figure 3-30 Camera Height 4 ft ............................................................................................... 37
Figure 3-31 Camera Height 5 ft ............................................................................................... 37
Figure 3-32 Camera Height 6 ft ............................................................................................... 37
Figure 3-33 Camera Height 7 ft ............................................................................................... 37
Figure 3-34 Camera Height 8 ft ............................................................................................... 37
Figure 3-35 Camera Height 9 ft ............................................................................................... 38
Figure 3-36 Camera Height 10 ft ............................................................................................. 38
Figure 3-37 Camera Height 11 ft ............................................................................................. 38
Figure 4-1  Poor Image Quality of PLC System, Company B ...................................................... 42
Figure 4-2  Troubleshooting Effort for the PLC System ............................................................. 42
Figure 4-3  Image Quality Comparison between PLC and Cable Systems .............................. 43
Figure 4-4  Timeline of Systems Deployment ......................................................................... 44
Figure 4-5  Normal Setup for PLC System .............................................................................. 45
Figure 4-6  Voltage Drop with Distance of Circuit .................................................................. 45

vi
Figure 4-7 Voltage Drop for a 16 AWG Wire ................................................................. 46
Figure 4-8 Voltage Drop Across a 14AWG Wire ............................................................ 46
Figure 4-9 Setup for Better Reception ............................................................... 47
Figure 4-10 Image of System with Voltage Drop .................................................. 49
Figure 4-11 Driver Age, Company A ........................................................................... 51
Figure 4-12 Years of Driving Experience, Company A ........................................ 52
Figure 4-13 Rearview System Easy to Use, Company A ........................................ 52
Figure 4-14 Comfortable Backing with Rearview System, Company A ............. 53
Figure 4-15 Accurately Can Judge Distance Using Rearview System, Company A 53
Figure 4-16 Image Clarity Suitable for Backing Maneuvers, Company A .......... 54
Figure 4-17 Rearview System is Reliable, Company A ............................................ 54
Figure 4-18 Still Necessary to Physically Check behind Truck before Backing with Rearview System, Company A ........ 55
Figure 4-19 Rearview System Helpful in Minimizing Backing Crashes? Company A .... 56
Figure 4-20 Legally Require Rearview Systems on All Trucks? Company A .... 56
Figure 4-21 Driver Age, Company B .......................................................................... 57
Figure 4-22 Driving Experience, Company B ............................................................ 57
Figure 4-23 Rearview System Easy to Use? Company B .......................................... 58
Figure 4-24 Comfortable Backing with Rearview System? Company B .......... 58
Figure 4-25 Accurately Judge Distance with Rearview System? Company B ...... 59
Figure 4-26 Image Clarity Suitable for Backing Maneuvers? Company B ........... 59
Figure 4-27 Rearview System Reliable? Company B ............................................... 60
Figure 4-28 Still Necessary to Physically Check Behind Truck before Backing? Company B ......... 60
Figure 4-29 Rearview System Helpful in Minimizing Backing Crashes? Company B .......... 61
Figure 4-30 Legally Require Rearview Systems on All Trucks? Company B .......... 61
Figure 4-31 Reason for Backing Crashes Based on Driver Opinion, Company C ........ 62
Figure 4-32 Driver Age, Company C .......................................................................... 62
Figure 4-33 Driving Experience, Company C ............................................................ 63
Figure 4-34 Easy to Use Rearview System? Company C ........................................ 63
Figure 4-35 Comfortable Backing with Rearview System? Company C .......... 63
Figure 4-36 Accurately Judge Distance Using Rearview System? Company C ...... 64
Figure 4-37 Image Clarity Suitable for Backing Maneuvers? Company C .......... 64
Figure 4-38 Rearview System Reliable? Company C ............................................... 65
Figure 4-39 Still Necessary to Physically Check Behind Truck before Backing? Company C ........ 66
Figure 4-40 Rearview System Effective for Minimizing Backing Crashes? Company C .......... 66
Figure 4-41 Legally Require Rearview Systems on All Trucks? Company C .......... 67
Figure 5-1 Accuracy Measurement during Test .................................................... 75
Figure 5-2 Straight Line Back Maneuver ................................................................. 76
Figure 5-3 Offset Back Right Maneuver ................................................................. 77
Figure 5-4 Parallel Park – Driver Side Maneuver .................................................... 78
Figure 5-5 Alley Dock Back Maneuver ................................................................. 78
Figure 5-6 Path of Pedestrian Dummy Passing behind Backing Truck ................. 79
Figure 5-7 Data Acquisition System ................................................................. 84
Figure 5-8 Location of Driver View Camera ......................................................... 85
Figure 5-9 Location of Rearview Cameras ............................................................ 85
Figure 5-10 Rearview Camera Close-Ups ............................................................... 86
List of Tables

Table 1-1  Timetable of Backing Crash and Countermeasure Studies .................................................. 6
Table 2-1  Severity of Backing Crashes Involving Large Trucks, U.S. .................................................... 11
Table 2-2  Percent of Backing Crash to Total Crashes, Florida, 2003 – 2006 ........................................ 12
Table 2-3  Contributing Causes for Backing Crashes Involving Trucks ............................................. 12
Table 2-4  Point of Impact on At-Fault Vehicle ..................................................................................... 13
Table 2-5  Estimated Speed Cross-Tabulation, Injury Severity Index 01, “No Injury” .......................... 14
Table 2-6  Estimated Speed Cross-Tabulation ..................................................................................... 16
Table 2-7  Estimated Speed Cross-Tabulation, Injury Severity Index 03, “Non-Incapacitating” Injury ........................................................................................................................... 16
Table 2-8  History of Backing Crashes, Company A ............................................................................. 17
Table 2-9  History of Backing Crashes, Company B ............................................................................. 18
Table 3-1  B/W CCD Camera Specifications ......................................................................................... 21
Table 3-2  LCD Monitor Specifications ................................................................................................. 22
Table 3-3  Comparison Matrix for Rearview Video Systems ................................................................. 28
Table 3-4  Identification of Objects ....................................................................................................... 29
Table 3-5  Testing Matrix ...................................................................................................................... 33
Table 4-1  Company Deployment Summary .......................................................................................... 41
Table 4-2  Summary of First Survey Responses ................................................................................... 51
Table 4-3  Summary of Second Survey Responses ............................................................................... 51
Table 4-4  Calculation Results of the Naïve Before-After Study ............................................................. 69
Table 5-1  History of Studies Related to Rear-Object Detection Technologies ........................................ 72
Table 5-2  Measures Taken during Maneuvers ...................................................................................... 76
Table 5-3  Summarized Raw Data ........................................................................................................ 92
Table 5-4  2X2 Contingency Tables ...................................................................................................... 93
Table 5-5  Result of McNemar Test ...................................................................................................... 94
Table 6-1  Backing Crash History (Companies B and C) ...................................................................... 101
Table 6-2  Benefit-Cost Analysis with 3% and 7% Discount Rate ......................................................... 103
Executive Summary

A backing crash occurs when a backing vehicle strikes another vehicle, stationary object, a bicyclist, 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.

In previous years, backup proximity sensors were utilized to provide the driver with an audiovisual warning about the closeness of objects behind the truck. As this technology was used throughout the automobile industry, certain limitations became clear: sensors were mainly developed as parking aids to avoid hitting other vehicles and parking structure walls while parking. Their performance on object-person detection was inconsistent and unreliable. A better solution was deemed to be the rearview video system (RVS) which provides a rear view of the vehicle to the driver, similar to how a rearview mirror would function. This way, the driver has a clear image of the rear and can make informed decisions about their backing maneuvers.

Three types of RVS including Power Line Carrier (PLC), wireless, and cable systems currently available in the market were compared as a countermeasure for truck backing crashes. The main difference of the systems is the signal transmission technology. Among these three systems there is no significant difference on the amount of time required for the system installation. Each of these three systems is easy to use. The cable system is the most reliable and can provide clear camera images to assist truck drivers on performing their backing maneuvers. Both the PLC system and the wireless system could not provide reliable camera images during field deployment. The three systems that were evaluated in this study performed well in the lab test but actual deployment revealed several limitations of the PLC rearview system, including poor image quality and unreliable performance. The PLC system is designed to provide convenience during the installation as well as actual use by using existing wire. However, it seems that the technology is not advanced enough to be used in daily operation as a countermeasure for backing crashes. As for the wireless system, unexpected and frequent signal interference rendered it unsafe for use as a crash avoidance technology at this point.

The quality of the image is an important component to promote the use of system as it was shown to be closely related to driver satisfaction. In general, drivers reported that the RVS is easy to use and had a positive attitude towards it. The majority of drivers also agreed that they were more comfortable performing backing maneuvers with the RVS system, and it would be helpful in minimizing potential backing crashes.

This study deployed a total of 100 RVS on the trucks of three different companies to evaluate their effectiveness in reducing backing crashes and obtained feedback from truck drivers participating in the study. Most drivers involved in the study had a positive attitude towards the system. The drivers took a minimal amount of time to get acquainted with the system for use in
their daily activities, and they agreed that it can aid in reducing and/or preventing potential backing crashes. The naïve before-and-after study based on the deployment and the results of the controlled study showed that the proper use of an RVS can result in approximately a 40 percent reduction in truck backing crashes.

A controlled test was designed and conducted to evaluate the effectiveness of the RVS system to reduce potential truck backing crashes in a controlled environment. The results showed that the presence of a RVS increased the stop rate (avoiding hitting an object) of drivers in the Straight Line Back maneuver by 46.7 percent, which can be interpreted as increasing the odds of avoiding potential backing crashes in the maneuver. The stop rate increased 4.4 percent and 17.8 percent for the Offset Right Back and the Alley Dock Back maneuvers, respectively.

The estimated benefit-cost ratio for the use of system is around 1.5 or higher. Thus, the widespread use of the RVS system will result in a vast savings and will also promote public safety. This study also found that the RVS can be effective in reducing truck backing crashes if it can function as intended. It is important to make sure that the system performs satisfactorily before it is used by drivers. Backing crashes are generally underreported due to a couple of characteristics of truck backing crashes, such as location and severity. For companies with combination trucks, it is recommended that the system be installed on all fleet vehicles and trailers at the same time so there are no trucks without the system due to the mismatch of equipped with non-equipped units. A rearview video system is an effective tool that provides the driver with a rear view to significantly reduce the rear blind spot.
1.0 Introduction

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 Related Research

A number of studies have been conducted concerning the problem of backing crashes in relation to all vehicles, including light, medium, and heavy trucks. These studies indicated that possible countermeasures for backing crashes are proximity sensors and video camera technologies. Video camera systems were first introduced in the 1980s as a countermeasure for crashes
involving large mining dump trucks. Research also has been conducted with radar systems for the same application by the National Institute for Occupational Safety and Health (NIOSH). In the early 1990s, the National Highway Transportation Safety Administration (NHTSA) showed interest in backing crashes and possible countermeasures. Two studies found important contributing factors, including the inability of the driver to see the struck vehicle/pedestrian or object, possibly because of limited or no view; improper backing due to driver inattention or distraction; backing at inappropriate velocities; and failure to check for obstacles before initiating a backing maneuver. The countermeasures examined included sensor-based technologies as well as camera-based (vision) technologies. The sensor technologies included ultrasonic, radar, and active infrared laser systems. The image-based technologies included rearview camera systems, which establish an object detection zone that has to be sufficiently large to cover the rear of the vehicle.

After the above studies, the Vision Enhancement Research and Technology Guide [5] was published by the Carnegie Mellon Research Institute with information on the specifications, influencing factors, and capabilities of technologies currently available at the time for vision enhancement systems. Further studies included research on the backing problem size, statistical description, and systems search. In the next decade, more specific information was sought to propose change in the Federal Motor Vehicle Safety Standards (FMVSS). NHTSA issued an advance notice of proposed rulemaking to gather further data on key issues with rear object detection systems. A number of car manufacturers began offering backup sensors as a parking aid to avoid low-speed crashes. In addition, a number of vendors offered similar systems in aftermarket products for both personal and commercial use vehicles.

The majority of these studies involved ultrasonic sensor systems because they were the most widely used. The sensors have limitations in their capabilities and are influenced by environmental factors such as temperature, humidity, rain; the object’s relative velocity, size, shape; and wave absorption rate. Since all the systems are electronic technologies, they are continuously improving due to their lower costs, size, and better performance. In addition, once-expensive systems such as camera systems are not as costly now as they were five years ago and are thus deemed appropriate to use for countermeasures.

In 2004, NHTSA issued a notice to change FMVSS No. 111: Rearview Mirrors to require a rear detection system for single-unit trucks. More research was conducted to measure or calculate the benefits from widespread deployment of such systems and setup specifications. In the next few years, NHTSA and the Federal Motor Carrier Safety Administration (FMCSA) conducted research to evaluate the sensor and camera systems on light, medium and heavy trucks. A recent Congressional study on vehicle backover avoidance technology conducted by NHTSA suggested that the parking aids found on vehicles that are sensor-based (radar and ultrasonic) do not provide a safe and reliable detection of objects or pedestrians, especially when the pedestrian is moving. According to NHTSA [1], “Of the technologies tested for their potential in backing incidents, the camera-based systems may have the greatest potential to provide drivers with reliable assistance in identifying people in the path of the vehicle when backing.”

In 2007, the Cameron Gulbransen Kids and Cars Safety Act required establishment of a rearward visibility performance standard. It provided drivers with a means of detecting the presence of a person behind the vehicle to prevent backing incidents involving death and injury, especially to
small children and persons with disabilities. In 2008, two studies conducted by NHTSA offered more insight into the benefit and use of these systems; one involved an on-road study of driver use of rearview video systems on minivans, and the other involved performance specifications for camera video imaging systems on heavy vehicles.

Sensor and camera systems are two alternatives for backing crash countermeasures. The primary difference between the two systems is based on two different deficits in driver awareness of the traffic situation: information deficits and attention deficits. Human factors literature distinguishes between the two needs as displays and warnings. Displays present information in a passive form; for the information to be used, the driver has to actively attend to it. Warnings are designed to be relatively intrusive and actively acquire the driver’s attention. In these terms, camera-based systems are usually designed as displays, and object-detection systems are usually designed as warnings. Countermeasures that involve displays are appropriate when drivers lack access to certain specific information such as visual information about vehicles in the blind zone. Countermeasures that involve warnings are appropriate when drivers are not attending to information that is already potentially available to them, either because they cannot sort through an overload of distracting information or because their arousal level is too low.

Research also focused on the actual benefits from such systems in real-life situations. Camera and sensor systems have a theoretical performance but when they are implemented, results are not exactly as expected. Recent studies performed by NHTSA showed that sensor backup systems or object detection systems are not adequate for detecting all possible objects or persons behind the vehicles, with primary emphasis on children who are short and small in size.

The latest reports to Congress showed that, out of the available backup systems, camera-based systems have the greatest potential for reducing crashes since they leave no rear blind spot; thus, the driver can potentially avoid all backing crashes. To evaluate the operational performance of rearview systems on heavy trucks, the USF Center for Urban Transportation Research (CUTR) under a project funded by the Florida Department of Transportation (FDOT) performed a study with widespread deployment of these systems as well as driver tests. The objectives of the study are explained in detail in the next section.

Table 1-1 shows a timetable of backing crash and countermeasure studies.

### 1.3 Study Objectives

The major objectives of this study are summarized as follows:

- Evaluate the effectiveness of rear vision systems in reducing backing crashes
- Determine the reliability of the Power Line Rear Vision System as compared to systems employing dedicated wiring or using wireless video data transfer
- Evaluate the ease of installation and ease of use of the products
- Estimate the potential savings due to widespread use of rear vision systems on commercial vehicles.
Table 1-1 Timetable of Backing Crash and Countermeasure Studies

<table>
<thead>
<tr>
<th>Year</th>
<th>Time Period Accomplishments and Study Names</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td>Introduction of the camera video system to the industry / • Backup camera system is used on mining dump trucks and garbage trucks</td>
</tr>
<tr>
<td>2000</td>
<td>More specific research by NHTSA to establish effectiveness of system and problems associated with usage / • Advanced Notice of Proposed Rulemaking to Gather Further Data on Key Issues with Rear Object Detection Systems (NHTSA) [8] / • Test Results of Collision Warning Systems for Surface Mining Dump Trucks (NIOSH) [9] / • Evaluation of Systems to Monitor Blind Areas Behind Trucks Used in Road Construction and Maintenance (NIOSH) [10]</td>
</tr>
<tr>
<td>2007</td>
<td>Research by NHTSA targeting issues with usage of the system and benefits from widespread deployment / • Cameron Gulbransen Kids and Cars Safety Act of 2007 requires establishment of a rearward visibility performance standard that will provide drivers with a means of detecting the presence of a person behind the vehicle in order to prevent backing incidents involving death and injury, especially to small children and disabled people [17]</td>
</tr>
</tbody>
</table>
The study was separated into the following tasks:

Task 1: Literature Review
A thorough literature review was conducted to identify related research that is pertinent to the successful completion of this project. The previous section compiles the results.

Task 2: Analysis of Video Crash Avoidance Technology
In this task, information was compiled on available rearview video crash avoidance systems. Of particular emphasis was technology intended to reduce backing crashes in heavy trucks. The available systems, including Power Line Carrier technology, were identified for evaluation, and a comparison matrix was developed that highlights and compares features of these systems.

Task 3: Development of a Detailed Evaluation Plan
A detailed plan was developed to evaluate the effectiveness of the Power Line Rear Vision System in reducing backing type crashes. It included the following sub-tasks:

- Examined the availability of data related to backing crashes
- Assessed the currently deployed Power Line Rear Vision System to determine if customers are willing to share crash information
- Investigated the practicality of controlled driver tests to evaluate the system’s effectiveness
- Coordinated with appropriate professional and trade organizations to participate in driver tests

Task 4: Deployments of Rearview Video Technologies in Motor Carriers
Actual deployments of rearview video systems including the Power Line rearview video system were performed in this task. The deployments were accomplished by supporting three trucking companies to purchase and install rearview video systems to obtain needed before-and-after crash data and to conduct interviews with safety officers and drivers of the participating trucking companies. A mutual agreement between CUTR and the participating trucking companies was signed before the deployment. Interviews with rear view system technicians were conducted as part of deployment to assess the ease of system installation. This report addresses the findings related to the deployments of available rearview video systems and the evaluation of the ease of system installations.

In addition, survey questionnaires were designed and distributed to several trucking companies with rearview video systems installed on their fleets to evaluate the effectiveness on crash reduction, system reliability, ease of installation, ease of use of the products, and cost savings. The analysis and results of the surveys are incorporated into the report.

Task 5: Evaluation of Deployed Systems on Crash Experience
The actual deployed systems from this project were constantly monitored, and the crash experience of equipped vehicles was collected from participating trucking companies and compared against the general motor carrier crash experience over a one-year period. The data were evaluated to determine whether a statistically-significant difference existed between vehicles that are equipped with rear view crash avoidance systems and vehicles that are not.
Task 6: Evaluation in Controlled Conditions
For this task, the project team designed and conducted a controlled driver test to evaluate rearview video system accuracy and effectiveness. An appropriate sample size of drivers was evaluated in backing maneuvers with and without the rearview video system. The drivers were timed in their backing maneuvers, and the scenarios included a variety of tasks that were designed to show if the rearview systems could help the driver identify a variety of potential hazards.

Task 7: Estimate of Cost Savings
For this task, the team evaluated the life-cycle costs of the Power Line rearview video system and the feasibility of widespread deployment of the technology. This task provided an estimate of the cost savings that can be expected from individual and widespread use of video collision avoidance technology, incorporated the results of previous tasks, and extrapolated the projected cost savings. Specific expected savings and reductions evaluated include the following:

- Reduction in fatalities
- Reduction in injuries
- Reduction in damage to motor carrier vehicles
- Reduction in damage to other objects
- Reduction in damage to cargo
- Reduction in time lost due to back-over crashes
- Reduction in motor carrier insurance cost

Task 8: Production of the Project Final Report
Based on the outcome of the previously outlined tasks, this preliminary draft report was developed and submitted to FDOT for review. The report documents the findings of the study and contains recommendations on the potential expanded use of rearview video systems in commercial vehicles. After FDOT review and comments have been received, the report will be finalized. Additional research activities on rear vision technology for motor carriers based on the research findings from Phase II will also be identified.

