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16. Abstract

This report documents the National Highway Traffic Safety Administration's (NHTSA's) evaluation of commercially-available rear object detection systems that are intended for use on medium straight trucks. For this study, NHTSA tested three sensor-based rear object detection systems, one rear object detection system that combined sensors with rearview video, one rearview video (only) rear object detection system and one rear cross-view mirror.

The results found for sensor-based rear object detection systems were similar to those found for light vehicles. Three of four systems tested had longer ranges than those tested for light vehicles. The sensors still had erratic detection of children, particularly for 1-year-olds. Overall, based on the test results, sensor-based systems performance in detecting people was inadequate.

Both rearview video systems tested provided excellent images of the area behind a vehicle in well lit conditions. The images were of good quality making it easy to see even small children behind a vehicle. Overall, rearview video systems are an effective means of allowing the driver to see behind the vehicle. NHTSA has a human factors study in progress that will assess the degree to which typical, non-commercial drivers effectively use image information provided by rearview video systems to avoid backover crashes.

The quality of the images displayed by the rear cross-view mirror was evaluated using a 1996 Grumman-Olsen step van with a 12-foot long box. The side-view mirror to rear cross-view mirror distance was 190 inches, slightly shorter than the maximum 197 inches that NHTSA is considering. Two aspects of image quality, distortion and minification were measured.

Rear cross-view mirror image quality distortion ratings ranged from Excellent (minimal distortion) to Impossible (extreme distortion). The least distortion was near the step van's bumper. The most distortion was on the step van's left side well away from (9 feet or more behind) the bumper.

Rear cross-view mirror minification measurements found that 1-year-old children are too small to see over almost the entire field of view of the mirror. Three-year-old children are too small to see in the right half of the field of view of the mirror. Adults can be seen anywhere in the blind zone. However, there are concerns that the combination of high distortion plus much minification will reduce detection likelihood in certain portions of the blind zone behind the step van.

This study found that rear cross-view mirrors are not a very effective means of allowing the driver to see behind a vehicle. Additionally, the human factors concerns that NHTSA has for rearview video also apply to rear cross-view mirrors (i.e., are drivers using them effectively?).

Rear cross-view mirrors are not a good means of seeing behind much of the vehicle but do provide some aid, although minimal. They are expected to prevent some backover crashes. In comparison, school bus cross-view mirrors on the front and right side of the vehicle have been shown, by comparing crash data from before better cross-view mirrors were required with data from the improved mirrors, to have 60% effectiveness. School bus cross-view mirrors have less minification because the driver is closer to the convex mirror and because school children are larger than the 1 to 3-year-olds that are the focus for backover crash prevention and less distortion than the rear cross-view mirror studied. Based upon worse minification and distortion, NHTSA researchers expect the rear cross-view mirror evaluated to have lower effectiveness than a school bus cross-view mirror.

In conclusion, in the opinion of NHTSA researchers, sensor-based systems do not perform well enough to effectively prevent backover crashes. We worry that they may lead to a reduction in driver vigilance and do more harm than good. Rearview video systems are an effective means of seeing behind the vehicle. NHTSA has a human factors study in progress to examine the extent to which drivers use rearview video systems during backing maneuvers.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Backover crashes are a tragic problem. Frequently, the victims of backover crashes are young children or elderly adults. One of the goals of the National Highway Traffic Safety Administration (NHTSA) is to prevent backover crashes from occurring.

On September 12, 2005, NHTSA issued a Notice of Proposed Rulemaking (NPRM) proposing to amend Federal Motor Vehicle Safety Standard (FMVSS) No. 111, Rearview Mirrors so as to provide a method for alerting drivers of the presence of persons and objects directly behind the vehicle and thereby reduce backover deaths and injuries. The NPRM proposed to accomplish this by requiring either a rear cross-view mirror or rear closed-circuit video on straight trucks with a GVWR of between 4,536 kilograms (kg) (10,000 pounds) and 11,793 kg (26,000 pounds).

In response to the NPRM, commenters noted the availability of a variety of commercially-available rear object detection devices, including both visual ones of the types specified in the NPRM and non-visual systems. Non-visual, sensor-based systems use technologies such as ultrasound, radar, and infrared to scan the area behind the vehicle. They include sensors which detect an object and provide an auditory and/or visual signal to the driver that an obstruction is behind the vehicle. Sensor-based systems were not considered in the NPRM due to past NHTSA research results having shown that they performed poorly, particularly in detecting people. However, industry commenters stated that system performance has improved in recent years and requested that NHTSA consider sensor-based electronic rear object detection systems on medium straight trucks as a means of preventing backover crashes.

While past NHTSA studies provided a thorough examination of the backover avoidance technologies available in 2006 for light vehicles, they did not examine commercially-available systems intended for use on medium straight trucks. Since there may be differences between backover avoidance systems intended for light vehicles and those meant for medium straight trucks, NHTSA decided to perform a study of backover avoidance systems for medium straight trucks. This document summarizes the findings of this study.

For this study, NHTSA tested three sensor-based rear object detection systems, one rear object detection system that combined sensors with rearview video, one rearview video (only) rear object detection system and one rear cross-view mirror. Since the sensor and rearview video portions of the combined systems were tested separately, NHTSA effectively tested four sensor-based systems, two rearview video systems, and one rear cross-view mirror. Three of the sensor-based systems used ultrasonic sensors; the fourth used frequency modulated continuous wave radar.

Testing of the sensor-based and video-based rear object detection systems was conducted using the same methodology as used by NHTSA for prior light vehicle system testing. This methodology is documented in the 2006 NHTSA report, “Experimental Evaluation of the Performance of Available Backover Prevention

Technologies [1]. The rear cross-view mirror testing, which was only performed statically, was based on a method developed by Satoh [2].

The results found for the four sensor-based rear object detection systems were similar to those found for light vehicles [1]. Three of the four systems tested had longer ranges than those tested for light vehicles. All sensor-based systems still had erratic detection of children, particularly for 1-year-olds. One ultrasonic system had many false alarms. The gap in coverage near vehicle bumpers for two sensor-based systems is of concern. Overall, based on the test results, sensor-based systems performance in detecting children was poor and inconsistent.

Both rearview video systems tested provided good images of the area behind a vehicle in well lit conditions. The images were of sufficient detail to permit identification of even small children behind a vehicle. However, weather effects, such as water droplets or ice, on the camera lens will obscure the view of rear objects. Depending upon the lighting provided, darkness may also prevent video systems from clearly showing people behind a vehicle. Overall, rearview video systems are an effective means of allowing the driver to see behind the vehicle. NHTSA has a human factors study in progress that will assess the degree to which typical, non-commercial drivers effectively use image information provided by rearview video systems to avoid backover crashes.