1.4 Summary
Backing crashes are predominantly crashes that involve a vehicle backing over and hitting or passing over a pedestrian, in which the driver cannot see because of a rear blind spot. Although crashes like these involve all types of vehicles, they are particularly significant and intensified when they involve a large commercial vehicle, usually a truck with a GVWR of more than 10,000 lbs. Backing crashes that involve large commercial trucks occur more often and are usually more severe in nature. These crashes can be reduced dramatically if the blind spots that surround the trucks are eliminated. Technology advancement provides new solutions. Rearview video systems can be used to eliminate blind spots, thus reducing backing crashes. These rearview video systems consist of camera(s) mounted at the rear and/or sides of the vehicles and a display and other control equipment located in the driver’s cabin. The driver has a view of the rear of the vehicle and can then back up having a clear view, similar to a rear view mirror in passenger cars.
The potential of this technology is tremendous. NHTSA has shown interest in mandating safety equipment such as rear view systems. Further evaluation needs to be done to determine the proportion of crash reductions achieved with optimum benefit-to-cost ratios.

References

7. NHTSA, Notice seeking information on cross-view mirrors and other alternative rear object detection systems. 1996.
8. NHTSA, ANPRM to gather further data on key issues related to rear object detection. 2000 (65 FR 70681).
9. Ruff T.M., Test Results of Collision Warning Systems for Surface Mining Dump Trucks. 2000, NIOSH.
20. NHTSA, Federal Motor Vehicle Safety Standards; Rearview Mirrors; Advance Notice of Proposed Rulemaking (ANPRM), DOT, 2009. NHTSA.
2.0 Backing Crashes

According to a report by NHTSA [1], it is estimated that backing crashes for all vehicles in the United States are underreported for two or more reasons. The first is that backing crashes are frequently low-speed and low-severity crashes and thus fall below reporting thresholds. The second is that many backing crashes occur off-road on private property. Therefore, it is not easy to assess the number of backing crashes in the U.S., and relatively little attention has been paid to this type of crash as compared to others.

2.1 Backing Crash Data

Various data sources related to backing crashes involving large trucks were examined by conducting a literature review. The purpose of gathering this information was to obtain an understanding of the circumstances, nature, and magnitude of backing crashes that involve large trucks. Several databases and reports were reviewed to obtain information on backing crashes involving large trucks: the Highway Safety Information System, the Motor Carrier Management Information System, the Large Truck Crash Causation Study of Analysis and Information database, the State Traffic Safety Information, and the Safety Policy Division of the American Trucking Association.

- **Highway Safety Information System**
  
The Highway Safety Information System (HSIS) is a multi-state database that contains crash data, roadway inventory, and traffic volume data for a select group of states. The HSIS is operated by the University of North Carolina Highway Safety Research Center (HSRC) and LENDIS Corporation under contract with the Federal Highway Administration (FHWA) [2]. HSIS uses crash data that are collected by states for the management of the highway system and for highway safety studies. HSIS is a roadway-based system that provides quality data on a large number of accidents, roadway, and traffic variables. The data are acquired annually from several states, processed into a common computerized format, documented, and prepared for analysis. HSIS includes a crash database from nine states and contains information on backing crashes. Backing crashes involving large trucks can be extracted directly from this database. Table 2-1 shows the frequency over a range of severities for backing crashes involving large trucks in California, Illinois, and North Carolina. It is noted that most backing crashes involving large trucks are “No Injury” (property damage only) crashes.

- **Motor Carrier Management Information System**
  
The Motor Carrier Management Information System (MCMIS) is operated by FMCSA and contains data describing the commercial vehicle crashes reported to the FMCSA [3]. The MCMIS contains data from state police crash reports involving drivers and vehicles of motor carriers operating in the U.S. Each report contains about 80 data elements pertaining to the motor carrier, driver, vehicles, and circumstances of a crash. Currently, the state-reported crash file elements are available post 1993.
Table 2-1 Severity of Backing Crashes Involving Large Trucks

<table>
<thead>
<tr>
<th>Crash Severity</th>
<th>Year (2000-2002)</th>
<th>Percent (Total)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CA</td>
<td>IL</td>
</tr>
<tr>
<td>Fatal</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Severe injury</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>Other visible injury</td>
<td>7</td>
<td>29</td>
</tr>
<tr>
<td>Complaint of pain</td>
<td>23</td>
<td>33</td>
</tr>
<tr>
<td>No injury</td>
<td>623</td>
<td>400</td>
</tr>
<tr>
<td>Unknown</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>664</td>
<td>477</td>
</tr>
</tbody>
</table>

- **Large Truck Crash Causation Study on Analysis and Information Database**
  The Large Truck Crash Causation Study (LTCCS) on Analysis and Information (A&I) national database is the first national study to attempt to determine the critical events and associated factors that contribute to serious large truck crashes [4]. This study allowed the U.S. Department of Transportation (USDOT) and transportation professionals to implement effective countermeasures to reduce the occurrence and severity of these crashes.

  The LTCCS was conducted at 24 data collection sites in 17 states by researchers from the National Automotive Sampling System (NASS) for NHTSA and state truck inspectors. Data were collected on crashes from 2001 through 2003. Although the LTCCS database can provide some information on backing crashes, it was not selected for further analysis since it includes only large truck crashes that involved fatalities or caused serious injury.

- **Other Databases and Resources**
  The State Traffic Safety Information (STSI) is operated by the National Center for Statistics and Analysis (NCSA) for NHTSA [5]. It provides detailed traffic data for each state, such as fatal crash statistics, economic costs, legislation status, funding programs, and county-level information for many of the state-level characteristics. The STSI database was not selected for use as it does not provide any information on backing crashes. Another resource is the safety policy division of the American Trucking Association (ATA) [6]. Although no additional database is available from ATA, some reports on truck safety were obtained for reference purposes.

2.2 **Florida Crash Database**

The Florida Crash Database (2003-2006) was analyzed with the purpose of understanding the contributing factors and distribution of the backing crashes involving trucks. As shown in Table 2-2, backing crash rates in Florida have remained constant over the years. It is noted that trucks have a relatively 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, and 92.1 percent of all the backing crashes were Property Damage Only (PDO) crashes.
Table 2-2 Percent of Backing Crash to Total Crashes, Florida, 2003 – 2006

<table>
<thead>
<tr>
<th>Year</th>
<th>Passenger Car (1,2,3*)</th>
<th>Truck (4,5,6*)</th>
<th>All Vehicle Types</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>Backing</td>
<td>%</td>
</tr>
<tr>
<td>2003</td>
<td>248,215</td>
<td>10,293</td>
<td>4.15</td>
</tr>
<tr>
<td>2004</td>
<td>265,124</td>
<td>11,162</td>
<td>4.21</td>
</tr>
<tr>
<td>2006</td>
<td>261,767</td>
<td>11,217</td>
<td>4.29</td>
</tr>
<tr>
<td>Total</td>
<td>1,045,542</td>
<td>43,840</td>
<td>4.19</td>
</tr>
</tbody>
</table>

* Denotes the vehicle type code in FDOT Crash Analysis Reporting (CAR) system

Table 2-3 lists the distribution of the contributing cause for backing crashes that involved trucks. The results showed that for 80.9 percent of these crashes, the contributing cause was “improper backing.” Due to a lack of details, no further information can be drawn about the cause of “improper backing.” Specifically, there was no information regarding if “improper backing” crashes were due to the driver lacking a clear rear view of the trucks or whether the “improper backing” could have been avoided by providing a rear view. 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.” Further investigation was needed to understand “improper backing” under common circumstances and whether “improper backing” could be eliminated by providing a rear view of the vehicles.

Table 2-3 Contributing Causes for Backing Crashes Involving Trucks

<table>
<thead>
<tr>
<th>Contributing Cause</th>
<th>Frequency</th>
<th>Percent</th>
<th>Contributing Cause</th>
<th>Frequency</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unknown/Not Coded</td>
<td>1</td>
<td>0.0</td>
<td>Improper Passing</td>
<td>1</td>
<td>0.0</td>
</tr>
<tr>
<td>No Improper Driving/Act</td>
<td>273</td>
<td>3.0</td>
<td>Drove Left of Center</td>
<td>1</td>
<td>0.0</td>
</tr>
<tr>
<td>Careless Driving</td>
<td>799</td>
<td>8.8</td>
<td>Obstructing Traffic</td>
<td>4</td>
<td>0.0</td>
</tr>
<tr>
<td>Failed to Yield</td>
<td>51</td>
<td>0.6</td>
<td>Improper Load</td>
<td>1</td>
<td>0.0</td>
</tr>
<tr>
<td>Improper Backing</td>
<td>7356</td>
<td>80.9</td>
<td>Driving Wrong Side/Way</td>
<td>1</td>
<td>0.0</td>
</tr>
<tr>
<td>Improper Lane Change</td>
<td>7</td>
<td>0.1</td>
<td>Fleeing Police</td>
<td>1</td>
<td>0.0</td>
</tr>
<tr>
<td>Improper Turn</td>
<td>6</td>
<td>0.1</td>
<td>Driver Distraction</td>
<td>16</td>
<td>0.2</td>
</tr>
<tr>
<td>Alcohol-Under Influence</td>
<td>10</td>
<td>0.1</td>
<td>All Other</td>
<td>542</td>
<td>6.0</td>
</tr>
<tr>
<td>Failed to Maintain Equipment/Vehicle</td>
<td>20</td>
<td>0.2</td>
<td>Disregarded Traffic Signal</td>
<td>2</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>9092</strong></td>
<td><strong>100.0</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Point of Impact**
  Based on the classifications from the original crash database, the vehicle point of impact was simplified into the following six parts: front end, rear end, left rear, right rear, left front, and right front, as shown in Figure 2-1.
For each type of vehicle point of impact, the backing crash amount was counted, as shown in Table 2-4. Results indicated that for at-fault drivers, the point of impact usually was the rear part of the vehicle, while for the next driver it was the front part of the vehicle. However, it is noted that 13.1 percent of backing crashes involved vehicle damage to the front side of the vehicle.

### Table 2-4 Point of Impact on At-Fault Vehicle

<table>
<thead>
<tr>
<th>Point of Impact</th>
<th>Frequency</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front End</td>
<td>962</td>
<td>13.1</td>
</tr>
<tr>
<td>Right Front Corner</td>
<td>141</td>
<td>1.90</td>
</tr>
<tr>
<td>Right Front Quarter Panel</td>
<td>79</td>
<td>1.10</td>
</tr>
<tr>
<td>Right Rear Quarter Panel</td>
<td>206</td>
<td>2.80</td>
</tr>
<tr>
<td>Right Rear Corner</td>
<td>1,064</td>
<td>14.50</td>
</tr>
<tr>
<td>Rear End</td>
<td>2,177</td>
<td>29.60</td>
</tr>
<tr>
<td>Left Rear Corner</td>
<td>724</td>
<td>9.80</td>
</tr>
<tr>
<td>Left Rear Quarter Panel</td>
<td>74</td>
<td>1.00</td>
</tr>
<tr>
<td>Left Front Corner</td>
<td>78</td>
<td>1.10</td>
</tr>
<tr>
<td>Trailer</td>
<td>1,421</td>
<td>19.30</td>
</tr>
<tr>
<td>Other</td>
<td>262</td>
<td>3.64</td>
</tr>
<tr>
<td>Total</td>
<td>7,188</td>
<td>100</td>
</tr>
</tbody>
</table>

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

As for vehicle movements, most of the at-fault vehicles were backing in the backing crashes, while nearly 41 percent of the next vehicles were slowing, stopped, or stalled. The most common scenarios for backing crashes were that the next vehicles were slowing, stopped, or stalled near the at-fault vehicles when they were backing.

It is interesting that almost all truck-related backing crashes in the FDOT CAR database involve two or more vehicles. Considering that many backing crashes for large trucks occurred when the vehicles were backing to load or unload cargo, which was later confirmed with the company’s crash history, it is plausible to assume that, generally, a single vehicle involving a backing crash is less likely to be reported unless it involves fatality or serious injury.

### 2.3 Florida Traffic Crash Reports

A total of 1,549 Florida Traffic Crash 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:

01 - No injury
02 - Possible injury
03 - Non-incapacitating injury
04 - Incapacitating injury
05 - Fatality

The review process began with crashes with incapacitating and fatal injuries. About fifty percent of these crashes involve 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 view” or “no view.” The effort was then extended to injury severity indexes 01-03. The remainder of the backing crashes reviewed include 98 non-incapacitating injury, 323 possible injury, and 1,035 no injury crashes. It appears that approximately 80 percent of these crashes occurred when both vehicles were traveling below 10 mph. These crashes fall into the category of crashes that can be potentially avoided by providing a rear view.

- **Back ing Crash Records Analysis (Injury severity index: 01- No injury)**

For the “No injury” category, coded as 01, the report showed that a total of 1,080 crashes involved trucks (vehicle type 04, 05, and 06). Of those, 45 were eliminated because the at-fault vehicle did not back up but rather rolled back and struck the vehicle behind it.

An 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 expected, the at-fault vehicle (the backing vehicle) was traveling at <10 mph speeds, and vehicle 2 also was traveling at <5 mph. As shown Table 2-5, 74 percent of the crashes with reported speeds occurred when both vehicles were traveling <5 mph. This includes the crashes when the second vehicle was stopped and the speed was 0 mph.

<table>
<thead>
<tr>
<th>Speed of Vehicle 1</th>
<th>0-5 mph</th>
<th>5-10 mph</th>
<th>10-15 mph</th>
<th>15-20 mph</th>
<th>20+ mph</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-5 mph</td>
<td>577</td>
<td>17</td>
<td>8</td>
<td>4</td>
<td>18</td>
<td>619</td>
</tr>
<tr>
<td>5-10 mph</td>
<td>110</td>
<td>10</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>127</td>
</tr>
<tr>
<td>10-15 mph</td>
<td>17</td>
<td>1</td>
<td>5</td>
<td>1</td>
<td>2</td>
<td>26</td>
</tr>
<tr>
<td>15-20 mph</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>20+ mph</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td>707</td>
<td>30</td>
<td>17</td>
<td>9</td>
<td>20</td>
<td>783</td>
</tr>
</tbody>
</table>
The major reasons for the backing crashes in this category are:

**Case 1** The truck 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 accesses, and highway entrance or exit ramps, etc.

**Case 2** The truck is in the wrong lane and backs to correct this mistake, striking the vehicle stopped behind it.

**Case 3** The truck 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).

**Case 4** The truck is stopped at a signal or stop sign intersection, and to make room for a second truck turning perpendicularly with the truck’s direction, backs into the vehicle behind it.

**Case 5** The truck 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.

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

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

**Case 8** The truck is backing out of a driveway or side street onto 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.

**Case 9** The tractor trailer 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.

Due to the nature of these crashes, the location and estimated speed of the vehicles and all cases except 8 and 9 above could have been avoided if a rear view was provided and the driver could see that there was a vehicle behind the truck when backing. Since no driver deliberately wants to hit another vehicle, the lack of view or limited view can be blamed as the cause of crash. It was also noted that small vehicles such as passenger vehicles tend to “disappear” in the rear blind spot of larger vehicles so drivers cannot see them prior to backing. It was found that 133 cases (12.9%) included a statement by the at-fault drivers that they checked their mirrors before
backing and did not see the vehicle behind them. In three crashes, the at-fault vehicle was equipped with a rear view system. In one, the system was not functional, in the second, the system was functional but the driver stated that sunlight glare on the monitor impaired his view, and in the third, there were no reported obstructions or system malfunction.

- **Backing Crash Records Analysis (Injury severity index: 02 - Possible injury)**
  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. Table 2-6 shows that 53 percent of the crashes with reported speeds occurred when both vehicles were traveling <5 mph. This includes the crashes when the second vehicle was stopped and the speed was 0 mph.

<table>
<thead>
<tr>
<th>Table 2-6 Estimated Speed Cross-Tabulation, Injury Severity Index 02, “Possible Injury”</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Speed of Vehicle 2</strong></td>
</tr>
<tr>
<td>0-5 mph</td>
</tr>
<tr>
<td>5-10 mph</td>
</tr>
<tr>
<td>10-15 mph</td>
</tr>
<tr>
<td>15-20 mph</td>
</tr>
<tr>
<td>20+ mph</td>
</tr>
<tr>
<td><strong>Total</strong></td>
</tr>
</tbody>
</table>

Two crashes occurred in which the at-fault vehicle was equipped with a rear view system. Both of these systems were functional. The first driver reported that he checked the monitor before backing, but the other vehicle also was backing, which could be the reason he did not see the vehicle. In the second case, the driver reported that the sun was at an angle that created glare in his camera and he could not see the vehicle behind him.

- **Backing Crash Records Analysis (Injury severity index: 03 - Non-incapacitating injury)**
  For the “non-incapacitating injury” category coded as 03, the Florida Crash Database had a total of 87 crashes involving trucks (vehicle codes 04, 05, and 06). As shown in Table 2-7, 45 percent of the crashes occurred while the vehicle speed was <5 mph.

<table>
<thead>
<tr>
<th>Table 2-7 Estimated Speed Cross-Tabulation, Injury Severity Index 03, “Non-Incapacitating” Injury</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Speed of Vehicle 2</strong></td>
</tr>
<tr>
<td>0-5 mph</td>
</tr>
<tr>
<td>5-10 mph</td>
</tr>
<tr>
<td>10-15 mph</td>
</tr>
<tr>
<td>15-20 mph</td>
</tr>
<tr>
<td>20+ mph</td>
</tr>
<tr>
<td><strong>Total</strong></td>
</tr>
</tbody>
</table>
The major reasons for the backing crashes in this category are:

**Case 1** The truck missed a turn, stopped in the road, and backed to make the turn, striking a vehicle that stopped behind the truck without the driver seeing the vehicle. (Note: Many truck drivers say that they did check their mirrors prior to backing and could not see the vehicle behind due to a blind spot. In addition, 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 and at intersections with side streets, driveway accesses, and highway entrance or exit ramps, etc.

**Case 2** The truck is negotiating a turn at an intersection, but due to the length of the trailer and not having adequate space, the driver needs to back up to complete the turn and strikes vehicle that follows too closely behind the truck.

**Case 3** The truck backs out of a driveway or side street onto the main street and strikes an oncoming vehicle that did not see the truck until it was too late or the driver could not stop in time.

**Case 4** The truck stops too far, passing the stop bar at the traffic signal or stop sign and backs to correct, striking the vehicle stopped behind the truck.

Due to the nature of these crashes, the location and estimated speed of the vehicles, all cases except the ones described in Case 3 above could be avoided if the driver could see that there was a vehicle behind the truck when backing.

### 2.4 Trucking Company Crash Database and Summary

Several trucking companies that agreed to participate in this study shared their backing crash records. A non-disclosure agreement was signed between CUTR and the participating companies. Therefore, company names are anonymous throughout the study. As shown in Table 2-8, backing crashes represent almost a 20 percent or higher portion of total crashes in one company. The fleet size for this company is around 150. This number is a much higher number than backing crash information that can be found in a public database.

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Crashes</th>
<th>Backing Crashes</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>50</td>
<td>19</td>
<td>38.0</td>
</tr>
<tr>
<td>2006</td>
<td>60</td>
<td>10</td>
<td>16.7</td>
</tr>
<tr>
<td>2007</td>
<td>66</td>
<td>19</td>
<td>28.8</td>
</tr>
<tr>
<td>2008</td>
<td>44</td>
<td>11</td>
<td>25.0</td>
</tr>
</tbody>
</table>

In addition, a truck driver survey revealed that backing crashes are one of the most frequent crashes for trucking companies. Table 2-9 shows the history of backing crashes from another trucking company. This company has about 50 trucks.
Table 2-9  History of Backing Crashes, Company B

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Crashes</th>
<th>Backing Crashes</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>7</td>
<td>3</td>
<td>42.0</td>
</tr>
<tr>
<td>2005</td>
<td>23</td>
<td>19</td>
<td>82.6</td>
</tr>
<tr>
<td>2006</td>
<td>8</td>
<td>3</td>
<td>37.5</td>
</tr>
<tr>
<td>2007</td>
<td>9</td>
<td>6</td>
<td>66.7</td>
</tr>
</tbody>
</table>

Throughout the review of various backing crash data, several findings are summarized as follows:

1) It is difficult to estimate backing crashes by using public databases in an effective and efficient manner. However, backing crashes represent a larger portion of crashes in most trucking companies than anticipated in general.