The quality of the behind the vehicle images displayed by the rear cross-view mirror was evaluated using a 1996 Grumman-Olsen step van with a 12-foot long box. The side-view mirror to rear cross-view mirror distance was 190 inches, slightly shorter than the maximum 197 inches that NHTSA is considering. Two aspects of image quality, distortion and minification (how small an object appears to be in the mirror) were measured.

Rear cross-view mirror image quality distortion ratings ranged from Excellent (minimal distortion) to Impossible (extreme distortion). The least distortion was near the step van's bumper; the most on the step van's left side well away from (9 feet or more behind) the bumper.

Measurements of image size in the rear cross-view mirror found that 1-year-old children are too small to see over nearly the entire field of view of the mirror. Three-year-old children are too small to see in the right half of the field of view of the mirror. Adults can be seen anywhere in the blind zone. However, there are concerns that the combination of high distortion plus much minification will reduce detection likelihood in certain portions of the blind zone behind the step van.

Overall, the quality of the rear cross-view mirror image was insufficient to allow drivers to resolve small objects behind the step van (or other vehicles of this length). It was found to be very hard to impossible to see small children over much of blind zone behind the vehicle. Larger children and adults are visible, although there are still concerns that the combination of high distortion plus much minification will reduce detection likelihood in certain portions of the blind zone. Weather effects, such as water droplets or ice on the mirror surface, will obscure the view of images in the rear cross-view mirror. People or objects behind a vehicle may not be sufficiently visible in the mirror in conditions of darkness.

This study found that rear cross-view mirrors are not a very effective means of allowing a driver to see behind a vehicle. Additionally, as with rearview video, NHTSA has concerns that drivers may not use the mirrors effectively.

Rear cross-view mirrors are not a good means of seeing behind much of the vehicle but do provide some aid, although minimal. They are expected to prevent some backover crashes. In comparison, school bus cross-view mirrors on the front and right side of the vehicle have been shown, by comparing crash data from before better cross-view mirrors were required with data from the improved mirrors, to have 60% effectiveness. School bus cross-view mirrors have less minification because the driver is closer to the convex mirror and because school children are larger than the 1 to 3-year-olds that are the focus for backover crash prevention and less distortion than the rear cross-view mirror studied. Based upon worse minification and distortion, NHTSA researchers expect the rear cross-view mirror evaluated to have lower effectiveness than a school bus cross-view mirror.

In conclusion, in the opinion of NHTSA researchers, sensor-based systems do not perform well enough to effectively prevent backover crashes. We worry that they may lead to a reduction in driver vigilance and do more harm than good. Rearview video systems are an effective means of seeing behind the vehicle. NHTSA has a human factors study in progress to examine the extent to which drivers use rearview video systems during backing maneuvers.

1.0 INTRODUCTION

Backover crashes are a tragic problem. Frequently, the victims of backover crashes are young children or elderly adults. One of the goals of the National Highway Traffic Safety Administration (NHTSA) is to prevent backover crashes from occurring.

The term “backover” crash is used in this report to refer to crashes in which a person is struck by a vehicle moving in reverse. This term is intended to distinguish all backing crashes (vehicle-vehicle, vehicle-property) from backing specifically into a person (pedestrian/bicyclist). While some “backovers” involve a person actually being run over by a vehicle, the term used here is also meant to include all cases in which a person was struck, but not necessarily backed over by a motor vehicle.

In 2006, NHTSA estimated that 183 fatalities and between 6,700 and 7,419 injuries result from backover crashes per year [6]. However, the true extent and nature of backover crashes are difficult to determine because they are not consistently nor accurately reported in currently available crash data bases. The inconsistency primarily stems from the criteria used for defining traffic crashes that are reported by police for inclusion in state and federal databases. To be included in crash data bases, the crash must involve “a motor vehicle in transport, and occur on a traffic way or while the vehicle is still in motion after running off the traffic way.” Thus, if the incident occurs on private driveways or parking lots, it is not considered a traffic crash and thus not included in the statistics on crashes, even though it is vehicle-related. For property damage back-over crashes, their relatively low cost of repairs usually means that drivers will not report the incident to either police or their insurance companies. Thus, the primary sources of data on traffic crashes very likely underestimate the true extent of the backover crash problem.

On September 12, 2005, NHTSA issued a Notice of Proposed Rulemaking (NPRM) [3] proposing to amend Federal Motor Vehicle Safety Standard (FMVSS) No. 111, Rearview Mirrors so as to provide a method for alerting drivers of the presence of persons and objects directly behind the vehicle and thereby reduce backover deaths and injuries. The NPRM proposed to accomplish this by requiring either a rear cross-view mirror or rear closed-circuit video on medium straight trucks with a GVWR of between 4,536 kilograms (kg) (10,000 pounds) and 11,793 kg (26,000 pounds). (These vehicles were selected because they have a large rear blind zone and NHTSA analyses show that they are involved in an unusually large number of backover crashes per registered vehicle.)

In response to the NPRM, commenters noted the availability of a variety of commercially-available rear object detection devices, including both visual ones of the types specified in the NPRM and non-visual systems (see Docket No. NHTSA-05-19239, http://dms.dot.gov). Non-visual, sensor-based systems use technologies such as ultrasound, radar, and infrared to scan the area behind the vehicle. They include sensors which detect an object and provide an auditory and/or visual signal to the driver that an obstruction is behind the vehicle. Non-visual, sensor-based systems were not considered in the NPRM due to past NHTSA research results (see discussion below) having shown that they performed poorly, particularly in detecting people. However, industry commenters stated that system performance has improved in recent years and requested that NHTSA consider sensor-based electronic rear object detection systems on medium straight trucks as a means of preventing backover crashes.

1.1. PRIOR NHTSA BACKOVER AVOIDANCE SYSTEM RESEARCH

During the 1990's, NHTSA performed two studies that examined the performance capabilities of commercially-available systems designed to reduce the incidence of injury and death outside of backing vehicles. The first of these studies examined systems designed for use with commercial motor vehicles (medium and heavy trucks) while the second study tested systems meant for use with passenger vehicles.

The first of the 1990's studies was performed in response to Section 6057 of the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991. This section of ISTEA required NHTSA to conduct a study to evaluate the then existing technology for two types of electronics-based object detection and warning systems for commercial vehicle application: those sensing the presence of objects to the rear of the vehicle, and those sensing the presence of objects on the right side of the vehicle. The resulting study will be called the 6057 Study.