2) A large portion of backing crashes occurred with low speed (<5 mph), and the lack of view and/or limited view seems to be a major cause of this type of crash. If a proper rear view is provided, there is a strong likelihood of reducing backing crashes, as it allows the driver to see objects behind the truck when performing backing maneuvers.

References

5. NHTSA, National Center for Statistics and Analysis. 2009. Available from http://www.nhtsa.dot.gov/portal/site/nhtsa/menuitem.a0bd5d5a23d09ec24ec86e10dba046a0/.
3.0 Rearview Video Systems

Rearview video systems 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 3-1 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 (13.5 ft from ground level) to eliminate the rear blind spot. Figure 3-2 and Figure 3-3 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 3-4 shows an example of a display mounted on the dashboard of a semi truck.

![Figure 3-1 Rear No Zone, Camera Location, and Field of View](image1)

![Figure 3-2 View from Rearview Camera Located at 3 ft Height](image2)
3.1 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 or 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 infrared LEDs are shown in Figure 3-5, which shows the camera type used for this study with the mounting bracket. The particular camera has a 1/3in. lens and requires 0 Lux illumination since it uses the infrared LEDs for light. The lens aperture is f/2.8. The technical specifications of the camera can be seen in Table 3-1. Figures 3-2 and 3-3 show views using the same 1/3in. camera.

Figure 3-5  1/3in. Rearview Camera

Table 3-1  B/W CCD Camera Specifications

<table>
<thead>
<tr>
<th>Feature</th>
<th>Technical Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>TV System</td>
<td>EIA</td>
</tr>
<tr>
<td>Effective Pixels</td>
<td>512 x 492 pixels</td>
</tr>
<tr>
<td>Sensing Area</td>
<td>4.9mm x 3.7mm</td>
</tr>
<tr>
<td>Scanning System</td>
<td>2:1Interlace</td>
</tr>
<tr>
<td>Sync. System</td>
<td>Internal</td>
</tr>
<tr>
<td>Resolution</td>
<td>420TV lines</td>
</tr>
<tr>
<td>Minimum Illumination</td>
<td>0 Lux</td>
</tr>
<tr>
<td>Horizontal Sync resolution</td>
<td>15,734KHz</td>
</tr>
<tr>
<td>Vertical Sync resolution</td>
<td>60Hz</td>
</tr>
<tr>
<td>Video Output</td>
<td>1.0vp-p, 75 Ohm</td>
</tr>
<tr>
<td>Microphone</td>
<td>No</td>
</tr>
<tr>
<td>Gamma Consumption</td>
<td>0.45</td>
</tr>
<tr>
<td>AGC</td>
<td>Auto</td>
</tr>
<tr>
<td>S/N Ratio</td>
<td>Better than 48dB</td>
</tr>
<tr>
<td>White Balance</td>
<td>Auto</td>
</tr>
<tr>
<td>Electronic Shutter</td>
<td>1/60 ~ 1/10,000</td>
</tr>
<tr>
<td>BLC</td>
<td>Auto</td>
</tr>
<tr>
<td>Current Consumption</td>
<td>Max. 300mA</td>
</tr>
<tr>
<td>Power Supply</td>
<td>DC12V</td>
</tr>
<tr>
<td>Operating Temperature</td>
<td>-20°C~70°C, RH95% MAX</td>
</tr>
<tr>
<td>Storage Temperature</td>
<td>-40°C~85°C RH95% MAX</td>
</tr>
<tr>
<td>Lens Aperture</td>
<td>f = 2.8</td>
</tr>
</tbody>
</table>
3.2  Monitors

The monitors used in RVS can be either CRT (cathode-ray tube) or LCD (liquid crystal display). 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 glass tube inside the monitor could injure 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, 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 3-2. Figure 3-4 shows an LCD monitor installed on the dashboard of a vehicle as a part of a rearview video system.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Technical Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Display Device</td>
<td>Color TFT-LCD</td>
</tr>
<tr>
<td>Screen Size</td>
<td>5 in.</td>
</tr>
<tr>
<td>Audio Output</td>
<td>200mW</td>
</tr>
<tr>
<td>Loudspeaker</td>
<td>One 4.0cm round loudspeaker</td>
</tr>
<tr>
<td>Connecting Terminal</td>
<td>Earphone jack, audio/video (AV) input jack, external power supply input jack, rearview connector</td>
</tr>
<tr>
<td>Application Power Supply</td>
<td>12V</td>
</tr>
<tr>
<td>Power Consumption</td>
<td>~ 8W</td>
</tr>
<tr>
<td>Outer Dimension</td>
<td>163mm(W), 125mm(H), 30.5mm(T)</td>
</tr>
<tr>
<td>Weight</td>
<td>430g</td>
</tr>
<tr>
<td>Resolution</td>
<td>960(H), 234(V)</td>
</tr>
<tr>
<td>Contrast</td>
<td>150:1</td>
</tr>
<tr>
<td>Brightness</td>
<td>300cd/m²</td>
</tr>
</tbody>
</table>

3.3  Transmission Technologies

The primary difference among the RVS currently available in the market is the method of video signal transmission from the camera located at the rear or side of the vehicle to the monitor located in the driver’s cabin. Other differences among RVS deal with the functions of the systems, as various cameras and displays are matched to create a system. Any kind of RVS that provides the driver with a rear view of the vehicle is adequate to be used as a crash avoidance technology for backing maneuvers. The systems’ differences have nothing to do with the safety aspect (unless tested); instead, they involve the transmission of the video signal. However, the reliability of the transmission method can affect the operation of some types of systems, thus making them unreliable. Three video signal transmission technologies have been identified as potential research interests:

- transmission via cable, the “cable” method
- transmission via wireless technology, the “wireless” method
- transmission via existing power cables, the “Power Line Carrier” (PLC) method
The operations of these three systems are explained in the next subsections of the report.

**Figure 3-6  5” LCD Monitor on Dashboard**

- **Cable Method**
The cable method is the traditional method used in video communications. The camera sends a signal that is transferred and connected to a monitor so the driver can have a visual of the camera view. The transmission of the signal is traditionally done using a cable directly connecting the camera and the monitor. Using this method, there are minimal problems of interference and cut-outs (no signal). Since the camera is directly connected to the monitor, there is no problem receiving the signal. Figure 3-7 shows the schematic of this system installed on a semi truck.

**Figure 3-7  Cable System Installed on a Semi Truck**

This system is more suitable for straight trucks, where no extra connection harness is needed between the trailer and the tractor. When installed on a semi truck, as shown in Figure 3-7, an extra harness is required to connect the trailer and the tractor. This harness requires the driver to connect it; if not connected, the system will not work.

- **Wireless Method**
The wireless method is becoming more popular than in the past due to advances in technology and the lower costs of these systems. The camera module consists of the camera and a transmitter that transforms the signal from analog to digital and sends it through the environment at a specific frequency. The monitor module is connected to a receiver, which picks up the signal from the transmitter and converts it so the monitor can show the camera view. No wiring is required except for power to the components. This method has a faster installation time, and the system components are easier to install than the cable method since there is no cable connecting.
the camera to the monitor. However, this method is the least reliable of the three types because, depending on the environment, the signal can be weakened or lost due to interference from the environment. Figure 3-8 shows the components of the wireless system, and Figure 3-9 illustrates how the components are installed on a semi truck.

![Figure 3-8 Wireless Rearview Video System Set](image1)

![Figure 3-9 Wireless System Installed on a Semi Truck](image2)

- **Power Line Carrier Method**
  The Power Line Carrier method is a new method of transmitting video and audio signals through power lines. It typically replaces the need for extra cables as in the cable method since existing power cables are used [1]. In this method, the camera is connected to a module responsible for transforming the signal into a specific frequency and sending it through the truck’s existing power cables. The power cables start from the engine, go through the driver’s cabin, and then connect to the trailer to power the truck’s position lights, indicator lights, reverse lights, brake lights, etc. The signal can then be picked up anywhere the cables run. In the case of trucks, a module is located inside the driver’s cabin where the signal is transformed again and sent to the monitor. This method eliminates the use of a cable connecting the camera and the monitor but still requires the camera and the monitor modules to be connected to power cables. The installation time is expected to be comparable to the wireless method, yet less than the cable method. The primary advantage of this method, and the fundamental difference from the cable method, is that for a tractor-trailer truck, the existing connector used for powering the back trailer can be used to connect the view system; in the cable method, a second connector to the
signal cable must be installed on the truck. Figure 3-10 illustrates the Power Line Carrier system installed on a semi truck.

![Diagram of Power Line Carrier System Installed on a Semi Truck](image)

**Figure 3-10  Power Line Carrier System Installed on a Semi Truck**

### 3.4 Lab Tests

The research team performed “bench tests” to obtain performance information on the systems before actual deployment. The three systems mentioned above were tested. All the systems performed very well. The image from the camera was clear and had bright colors and clear detail. The PLC system has a black & white image because the camera currently is limited to black & white. Figure 3-11 shows a view of the camera’s image from a cable system during testing.

During the bench tests, the power was supplied by a power adaptor converting the 120VAC to 12VDC. All three systems performed well with the same result in image clarity. A main difference was that the PLC system provided was black & white with no color capability. Also, the wireless system was tested by placing the two modules apart as far as 100 ft with nothing between them.

### 3.5 Results from Initial Installation

Two of the three systems were installed on tractor-trailer trucks of Company R after an agreement was signed with CUTR. The company provided four trucks on which two cable and two PLC systems were installed. Figure 3-12 (a-l) shows installation pictures. Figure 3-12a) shows the new wiring box installed on the trailer for the cable system. Figure 3-12b) shows the coil cable connected to the box. Figure 3-12c) shows the connection of the coil cable to the tractor. Figure 3-12d) shows the fuse box of the truck open for connection. Figure 3-12e) shows the rearview camera installed next to the license plate. Figure 3-12f) shows the monitor of the system installed on the dashboard of the vehicle. Figure 3-12g) shows the receiver module of the PLC system installed inside the cabin. Figure 3-12h) shows the fuse box of the truck open for the PLC installation. Figure 3-12i) shows the monitor of the PLC system installed inside the driver’s cabin. Figure 3-12j) shows the transmitter module connected to the camera ready for installation. Figure 3-12k) shows the camera installed in the same location for the PLC system. Figure 3-12l) shows the monitor with rear view of the truck.
The cable systems took 2-3 hours per system to be installed and worked as well as during the lab test. The PLC system, after initial installation, was not functional. Through troubleshooting, the installer was able to identify that the signal was not coming through the power lines to the cabin. One reason for this was that the trailer was old and the power cables might have been corroded, resulting in the signal loss. The lights of the trailer were functional. The installer also mentioned that in many applications the ABS brake power lines are used because they have uninterrupted clear power 12VDC, which is optimum for the video signal to be carried over. The solution was to carry the signal cable from the transmission module and connect it directly to the pins of the power box so it could be carried over to the tractor by the power coil cable. In this way, although the PLC technology was not taken advantage of completely, the signal was able to be carried over and picked up by the receiver module where the image was sent to the monitor. The main goal of the manufacturer of the PLC system to eliminate an extra wiring harness and cable was successful, but it required a few extra hours of troubleshooting.

The team installed a temporary wireless system on one truck to observe any interference patterns with the system. It was observed that, although the signal did reach the receiver and displayed an image, the location of the antenna of the receiver was highly sensitive, and thus the signal cut out from time to time. A suitable location for the receiver that provides a clear image was not found.
A comparison of the rearview systems is shown in Table 3-3 and explains why a particular system might have advantages over others. The comparison was performed based on the specifications of the devices and values that the research team was able to obtain. The features of the systems are described in more detail in Appendix A.
Table 3-3 Comparison Matrix for Rearview Video Systems

<table>
<thead>
<tr>
<th>Feature</th>
<th>Cable</th>
<th>Wireless</th>
<th>Power Line Carrier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of cameras</td>
<td>unlimited</td>
<td>up to 2</td>
<td>1</td>
</tr>
<tr>
<td>Lens</td>
<td>same</td>
<td>same</td>
<td>same</td>
</tr>
<tr>
<td>Color</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>B &amp; W</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Monitor size</td>
<td>same</td>
<td>same</td>
<td>same</td>
</tr>
<tr>
<td>Infrared LEDs</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Sound</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Ease of installation</td>
<td>3*</td>
<td>1*</td>
<td>2*</td>
</tr>
<tr>
<td>Ease of use</td>
<td>3</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Installation time</td>
<td>3</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Life cycle</td>
<td>same</td>
<td>same</td>
<td>same</td>
</tr>
<tr>
<td>Reliability</td>
<td>1</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Price</td>
<td>1</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Applicability to tractor-trailer</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

*Note: The scale 1, 2, 3, used in the comparison means 1=best/lowest (price) and 3=worst/highest (price).

After initial installation of the four systems, a test was performed to evaluate how well drivers can identify objects behind the truck using the RVS. The drivers were asked to identify the following objects using the RVS:

![Volley Ball](image1.png) ![Box](image2.png) ![Coffee Cup](image3.png)

**Figure 3-13 Volley Ball (7in.)  Figure 3-14 Box (9x7x5in.)  Figure 3-15 Coffee Cup (4in.)**

![Traffic Cone](image4.png) ![Radio Controlled Car](image5.png)

**Figure 3-16 Traffic Cone (3ft)  Figure 3-17 Radio Controlled Car**
The above items were placed in a single line, at distances 5, 10 and 15 ft away from the bumper of the trailer (where the camera is located). The drivers were asked to identify what those items were with the vehicle being stationary. Two drivers were tested. Table 3-4 shows the results. The X marks the item and corresponding distance that the driver was able to correctly identify the object.

<table>
<thead>
<tr>
<th>Item</th>
<th>Driver 1</th>
<th>Driver 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5’</td>
<td>10’</td>
</tr>
<tr>
<td>Toy ball</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Coffee cup</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Box</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Traffic cone</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Toy Car</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

The drivers were also asked to say if they could identify a person moving behind the truck. First, the drivers were asked if they saw a person moving behind the truck using only their side-view mirrors. As expected, none of the drivers could say with certainty if there was a person or object behind their truck due to the very large blind spot behind the truck. It is clear that if the driver was using the side-view mirror at the time the person passed through its view, the driver would be able to see the person passing in the mirror. Otherwise, the driver did not know that someone
was behind the truck. The drivers tested mentioned that the only way they could know if there was someone behind the truck was to step out before backing and check if it was clear. Even doing so, the drivers could not be completely sure that someone did not walk behind the truck after their check.

The drivers were asked to use the RVS to identify if there is a person behind the truck. Even if the driver was not constantly watching the monitor, at some point in a few seconds time, they identified that a person was behind the truck. The walking path of the person ranged between 3, 5, 7, 10, 12, 14, and 16 ft away from the truck. Both drivers using both PLC and cabled systems identified the person. The truck was initially stationary. Then the task was repeated, but this time both the truck and the person were moving; the truck was backing and the person was walking perpendicular to the path of the truck crossing in their blind spot, as shown in Figure 3-19. The same distances were used as before, except from the 3 ft, which was too close to the truck. For safety reasons, real persons were not used. Instead, real life cut-out figures of an adult and a child mounted on top of a radio-controlled car were used to simulate a walking pedestrian. The drivers were asked to use the lowest and highest backing speed they deemed safe. Both systems used were successful to help the driver stop the truck in an emergency-stop manner when they saw the person-figure passing behind the truck. Figure 3-20 shows the child figure used, and Figure 3-21 shows the adult figure used. Figure 3-22 shows the child figure through the monitor of the RVS as seen by the drivers.
Figure 3-20  Child Figure (3 ft)

Figure 3-21  Adult Figure (6 ft)
3.6 System Configuration

All rearview systems work in a similar manner. The transmission technology is the primary difference between the systems. The system configuration has to be such that the rear view leaves no blind spot behind the vehicle, and the image is transferred directly, clearly, and in real-time to the driver. Certain equipment tests were performed to understand how the system performs and the best possible configuration for the rearview camera and the monitor. The primary objectives of the equipment tests were to evaluate the rearview system’s specifications and reliability. Testing of the rearview equipment yielded to the field of view, the optimum mounting height of the camera on the body of the truck to maximize the field of view, and the optimum location for the monitor installation. This equipment test also helped identify sources of potential malfunction of the systems, if any, for electronic interference with the systems.

- Equipment

The equipment tested was existing rearview systems that provide the driver with a view of the area behind the truck when the reverse gear is engaged, with the aid of a camera and monitor comprising the rearview system. Using this system, the blind spot behind the truck is eliminated, reducing the potential of a backing crash. For the purposes of this study, three different systems were tested as outlined in section 2.2: the cabled system, the wireless system, and the Power Line Carrier system. All components of the systems require electrical power to work; in this case, the system is powered by the truck’s electrical system, which is 12 volts of direct current (VDC). Table 3-5 shows components and aspects of the tested system.
Table 3-5 Testing Matrix

<table>
<thead>
<tr>
<th>Component</th>
<th>Camera</th>
<th>Monitor</th>
<th>Transmission</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angle</td>
<td>Different angles of the camera have different projected visible area on the ground.</td>
<td>Color vs. black &amp; white The color of the image was tested for the best results.</td>
<td>Cable The cable connection was tested for performance and reliability compared to the other two technologies.</td>
</tr>
<tr>
<td>Height</td>
<td>Different heights of the camera have different projected visible area on the ground.</td>
<td>Location in cabin Rearview mirror standards were reviewed to check for compatibility.</td>
<td>Interference with Wireless The transmission reliability was tested to check for interference patterns with the wireless connection.</td>
</tr>
<tr>
<td>Visibility Tests</td>
<td>Visibility was tested in different weather conditions (rain, fog, day, night).</td>
<td></td>
<td>Power Line Carrier The PLC connection was tested for loss of signal.</td>
</tr>
<tr>
<td>Color vs. black &amp; white</td>
<td>The color or black &amp; white camera was tested for the best results.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Field of View**
  The field of view of the camera was tested on a grid so that the exact area of coverage could be identified. This ensured that the camera covered the entire width of the truck and all blind spots were eliminated. Figure 3-23 shows the apparatus of this test. This test was specific as related to the camera lens size and camera mounting angle and height since different camera specifications yield to a slightly different field of view. Since the camera was a wide angle camera with a visible horizontal angle of 85°, the field of view was not rectangular but a trapezoidal shaped area. The more angled from the horizontal the camera was installed, the more trapezoidal the area became; as the height increased from the ground, the area became larger in square footage. The combination of the mounting height and the mounting angle of the camera had a significant effect on the coverage area of the system.

![Figure 3-23 Field of View Peripheral Limits](image-url)
To identify the optimum position of the camera, a series of observations was graphed to produce a certain profile for a given truck type. The graphs helped installers with the correct setup of the camera location based on the type of the truck. Figure 3-24 shows the angle $\Theta$ and height D of the camera. The camera for the rearview system needed to be installed at such an angle as to leave no blind spot behind the vehicle. For the camera used in the tests, this angle was 60°. A different configuration, however, is to install the camera at the license plate area of the truck, with an angle of 0° to the horizontal.

![Figure 3-24 Camera Angle $\Theta$ and Height D](image)

The specific camera used for the tests had a field of view shown in Figure 3-25. At angles between $0^\circ$-90° from the horizontal, the camera has a trapezoidal shape field of view. Even the regular view of this camera is not a complete rectangle, as shown in Figure 3-26 where the camera is facing directly on the floor at 90°. The area should ideally be rectangular but is not due to the wide lens.

From testing, it was obvious that the lower the height of the camera, the smaller the coverage area. If no blind spot is to be left uncovered, the angle of the camera needs to be at 60° from the horizontal. Figure 3-27 shows the shapes of the field of view of the camera, ranging from 3 ft to 11 ft height at an angle of 60° only. In the figure, the smallest area represents the 3 ft height and as the height increases so does the area. The shaded area represents the size of the truck.

The distance of the center line of the far limit of the coverage area ranges from 5.5 ft at 3 ft height to 19 ft at 11 ft height. This, however, is only one way to install the camera. The other location is next to the license plate area beneath the cargo box at an angle of 0° to the horizontal. This increases the length of the coverage to virtually infinity, but there is a small area behind the truck left uncovered. Most truck drivers mentioned that they would like to have a view of the bumper of the truck for reference when they back towards a fixed object. The users of this system should be aware of the distance behind the truck that they can clearly see and identify a
person or objects of different size, i.e., cars, electrical poles, bicycles, bikes, or any object found on the road.

Figure 3-25 Field of View of Camera at an Angle (top view)

Figure 3-26 Field of View of Camera at 90° Angle (top view)
• **Shortest Height of Object or Person behind Truck**
To determine the shortest height of an object or person detectable behind the truck using the rearview system, varying angles and heights of the camera were graphed to establish the optimum setup. As shown in Figure 3-28, if the camera is at an angle from the horizontal, there is an area not covered by the FOV. This area is still blind to the driver, and it is important to establish how large it is. This area for different camera heights and angles is shown in Figures 3-29 through 3-37. These figures identify the angle at which there is enough height and distance behind the truck that is not covered by the rearview system. In these figures, the last angle is 60° from the horizontal (violet line). At this angle, there is no blind spot left since the origin point (0,0) and past can be seen. The lines represent the lower (bottom) limit of the camera at each angle. The visible area is above and to the right of the lines.
Figure 3-29  Camera Height 3 ft

Figure 3-30  Camera Height 4 ft

Figure 3-31  Camera Height 5 ft

Figure 3-32  Camera Height 6 ft

Figure 3-33  Camera Height 7 ft

Figure 3-34  Camera Height 8 ft
Figures A-1 through A-9 in Appendix A were developed using the same process described previously. The camera was positioned at a range of 3 ft to 11 ft height with 1 ft increments, and the angle $\Theta$ was varied from 0° to 60°. The grid shown has 1 ft increments, and the shaded area on the bottom of the figures represents the back of a standard box truck. The grid area was 35 ft wide (east-west) and 45 ft long (north-south). When a boundary did not make it into the grid area, it was not included in the figure. Following the figures, one can see that the higher the camera location, the more the area covered. As before, the 60° angle of the camera is of the most interest at all heights, since it is the only angle that leaves no blind spot behind the truck. The far limit (located at the north of the figure) shows the limit of the area covered by the camera. The distance from the truck to this line is the lateral size of the area, and it becomes longer with higher camera locations. For example, in Figure A-1, with a camera height of 3 ft, this distance is 5.7 ft, whereas in Figure A-9 with a camera height of 11 ft, this distance becomes 19 ft. This is very significant as the largest coverage area of the camera is needed for this implementation.
3.7 Installation of Equipment

When installing a rearview video system, installation time, relative ease of installation, and necessary tools and personnel are important to compare. A system that is difficult to install or is more time-consuming or expensive than the others could pose a limitation for that system. When installing the rearview system, Federal Motor Vehicle Safety Standards are considered. The location of the camera and the monitor must comply with all standards. In addition to the standards, certain parameters of the systems’ installation were measured to compare them for all systems. These parameters and factors are:

- time needed for a complete installation
- number of personnel and skill level needed to efficiently install a system
- level of sophistication of the tools needed
- relative ease of installation (in scale) as the installer perceives it

The time needed for one installation ranges from two to three hours, more if unexpected problems arise. One installer can install the system with the use of generic tools for automotive electrical system applications (drill, multimeter, connectors, etc.) The installation of the cable and PLC systems is the same, as they both require additional components to make the system work: the cable system requires two new wire harness boxes on the trailer and tractor, and the PLC system the two transmission modules. The wireless system requires a shorter time to install. The installer does not need special skills; a general understanding of automotive electrical systems is adequate. The installers interviewed were of two types: one was a professional rearview system installer, and the other was a mechanic working for a trucking company. Both installers said that the installation of these systems is “not very difficult” and is well within their abilities, including the mechanic who did not do this in his everyday work.

3.8 Summary

Three rearview systems were tested and compared for their performance. The main difference of the systems is the signal transmission technology. The cable system was reliable and had no limitations related to performance. It can accommodate color or black & white images as well as sound. The camera and monitor used for this system can be the same as the other two systems. This system can be implemented for tractor-trailer trucks with an extra wiring harness connecting the two units. The cabled system performed well under all tests and was deemed appropriate for use as a rearview system.

The wireless system was tested for interference and performance. Although it worked well if the signal is strong, the source of interference is not always known. Since the truck is moving and comes across interference sources at different times unexpectedly, the system did not work on a number of occasions while being tested. The truck itself provided interference, and the signal was lost because it has to travel through the cargo box. Due to the interference issues, the wireless system was deemed unreliable for use as a rearview system.

Although the PLC system performed well in bench tests, interference sometimes rendered it useless. When deployed with two different trucking company fleets, the PLC system worked initially, but after a couple of months the system did not continue to work as it should, providing
no image to the driver. After troubleshooting, the system components worked but the image still
did not appear on the monitor. A possible explanation is that the qualities of the system
components were not up to standards. It was also shown that the longer the distance for the
signal to travel, the lower the chances of it working. The PLC system has a limitation in actual
implementation if vehicles cannot provide adequate power (or required voltage) for the system.
Therefore, the widespread use of the PLC system in the future may be very limited.

For the deployment stage, all three systems were used, but only the cable system was found to be
able to provide the required performance.

References

4.0 Deployment Study

4.1 Company Recruitment

As outlined in Task 4 of the study objectives section in the Introduction, actual deployments of the rearview systems were conducted to assess the effectiveness of system in daily operation. Initially, the deployment plan was prepared including partial subsidy for system purchase. Several rearview video vendors were contacted to see if potential participants could be recruited from their existing or future customers. However, the trucking companies were very reluctant to share their crash data, which was part of the requirements for the participating companies.

To recruit participating companies in a timely manner, after consulting with the FDOT project manager, the project team decided to offer a 100 percent subsidy for purchasing the parts, and the installation cost was included, if necessary. In the meantime, a data procurement plan was prepared to obtain before/after crash data regarding the use of the rearview video systems from existing users. Multiple advertisements were published in trucking magazines, and a website was launched to advertise the data need.

Three companies were recruited for the deployment study. A general summary of the deployment is summarized in Table 4-1; no further details about the companies can be released, as a non-disclosure agreement was made. These three companies are denoted as Company A, Company B and Company C throughout the report.

<table>
<thead>
<tr>
<th>Company</th>
<th>Company A</th>
<th>Company B</th>
<th>Company C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fleet Size</td>
<td>46</td>
<td>56</td>
<td>148</td>
</tr>
<tr>
<td>Business</td>
<td>Intrastate Delivery</td>
<td>Intrastate Delivery</td>
<td>Intrastate Delivery</td>
</tr>
<tr>
<td>Deployed Rearview Video System Type</td>
<td>Cable</td>
<td>PLC / Cable*</td>
<td>PLC / Cable*</td>
</tr>
<tr>
<td># of Deployed Systems</td>
<td>46</td>
<td>25</td>
<td>25</td>
</tr>
</tbody>
</table>

*PLC systems were replaced with cable systems in the middle of evaluation.

4.2 System Installation

- **Company A**
  This company responded to solicitation efforts and was interested in participating in the study. The company was about to install cable-based rearview video systems on its fleet in December 2007. The agreement was signed, and cable-based systems were installed on 46 trucks.

- **Company B**
  In December 2007, a total of 25 PLC rearview systems were purchased for installation on the trucks of Company B. The technician completed installation on December 2007. According to the installation report, the systems were functioning properly; however, serious problems with image quality for a majority of the deployed trucks occurred. As shown in Figure 4-1, the image quality from the PLC system was very poor due to unexplained signal noise.
Company B’s drivers and safety manager reported that the connection of the PLC system interfered with other systems in the trucks - the headlights would not come on, the cabin lights would switch off, or the air conditioning system had problems. There was no foreseeable reason for this interference. Even after consulting with the technician the cause of the problems of the PLC system remain unknown. As shown in Figure 4-2, efforts to remedy this included moving the location of PLC transmitter closer to the receiver and testing all available power sources to find clean/good power, since image quality is closely related to power quality.

In September 2008, after the decision was made by CUTR and FDOT to change the system from PLC to cable, a member of the research team visited the company to document the conversion. Before the conversion from PLC to cable, only 8 out of the 25 systems were functioning with moderate to poor image quality. In January 2008, the drivers and safety manager reported that
the systems after conversion worked as they should and provided the drivers with a rear view of the truck.

- **Company C**
  A total of 25 PLC systems and four wireless systems were deployed in February 2008. Due to a backorder of the part and internal issues at Company C, the installation of the PLC systems took longer than Company B. The installation of all 25 PLC systems was completed by the technicians of Company B one month later after the receipt of the required parts.

  Similar to the situation of Company B, after several months of deployment, it was found that the PLC systems were not working as expected. Both the technician and senior engineer from the vendor were called to the site to check for errors in installation and troubleshoot the problem. After a thorough check, the source of the problem could not be determined, so the decision was made to change the PLC systems to cable (hard-wire) to continue the deployment. Due to limited time and technicians allocated from Company C, a technician from the vendor was hired to help with installation of the cable system. The conversion from the PLC system to the cable system was scheduled in December 2008, a year after initial purchase of the PLC systems.

  Figure 4-3 shows the comparison between the PLC and cable systems in terms of image quality. After installation of the cable system, truck drivers in Company C had a much more reliable system for their daily backing maneuvers.

  The timeline of the deployment is shown in Figure 4-4. Two surveys were administered after installation at companies A and C, and a second was administered after five months of use.
4.3 **Power Line Carrier (PLC) System**

The Power Line Carrier RVS was developed as a crash avoidance technology, particularly for combination trucks. The system operates by impressing a modulated carrier signal on the wiring system. A transmitter module receives the signal from a rearview camera and impresses it in the form of voltage on the existing power lines of the vehicle. The signal is then present at any point along those power wires. This system was developed to bridge the gap between the tractor and trailer on a combination truck without any additional wiring harness. Since the signal is carried through the existing power lines on the truck, there is no need for extra wire installation. It is expected to be especially useful for combination trucks.

During the “bench” testing, the system performed well under specific conditions, specifically when the image provided on the monitor was clear enough to be able to see details and could be used as a rearview while backing. This was not a real-life test because the system was not installed and tested on a truck but rather by itself in a lab. However, the actual deployment of PLC systems revealed a serious technical issue. The PLC system is very sensitive to the quality of power or internal power connections of truck. The time and effort to find a clean source of power to connect a receiver was unpredictable, and the selected location of connection was different from one truck to the other. A trial-and-error effort was required, which became frustrating to the trucking companies, which are generally sensitive to vehicle downtime.

Through further close investigation, it was found that certain limitations appeared when the voltage of the system dropped. The transmitter module (connected to the camera) required at least 3.8VDC and 0.02A of power to work. When the voltage is 12VDC, the module consumes 0.26A of power. The receiver module (connected to the monitor) required at least 3VDC and 0.01A of power to work. When the voltage is 12VDC, the module consumes 0.25A of power. These values are not important if it is considered that the system is designed to work on a vehicle with 12VDC. The camera, however, requires at least 8.5VDC and consumes 0.12A to work. The monitor requires 10VDC and consumes 0.61A to be operational. When the entire system is connected at 12.55VDC, it has to meet the requirement of consuming 1.26A of power to be operational. These numbers are important because if the overall system does not provide enough power to the PLC system, the PLC system will not be operational.

---

**Table 4-1: Systems Deployment**

<table>
<thead>
<tr>
<th>M1</th>
<th>M2</th>
<th>M3</th>
<th>M4</th>
<th>M5</th>
<th>M6</th>
<th>M7</th>
<th>M8</th>
<th>M9</th>
<th>M10</th>
<th>M11</th>
<th>M12</th>
<th>M13</th>
</tr>
</thead>
</table>

**Figure 4-4 Timeline of Systems Deployment**

- **46 Cable/Co.A**
- **25 PLC/Co.B**
- **25 PLC/Co.C**
- **4 Wireless/Co.C**
- **25 Conversion kits/Co.B**
- **10 Conversion kits/Co.C**
- **15 Conversion kits/Co.C**
As shown in Figures 4-6 through 4-8, the voltage on different gauge wires drops as the length of the system increases. Depending on the electrical current (A) running through the wire, the more the current and the smaller the diameter of the wire, the more the voltage drops. The smallest gauge of wire used on trucks is 18 AWG. This shows that at the end of the trailer, there is a possibility of a drop so that the camera does not work (requires at least 8.5VDC). The graphs show values of a new copper wire. Used wires on trailers have worse performance due to rust and insulation problems.

![Figure 4-6 Voltage Drop with Distance of Circuit](image-url)
Figure 4-7  Voltage Drop for a 16 AWG Wire

Figure 4-8  Voltage Drop Across a 14AWG Wire
In a tractor-trailer setup, the trailer could have power for the lights but not enough for the RVS to work. A major factor affecting the system is the distance of the cable from the end of the trailer to the front connection harness and then to the tractor, as shown in previous figures. This distance causes a power drop, thus affecting the video signal traveling through the power lines. A solution to this problem is to bring the transmitter and receiver closer together (Figure 4-9) so the distance the video signal has to travel through the power lines is minimized as much as possible.

![Diagram of a tractor-trailer setup](image)

**Figure 4-9 Setup for Better Reception**

In the later field deployment, it was found that the performance of the PLC RVS depends heavily on the electronic system of the truck. Major interference was also found to render the system unusable. The interference came from lights, radio, or other electronics on the truck. The image quality of the system drops dramatically with a voltage drop simply because with lower voltage, the video signal cannot be sent or received through the wires. Figure 3-28 shows different images of the PLC system as the voltage drops.

<table>
<thead>
<tr>
<th>Voltage at Beginning of Circuit (VDC)</th>
<th>Current through System (A)</th>
<th>Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.00</td>
<td>1.26</td>
<td><img src="image" alt="Image of PLC system in low voltage" /></td>
</tr>
<tr>
<td>Time</td>
<td>Value</td>
<td></td>
</tr>
<tr>
<td>-------</td>
<td>-------</td>
<td></td>
</tr>
<tr>
<td>11.50</td>
<td>1.26</td>
<td></td>
</tr>
<tr>
<td>11.00</td>
<td>1.25</td>
<td></td>
</tr>
<tr>
<td>10.75</td>
<td>1.24</td>
<td></td>
</tr>
<tr>
<td>Voltage (V)</td>
<td>Current (A)</td>
<td></td>
</tr>
<tr>
<td>------------</td>
<td>-------------</td>
<td></td>
</tr>
<tr>
<td>10.50</td>
<td>1.23</td>
<td></td>
</tr>
<tr>
<td>10.00</td>
<td>1.21</td>
<td></td>
</tr>
<tr>
<td>9.50</td>
<td>1.20</td>
<td></td>
</tr>
</tbody>
</table>

*Figure 4-10  Image of System with Voltage Drop*
4.4 Interference with Wireless Systems

One of the methods of signal transmission of the rearview systems is the “wireless method.” Using wireless technology, two components equipped with a transmitter and a signal receiver can communicate and transmit information. In this case, the information is the video feed from the camera. A problem of reliability of this technology occurs when the signal is not strong, so that by the time it reaches the receiver, it is very weak and cannot transmit the video. The weakness of the signal is related to the distance between the transmitter and receiver: the longer the distance, the weaker the signal. In addition, the signal does not travel through heavy barriers such as the cargo box of a semi truck. On the other hand, if the system seems to be working well, then an outside source (such as a strong electromagnetic field emitted from any electrical device, both inside or outside of the vehicle, as well as other wireless signals) interferes with the video signal and eventually cause its loss. This can happen without warning, and since it cannot be controlled by the driver, it renders the system unsafe and unreliable.

Another limitation is that each individual system requires a slightly different frequency of transmission to make a different channel. A company with a fleet of trucks with wireless systems might have problems with the systems interfering with each other when they come into close proximity. The signal was tested, and this particular system designed for the use on heavy trucks was deemed unreliable since the team was not able to get an uninterrupted signal for long periods of time. This is because the wireless transmission takes place in the 2.4GHz public bandwidth, which is the most widespread use for data transmission such as the internet or other applications. Therefore, if there is a wireless internet router near the system, it can potentially interfere with the video signal. Since most buildings now have wireless routers for internet use, there is a great potential for interference.

4.5 Driver Surveys

Driver surveys were administered to the drivers of all three participating companies, the first in January 2008 after installation, and the second in May 2008 after five months of use. The surveys can be found in Appendix B. The purpose of the surveys was to get feedback from the drivers in evaluating the effectiveness of the systems in crash reduction, system reliability, ease of use, and overall performance.

The first driver survey was sent to the safety managers of Company A and Company B immediately after completion of installation (cabled system for Company A and PLC system for Company B). For Company C, the first driver survey was conducted prior to PLC system deployment due to delay of system installation. The surveys were distributed to the drivers; after completion of the questionnaire, the surveys were sealed in envelopes provided by CUTR and submitted to the managers for return to CUTR. The surveys were paper-based and included 27 questions and a general comment section open to the drivers. Identification questions were also asked in order to match follow-up surveys (second survey) with drivers without asking personal questions.

Tables 4-2 and 4-3 show the summary of survey responses from the companies for the first and second survey respectively. Personal interviews also were conducted with drivers in Company B
to collect their personal feedback on use of system. It was noted that Company B had a large rate of driver turnover, and more than half of its drivers changed from January to June 2008.

Table 4-2  Summary of First Survey Responses

<table>
<thead>
<tr>
<th></th>
<th>Company A</th>
<th>Company B</th>
<th>Company C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fleet size</td>
<td>47</td>
<td>56</td>
<td>148</td>
</tr>
<tr>
<td>Deployed systems</td>
<td>47 - cable</td>
<td>25 - PLC</td>
<td>Prior to PLC installation</td>
</tr>
<tr>
<td>Truck size</td>
<td>20 ft</td>
<td>36 ft</td>
<td>34 ft</td>
</tr>
<tr>
<td>Surveys distributed</td>
<td>48</td>
<td>29</td>
<td>52</td>
</tr>
<tr>
<td>Responses</td>
<td>48</td>
<td>29</td>
<td>52</td>
</tr>
</tbody>
</table>

Table 4-3  Summary of Second Survey Responses

<table>
<thead>
<tr>
<th></th>
<th>Company A</th>
<th>Company B</th>
<th>Company C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fleet size</td>
<td>47</td>
<td>56</td>
<td>148</td>
</tr>
<tr>
<td>Deployed systems</td>
<td>47 - cable</td>
<td>25 - cable</td>
<td>25 - cable</td>
</tr>
<tr>
<td>Truck Size</td>
<td>22 ft</td>
<td>36 ft</td>
<td>34 ft</td>
</tr>
<tr>
<td>Surveys distributed</td>
<td>48</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Responses</td>
<td>48</td>
<td>23</td>
<td>16</td>
</tr>
</tbody>
</table>

- **Company A**
  The first survey was conducted in January 2008, and the second was in May 2008. This company’s drivers had average age of 31-40 years and average driving experience of 10-15 years (Figures 4-11 and 4-12).
Figure 4-13 shows a clear change of perception of the drivers on how easy it was to use the rearview system. After five months, the majority (91%) of drivers tended to agree that it is easy to use the rearview system. The drivers were asked if they felt more comfortable backing with the rearview system than without. Figure 4-14 shows again that the drivers of Company A felt more comfortable backing with the rearview system after five months of use.

Figure 4-12  Years of Driving Experience, Company A

1st Survey      2nd Survey

Figure 4-13  Rearview System Easy to Use, Company A

1st Survey      2nd Survey
As mentioned in earlier sections of this report, a main issue of using imaging systems such as the rearview system is the magnification of the image. Also, drivers need to be able to calculate distance correctly using the system in order to know how close the rear of the vehicle is in reference to objects behind them. Figure 4-15 shows that with more experience comes better results in this matter.
Driver opinion also changed when asked if the image was clear enough for backing maneuvers. After using the system for five months, more drivers (98%) agreed that the image was clear enough to help with backing maneuvers.