The 6057 Study [4] tested six commercially available backover avoidance systems (referred to as Rear Object Detection Systems during the study): five ultrasonic systems and one rearview video system. Note that none of these systems were installed in the vehicle as original equipment; they were all aftermarket add-ons. Quoting the most significant and relevant 6057 Study result from [4]:

> "For rear object detection systems, the drivers were helped by the device when backing slowly to a loading dock and for warning of pedestrians. However, the low [adult] pedestrian detection rate found for some systems, the limited coverage area of all systems, and the variability of detection performance suggests that drivers cannot solely rely on these systems to back up safely under all situations."

The second of the 1990's studies was performed as part of NHTSA's Intelligent Transportation Systems research. This study, which will be referred to as the Performance Specification Study [5], was performed collaboratively by TRW Space Systems and NHTSA's Vehicle Research and Test Center.

The Performance Specification Study evaluated, along with side-facing sensors, the performance of two commercially-available ultrasonic backover avoidance systems and two commercially- available rearview video systems for passenger cars. Note that again none of these systems were installed in the vehicle as original equipment; they were all aftermarket add-ons.

There were two significant and relevant conclusions from the Performance Specification Study [5] for ultrasonic backing systems. This study found that, with respect to the fields of view of the two ultrasonic systems examined:

> "With respect to the functional goals of a backing system, neither of these two systems meets any of the requirements. Even for near zone detection both systems have a maximum range of about 3m, not the 5m called for [in another report on this study.] Although this may seem like a small price to pay, simulations have shown that systems with range out to 5m can achieve a crash avoidance potential in excess of 90%."

For the detection sensitivity and false positives of the two ultrasonic systems examined, [5] summarizes this study's results with:

> "[Ultrasonic backing systems] were found to be extremely sensitive and prone to false alarms. Backing systems suffer from orthogonal requirements. On the one hand one doesn't want the system to go off all the time, while on the other hand one would like to be sensitive to small targets, such as children, in an environment with a large amount of ground return."

For rearview video systems, [5] states:

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

NHTSA acknowledges that the two studies discussed above are now somewhat out of date. Testing the 6057 Study was performed during 1993 while testing for the Performance Specification Study was done in 1994. In the years that have passed since the Performance Specification Study was performed, the rapid pace of development of electronics may have significantly changed the capabilities of current, commercially-available, backover avoidance systems. There was a need for research to update NHTSA's information on the performance capabilities of backover avoidance systems. Part of this need was fulfilled during 2006 by the research described below to examine the capabilities of backover avoidance systems for passenger vehicles.

Section 10304 of the Safe, Accountable, Flexible, and Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) directed the NHTSA to do the following:

1. Conduct a study of effective methods of reducing the incidence of injury and death outside of backing passenger vehicles

2. Identify, evaluate, and compare the available backover avoidance technologies for detecting people or objects behind a passenger vehicle for their accuracy, effectiveness, cost, and feasibility for installation

3. Estimate the cost savings that would result from widespread use of backover prevention devices (injuries, fatalities, vehicle, and property damage)

During 2006, NHTSA performed the study directed by Congress. (This will be called the SAFETEA-LU Study.) Two reports were written as a result of the SAFETEA-LU Study. One was a report to Congress [6] that summarized all of the findings of this study. A second, more technical report, [1], examined the capabilities of a broad variety of commercially-available systems for preventing backover crashes for passenger (light) vehicles.

For the SAFETEA-LU Study, NHTSA performed objective testing of existing, commercially-available, systems designed to reduce the incidence of passenger vehicle backover crashes. The goal of this testing was to determine the performance capabilities of these systems. The SAFETEA-LU Study evaluated and compared the accuracy of available backover avoidance technologies. It also made a partial examination of system effectiveness. Note that a complete examination of backover avoidance system effectiveness requires that complex human factors testing be performed. There was not enough time prior to the required date for submission of a report to the Congress on this topic for such testing to be performed. However, NHTSA is currently in the process of performing such research for rearview video systems and systems that combine rearview video with rear parking sensors.

For the SAFETEA-LU study, eight sensor-based systems were examined: four original equipment systems and four aftermarket systems. One of the original equipment sensor systems included rearview video as part of the system. One original equipment rearview camera only system was examined. Two mirror systems were examined: one original equipment system and one aftermarket system.

NHTSA conducted testing to measure a variety of aspects of object detection performance of sensor-based systems with the ability to detect objects at short range. Measurements included static field of view, static field of view repeatability, and dynamic detection range for a variety of test objects. The ability of systems to detect an adult male walking in various directions with respect to the rear of the vehicle was assessed. Sensor system detection performance was also assessed in a series of static and dynamic tests conducted using 1-year-old and 3-year-old children. Response time of sensor-based systems was also measured for a standard object. An examination of rearview video and auxiliary mirror systems was also conducted which involved measurement of field of view.

Sensor-based systems generally exhibited poor ability to detect pedestrians, particularly children, located behind the vehicle. Systems' detection performance for children was inconsistent, unreliable, and in nearly all cases quite limited in range. Based on calculations of the distance required to stop from a particular vehicle speed, detection ranges exhibited by the systems were not sufficient to prevent many collisions with pedestrians or other objects.

The rearview video systems examined had the ability to show pedestrians or obstacles behind the vehicle and provided a clear image of the area behind the vehicle in daylight and indoor lighted conditions. While the auxiliary mirror systems tested also displayed any rear obstacles present, their fields of view covered a smaller area behind the vehicle than did the video systems tested, and the displayed images were subject to distortion caused by mirror convexity and other factors (e.g., window tinting) making rear obstacles more difficult to recognize in the mirror. In order for visual backing systems to prevent crashes, drivers must look at the video display or auxiliary mirror, perceive the pedestrian or obstacle, and respond correctly.

While the SAFETEA-LU Study performed a thorough examination of the backover avoidance technologies available in 2006 for light vehicles, it did not examine commercially-available systems that are intended for use on medium straight trucks (trucks with a GVWR of between 4,536 kg (10,000 pounds) and 11,793 kg (26,000 pounds)). Since there are differences between backover avoidance systems intended for use on light vehicles and those meant for medium straight trucks, NHTSA decided that, in order to respond to the FMVSS No. 111 NPRM, a study of backover avoidance systems for medium straight trucks needed to be performed. This report documents this study.

1.2. <u>STUDY OBJECTIVES</u>

For this research, NHTSA performed objective testing of existing, commercially-available, rear object detection systems for medium trucks (with an emphasis on delivery vans). The goal of this testing was to evaluate the performance of these systems.

The following testing was performed for this research:

1. Static field-of-view measurements for selected backover avoidance systems based upon radar and/or ultrasonic sensors using a variety of test objects.

2. Repeatability of static field-of-view measurements for selected backover avoidance systems based upon radar and/or ultrasonic sensors using four test objects.

3. Dynamic range measurements for selected backover avoidance systems based upon radar and/or ultrasonic sensors using a limited set of test objects.

4. Response time measurements for selected backover avoidance systems based upon radar and/or ultrasonic sensors.

5. Field-of-view measurements for selected rearview video systems. Qualitative, subjective, evaluations were also made of the quality of the images generated by the rear-pointing video cameras.

6. Quantitative image quality measurements for a rear cross-view mirror designed to augment driver rearward visibility. This evaluation was performed to determine at what vehicle length (or inter-mirror distance) rear cross-view mirror image quality becomes insufficient for rapid visual object detection by the driver. In other words, is the quality of image that the driver sees in the rear cross-view mirror good enough to prevent backover crashes from occurring?

   The original intention was to make image quality measurements for multiple flat side-view mirror to rear cross-view mirror distances. However, this testing was only performed for one length because the shortest attainable distance (with the 1996 Grumman-Olson 4x2 step van test vehicle) was already a length at which the rear cross-view mirror image quality was unacceptable.

7. Measurement of the rear field-of-view dimensions for a medium truck (the 1996 Grumman-Olson 4x2 step van test vehicle).

2.0 AVAILABLE VEHICLE-BASED BACKING CRASH COUNTERMEASURE TECHNOLOGIES FOR MEDIUM STRAIGHT TRUCKS

There are a variety of commercially-available backover avoidance technologies for detecting people or objects behind a small commercial truck. Technologies identified include sensor-based and visual systems. This section outlines available technologies and describes the specific systems examined in this research.

2.1. DESCRIPTION OF TECHNOLOGIES

In 2006, there were many companies offering aftermarket rear object detection systems for small commercial trucks in the U.S. market. (NHTSA was not aware of any small commercial trucks that were fitted with rear object detection systems by their manufacturers as original equipment.) These systems can be divided into two main types – senor based and visual.

2.1.1. Sensor-Based Systems

These systems are intended to aid drivers in performing low-speed (typically at or below 3 mph) backing and parking maneuvers by using one or more sensors to detect the presence of people or objects behind the vehicle and then providing some form of warning to the driver (typically an auditory tone). Some systems also indicate the distance to the closest obstacle.

There are two main technologies used for the sensors that detect people and obstacles behind vehicles: ultrasonic and radar. The radar technology can be further subdivided into sensors that use the Doppler effect to detect the presence of objects and those that use frequency modulated continuous wave radar to determine the position of obstacles relative to the vehicle. The systems tested in this study used ultrasonic and frequency modulated continuous wave radar.

Ultrasonic object detection systems emit a burst of ultrasonic (a typical frequency is 40 kHz) sound waves backward from the vehicle. Objects struck by the impinging sound waves reflect them; the reflected waves are called the echo. Quoting from [7]:

> "The amplitude of the echo depends upon the reflecting material, shape and size. Sound-absorbing targets such as carpets and reflecting surfaces less than two square feet in area reflect poorly."

After emitting a burst of ultrasonic sound waves, the ultrasonic object detection system listens for the corresponding echo. Since sound travels at approximately 1,100 feet per second in room temperature air, the time from the emission of the sound waves to hearing the echo can be used to determine the distance to the reflecting obstacle.

Ultrasonic object detection systems are available as aftermarket equipment on medium straight trucks at prices ranging from approximately $56 to $400 (equipment only, installation is an added expense). The system for a vehicle consists of two to four ultrasonic sensors, a driver interface, and the necessary wiring.

Radar sensors, noted by Consumer Reports [8] as suited "best for a parking aid to help drivers avoid denting fenders and bumpers," come in two varieties for short-range, vehicle-based applications. One type of radar sensor uses the Doppler effect to detect the presence of objects behind the vehicle that are moving with respect to the vehicle (i.e., if the vehicle is stationary, then the object must be moving to be detected, if the vehicle is moving then the object must either be stationary or moving at a different velocity than the vehicle to be detected). The difference in relative velocities changes the frequency of the reflected radar waves. The amount of frequency shift is proportional to the relative velocity difference. Note that Doppler effect radar systems cannot, in general, detect stationary objects while the vehicle is stationary. Doppler radar can determine relative velocities with high accuracy.

Doppler radar can also determine the distance to objects behind the vehicle. This can be done by changing the frequency of the emitted radar waves (the technique used by the Doppler radar sensor studied during this research) or by emitting multiple bursts of radar waves.

Doppler radar object detection systems are available for aftermarket installation at prices ranging from approximately $200 to $300. The system for a vehicle will consist of a Doppler radar sensor, a driver interface, and the necessary wiring.

A second type of radar sensor uses frequency modulated continuous wave radar to determine the position of obstacles relative to the vehicle. This technology can detect objects that are not moving relative to the vehicle and gives a more accurate measurement of distance to an object than does Doppler radar. The ability to detect objects that are not moving relative to the vehicle is both an advantage and a disadvantage; it is advantageous in that it gives the ability to detect stationary objects behind the vehicle when the vehicle is not moving (think of a bicycle parked behind the stationary vehicle) but a drawback in that the field of view of the system must be such as to avoid objects that are not a problem (e.g., the concrete of the driveway). Having to avoid objects that are not a problem tends to leave holes in the detection zone in which objects that should be detected will not be seen.

Frequency modulated continuous wave radar object detection systems are available as aftermarket systems for medium straight trucks. The system for a vehicle will consist of one radar sensor, a driver interface, and the necessary wiring.

For both types of radar sensors, the detectability of objects within their field of view depends upon their radar cross section; the larger the radar cross section the more likely an object in the field of view is to be detected. (For Doppler-effect sensors, detectability also depends upon whether the object is moving relative to the sensor. Objects that are stationary relative to the sensor will not be detected.) The radar cross section of an object depends upon its size, geometry, and material composition. For example, large, angular, metallic objects have very large radar cross sections. On the other hand, some geometries and materials are virtually invisible to radar.

2.1.2. Visual Technologies

Visual technologies for detecting people and objects behind a backing vehicle include rear camera systems, convex mirrors, and Fresnel lenses. These systems show the driver what is behind the vehicle, but unless coupled with sensor technology, do not alert the driver to any unseen obstacles.