Drivers were asked if they thought the system was reliable. The clear change in their perception is shown in Figure 4-17.

![Figure 4-16 Image Clarity Suitable for Backing Maneuvers, Company A](chart1)

![Figure 4-17 Rearview System is Reliable, Company A](chart2)
For safety reasons, many companies require their drivers to physically step out of the truck and check behind for people, objects, or other obstructions before they back. A question designed to capture the drivers’ trust in the system asked if they thought it was still necessary to do this with a rearview system. A total of 79 percent of drivers agreed in the first survey, but only 71 percent agreed in the second survey. Based on placement of the camera, it is possible to leave a small blind spot behind the truck. Also, it is not clear if their answers were biased because of company requirements.

![1st Survey](image1)

![2nd Survey](image2)

**Figure 4-18 Still Necessary to Physically Check behind Truck before Backing with Rearview System, Company A**

The same percentage of drivers (90-92%) agreed that the rearview system was helpful in minimizing potential backing crashes, which is one of the most useful results of the surveys (Figure 4-18). Also, a similar percentage of drivers (83-92%) agreed that it should be legally required to have a rearview system on all trucks in light of the NPRM from NHTSA for the same reason (Figure 4-19). In addition, drivers of Company A believed from the beginning that the system should be required on all trucks as a safety device. Their change of opinion in the second survey was small.
The drivers of Company B took both surveys the same time as Company A, the first in January 2008 and the second in May 2008. The first survey had 29 responses; the second had 23. The average age of the drivers was 31-40 years, consistent with Company A, as shown in Figure 4-21. For this company, there was significant driver turnover between the two surveys. Driving experience, however, was not consistent with Company A. Responses to the second survey indicate that driving experience average was 5-10 years.
The drivers were asked about ease of use of the rearview system. Their responses show no significant difference from the first to the second survey, and overall they provided a mixed opinion. The PLC rearview system installed on the trucks of this company stopped working between the surveys and had to be changed to a cable system. This might be a reason for the mixed results. When the drivers were asked if they felt more comfortable backing with the rearview system, the results were mixed with no clear pattern, as shown in Figure 4-24. Results similar to those previously observed occurred in the next few questions as well. The drivers could not provide an informed decision since their system failed.
**Figure 4-23** Rearview System Easy to Use? Company B

**Figure 4-24** Comfortable Backing with Rearview System? Company B
Figure 4-25  Accurately Judge Distance with Rearview System? Company B

Figure 4-26  Image Clarity Suitable for Backing Maneuvers? Company B
Figure 4-27 Rearview System Reliable? Company B

Figure 4-28 Still Necessary to Physically Check Behind Truck before Backing? Company B
The first survey (prior to rearview system installation) of Company C had 52 respondents. Only 16 of the 25 with a functioning rearview system at the time of the survey responded to the second. Of the 52 drivers who participated in the first survey, 17 indicated that they had at least one crash during the last three years (total of 21 crashes), and 71 percent of those crashes (17 crashes) were backing-related, with an average estimated incurred cost per crash of $2,000. Figure 4-31 shows the drivers’ responses regarding the cause of their backing crash.
Driver average age for Company C was 31-40 years, consistent with the other two companies, shown in Figure 4-32. Average driving experience (commercial vehicles) was 10 years, as shown in Figure 4-33. Figures 4-28 through 4-33 indicate Company C’s driver responses to the second survey only.

Figure 4-31 Reason for Backing Crashes Based on Driver Opinion, Company C

Figure 4-32 Driver Age, Company C
Figure 4-33  Driving Experience, Company C

Figure 4-34  Easy to Use Rearview System? Company C
Figure 4-35 Comfortable Backing with Rearview System? Company C

Figure 4-36 Accurately Judge Distance Using Rearview System? Company C
Figure 4-37  Image Clarity Suitable for Backing Maneuvers? Company C

Figure 4-38  Rearview System Reliable? Company C
In the first survey of Company C, most drivers said that they had heard about rearview video systems but, as shown in Figure 4-40, they showed mixed expectations regarding the effectiveness of a rearview system for minimizing backing crashes. In the second survey, however, there was a trend towards agreement, 81 percent.

Figure 4-39 Still Necessary to Physically Check Behind Truck before Backing? Company C

Figure 4-40 Rearview System Effective for Minimizing Backing Crashes? Company C
The drivers showed mixed responses when asked if the system should be required legally on all trucks. This question is indirectly related to the system’s performance, since if the drivers think it works well and is necessary, they would be expected to agree with the statement.

![2nd Survey](image)

**Figure 4-41 Legally Require Rearview Systems on All Trucks? Company C**

### 4.6 Camera Location

As mentioned earlier in subsection “Shortest Height of Object or Person behind Truck”, in order for the camera to eliminate the rear blind spot completely, it has to be installed as high as possible and at an angle of about 60°. The image provided to the driver would then include the rear bumper as a reference so that the view can be used not only for safety purposes, but also for backing maneuver precision. In the deployment, one company had the camera installed at the top of the cargo box (13ft), and two had the camera installed at the floor level (3ft). Although no statistical analysis was performed, all the drivers of the company with the cameras at the top seemed to like the location of the camera, whereas a number of the drivers from the other two companies with the camera at the floor level had mixed opinion about the location, with a lot agreeing that the top of the cargo box would be a more suitable solution. Their main complaint was that they could not see the bumper of the truck and had no reference point so it was not easy to estimate where the truck’s rear end was when backing towards a building such as a loading dock.

The RVS can be used for two main purposes: first to help avoid backing crashes, and second to help with the backing maneuvers. The optimum location for the first purpose is anywhere on the back of the truck as long as there is no blind spot, and the second is as high as possible, with the rear edge or bumper visible in the image. It seems that the best location to install the camera would be at the top of the cargo box. Also if the camera is installed at this location, it makes it more difficult for bystanders to tamper/damage or steal the camera from the truck when it is
parked. Also in case of a rear end crash, the camera is less likely to be damaged if it is installed at the top of the cargo box instead of at the floor level. However, based on the use of the trucks and the environment they operate in, the top of the box might not be a feasible option. It should be also noted that special protective brackets might have to be installed to protect the camera from tree branches, loading dock curtains or other objects that might come to contact during operation of the truck.

4.7 Backing Crashes

One of the objectives of the deployment of the rearview systems was to collect data on the number of backing crashes and associated crash data of the participating companies for a period before and after installation of the systems in order to perform a before and after study. This task proved to be much more difficult than initially considered due to several unforeseen circumstances. The participating trucking companies provided their backing crash data for some period before the installation, but, as stated in the previous section, the after period was shortened due to problems with the initial PLC system deployment. Also, economic impacts on the participating companies due to the 2008 recession seemed to play a major role for the companies to reduce their efforts on crash data collection. The participating companies provided only limited data for a basic statistical analysis. Based on these limited data, a naïve before-after study method was used to evaluate the effectiveness of the camera-based rearview system in reducing backing crashes.

- Methodology

The basic assumption for the naïve before-after study was that nothing but the safety enhancement changed from the before to the after period, and therefore all changes in the number of crashes were as a result of the device. In truck company \(i\), the number of backing crashes recorded in the before and after periods are denoted as \(K(i)\) and \(L(i)\), and the ratio of duration of the after period to the before period are denoted as \(r_d(i)\). Let \(\lambda\) be the expected number of backing crashes in the after period for trucks with rearview systems in all these companies, and \(\pi\) be the expected number of backing crashes in the after period had the rearview systems not been deployed. The following equations can be used to evaluate the effectiveness of the rearview systems in reducing backing crashes in these companies.

\[
\hat{\lambda} = \sum L(i) \quad (1) \\
Var(\hat{\lambda}) = \sum L(i) \quad (2) \\
\hat{\pi} = \sum r_d(i)K(i) \quad (3) \\
Var(\hat{\pi}) = \sum r_d(i)^2K(i) \quad (4) \\
\delta = \pi - \lambda \quad (5) \\
Var(\hat{\delta}) = Var(\hat{\pi}) + Var(\hat{\lambda}) \quad (6)
\]
69

\[ \theta^* = \frac{\hat{\lambda}}{\pi} \sum L(i) 1 + \frac{\text{Var}(\hat{\pi})}{\pi^2} \]  

\[ \text{Var}(\hat{\theta}) \approx \theta^2 \frac{\hat{\lambda}^2}{\pi^2} + \frac{\text{Var}(\hat{\pi})}{[1 + \frac{\text{Var}(\hat{\pi})}{\pi^2}]^2} \]  

- **Backing Crash Data Collection**

The before and after period backing crash records from companies A and B were obtained. For each company, the lengths of the before and after periods, together with the backing crash amounts in the time period, are shown in Table 4-5. All other variables were calculated based on equations (1) through (8).

The expected number of backing crashes in the after period in these two companies (\( \hat{\lambda} \)) was 2 for Company A and 1 for Company B; had the systems not been installed, the expected number of backing crashes in the after period (\( \hat{\pi} \)) was 2 for Company A and 2.782 for Company B.

<table>
<thead>
<tr>
<th>Company</th>
<th>Before Period (Years)</th>
<th>Backing Crashes After (9 months)</th>
<th>( \text{Var}(\hat{\lambda}) )</th>
<th>( \hat{\pi} )</th>
<th>( \text{Var}(\hat{\theta}) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Company A</td>
<td>8</td>
<td>2</td>
<td>2</td>
<td>0.250</td>
<td>2.000</td>
</tr>
<tr>
<td>Company B</td>
<td>26</td>
<td>1</td>
<td>1</td>
<td>0.107</td>
<td>2.782</td>
</tr>
<tr>
<td>Company C</td>
<td>59</td>
<td>No after data was collected</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sum</td>
<td></td>
<td>3</td>
<td></td>
<td>4.782</td>
<td>0.798</td>
</tr>
</tbody>
</table>

The backing crashes reduction (\( \delta \)) in these companies was 0 for Company A and 1.782 for Company B, and the ratio of backing crash with and without the rearview system (\( \theta \)) was 0.880 for Company A and 0.346 for Company B. This indicates that for Company A there was zero reduction, but for Company B, about 43.8 percent of backing crashes were avoided with the rearview system. Based on the naïve before-after study, it can be concluded that the rearview system is effective in reducing the number of backing crashes. Interestingly, this 43.8 percent reduction in backing crashes is very close to testimonial statements from safety managers of the trucking companies that have used the system.

- **Limitations of Before and After Analysis**

This particular analysis, as mentioned earlier, is called “naïve.” It has certain limitations and does not account for a number of factors. This analysis cannot support conclusive results yet because a larger data sample is needed. The analysis does not take into account the randomness.
of the data; therefore, it is uncertain if a crash was avoided in the after period due to the rearview system only. However, this crash data analysis does provide insight into the use of camera-based rearview system for reducing backing crashes, and the result is consistent with the testimonial statements from trucking companies using the rearview systems.

4.8 Deployment Study Results

The driver surveys offered great insight into the truck drivers’ opinions and acceptance of the system. Since the drivers cannot be forced or required to use the system when backing, it is best if they accept and approve its performance and capabilities. This way the system will be used more, and then it can provide the maximum effectiveness. In general, the drivers of the three companies participating in the study showed significant change in their opinion about the rearview systems after five months of use. They seemed to agree that the system can help identify hazards behind the vehicle while backing and help them avoid crashing. Based on their responses, the system is easy to use, reliable, provides a clear image for object identification, and is recommended to other drivers. Since there was an NPRM from NHTSA about requiring an object detection technology on single-unit trucks, the effort was to investigate if this would be true for double-unit trucks as well.

From the deployment study, it is clear that if the system works with no problems and the drivers can have a consistent experience with it, the rearview system can be a great tool for truck safety. Most drivers in Company A, which used the cable system with clear and reliable images, had very positive feedback on the system. For the companies B and C, where the original PLC system installed had to be replaced, the drivers showed a justifiable confusion in their responses, which changed after the cable systems were replaced and functional again. Based on the testing conducted by the research team, the PLC system can provide a clear camera image only when the system receives adequate power voltage. However, many trucks on roadways may not be able to provide the power voltage required by the PLC system after consumption by other devices in the truck. Based on the surveys received from companies A and B, the PLC system, which is sensitive to its received power voltage, was not satisfactory to most drivers in companies A and B who used the system.

One of the questions asked in the surveys was the location of the monitor on the dashboard and the location of the camera on the back of the trailer. The three companies had the monitor installed at a similar location (middle of the dashboard) so the driver could observe the monitor with a quick glimpse while scanning from the driver side mirror to the passenger side mirror and back. The cameras, however, were not installed at the same location. For Company A, the cameras were installed on top of the cargo box and angled down, providing a clear view from the truck’s bumper to approximately 20 ft behind the truck. For the other two companies, the cameras were installed at an approximate height of 3 ft next to the license plate area with no angle. This provided more field of view behind the truck, but there was no bumper reference for the drivers, who stated that they would prefer the camera to be on top of the cargo box. This issue needs more investigation.
5.0 Controlled Driver Test

Since truck backing crashes are rare events and detailed data are not easily available, a well-designed controlled test can be a very effective means to assess the potential of the rearview video system as a countermeasure for truck backing crashes.

The scope of the testing, as described in the contract scope of work, is to evaluate rearview video system accuracy and effectiveness with an appropriate sample size of truck drivers. The participants were recruited from a trucking company that participated in the deployment study. Several performance measures were adopted, and the test plan was developed accordingly. The main objective was to determine if the system would help the drivers with their backing maneuvers and make backing safer by reducing the potential of backing crashes due to rear blind spots.

5.1 Literature Review of Previous Testing Efforts on Similar or Same Products in a Controlled Environment

Previous efforts on similar technologies include a number of studies performed by NHTSA or other agencies for sensor-based systems as well as camera-based systems [1-8]. 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 see if the response of the system was adequate. More 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 [7,8], 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 5-1 shows the history of these studies and the outcome. Several studies, especially in the 1990s, 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” [9]. 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 5-1  History of Studies Related to Rear-Object Detection Technologies

<table>
<thead>
<tr>
<th>Year</th>
<th>Agency</th>
<th>Title</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>1994</td>
<td>NHTSA</td>
<td>A Study of Commercial Motor Vehicle Electronics-Based Rear and Side Object Detection Systems</td>
<td>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.</td>
</tr>
<tr>
<td>1995</td>
<td>NHTSA</td>
<td>Hardware Evaluation of Heavy Truck Side and Rear Object Detection Systems</td>
<td>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.</td>
</tr>
<tr>
<td>2006</td>
<td>NHTSA</td>
<td>Experimental Evaluation of the Performance of Available Backover Prevention Technologies</td>
<td>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.</td>
</tr>
<tr>
<td>2007</td>
<td>NHTSA</td>
<td>Evaluation of Performance of Available Backover Prevention Technologies for Light Vehicles</td>
<td>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.</td>
</tr>
<tr>
<td>2007</td>
<td>NHTSA</td>
<td>Experimental Evaluation of the Performance of Available Backover Prevention Technologies for Medium Straight Trucks</td>
<td>The same study was performed for medium trucks. The outcome showed that video systems are the most reliable to show objects behind a truck.</td>
</tr>
<tr>
<td>2007</td>
<td>NHTSA</td>
<td>Use of Advanced In-Vehicle Technology by Young and Older Early Adopters</td>
<td>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.</td>
</tr>
<tr>
<td>2008</td>
<td>NHTSA</td>
<td>Development of Performance Specification for Camera-Video Imaging Systems on Heavy Vehicle</td>
<td>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.</td>
</tr>
<tr>
<td>2008</td>
<td>NHTSA</td>
<td>On-Road Study of Drivers’ Use of Rearview Video Systems</td>
<td>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.</td>
</tr>
</tbody>
</table>
5.2 Performance Measures for Controlled Driver Test

- **Identification of Potential Hazards – Safety**
  One of the most important aspects, if not the most important, of having a rearview system is to help the driver identify potential hazards while backing, thus helping the driver react more quickly and potentially avoid backing crashes. As mentioned earlier, analysis performed for backing crashes involving trucks in Florida for the years 2003-2006 showed that backing crashes happen at unexpected locations such as road sections, intersections, driveways, and exit and entrance ramps, which should not involve backing. In reality, however, truck drivers back in roadways usually to create enough space to make a turn or because they missed a turn, thus striking vehicles that were stopped too close behind the trailer. On these occasions, which usually result in property-damage-only crashes, the truck drivers check the side mirrors and, since they cannot see a vehicle behind them, slowly start backing.

  On many occasions, the driver of the vehicle about to be hit tries to warn the truck driver with their horn, or even tries to back the vehicle out of the truck’s way. On some occasions, usually resulting in higher severity crashes, the truck driver does not hear or sense that they have struck a vehicle and keep backing, dragging the other vehicle with the massive trailer, thus resulting in more serious injuries. These crashes, since they occur at low speeds, could potentially be avoided if the truck driver had a view behind the trailer of the truck. The rearview system was proposed as a countermeasure for these crashes.

  In a controlled test, this aspect was simulated for safety reasons. The worst case in a backing crash is one that involves a fatality. Although all fatal backing crashes usually involve the driver or passenger of a vehicle being struck by the truck, the worst possible scenario, where a pedestrian walks into the path of a backing truck and is struck by the rear of the truck or trailer, was tested for this study. To represent this scenario, a pedestrian dummy was used in the place of an actual person. The apparatus was remote-controlled to ensure the safety of the test administrators involved. As the driver was backing during a maneuver, a pedestrian dummy was moved into the path of the truck, and the reaction of the driver was observed. The desirable reaction was for the driver to see the pedestrian and perceive the danger, brake, and stop the vehicle before striking the pedestrian. For every run, when the truck stopped, the outcome was recorded as was the distance from the truck’s rear bumper to the pedestrian and the driver’s reaction time.

- **Time Efficiency**
  This test is specifically interested in the time it takes for drivers to perform backing maneuvers. In the test, the drivers were asked to perform the following backing maneuvers:

  1. Offset back left
  2. Straight back
  3. Offset back right
  4. Parallel parking driver side
  5. Parallel parking conventional side
  6. Alley dock
These maneuvers are discussed in detail in the experimental design section. The time taken for every driver was expected to be different. The overall time value was not as important, since the drivers typically had as much time as needed to perform a maneuver. The time of each maneuver was compared to the time with and without the use of the rearview system. The backing maneuvers were taken from the Commercial Driver License (CDL) skill test, as is required to get a commercial license. Also, many of these maneuvers are performed by drivers in their everyday backing tasks. The overall time taken by each driver to perform these maneuvers was recorded. The time taken to perform a maneuver with the rearview system was compared to the time taken to perform the same maneuver without the system. It was not important to perform the maneuvers quickly because the drivers typically have as much time as needed to perform them in real life and are only limited by the overall load of their delivery schedule. More details on the maneuvers can be found in the experimental design section.

• **Accuracy**

Although safety is the primary benefit of the rearview system, the system can also help the driver with everyday backing task accuracy. Since the system provides a rear view that the driver did not have before, it is expected that when performing a backing maneuver to a specific location, such as a loading dock, the view from the monitor will help the driver position the vehicle as accurately as possible on the first attempt. Additional maneuvering requires more time; thus, there are more possibilities for crashes.

One of the measures used for the tests was accuracy of the placement of the vehicle in the given lane/area. This is important because, in most cases, the drivers have to back into limited spaces, next to other trucks or next to buildings, with little room for error. It is important that the driver is able to maneuver the truck towards the intended position accurately in a controlled manner. If the driver is not able to do so, there is a large possibility of a crash. The most important thing is to stay within the limits of the given lane/area. The boundaries of these areas can be building walls, fences, or other vehicles.

The method used to evaluate the accuracy of the drivers was to measure how close the driver placed the truck to the loading dock door/wall. To measure this, when the driver was asked to back into a loading dock, the distance from the back of the trailer to the door was measured. The drivers were always asked to park the truck at a distance of 3 ft from the door. This was used to determine if the rearview system helped the driver assess distance calculations better than mirrors. Figure 5-1 shows the measurement for accuracy.
5.3 Test Design

Seven different maneuvers were designed to test the effectiveness of the RVS. Most of maneuvers were adopted from the CDL (Commercial Driver License) test.

- Straight Line Back
  This maneuver is the most typical backing maneuver in a driver’s everyday job, that is, positioning the truck at a loading dock to load or unload or parking the truck in the company’s parking yard. As shown in Figure 5-2, the driver had to start the vehicle at a distance from the box marked by cones and back the truck straight through the box without touching any of the cones or passing on top of any boundary lines.

Each driver performed each maneuver twice, and an average value was calculated to represent the measures for each maneuver. Table 5-2 shows measured quantities recorded during the maneuver. These quantities include:

  - overall time taken in seconds
  - number of times the driver had to pull-up or change the direction of the truck to reposition
  - number of times the driver crossed a boundary line defined by cones
  - number of glances the driver takes on the left and side mirrors and the monitor area

Also, measures such as mean total glance time and mean glance duration can be drawn from the video of the driver.
Figure 5-2  Straight Line Back Maneuver

Table 5-2  Measures Taken during Maneuvers

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>H</td>
<td>6.0</td>
<td></td>
<td>0</td>
<td>H</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>H</td>
<td></td>
<td></td>
<td>0</td>
<td>H</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>S</td>
<td>12.58</td>
<td>D</td>
<td>0</td>
<td>S</td>
<td>19.58</td>
<td>C</td>
</tr>
<tr>
<td>.</td>
<td>0</td>
<td>S</td>
<td>22.42</td>
<td>P</td>
<td>0</td>
<td>S</td>
<td>5.67</td>
<td>B</td>
</tr>
<tr>
<td>.</td>
<td>0</td>
<td>H</td>
<td></td>
<td></td>
<td>0</td>
<td>S</td>
<td>19.75</td>
<td>B</td>
</tr>
</tbody>
</table>

Legend:
CR: Number of crossings of boundary lines
React.: Reaction of driver on object: H = Hit, S = Stop
Dist. Obj.: If driver stopped for object, the distance from the object to the rear of the truck was measured
Where Saw Obj.: Location where driver saw the object and stopped. D = driver mirror, P = passenger mirror, M = monitor

- **Offset Back Left**
  This maneuver was the exact opposite of the offset back left maneuver. The driver had to start he vehicle in the same location as in the straight line backing but had to maneuver the truck into the box on the right side of the straight line box. All measures recorded were the same as the previous two maneuvers.
• **Offset Back Right**
This maneuver required the driver to start the vehicle in the same location as in the straight line backing, but the driver had to maneuver the truck into the box to the right of the straight line box and park the vehicle (both tractor and trailer) inside the box again without touching the boundary lines. Figure 5-3 shows the diagram of this maneuver. The driver performed this maneuver in a similar manner as the straight line back maneuver, and the same metrics were collected.

![Figure 5-3 Offset Back Right Maneuver](image)

• **Parallel Park – Conventional**
This maneuver was the exact opposite of the parallel park driver side maneuver. The driver had to pull the truck past the box, stop and reverse the vehicle, and try to park it inside the box without crossing the boundary lines. The same metrics as before were recorded.

• **Parallel Park - Driver Side**
This maneuver was more difficult that the first three maneuvers and required the driver to pass the box, stop and reverse the vehicle, and park it inside the box, bringing the rear of the trailer close to the rear cones. The entire vehicle had to be inside the box, and had to occur without crossing any of the boundary lines.
- **Alley Dock Back**
  This maneuver is considered to be one of the most difficult maneuvers a driver has to perform. As shown in Figure 5-5, the driver had to position the truck parallel to the barrier line, which is 70 ft from the box. Then the driver had to carefully maneuver the trailer into the box and stop the truck at the loading door. An actual loading dock was used in the test so the drivers had to place the rear of the trailer adjacent to the door for loading. The same metrics as in all other maneuvers were recorded. In addition, the lateral distance of the centerline of the trailer to the centerline of the loading dock was measured for accuracy measurements. Figure 5-1 shows the accuracy measurement diagram. This is important since the system is believed to help drivers maintain better lateral control of the trailer’s end position within the lane.
• **Surprise Obstacle Event**

For each driver, an extra maneuver performed in random order was to test driver reaction time and the outcome of a pedestrian dummy walking into the path of the backing truck. In random order created with software, the pedestrian dummy passed behind the truck as the driver was performing a straight line back maneuver. The path of the pedestrian dummy as well as the angle and distance behind the trailer were recorded for reference. The distance of the path was greater than 7.33 ft and the speed was equal to 4ft/sec (avg pedestrian walking speed). Review of crash reports show that almost 75 percent of backing crashes occur with vehicles traveling below 5 mph. This number was taken as the base maximum. If a driver stops the truck before hitting a pedestrian when traveling at this speed, it is assumed that at any lower speed the pedestrian will be safe, assuming that all other factors remain the same. Since a truck moving at 5 mph (7.33ft/sec) can cover the 7.33 ft in one second, it is assumed that if a pedestrian starts walking in a path closer than this distance, the truck will hit the pedestrian 100 percent of the time. In the controlled test, the dummy simulated a pedestrian walking into the backing path of the truck after the driver had initiated the backing maneuver. Figure 5-6 shows a diagram of this task.

![Diagram of the path of the pedestrian dummy passing behind the backing truck.](image)

**Figure 5-6  Path of Pedestrian Dummy Passing behind Backing Truck**

**5.4 Pre-Test**

Before the actual driver test could take place, a pre-test was needed to evaluate the developed testing maneuvers and make adjustments if necessary. According to the developed plan, six different maneuvers and popping a pedestrian dummy into the path of the backing truck were performed. The maneuvers were performed both with and without the rearview system to compare the difference. The experiment was video-logged and analyzed. After the test, participant feedback was collected. Pictures of the maneuvers in the pre-test of controlled driver test are shown in the following figures.
Figure 5-7  Truck Approaching to Perform Straight Line Back Maneuver

Figure 5-8  Offset Right Back Maneuver
Figure 5-9  Offset Left Back Maneuver

Figure 5-10  Parallel Park Conventional Back Maneuver
Figure 5-11 Parallel Park Driver Side Back Maneuver

Figure 5-12 Surprise Obstacle Maneuver
It was found that the two parallel parking maneuvers took too much time for the driver to execute and offered limited benefit to the study. Also, it was noted that the maneuvers are seldom performed in daily truck driving. It was decided that these two maneuvers would be omitted from the final test. Also, the two offset maneuvers were repeating maneuvers, offering no extra information, so it was decided that only the offset right maneuver would be included in the final test because it is deemed more difficult since the driver had to back towards the right blind spot.

Since the purpose of study is to evaluate the potential of rearview systems to minimize potential backing crashes, the detection of potential backing hazards was included in all maneuvers - either a stationary or a moving object was added in all maneuvers to create more conflict points and make the analysis more meaningful. According to these findings, the test plan was updated.

5.5 Test Procedure

Based on the findings from the pre-test, the controlled testing plan was updated as follows:

(1) Removed two parallel parking maneuvers that take too much time to be executed and offer limited benefit to the study.

(2) Did not test both the left and right offset backing since they offer similar benefits to the study. The left offset backing maneuver was deemed unnecessary because the drivers used the driver side mirror for the majority of the maneuver. To conduct the test in an effective and efficient manner, it was decided to omit the left offset backing maneuver.

Figure 5-13 Close-up of Pedestrian Dummy

83
The final version of the test was designed to have the following maneuvers:

1. Straight Line Back – the most basic maneuver required from all drivers during the majority of their backing. It is also one of the required maneuvers in the CDL skill test.

2. Offset Right Back – also a basic maneuver, required by most scenarios during backing. The right side was chosen rather than the left since it is believed to be more difficult since the drivers are backing towards the passenger side of the truck.

3. Alley Dock Back – a very important maneuver since it requires more skill from the drivers in order to back the truck in a specific target. It also allows for the accuracy measurement of 3 ft from the dock.

- **Data Acquisition System (DAS)**
  The data collected from the experiment came in two forms: (1) video, audio and sensor data recorded in the digital video recording (DVR) device and (2) from observations and measurement from the field personnel taken during the test.

The truck was equipped with a total of three cameras. One camera was installed inside the cabin next to the monitor, as shown in Figure 5-15. A second camera was installed on the top of the cargo box trailer in the center looking down at an angle of 60° to the horizontal. A third camera was installed under the lights of the trailer at an angle of 0° to the horizontal. The location of the two rear cameras is shown in Figure 5-16 and a close up of the cameras is shown in Figure 5-17.

The view from the three cameras is shown in Figure 5-18. The fourth view is from the side camera located under the step on the passenger side of the truck. This camera view was not recorded since it is not needed in the test for data space preservation. The DAS also recorded sensor information from the reverse gear, the brake pedal, and the GPS for location and speed.
Figure 5-15 Location of Driver View Camera

Figure 5-16 Location of Rearview Cameras
Figure 5-17 Rearview Camera Close-Ups

Figure 5-18 View from Cameras during Test: a. Driver View Camera, b. Top View Camera, c. Bottom View Camera, d. Side View Camera – not used
• **Test 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 gave their permission to participate in the test. At this point, the drivers were assigned a number that would serve as an identifier for all stages and forms of the test for anonymity purposes (Appendix C).

(2) After this, the drivers were given a flyer showing diagrams of the three maneuvers that were included in the test, with details for each. Each driver entered an equipped truck, a Sterling day cab tractor with a Great Dane 34 ft food cargo trailer. A second team member was inside the truck to guide the driver through the maneuvers.

(3) Drivers were asked to perform two sets (with and without a rearview system) of three different maneuvers (straight line back, offset right back, and alley dock). 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 driver was asked to complete a survey to provide his/her feedback for the system (Appendix C).

• **Maneuvers**

1. **Straight Line Back**

   This maneuver required the driver to back the truck in a straight line for a total of 195 ft. The schematic diagram is shown in Figure 5-19. When the back of the trailer reached the line connecting the first two cones, as shown, a team member crossed behind the trailer along the line in the center of the box. The team member, who was carrying two cones 3 ft high, passed at normal walking speed, then dropped the bottom cone within the center box in the path of the backing truck and continued walking out of the box while carrying the second cone. This was done so that if the driver saw the member passing through the mirrors, he/she would not be able to detect immediately that the member dropped a cone since it appeared that the cone was transferred all the way to the other side of the box. 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 was noted from the back of the trailer to the cone. 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.
Figure 5-19 Schematic Diagram of Straight Line Back

Position of back of trailer when team member crossed

Path of team member carrying cones

Location team member dropped cone
1. A person carries a stack of two cones.
2. The person walks behind the backing truck and drops a cone and walks 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 vehicle.
4, 5. The driver continues to make a straight backing maneuver as instructed.
6. If the driver fails to detect the presence of the cone, the vehicle will knock it down.

2. Offset Right Back

This maneuver required the driver to start from a position similar to the first maneuver, backing the truck and curving to the right at a box, as shown in Figure 5-21. 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 25 ft from the loading dock, a team member introduced a dummy in the shape of a small child 3 ft high. The figure was mounted on top of a remote-controlled car and steered from a safe distance. The dummy was introduced at approximately 15 ft from the back of the trailer. If the driver stopped, the distance between the dummy and the trailer was recorded. If the driver continued the
maneuver, the distance stopped from the loading dock was recorded. A picture of this maneuver is shown in Figure 5-22.

Figure 5-21 Schematic Diagram of Offset Right Back
3. Alley Dock Back

This maneuver required the drivers to position the truck a 90° angle from a box leading to a loading dock and steer the truck into the box again, parking the truck 3 ft from the door. A schematic diagram is shown in Figure 5-23. As with the offset right maneuver, when the trailer reached approximately 25 ft from the door, a pedestrian dummy was introduced to observe the reaction of the driver. If the driver stopped, the distance from the dummy to the trailer was recorded, and the distance from the door at the end of the maneuver also was recorded.

As mentioned earlier, all drivers performed the three maneuvers twice, for a total of six maneuvers per driver. Data captured during the testing included the reaction time of the drivers when they braked for the dummy as well as glance times and glance duration per location for each maneuver. These data were extracted at a later time.

After the drivers completed all maneuvers, they were asked to complete an evaluation form about the test and then were released. The informed consent form and evaluation form are shown in Appendix C.
5.6 Analysis of Test Results

A total of 45 drivers participated in the controlled test, and each driver took about 21 minutes on average to complete all maneuvers. First, differences in the stopping rates (not hitting cone or dummy object) were tested with and without a rearview system. To test the null hypothesis is the same as testing the difference of the probabilities of stopping with and without a RVS (\( H_0 : P_{s1} = P_{s4} \) and \( H_1 : P_{s1} > P_{s4} \)). Table 5-3 shows the summarized raw data.

<table>
<thead>
<tr>
<th>Without RVS</th>
<th>S</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>With RVS</td>
<td>( P_{11} )</td>
<td>( P_{12} )</td>
</tr>
<tr>
<td>S</td>
<td>( P_{21} )</td>
<td>( P_{22} )</td>
</tr>
</tbody>
</table>

\( S = \) Stop, \( H = \) Hit

\[ P_{s1} = P_{11} + P_{12} = \Pr(\text{Stop} \mid \text{With Camera} = W) \]

\[ P_{s4} = P_{11} + P_{21} = \Pr(\text{Stop} \mid \text{Without Camera} = O) \]

The dataset includes three types of test - Straight Line Back, Offset Right Back, and Alley Dock Back. These were analyzed using only the reaction information, including hit and stop information. The other variables are not considered due to missing information or because they were non-informative. The following are the summarized 2X2 contingency tables.

Figure 5-23 Schematic Diagram of Alley Dock Back
Table 5-4  2X2 Contingency Tables

<table>
<thead>
<tr>
<th></th>
<th>Straight Line Back</th>
<th>Offset Right Back</th>
<th>Alley Dock Back</th>
<th>Total Back</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Without RVS</td>
<td>Without RVS</td>
<td>Without RVS</td>
<td>Without RVS</td>
</tr>
<tr>
<td><strong>With RVS</strong></td>
<td>S 11</td>
<td>H 21</td>
<td>S 30</td>
<td>7</td>
</tr>
<tr>
<td><strong>H 0</strong></td>
<td>13</td>
<td></td>
<td>H 5</td>
<td>3</td>
</tr>
</tbody>
</table>

S=Stop, H=Hit

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.

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

The value in parentheses is the asymptotic calculation, and the rates and variances are calculated from the above equations.

Example: Straight Line Back Increase stop Rate = \( \frac{(P_{11} + P_{12})}{n} - \frac{(P_{11} + P_{21})}{n} = \frac{32}{45} - \frac{11}{45} = 0.4666 \)

Straight Line Back Variance = \( \frac{P_{12} + P_{21} - (P_{12} - P_{21})^2}{n} = \frac{21 + 0 - \left(\frac{21 - 0}{45}\right)^2}{45} = 0.00553 \)

Table 5-5 shows that the presence of an RVS increased the stop rate of driver in Straight Line Back maneuver by 46.7 percent, which can be interpreted as the increase of odd to avoid potential backing crash in the maneuver. Respectively, the stop rate is increased 4.4 and 17.8 percent for Offset Right Back and Alley Dock Back maneuver.

It is important to note that the size of blind spot and the required maneuver effort for both Straight Line Back and Offset Right Back are nearly same in general, but this test introduced a dummy object with different methods. As for Straight Line Back, the dummy object was positioned directly behind the vehicle while a dummy object was moved from the either side of vehicle to the back for Offset Right Back. When the object was approached from the side, the driver had a chance to spot it with both side mirrors, but the object would be relatively difficult to detect when positioned from the right rear of 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 rearview video systems to detect objects from different sides of a vehicle.
Also, it is noted that there is a difference in the increase of the stop rate for Offset Right Back and Alley Dock Back, although the same method was used to introduce a dummy object into the test. It appears that Alley Dock Back requires more attention and effort by the driver to control the vehicle compared to Offset Right Back, and it can result in more opportunity for the driver to miss the approached object with traditional side mirrors.

<table>
<thead>
<tr>
<th>Maneuver</th>
<th>P-value</th>
<th>Increase Stop Rate</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Straight Line Back</td>
<td>4.593e-06</td>
<td>46.7%</td>
<td>0.55%</td>
</tr>
<tr>
<td>Offset Right Back</td>
<td>0.5637</td>
<td>4.4%</td>
<td>0.59%</td>
</tr>
<tr>
<td>Alley Dock Back</td>
<td>0.0114</td>
<td>17.8%</td>
<td>0.42%</td>
</tr>
<tr>
<td>Total (45) Back Test</td>
<td>2.274e-06</td>
<td>23.0%</td>
<td>0.20%</td>
</tr>
</tbody>
</table>

To test variables having a significant effect on the increase of the stop rate, five variables such as ID(Driver ID), Type(Maneuver Type), Cam(RVS), Age(Driver Age), Yr(CDL Experience), and ExpRVS(RVS Experience) were evaluated. Initially, ID was not a significant variable and therefore was dropped. The second time, four variables were used (Type, Cam, Age, Yr, and ExpRVS). Also, two interaction terms were introduced and the final mathematical model is as follows:

\[
\begin{align*}
\text{Coefficients:} & \\
\text{Intercept} & = 1.1285 \\
\text{Type 2} & = -2.3812 \\
\text{Type 3} & = -2.5148 \\
\text{Cam} & = -2.0293 \\
\text{Type 2: Cam} & = 1.7505 \\
\text{Type 3: Cam} & = -0.3686 \\
\end{align*}
\]

Significant Codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Type2 coefficient represents the difference of log of the odds of hitting between M1 and M2. Type3 coefficient represents the difference of log of the odds of hitting between M1 and M3.

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

\[
\log \frac{\Pr(Y = 1)}{\Pr(Y = 0)} = \alpha + \beta_1 X_1 + \beta_2 X_2 + \gamma X_3 + i_1 X_1 X_2 + i_2 X_2 X_3
\]

Probability of having a crash \( \Pr(Y = 1) = \frac{e^{1.1285-2.3812X_1-2.5148X_2-2.0293X_3}}{1+e^{1.1285-2.3812X_1-2.5148X_2-2.0293X_3}} \)
The probability of hitting an object can be estimated by using the final mathematical model as follows:

**Maneuver 1 (Straight Line Back)**

\[
Pr(\text{Hitting} \mid M1 \text{ with Camera}) = \frac{e^{\frac{1.1285 - 2.0293}{2.0293}}}{1 + e} = 0.2888861 = 28.89\%
\]

\[
Pr(\text{Hitting} \mid M1 \text{ without Camera}) = \frac{e^{\frac{1.1285}{2.0293}}}{1 + e} = 0.755562 = 75.56\%
\]

Difference of hitting rate for M1 with/without Camera = 75.56\%-28.89\%=46.67\%

**Maneuver 2 (Offset Right Back)**

\[
Pr(\text{Hitting} \mid M2 \text{ with Camera}) = \frac{e^{\frac{1.1285 - 2.3812 + 1.7505 - 2.0293}{2.0293}}}{1 + e} = 0.1777743 = 17.78\%
\]

\[
Pr(\text{Hitting} \mid M2 \text{ without Camera}) = \frac{e^{\frac{1.1285 - 2.3812}{2.0293}}}{1 + e} = 0.2222331 = 22.22\%
\]

Difference of hitting rate for M2 with/without Camera = 22.22\%-17.78\%=4.44\%

**Maneuver 3 (Alley Dock Back):**

\[
Pr(\text{Hitting} \mid M3 \text{ with Camera}) = \frac{e^{\frac{1.1285 - 2.5148 - 2.0293 + 0.3686}{2.0293}}}{1 + e} = 0.02222200 = 2.22\%
\]

\[
Pr(\text{Hitting} \mid M3 \text{ without Camera}) = \frac{e^{\frac{1.1285 - 2.5148}{2.0293}}}{1 + e} = 0.1999991 = 20.00\%
\]

Difference of hitting rate for M3 with/without Camera = 20.00\%-2.28\%=17.72\%

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. To conduct the analysis, the video data recorded during the controlled test were analyzed using software that multiplexes all cameras at the same time in a single screen. Figure 5-24 shows a screenshot from the Video Log Analysis software. The video from each camera can be seen in 30 frames per second. For every frame, the driver glance position was recorded. CUTR’s team members watched the videos and counted each frame with its corresponding glance location. A database was created that includes all driver maneuvers, total maneuver duration, glance duration, and frequency per location.
As shown in Table 5-6, drivers took a little more time to complete the maneuvers with an RVS.