Several models of aftermarket video backing aid systems were found to be sold on the internet for prices ranging from approximately $400 - $600 or more. These rear camera systems often came with Liquid Crystal Diode (LCD) displays that required a mounting location on the dashboard, while a few were offered that included the LCD display as part of a replacement rearview mirror. Another aftermarket rearview video system tested offered a rearview mirror display embedded in a replacement rearview mirror that could be mounted over top of the face of the original rearview mirror.

Rear-mounted convex mirrors, frequently called "cross-view mirrors," are available which seek to provide improved indirect rear visibility. These convex mirrors are fairly inexpensive ($75 or less) and easy to install. For medium duty trucks (such as delivery trucks), cross-view mirror systems usually consist of a single convex mirror mounted diagonally out from the left rear corner of the vehicle using an overhead bracket.

2.2. SYSTEMS TESTED

Systems were chosen for evaluation to provide a representative sample of each type of technology. Systems from different manufacturers were included to provide a balance of brands as well as to observe any differences that might be present in terms of how different manufacturers implement a particular sensor technology (e.g., ultrasonic). For this study, NHTSA tested three sensor-based rear object detection systems, one rear object detection system that combined sensors with rearview video, one rearview video (only) rear object detection system and one rear cross-view mirror. Since, as discussed in 2.2.2, below, the sensor and rearview video portions of the combined system were tested separately, NHTSA effectively tested four sensor-based systems, two rearview video systems, and one rear cross-view mirror. Three of the sensor-based systems used ultrasonic sensors; the fourth used frequency modulated continuous wave radar.

Table 1 lists these systems and presents a summary of their characteristics.

Table 1. Rear Object Detection Systems Tested

System Type	System Name	Sensor Technology	Number of Sensors	Information Displayed	Manufacturer
Sensor-Based Systems	Eagle Eye	Ultrasonic	2	Obstacle warning, distance information	Transportation Safety Technologies
	HaoDi PAS-405	Ultrasonic	4	Obstacle warning, distance information	HaoDi USA
	VORAD Backspotter	Radar	1	Obstacle warning, distance information	Eaton VORAD
Multiple Technology System	Hindsight 20/20	Ultrasonic and video	2 sensors, 1 camera	Image of area behind vehicle and obstacle warning	Sensor Safety Systems
Rear Video System	Audiovox	Video	1 camera	Image of area behind vehicle	Audiovox Specialized
Rear Cross-view Mirror	RXV	10” diameter convex mirror	1 mirror	None	Velvac

2.2.1. Single-Technology Sensor-Based Systems

Three single-technology sensor-based systems were examined. These were:

1. The Eagle Eye Electronic Obstacle Detection System from Transportation Safety Technologies. This system was composed of two sensors and an audio-visual display. The two ultrasonic sensors, which are shown in Figure 1, are mounted fairly low down on the rear of a truck. The audio-visual display, shown in Figure 2, is mounted on top of the vehicle’s dashboard where it can clearly be seen by the driver. This display warns the driver, both audibly and visually, of the presence of an obstacle behind the vehicle and conveys distance information. The Eagle Eye system was purchased as an aftermarket add-on. It was mounted onto the 2002 Mack MV222L test vehicle by representatives of Transportation Safety Technologies. NHTSA personnel mounted this system onto the 1996 Grumman-Olson step van test vehicle.

Figure 1. Eagle Eye Ultrasonic Sensor

Figure 2. Eagle Eye Audio-visual Display

2. The HaoDi PAS-405 from HaoDi USA. This system was also composed of four sensors and an LCD screen (with sound) display. The four ultrasonic sensors, which are shown in Figure 3, are mounted across the back bumper of a truck. The 2.75 inch diagonal LCD screen display, shown in Figure 4, is mounted on top of the vehicle's dashboard where it can clearly be seen by the driver. This display warns the driver, both audibly and visually, of the presence of an obstacle behind the vehicle and conveys distance information. The HaoDi PAS-405 system was purchased as an aftermarket add-on and mounted on the test vehicles by NHTSA personnel.

Figure 3. HaoDi Ultrasonic Sensor

Figure 4. HaoDi LCD Screen Audio-visual Display

3. The VORAD Backspotter Rear Object Detection System from Eaton-VORAD. This system was composed of one frequency modulated continuous wave sensor and an audio-visual display. The radar sensor, which is shown in Figure 5, is mounted low down on the rear of a truck. The audio-visual display, shown in Figure 6, is mounted on top of the vehicle's dashboard where it can clearly be seen by the driver. This display warns the driver, both audibly and visually, of the presence of an obstacle behind the vehicle and conveys distance information. The VORAD Backspotter system was purchased as an aftermarket add-on and mounted on the test vehicles by NHTSA personnel.

Figure 5. Vorad Backspotter Radar Sensor

Figure 6. Vorad Backspotter Audio-visual Display

2.2.2. Multiple-Technology System

One multiple-technology system was examined. This was the Hindsight 20/20 System from Sensor Safety Systems. This system was composed of two ultrasonic sensors, a rear pointing video camera, and an LCD screen (with sound) display. The two ultrasonic sensors, which are shown in Figure 7, are mounted low down on the rear of a truck. The video camera, which is shown in Figure 8, is mounted high up above the rear door of the truck. The 7 inch diagonal LCD screen display (actually 6.875 inches diagonally), shown in Figure 9, is mounted on top of the vehicle's dashboard where it can clearly be seen by the driver. This LCD screen displays an image of area behind the vehicle to the driver. It also warns the driver, both audibly and visually, of the presence of an obstacle behind the vehicle and conveys distance information. The visual warning consists of a multi-colored bar presented at the lower, right-hand corner of the screen. The bar changes from green to yellow to red to indicate the relative proximity of an obstacle. The Hindsight 20/20 system was purchased as an aftermarket add-on and mounted on the test vehicles by NHTSA personnel.

Since the sensor and rearview video portions of the Hindsight 20/20 system were tested separately, NHTSA effectively treated this as two separate systems, an ultrasonic sensor-based system and a rearview video system. It will be clear from the context whether a reference is to the ultrasonic or to the video portion of the Hindsight 20/20 system.