Table 5-6  Average Maneuver Time

<table>
<thead>
<tr>
<th>Maneuver Type</th>
<th>Without Rearview System (sec)</th>
<th>With Rearview System (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Straight Line Back</td>
<td>65.5</td>
<td>72.2</td>
</tr>
<tr>
<td>Offset Right Back</td>
<td>60.3</td>
<td>66.0</td>
</tr>
<tr>
<td>Alley Dock Back</td>
<td>70.5</td>
<td>77.5</td>
</tr>
</tbody>
</table>

Since the duration of backing maneuvers is different by individuals in the test, the updated frequency ($F^*$) was used for further analysis as follows:

$$F(K)_{\text{Driver}_i} = F_{\text{Driver}_i} \cdot \frac{\text{Duration of Maneuver } k_{\text{Driver}_i}(t)}{\text{Average Duration of Maneuver } k(t) \forall \text{Drivers}}$$

$F(K)_{\text{Driver}_i} =$ Frequency of Driver (i) is watching the monitor during backing maneuver k
The likelihood of hitting an object with the frequency of monitor glancing was tested as follows:

$$mcnt = F(k)_{\text{Driver}}$$

| Coefficients | Estimate | Std. Error | z value | Pr(|z|)       |
|--------------|----------|------------|---------|--------------|
| Intercept    | -1.18961 | 0.35382    | -3.362  | 0.000773 *** |
| Mcnt         | -0.05694 | 0.03827    | -1.488  | 0.136806     |

Significant Codes: 0 ‘****’ 0.001 ‘***’ 0.01 ‘**’ 0.05 ‘*’ 0.1 ‘.’ 1

Odd ratio is decreased by the factor $$e^{-0.05694} = 0.9446507$$

Example:

Pr(H11)=Probability hitting when driver look at monitor for 11 times during backing maneuver
Pr(H10)= Probability hitting when driver look at monitor for 10 times during backing maneuver

$$\frac{\text{Pr}(H11)}{1 - \text{Pr}(H11)} = 0.9446507 \frac{\text{Pr}(H10)}{1 - \text{Pr}(H10)}$$

It appears that the likelihood of hitting an object is more closely associated with the ratio of time spent watching the monitor during backing maneuver. The probability of hitting an object is reduced as the duration of looking at the monitor is increased.

$$mt = \frac{\text{Duration of looking at the monitor}}{\text{Duration of backing maneuver}}$$

| Coefficients | Estimate | Std. Error | z value | Pr(|z|)       |
|--------------|----------|------------|---------|--------------|
| Intercept    | -1.0905  | 0.3496     | -3.119  | 0.00182      |
| Mt           | -0.1801  | 0.1006     | -1.791  | 0.07326      |

Significant Codes: 0 ‘****’ 0.001 ‘***’ 0.01 ‘**’ 0.05 ‘*’ 0.1 ‘.’ 1

Odd ratio is decreased by the factor $$e^{-0.1801} = 0.8351867$$

Example:

Pr(H11)=Probability hitting when driver look at monitor for 11 sec
Pr(H10)= Probability hitting when driver look at monitor for 10 sec

$$\frac{\text{Pr}(H11)}{1 - \text{Pr}(H11)} = 0.8351867 \frac{\text{Pr}(H10)}{1 - \text{Pr}(H10)}$$

As shown Figure 5-25 and 5-26 drivers expressed positive attitudes toward using rearview systems in the follow-up survey after the test. Most drivers agreed that a rearview system can help them reduce potential backing crashes. Also, more than 90 percent of respondents agreed that rearview systems can reduce the rear blind spot for large trucks.
5.7 Summary

To evaluate the effectiveness of rearview video system in a controlled environment, a driver test was designed. First, previous studies were reviewed including the history of studies related to rear object detection technologies.
Three performance measures were selected: (1) identification of potential hazards, (2) time efficiency, and (3) accuracy. Seven different scenarios were developed to test that the presence of rearview systems can help drivers perform backing maneuvers in an efficient and safe manner. Most of maneuvers were adopted from the CDL (Commercial Driver License) test and modified to meet the purpose of the test. A pre-test was conducted to evaluate the test plan, and several modifications were made, including eliminating several maneuvers that offer less benefit to the study while taking much longer to be evaluated.

Based on the updated test plan, three maneuvers - (1) Straight Line Back, (2) Offset Right Back and (3) Alley Dock Back - were tested for scenarios with and without rearview video system. Also, the detection of potential backing hazards was tested in all maneuvers.

The results showed that the presence of a rearview system increased the stop rate of drivers in the Straight Line Back maneuver by 46.7 percent, which can be interpreted as increasing the odds of avoiding potential backing crashes in the maneuver. The stop rate increased 4.4 percent and 17.8 percent for Offset Right Back and Alley Dock Back maneuvers, respectively. The same results were obtained from both non-parametric and parametric tests.

Further analysis of the video log revealed that the likelihood of hitting an object is associated with the ratio of time spent watching a monitor during a backing maneuver. In general, the participants showed a positive attitude toward using rearview systems, and more than 90 percent of respondents agreed that a rearview system could reduce the rear blind spot for large trucks.

References

9. NHTSA, Federal Motor Vehicle Safety Standards; Rearview Mirrors; Advance Notice of Proposed Rulemaking (ANPRM), DOT, Editor. 2009, NHTSA.
6.0 Benefit-Cost Analysis

To promote the use of a new safety enhancement device, it is very important to demonstrate that the adoption of the new device would bring a positive result, including a financial benefit. Therefore, it is necessary to evaluate the benefits and costs that are associated with the use of a Rearview Video System (RVS). For the benefit-cost analysis, the potential benefit is in terms of crash cost avoidance, which is measured against the purchase and installation cost of the RVS. In general, the RVS mainly focuses on reducing backing crashes.

6.1 Estimate Backing Crash Cost

This study confirmed that the size and cost of backing crashes for trucks are likely underestimated. Most truck backing crashes are property-damage-only (PDO) crashes, and they usually occur in private parking lots or facilities. Therefore, many backing crashes may not be reported through a police crash report.

A U.S. DOT report indicated that 2.81 percent of all police reported crashes are backing crashes (all vehicle types), and during its operational life, a vehicle can be expected to be involved in 0.0123 police-reported backing crashes as a backing vehicle.

Analysis of the Florida Crash Database (2004-2006) in this study revealed that backing crash rates in Florida have remained constant over the years, and trucks have a relatively higher backing crash rate (as much as twice compared to passenger cars). There were a total of 4,506 backing crashes that involved trucks for three years, which corresponds to 7.8 percent of total truck involved crashes. Of all backing crashes, 92.1 percent were PDO crashes.

The Federal Motor Carrier Safety Administration (FMCSA) estimates that damage to equipment and freight, medical costs, and cleanup are substantial parts of the crash cost. It is estimated that each truck has a 1-in-6 chance of being in such a crash each year. Additionally, it is estimated that each truck has a 1-in-20 chance of being in a crash resulting in injury, with an average cost of $245,000, which represents the costs of all parties involved in an accident.

According to the Unit Costs of Medium and Heavy Truck Crashes study from FMCSA, the estimated cost of PDO crashes involving trucks with a GVWR of more than 10,000 pounds averaged between $4,500 and $6,500 (in 2005 dollars). It includes medical-related costs, emergency services costs, property damage costs, lost productivity, and the monetized value of the pain, suffering, and quality of life that the family loses because of a death or injury. The property damage portion represents around $2,000, and the loss of productivity due to the crash including related administration costs is almost the same amount or a little higher.

According to the data from a participating company, the average incurred cost for 31 backing crashes in three years was $1,812, including indemnity, medical expenses, and property damage. However, this number does not reflect loss of productivity. There was no fatality or injury.
involved in these crashes. It is reasonable to assume that the typical cost for a backing crash can be itemized as follows:

1. Incurred Cost
   a. Indemnity
   b. Medical expenses
   c. Property damage

2. Loss of Productivity
   a. Out-of-service vehicle
   b. Out-of-duty driver
   c. Crash investigation and follow-up administration

Based on the previous studies and collected data from this study, the estimated cost for a backing crash is $4,000 ($2,000 incurred cost + $2,000 lost productivity). However, this estimated cost excludes a potential for injury and fatality due to backing crash.

### 6.2 Backing Crash Frequency and Potential Benefit with RVS

The estimated backing crash rate for a trucking company can be varied based on many different factors; in particular, the type of business and the frequency of backing maneuvers may have a great impact, but it is not easy to quantify in an effective and efficient manner. In this study, the number of average backing frequencies was estimated from the results of the driver survey. Most drivers reported that they need to perform 5-10 backing maneuvers on any given day, and the annual average mileage per truck is around 30,000 miles.

<table>
<thead>
<tr>
<th>Year</th>
<th>Company B - Fleet size (70) Backing Crash</th>
<th>Company C - Fleet Size (145) Backing Crash</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td>2005</td>
<td>19</td>
<td>19</td>
</tr>
<tr>
<td>2006</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>2007</td>
<td>6</td>
<td>19</td>
</tr>
<tr>
<td>2008</td>
<td>-</td>
<td>10</td>
</tr>
<tr>
<td>Average / year</td>
<td>7.75 crashes</td>
<td>14.5 crashes</td>
</tr>
<tr>
<td>Average per truck per year</td>
<td>0.11 crash / truck / year</td>
<td>0.1 crash / truck / year</td>
</tr>
</tbody>
</table>

As shown in Table 6-1, the estimated backing crash rate for trucks based on the collected data is 0.1 crashes per truck per year, with 30,000 annual average mileage. The controlled study also confirmed that potential reduction of backing crashes when using an RVS is around 18-47 percent, depending on the maneuver type; the deployment study showed around a 40 percent of reduction in backing crashes with an RVS.
The cost of an RVS for commercial trucks or RVs is usually more than the systems for passenger cars, light trucks, or vans because the cameras for the commercial trucks and RVs usually have infrared LEDs for night-time operation, they have a wider angle to capture the width of the truck, they are waterproof, and they have more rugged construction due to vibration issues of the truck. Also, the monitor is usually larger since a small monitor cannot help the truck driver identify objects very well.

Most systems come ready for two or three cameras due to the size of the vehicle that can be used, either while driving or for security purposes. In addition, the one main component that is different from smaller vehicles is the installation of the main cable for video transmission from the camera located in the rear to the monitor located in the driver cabin. The cable itself is not expensive, but the installation requires a longer time, especially if the cable has to be installed in inconspicuous places. Certain companies offer a wireless system, but these systems are relatively more expensive and have been shown to have transmission problems at long distances and interference.

Most products in the current market include camera(s), monitor, mounting hardware, cables, etc., which are priced from $200 to $400 for parts; installation costs another $100 to $200.

### 6.3 Benefit/Cost Analysis for an RVS

In the system benefit-cost analysis, some events occur in the whole life-cycle of the system, such as a reduction in backing crashes, while some events occur only one or limited times, such as the purchase and installation of the system. To estimate b/c ratio for the use of an RVS, the present worth of the benefits was calculated and compared to the cost in today’s dollars. The benefit-cost analysis was performed as follows:

#### Assumptions:
- Estimated Backing Crash Rate = 0.1 crashes per truck per year
- Incurred Cost per Crash = $4,000
- Estimated reduction of backing crashes with RVS = 40%
- Capital cost (parts + installation) = $450 ($300 + $150)

\[
\frac{\text{Benefit}}{\text{Cost}} \text{ Ratio} = \frac{\text{Potential Annual Savings} \times \frac{(1 + i)^n - 1}{i(1 + i)^n}}{\text{Capital Cost}}
\]

Where:
- Benefit = Estimated savings throughout system’s life-cycle
- Cost = Capital cost of system
- \( i \) = discount rate,
- \( n \) = no. of years for life cycle
The B/C ratio for a RVS installation with the estimated 40 percent reduction of backing crash and the five year of Life-cycle for RVS can be calculated as follows:

Capital cost (parts + installation) = $450 ($300 + $150)

Benefit:
0.1 backing crash per truck
Incurred Cost per Backing Crash = $4,000
Estimated potential annual saving = $4,000 * 0.1*0.4=$160 per year
With discount rate of 3%

\[
\text{Savings in today's dollars} = \text{Estimated potential annual savings} \times \frac{(1 + i)^n - 1}{i}\frac{1}{(1 + i)^n}
\]

\[
\text{Savings in today's dollars} = 160 \times \frac{(1 + 0.03)^5 - 1}{0.03(1 + 0.03)^5}
\]

Cost:
Capital cost (parts + installation) = $450 ($300 + $150)

\[
\frac{B/C}{450} = 1.63
\]

Table 6-2  Benefit-Cost Analysis with 3% and 7% Discount Rate

<table>
<thead>
<tr>
<th>Estimated Reduction in Backing Crashes w/ RVS</th>
<th>Estimated Life-Cycle of RVS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3 years</td>
</tr>
<tr>
<td></td>
<td>3%</td>
</tr>
<tr>
<td>20%</td>
<td>0.51</td>
</tr>
<tr>
<td>30%</td>
<td>0.76</td>
</tr>
<tr>
<td>40%</td>
<td>1.02</td>
</tr>
<tr>
<td>50%</td>
<td>1.27</td>
</tr>
</tbody>
</table>

*Note: Shaded area represents negative B/C ratio.

Benefit/cost ratios shown in Table 6-2 were calculated for different reduction rates in backing crashes with an RVS. Three different life-cycles of an RVS were assumed. The life-cycle of an RVS was not directly investigated as a part of this study. However, empirical data showed that the systems usually last more than five years with minimal or no maintenance effort. Considering that this study showed that the use of an RVS could reduce about 40 percent of backing crashes, the expected benefit/cost ratio would be 1.5 or higher.
7.0 Conclusions and Recommendations

7.1 Summary of Findings

To evaluate the effectiveness of RVS in an effective and efficient manner, various study efforts were made including:

- Backing crash review and analysis to identify size and causes
- Review of rearview video systems currently available in the market
- Deployment of rearview video systems with trucking companies
- Driver-controlled tests with 45 truck drivers to assess the potential reduction in backing crashes with the use of RVS cost-benefit analysis to show monetary investigation of system ownership

1. Several crash databases were reviewed to understand truck backing crashes in the U.S. It was learned that most crash databases have limited information regarding truck backing crashes. The Florida crash database and actual crash reports were reviewed. It was found that the truck backing crash rate (compared to all crashes) is two times higher than that for passenger cars, which shows that backing crashes are a more significant problem for trucks than passenger cars.

2. It was learned that backing crashes involving fatalities and incapacitating injuries happen mostly due to extreme and irrational driver behavior. However, a large portion of backing crashes occurred at low speeds (<5 mph), and the lack of view and/or limited view seems to be a major cause of this type of crash. If a proper rear view is provided, there is a strong likelihood of reducing backing crashes, as it allows the driver to see objects behind the truck while performing backing maneuvers.

3. Three types of rearview video systems currently available in the market were compared for their advantages/disadvantages. The basic idea of three systems is the same: they enable the driver to obtain the rear view of vehicle by using one or more cameras mounted at the back of vehicle. A monitor is located inside the cabin and is connected to the camera. The main difference in the three systems is the method of signal transmission. During the bench/lab tests, the three systems performed almost the same.

4. The PLC system is currently limited to one black & white camera image transmission, while the cable system can have multiple color cameras. Theoretically, the PLC system is easier to install since it uses the existing wiring of truck to transmit the video image from camera to monitor. It has a relative advantage in use for combination trucks because it does not require an additional cable harness since it utilizes existing power lines. It is, however, slightly more expensive to purchase than the cable system. The wireless system performed well in the bench tests, providing color images and sound from one or two cameras. It is as expensive as the PLC system and requires less installation time than the PLC system. It is suitable for combination trucks since it requires no cable connection between its components. The cable system is the least expensive but requires slightly more time to install than the other two systems. It provides a good quality image and sound. It can be color or black & white. With an additional wiring harness, it can be
installed on combination trucks as well as straight (single-unit) trucks. All three systems were deemed appropriate to be used in the deployment.

5. For the deployment stage, all three systems were used, but only the cable system was found to be able to provide a reliable performance. A total of 50 PLC rearview systems had to be converted to cable systems a few months after initial installation because they did not function properly and the drivers could not use the system. The performance of the PLC system heavily depends on the quality of the existing wiring in the truck, and it is a very time-consuming and unreliable process to find a proper power source to which the system can be attached. Also, the image quality of the PLC system deteriorates significantly as other electronic powered systems are used in the truck.

6. Most truck drivers involved in the study showed a positive attitude towards the system, with a few exceptions. The drivers did not take much time to become comfortable with using the system in their daily activities, and they agreed that it can help in minimizing potential backing crashes.

7. To evaluate the effectiveness of rearview video systems in a controlled environment, a driver test was designed after previous studies were reviewed, including the history of studies related to rear-object detection technologies. Three performance measures were selected: (1) identification of potential hazards, (2) time efficiency, and (3) accuracy. Three maneuvers - (1) Straight Line Back, (2) Offset Right Back and (3) Alley Dock Back - were tested for scenarios with and without rearview video system. Also, the detection of potential backing hazards was tested in all maneuvers.

8. The results showed that the presence of a rearview video system increased the stop rate (avoiding hitting an object) of drivers in the Straight Line Back maneuver by 46.7 percent, which can be interpreted as increasing the odds of avoiding potential backing crashes in the maneuver. The stop rate increased 4.4 percent and 17.8 percent for Offset Right Back and Alley Dock Back maneuvers, respectively. The same results were obtained from both non-parametric and parametric tests.

9. Further analysis of the video log revealed that the likelihood of hitting an object is associated with the ratio of time spent watching a monitor during a backing maneuver. In general, the participants showed a positive attitude toward using rearview video systems, and more than 90 percent of respondents agreed that a rearview video system could reduce the rear blind spot for large trucks.

10. Benefit-cost analysis was conducted based on the collected data. Assuming a 40 percent crash reduction with the rearview video system, estimated cost for a truck backing crash of $4,000 ($2,000 incurred cost + $2,000 lost productivity), backing crash involvement 0.1 and five years of system life-cycle, the estimated B/C ratio is 1.5 or higher.
7.2 Conclusion

This study focused on evaluating the effectiveness of rearview video systems as a backing crash countermeasure for large trucks. Reviewing backing crashes from public and private (company) crash databases revealed that the main cause of backing crashes is closely related to a limited or no rear view. It was also confirmed that backing crashes are underreported in general due to a couple of characteristics of truck backing crashes, such as location and severity.

The three systems that were evaluated in this study performed well in the lab test, but actual deployment revealed several limitations of PLC rearview system, including the poor quality of image and unreliable performance. The PLC system is designed to provide convenience during the installation as well as actual use by using existing wire. However, it seems that the technology is not mature enough to be used in the daily operation as a countermeasure for backing crashes. As for the wireless system, unexpected and frequent signal interference rendered it unsafe for use as a crash avoidance technology.

The cable-based rearview video system was relatively reliable and offers better quality images. The quality of the image is an important component to promote the use of system because it was shown to be closely related to driver satisfaction. In general, drivers reported that the rearview video system is easy to use and showed a positive attitude towards it. The majority also agreed that they feel more comfortable performing backing maneuvers with the system, and it can help in minimizing potential backing crashes.

The naïve before-and-after study based on the deployment and the result of controlled study showed that the proper use of an RVS can result around a 40 percent reduction in truck backing crashes.

The estimated B/C ratio based on PDO crashes for the use of system is around 1.5 or higher, which means the widespread use of rearview video systems will result in a great savings and promote public safety.

In conclusion, the rearview video system can be effective in reducing backing crashes if it can function as intended. It is important to make sure that the system performs satisfactorily before it is used by drivers. The initial positive experience with the system is critical to promote its use by truck drivers.

For companies with combination trucks, it is recommended that the system be installed on all fleet vehicles and trailers at the same time so there are no trucks without the system due to the mismatch of equipped with non-equipped units.

A rearview video system is a tool that provides the driver with an additional view. The responsibility of using the system and achieving the effectiveness still lies with the driver. It should be reiterated that extreme backing crashes involving severe injuries or fatalities occur due to irrational driver behavior, rather than visibility limitations.
7.3 Future Study

The best location of the camera for a rearview video system should be investigated in the future. Also, more driver tests can confirm or add data to the limited first study described in this report. Additional backing crash records and surveys after a given period can provide more data points for further analysis of using rearview video systems in the future.
APPENDIX A: RVS Technical Specifications

Rearview Video System Features

**Number of cameras:** The number of cameras a rearview system can support can play a significant role in the performance of the system and in the aid that the system can give to the driver. The three systems identified can support multiple cameras except PLC. For the purpose of rearview systems on trucks, this number is deemed adequate.

**Camera lens:** The lens of each camera has a specific field of view. The wider the lens, the more area is covered but with a “fish eye” effect, where objects get distorted. The cameras used for most of the rearview systems have a lens angle of 85°, which is considered adequate.

**Color/B&W:** This feature refers to the system’s ability to show an image in color or black & white. Some specialists argue that it is better to view the image in black & white rather than color because there is better clarity and contrast.

**Monitor size/type (LCD-CRT):** The monitor size is very important because if the image is very small, the driver will have difficulty identifying objects in the image. For the purposes of classification, the size of the monitor is the same for all systems. A CRT monitor can be more dangerous because it is made from glass, which could be harmful to the driver in an accident. LCD monitors are more lightweight, clearer, and thinner, thus making them the first choice. LCD monitors are more expensive than CRT monitors.

**Infrared LEDs:** This feature is important because cameras need a light source for a good image. At night or under shade, the ambient light is not enough for a good image in a regular camera. Infrared LEDs surrounding the lens illuminate the area with infrared light waves that the camera uses to produce a better image. Since the systems are used on trucks at night, with no direct light to support the camera, it is imperative that it is equipped with infrared LEDs.

**Sound:** Sound can be used to complement rear views. A microphone placed on the camera can pick up motion or warnings (such as someone at the back of the truck vocally warning the driver), which the driver will be able to hear through a speaker in the driver’s cabin.

**Ease of installation:** Ease of installation is a measure of the degree of difficulty the installation crew faces in installing any one of the systems on a truck and if this could become a deterrent for use of the system. A qualitative scale of 1 to 3 has been used for this specification. For this phase, ease of installation of the systems was ranked based on the judgment of the research team. A more accurate ranking will be provided after the planned driver-controlled test.

**Installation time:** This is a measure of time in minutes that the installation crew needs to install one complete system on a truck. For this phase, installation time was estimated based on the judgment of the research team.
**Ease of use:** This specification describes the degree of difficulty in using the systems after they are installed on the trucks. If a system is not easy to use, it could prevent the driver from using it often or at all. The same 1 to 3 scale is used. The driver-controlled test will help in obtaining more realistic results.

**Life cycle:** This is the working life of a system until it needs to be replaced; a life cycle that is too short might render the system to not be cost effective.

**Reliability:** This is an overall measure of how reliable a system is at any given time after installation until it needs replacement. A scale of 1 to 3 is applied based on the judgment of the research team.

**Price:** The price of a system, including installation, can render a system not cost effective or might deter companies from choosing it over others. A detailed cost analysis will be conducted after the installation test.

**Applicability to tractor-trailer truck:** The three systems are ranked on their applicability on a tractor-trailer, with 1 being least applicable and 3 being most applicable. The scale used to rank the features is an ordinal scale where the values indicate only order or ranking and have no meaning if used separately.
Figure A-0-1  Camera Height 3 ft (top view)
Figure A-0-2  Camera Height 4 ft (top view)
Figure A-0-3 Camera Height 5 ft (top view)
Figure A-0-4  Camera Height 6 ft (top view)
Figure A-0-5  Camera Height 7 ft (top view)
Figure A-0-6 Camera Height 8 ft (top view)
Figure A-0-7  Camera Height 9 ft (top view)
Figure A-0-8  Camera Height 10 ft (top view)
Figure A-0-9  Camera Height 11 ft (top view)
APPENDIX B: Driver Survey Questionnaires
1st Driver Survey Form

Introduction

The limited visibility has been blamed for major cause of heavy vehicle backing crashes. To address this problem, the National Highway Traffic Safety Administration (NHTSA) proposed that heavy trucks weighing between 10,000 and 26,000 pounds be equipped with rear object detection systems such as the camera-based rear vision systems.

Initial study effort concluded that camera-based rear vision system has a potential to address the visibility issue in an effective and efficient manner. As a continued effort, the Center for Urban Transportation Research (CUTR) at University of South Florida (USF) is working with the Florida Department of Transportation (FDOT) and Federal Highway Administration (FHWA) to evaluate the effectiveness of camera-based rear vision system for eliminating potential backing crashes of heavy vehicles.

This survey is intended to collect feedback on the system includes drivers perception and comments from hands-on experienced drivers. Please understand that only selected number of drivers are invited to this survey, your response will be very important to evaluate the system and make policy decision to promote truck safety.

CUTR warrants that the collected information will be used solely for the purpose of scientific and public policy research, and not for any administrative, proprietary, or law enforcement purposes. Any information related to the interests of the driver and the company will be presented anonymous if wished so.

You are greatly appreciated in participating in our survey and any of your inputs will be of great value to our research program. If you have question, please contact Dr.Chanyoung Lee (813-974-5307) at the Center of Urban Transportation Research in University of South Florida.

Sincerely

ITS Group
Center for Urban Transportation Research
University of South Florida
Date: ______________________(MM/DD/YYYY)

1. What’s your age?  
   A) Under 25  
   B) 26-30  
   C) 31 to 40  
   D) 41 to 50  
   E) 50+  
   
   You are: (Male, Female)

2. When did you obtain your 1st CDL (Commercial Driver License)?  (Year _______)
   Classes of CDL (            ) Any endorsement? (            )

3. Currently, you mainly drive a straight truck (Size:          ) or a tractor with a trailer
   (Size:            )

4. How long have you been driving commercial vehicles? _______ years or _______ months

5. How long have you been working for current job? _______ years or _______ months

6. Have you had any kind of crash during last 3 years while you were driving commercial vehicle?
   (Please include crashes that were not reported officially)  
   A) Never  
   B) 1 times  
   C) 2 times  
   D) 3 times  
   E) 4 times  
   F) More than 5 times

7. Have you ever had any kind of backing related crash while you were driving commercial vehicle?
   (Please include crash that was not reported officially)  
   A) Never  
   B) 1-2 times  
   C) 3-5 times  
   D) 6-10 times  
   E) More than 10 times

8. How long have been using the rear vision system?  
   A) less than 1 week  
   B) 1-2 weeks  
   C) 3-4 weeks  
   D) 1-2 months  
   E) More than 2 months

9. How long did it take you to become comfortable with using the rear vision system for backing?  
   A) less than a day  
   B) 2-3 days  
   C) 1 week  
   D) 2-3 weeks  
   E) More than 3 weeks

10. Do you think it is easy to use the rear vision system?  
    1 (Strongly disagree)  
    2  
    3  
    4 (Neutral)  
    5  
    6  
    7 (Strongly Agree)

11. Do you feel more comfortable to back with the rear vision system?  
    1 (Strongly disagree)  
    2  
    3  
    4 (Neutral)  
    5  
    6  
    7 (Strongly Agree)

12. Do you think you can judge the distance correctly with the rear vision system?  
    1 (Strongly disagree)  
    2  
    3  
    4 (Neutral)  
    5  
    6  
    7 (Strongly Agree)

13. How far behind the truck can you see in the monitor? (Distance in feet:_______________)

14. Can you see the edge of the trucks bumper in the monitor? (Yes, No)

15. Do you think the image on the monitor is clear enough for the backing maneuvers?  
    1 (Strongly disagree)  
    2  
    3  
    4 (Neutral)  
    5  
    6  
    7 (Strongly Agree)

16. Do you think that the image of the rear vision system is as good at night as during daytime?
17. Are you satisfied with the current location of your camera?
   1 (Strongly disagree)  2  3  4 (Neutral)  5  6  7 (Strongly Agree)
   If not, please tell us where it should be located in the following figure.

18. Are you satisfied with the current location of monitor inside your cabin?
   1 (Strongly disagree)  2  3  4 (Neutral)  5  6  7 (Strongly Agree)
   If not, please tell us where it should be located in the following figure.

19. Do you think the rear vision system is reliable?
   1 (Strongly disagree)  2  3  4 (Neutral)  5  6  7 (Strongly Agree)

20. Would you like to have the camera on while driving forward? (Yes, No)

21. In general, drivers are required/recommended to check behind of the truck by walking before backing.
   Do you think this is still necessary with the system?
   1 (Strongly disagree)  2  3  4 (Neutral)  5  6  7 (Strongly Agree)

22. Do you think the rear vision system is helpful in minimizing potential backing crashes?
   1 (Strongly disagree)  2  3  4 (Neutral)  5  6  7 (Strongly Agree)

23. Do you feel it is necessary to legally require the rear vision system on heavy trucks?
   1 (Strongly disagree)  2  3  4 (Neutral)  5  6  7 (Strongly Agree)

24. If you are independent driver and ought to install the system with your own expense, how much are you willing to pay for it? $____________________

25. Would you recommend the rear vision system to other commercial vehicle drivers?
   1 (Strongly disagree)  2  3  4 (Neutral)  5  6  7 (Strongly Agree)
26. In general, do you think that the rear vision system meets your expectations?
   1 (Strongly disagree)  2  3  4 (Neutral)  5  6  7 (Strongly Agree)

27. Please rank what you like most about the rear vision system. Use 1 (Best to 4 (Least)
   ( ) I feel safe backing
   ( ) I am faster, more efficient for backing
   ( ) I have less stress about backing
   ( ) Please give us your own benefit: ________________________________

28. Any Comments?

Thank you for your participation in the survey. For the completion of our study we will need you
to complete multiple surveys in this year. We need a way to keep track of the participants but we
don’t want to collect your personal information for anonymity purposes.

The following questions were designed to identify and organize survey forms while maintaining
the participants’ anonymity. It’s expected that the same participant will give the same answer to
these questions each time and that all the survey forms submitted by the same person can be
clustered together based on their answers to these questions. Please realize that no personal
information will be explored from these questions, and try to answer them truthfully:

1. Your favorite color________________________

2. Your favorite hobby________________________ and favorite TV Show ____________________.

3. Your favorite baseball (or football) team______________________________.
To monitor the performance of the rear vision system, a 2nd driver survey is prepared to collect feedback on the system. It includes driver perceptions and comments from hands-on experienced drivers. Please understand that only selected drivers are invited to this survey, your response will be very important in evaluating the system and making policy decisions to promote truck safety.

CUTR guarantees that the collected information will be used solely for the purpose of scientific and public policy research, and not for any administrative, proprietary, or law enforcement purposes. Any information related to the interests of the driver and the company will be presented anonymous upon request.

We sincerely appreciate your participation in our survey and all of your input will be of great value to our research program. If you have questions, please contact Dr. Chanyoung Lee (813-974-5307) at the Center of Urban Transportation Research, University of South Florida.

Sincerely

ITS Group
Center for Urban Transportation Research
University of South Florida
Date: ______________/____________/ 2008 (MM/DD/YYYY)

* Question 1 and 2 will help us to connect the result of 1st survey and 2nd survey without collecting your private information. Please make sure that your answers remain consistent with the 1st survey.

1. What is your age?  
   A) Under 25  
   B) 26-30  
   C) 31 to 40  
   D) 41 to 50  
   E) 50+

Your favorite color ____________________  
Your favorite TV show_____________________

Your hobby__________________________  
Brand of first car you owned__________________

2. How long have you been driving commercial vehicles? _______ years

3. Currently, you mainly drive: a straight truck (Size:_______) or a tractor with a trailer (Trailer Size:_______)

4. Please explain about your daily job duty including destinations.
   (a) What are your regular destinations? Please be as specific as possible (ex: Restaurants in downtown Baltimore)
      (____________________________________________________________________)
   (b) In general, how many stops on your route per day? (_______) stops / day
   (c) How many times do you need to perform backing maneuvers in a day? (_______) times / day

5. Please fill out the following table with the number of total crashes and backing crashes you had during these years. For the backing crashes only, please also include the estimated average cost per backing crash incurred. It is important that you tell us all crashes you can remember. Please try to be truthful.

<table>
<thead>
<tr>
<th>Year</th>
<th>All Crashes</th>
<th>Backing Crashes</th>
<th>Cost ($) per backing Crash</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2005</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2007</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6. How long have you been using the rear vision system?
   A) 1-2 months  
   B) 2-4 months  
   C) 4-5 months  
   D) 5-6 months  
   E) More than 6 months  
   F) Never

7. How long did it take you to become comfortable with using the rear vision system for backing?
   A) less than a day  
   B) 2-3 days  
   C) 1 week  
   D) 2-4 weeks  
   E) More than a month

   Please rate your experience with rear vision system. Use a range from one(1) to six(6), where “1” stands for “Strongly disagree” and “6” stands for “Strongly Agree.” For example, if you “strongly agree” with the statement, circle the “1”

8. The rear vision system is easy to use.
   1 (Strongly disagree)  2  3  4  5  6 (Strongly Agree)
9. I felt more comfortable performing the backing maneuver with the rear vision system.
   1 (Strongly disagree)  2  3  4  5  6 (Strongly Agree)

10. I can correctly judge the distance using the system and know exactly how close I am to objects in the rear.
    1 (Strongly disagree)  2  3  4  5  6 (Strongly Agree)

11. Can you see the edge of the truck’s bumper in the monitor? (Yes, No)

12. The image in the monitor is clear enough to help me identify any potential hazard behind the vehicle.
    1 (Strongly disagree)  2  3  4  5  6 (Strongly Agree)

13. In general, the rear vision system is reliable.
    1 (Strongly disagree)  2  3  4  5  6 (Strongly Agree)

14. Please indicate the current location of the monitor by circling the corresponding number in parenthesis. If you do not think that this is the best location, please select a suggested location by circling the corresponding number in parenthesis.

   Current Monitor Location  (1) (2) (3) (4) (5) (6)
   Suggested Monitor Location (1) (2) (3) (4) (5) (6)

15. Please indicate the current location of the camera by circling the corresponding number in parenthesis. If you do not think this is the best location, please select a suggested location by circling the corresponding number in parenthesis.

   Current Camera Location  (1) (2) (3) (4) (5) (6)
   Suggested Camera Location (1) (2) (3) (4) (5) (6)
16. In general, most drivers are asked to walk to the back and check the rear of the truck before backing. Now with the rear vision system, you don’t need to walk to the back of the truck to check before you back up.
   1 (Strongly disagree)  2 3 4 5 6 (Strongly Agree)

   If you circled number 1 or 2 above, can you please explain why?

17. The rear vision system is helpful in minimizing potential backing crashes.
   1 (Strongly disagree)  2 3 4 5 6 (Strongly Agree)

18. The rear vision system should be required on all heavy trucks by federal regulation (straight or tractor-trailer).
   1 (Strongly disagree)  2 3 4 5 6 (Strongly Agree)

19. If you were an independent driver (owner of your own truck) and need to install the system at your own expense, how much would you be willing to pay?
   A) Not more than $200  B) $200-300  C) $300-400  D) $400-500  E) $500+  E) $500+

20. Please elaborate on your personal experience with the rear vision system? (what you like, what you don’t like, the system works as it should be, etc)

21. I would recommend the rear vision system to other commercial vehicle drivers.
   1 (Strongly disagree)  2 3 4 5 6 (Strongly Agree)

22. In general, I am satisfied with the rear vision system because it helps my backing maneuver.
   1 (Strongly disagree)  2 3 4 5 6 (Strongly Agree)

   If you circled number 1 or 2 above, please explain why?

23. The following are some advantages and disadvantages of having a rear vision system installed on your truck. Please indicate by circling if you believe they are true or false.
   • With the system I am faster/more efficient in my deliveries  (TRUE / FALSE)
   • With the system I can be sure not to hit anything  (TRUE / FALSE)
   • The system can help me respond faster in emergency situations  (TRUE / FALSE)
   • The system increases my workload because I have to put in more effort and concentrate more  (TRUE / FALSE)
   • The system can distract me when backing  (TRUE / FALSE)
   • Having the system did not change the way I back  (TRUE / FALSE)
24. There are many technologies which can improve truck safety. Have you heard about the following systems?

<table>
<thead>
<tr>
<th>System</th>
<th>Description</th>
<th>(YES / NO)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collision Warning System (CWS)</td>
<td><em>This system warns the driver with an alarm when they come too close to a vehicle in front of them.</em></td>
<td>(YES / NO)</td>
</tr>
<tr>
<td>Adaptive Cruise Control (ACC)</td>
<td><em>This system works like a cruise control but instead of only speed, the driver sets also the distance to keep from the front vehicle. If this distance gets smaller, the system reduces speed.</em></td>
<td>(YES / NO)</td>
</tr>
<tr>
<td>Roll Advisor and Control (RA&amp;C)</td>
<td><em>This system monitors the truck’s speed and angular velocity and alerts the driver if there is a danger of rollover.</em></td>
<td>(YES / NO)</td>
</tr>
<tr>
<td>Lane Departure Warning (LDW)</td>
<td><em>This system monitors the lane markings and alerts the driver if the truck is moving out of a lane without the driver’s control.</em></td>
<td>(YES / NO)</td>
</tr>
</tbody>
</table>

25. If you were to install the following systems in your truck, please rank them in order of your priority with the most needed being “1” and the least “5”

<table>
<thead>
<tr>
<th>System</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collision Warning System (CWS)</td>
<td>(     )</td>
</tr>
<tr>
<td>Adaptive Cruise Control (ACC)</td>
<td>(     )</td>
</tr>
<tr>
<td>Roll Advisor and Control (RA&amp;C)</td>
<td>(     )</td>
</tr>
<tr>
<td>Lane Departure Warning (LDW)</td>
<td>(     )</td>
</tr>
<tr>
<td>Rearview Video System (RVS)</td>
<td>(     )</td>
</tr>
</tbody>
</table>

26. Do you have any comments about the rear vision system that you would like to share with us?
APPENDIX C: Informed Consent for Driver Test and Follow-Up Survey

Informed Consent
Title of Project: Yard Tests for Rearview Video System
Experimenters: Dr. Chanyoung Lee, Achilleas Kourtellis

I. 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 WCF SYSCO located in Palmetto, FL 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.

II. 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 maneuvers. 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.

III. 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.
IV. 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.

V. 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.

VI. Compensation
You will receive payment in the amount of $30 per hour for your time and participation. This payment will be made through SYSCO (please note that expected processing time 8-12 weeks).

VII. 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.

VIII. 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 # for Test (This will be assigned by CUTR)

_________________________

Participant’s Signature

_________________________

Date
After Test Evaluation Form

Driver #:__________

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

Years of CDL driving experience:______________________________yrs.

Experience with Rear View System:    YES 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

Ever had backing crashes during CDL driving?    YES  NO
If YES above: How many backing crashes:___________

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%

Backing Related Ratings

With the rear view camera system I feel more comfortable to perform the straight backing
maneuver.    2  3  4  5  6

Strongly Agree    Somewhat Agree    Somewhat Disagree    Strongly Disagree

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

1  2  3  4  5  6

Strongly Agree    Somewhat Agree    Somewhat Disagree    Strongly Disagree

With the rear view camera system I feel more comfortable to perform the offset right backing
maneuver.    2  3  4  5  6

C - 3
The rear view camera system helps me to reduce potential crashes during offset right backing maneuver.

<table>
<thead>
<tr>
<th>Strongly Agree</th>
<th>Somewhat Agree</th>
<th>Somewhat Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Strongly Agree</th>
<th>Somewhat Agree</th>
<th>Somewhat Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Strongly Agree</th>
<th>Somewhat Agree</th>
<th>Somewhat Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Video System-Related Ratings**

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

<table>
<thead>
<tr>
<th>Absolutely No</th>
<th>Probably No</th>
<th>Probably Yes</th>
<th>Absolutely Yes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>

**If you answered NO above why not?**
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. Somewhat Disagree
4. Strongly Disagree

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. Somewhat Disagree
4. Strongly Disagree

Additional Comments

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

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________