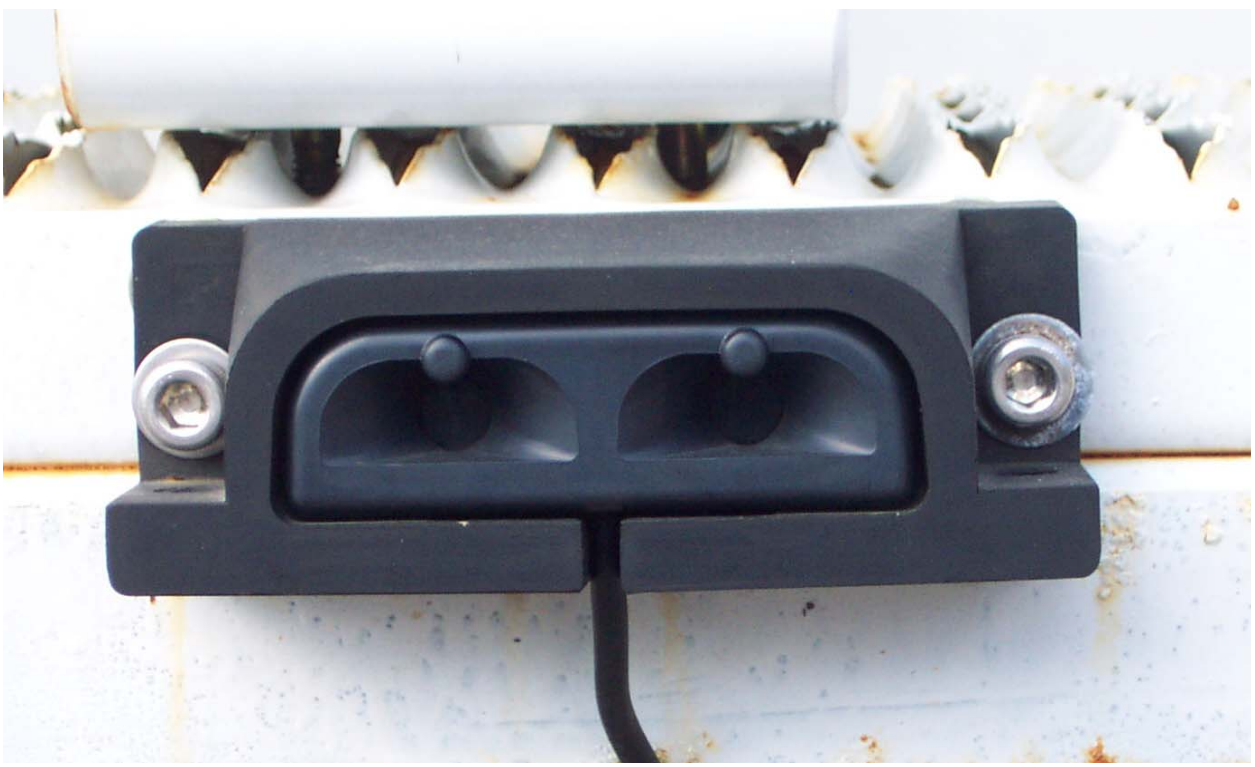

Figure 7. Hindsight 20/20 Ultrasonic Sensor

Figure 8. Hindsight 20/20 Video Camera

Figure 9. Hindsight 20/20 Audio-visual Display

2.2.3. Rearview video System

One rearview video (only) system was examined. This was the Audiovox System from Audiovox. This system was composed of a rear pointing video camera and a LCD screen display (no sound). The video camera, which is shown in Figure 10, is mounted high up above the rear door of the truck. The 7 inch diagonal LCD screen display (actually 6.8125 inches diagonally), shown in Figure 11, is mounted on top of the vehicle's dashboard where it can clearly be seen by the driver. This LCD screen displays an image of area behind the vehicle to the driver. The Audiovox system was purchased as an aftermarket add-on and mounted on the test vehicle's by NHTSA personnel.

Figure 10. Audiovox Video Camera

Figure 11. Audiovox LCD Screen Display

2.2.4. Rear Cross-view Mirror

One rear cross-view mirror was examined. This was a RXV 10” diameter convex mirror made by Velvac that was mounted from the upper rear corner of the test vehicles. This system was composed of a 200 mm radius of curvature convex mirror along with appropriate mounting hardware. The rear cross-view mirror is viewed by the driver looking in the flat side-view mirror on the left side of the vehicle. The RXV mirror is shown in Figure 12. A three-quarters view of a test vehicle (the 1996 Grumman-Olson 4x2 step van) showing the flat left side-view mirror and the rear cross-view mirror is shown in Figure 13. The RXV mirror was purchased as an aftermarket add-on and mounted on the test vehicles by NHTSA personnel. Figure 14 shows the view seen by the driver of the rear cross-view mirror in the flat side-view mirror for the 1996 Grumman-Olson 4x2 step van.

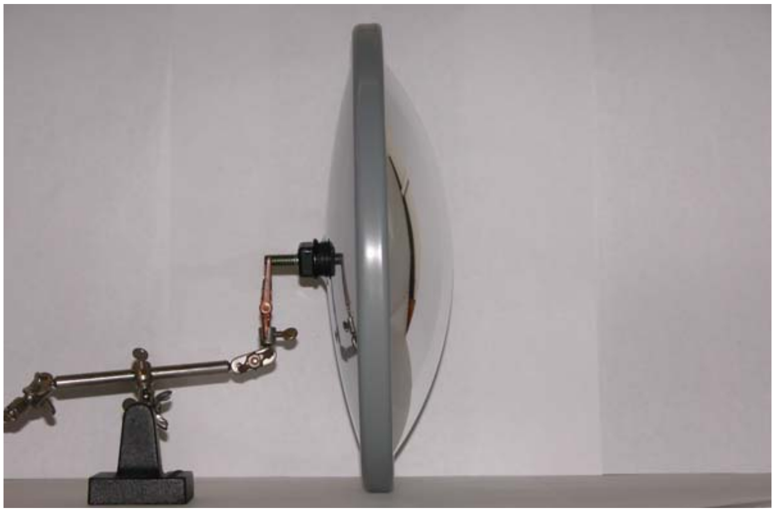

Figure 12. Velvac RXV 10” Diameter Convex Mirror

Figure 13. 1996 Grumman-Olson 4x2 Step Van Showing Flat Left Side-view Mirror and Rear Cross-view Mirror

Figure 14. Driver's View of the Rear Cross-view Mirror as Seen in the Planar Side-view Mirror on the 1996 Grumman-Olson 4x2 Step Van

3.0 METHOD

This section describes equipment used and general test procedures for all of the different types of tests conducted. To improve readability, Section 4.0 describes details and procedures for individual test scenarios.

3.1. <u>TEST VEHICLES</u>

Two medium straight trucks were used for testing. This provided for consistency of platforms between systems thereby allowing isolation of system and sensor performance factors. The two medium straight trucks used as test vehicles were:

1. A 2002 Mack MV222L 4x2 medium straight truck. This vehicle, which is shown in Figure 15, is equipped with a 22-foot long cargo box. It has a wheelbase of 175.5 inches, and an overall length of 340.0 inches. This vehicle is a Class 6 truck with a Gross Vehicle Weight Rating (GVWR) of 25,995 pounds.

   All outdoor sensor and video camera testing for this program was conducted using the 2002 Mack MV222L truck.

Figure 15. 2002 Mack MV22L Medium Straight Truck

2. A 1996 Grumman-Olson 4x2 step van. This vehicle's chassis was manufactured by General Motors Corporation in August, 1996. This vehicle is a Class 3 truck with a GVWR of 11,000 pounds.

   The1996 Grumman-Olson 4x2 step van (shown in Figure 13) was equipped with a 12-foot long cargo box. It has a wheelbase of 134.0 inches, and an overall length of 244.5 inches. Figure 16 contains a left-side outline drawing of this test vehicle showing other dimensions that are relevant to this work. Of particular interest is the left side-view mirror to rear cross-view mirror distance of 190.0 inches. Figure 17 shows the rear side of the vehicle and locations of sensors, rearview video cameras, and the rear cross-view mirror as installed for testing. The vehicle had a center rearview mirror and windows in the rear doors, which made it possible for the driver to see some of the area behind the vehicle.

All indoor sensor and video camera testing as well as the outdoor rear cross-view mirror testing for this program was conducted using the1996 Grumman-Olson 4x2 van. This was primarily the sensor and video testing that was performed with actual children. Also, the rear cross-view mirror testing was performed using this vehicle because, at the time this research was performed, NHTSA was considering allowing rear cross-view mirrors as a backover avoidance compliance option for vehicles for which the left side-view mirror to rear cross-view mirror distance was less than 197.0 inches. The1996 Grumman-Olson 4x2 step van's left side-view mirror to rear cross-view mirror distance of 190.0 inches is less than maximum distance that was under consideration but close enough to make for a good "worst case" test bed.

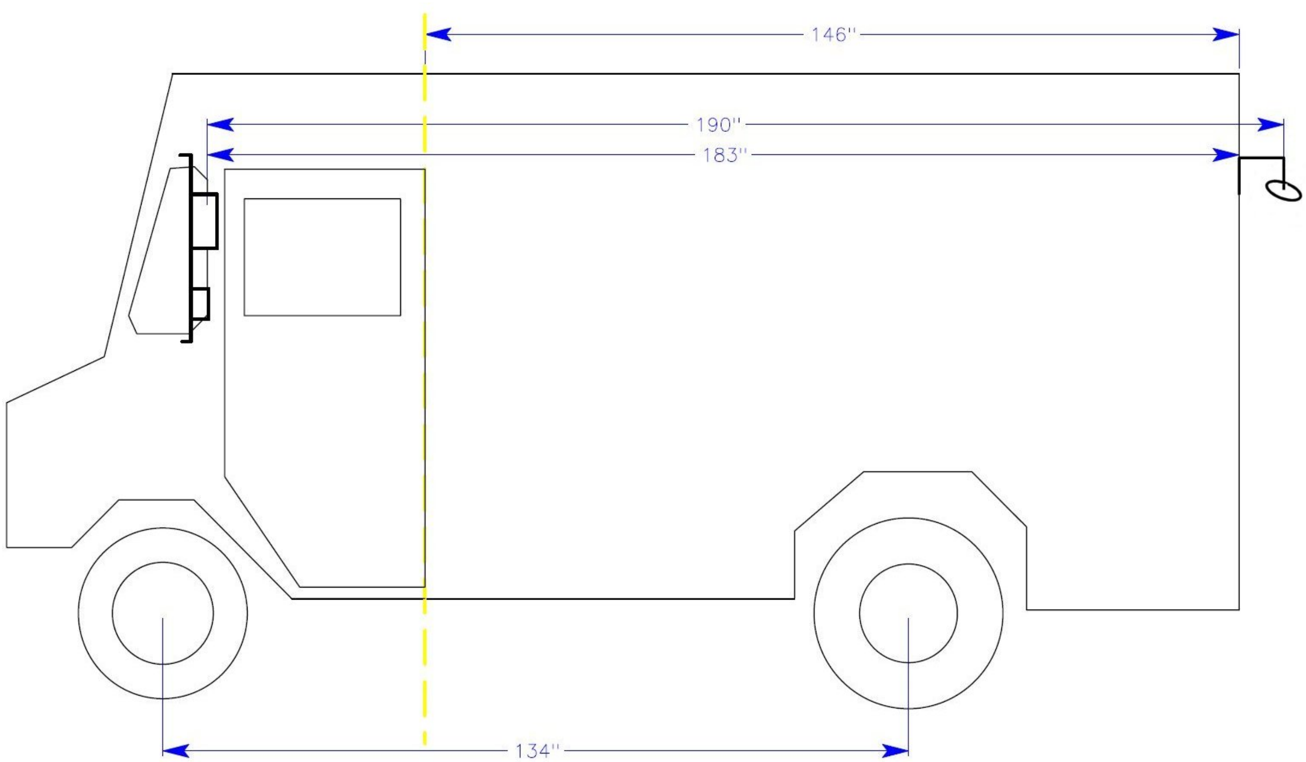

Figure 16. Outline Drawing of 1996 Grumman-Olson 4x2 Step Van Showing Relevant Dimensions

Figure 17. Rear of the 1996 Grumman-Olson 4x2 Step Van Showing Sensor Showing Installed Sensor, Camera, and Mirror Locations

3.2. VEHICLE PREPARATION PROCEDURE

Each test vehicle's tires were inflated to the pressure value(s) recommended by the vehicle manufacturer, and the fuel tank was filled so as to achieve a standard vehicle pitch. Backing system sensors were wiped to ensure they were free of dirt and other substances that might affect sensor performance. A plumb bob was hung from the rear bumper to ensure that the bumper was properly aligned on the test grid.

Testing was conducted with the vehicle's engine off, but the transmission in reverse gear and the ignition on to provide power to the sensor system being tested. Conducting testing with the vehicle's engine off ensured the safety of test staff and participants. To prevent draining of the vehicle's battery, a 12 volt power supply was connected during testing.

3.3. FIELD OF VIEW MEASUREMENT GRIDS

Dimensioned grids were used to facilitate measurement of the horizontal area in which objects were detected by sensors, video, and cross view mirrors. One grid was set up indoors and a second outdoors. The grids were comprised of 1 foot squares. The 50 by 50 foot indoor grid is shown in Figure 18, was constructed on a flat, painted concrete floor. The 50 by 55 foot outdoor grid, shown in Figure 19, was painted on level asphalt pavement.

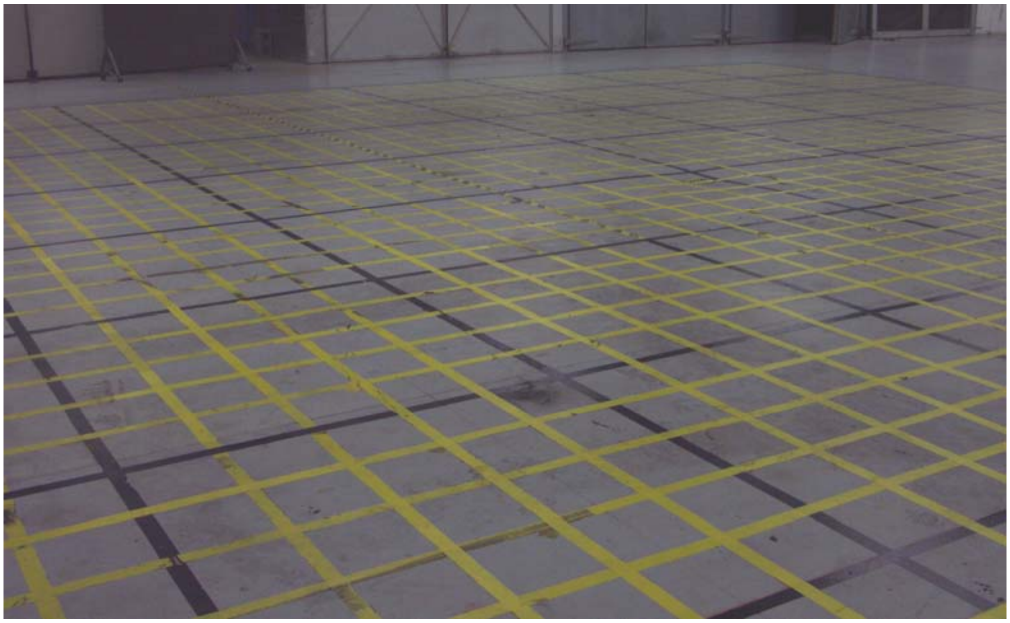

Figure 18. Indoor Field of View Measurement Grid

Figure 19. Outdoor Field of View Measurement Grid

For testing with actual children, pictures (e.g., shapes, cartoon characters) were placed within the squares of the indoor grid to assist in instructing the children as to where to stand. (These can be seen later in Figures 48 and 50).

3.4. TEST OBJECTS

How well a sensor system can detect a particular object depends on a variety of factors including the composition of the object, its shape, size, and distance from the sensor. The object detection capabilities of sensor-based object detection systems were measured using a variety of "test objects". Test objects (e.g., traffic cones) of various heights, diameters, and shapes were chosen to assess the size of the detection zone. These objects were comprised of a range of cross-sections that represent obstacles that a backing system are likely to encounter in the real world.

Table 2 presents the complete list of objects used in sensor performance testing and indicates whether the object was presented statically or dynamically. All tests were conducted with the test objects oriented in an upright orientation (e.g., standing), except where noted.

Table 2. Sensor Test Objects and Test Type

Test Object	Static	Dynamic	Repeatability
12, 18, 28, 36-inch traffic cone	X		28-in. only
20-inch PVC pole	X		
40-inch PVC pole (as per ISO 17386)	X	2, 3 mph	X
20-foot PVC pole, positioned horizontally	X (vertical test)		
Parking curb, plastic	X		
CRABI 12-month-old ATD*	X	2, 3 mph	
Hybrid III 3-year-old ATD	X	2, 3 mph	X
Child, 1 year old	X	Walking, riding toy	
Child, 3 years old	X	Walking, running, riding toy	
Adult, male (height 6 feet 2.75 inches, weight 183 lbs)	X	Walking (laterally, longitudinally, diagonally with respect to vehicle)	X
Cozy coupe (toy car)		2, 3 mph	

*Note: Referred to in this report as "1-year-old ATD."

Traffic cones and poles were chosen as test objects since their conical and cylindrical shapes, when positioned vertically upright, present the same appearance to the sensors despite any rotation about their vertical axis. This quality renders them likely to achieve a more repeatable response in objective testing. This is likely the reason that a PVC pole was recommended as a test object in the International Standard's Organization's (ISO) Standard 17386, "Transport information and control systems – Manoeuvring Aids for Low Speed Operation (MALSO) – Performance requirements and test procedures" [9]. The 40-inch "ISO pole" (pictured in Figure 20) was included in this testing to assess the performance of systems in detecting this object.

Figure 20. ISO 40-inch pole Set Up on Indoor Field of View Measurement Grid Behind a Light Vehicle

Human subjects, including 1-year-old and 3-year-old children as well as an adult male participated as “test objects.” Protocols involving human subjects were approved by an independent institutional review board. Vehicles were stationary and secure during all test trials with pedestrians. All test trials involving children were conducted with a parent or guardian present, as well as at least two research staff. Children participating in testing wore long sleeved shirts, long pants, and shoes.

Anthropometric Test Devices (ATDs), or crash dummies were also used to assess sensor system responses. The goal of this testing was to determine whether an ATD would make an acceptable, but far easier to test, surrogate for actual children for backover sensor testing. While the physical dimensions of an ATD match that of a child of corresponding age, the difference in composition between an ATD and an actual child will result in differences in systems’ ability to detect them.

The particular ATDs used in this testing included the Hybrid III 3-year-old ATD (H-III3C) and the Child Restraint/Air Bag Interaction (CRABI) 1-year-old ATD. The crash dummies are constructed from steel and rubber with fiberglass heads surrounded by polyurethane skins. Table 3 contains some basic data about these devices. For testing, the crash dummies were dressed in long-sleeved knit shirts and long knit pants typically worn for crash testing. Crash dummies were also fitted with knit hats to simulate hair, and the 3-year-old ATD was fitted with shoes. Photographs of these ATDs are presented in Figure 21.

Table 3. ATD Weight and Height Information

Property	1-year-old ATD	3-year-old ATD
Weight (lbs)	22.0	34.2
Standing Height (inches)	29.4	37.2
Sitting Height (inches)	18.9	21.5

Figure 21. Photographs of ATDs Used in Testing

Test objects that were too heavy to be moved repeatedly by hand or that were not self-supporting were suspended from above using a modified engine hoist and boom fixture. The hoist was also used to suspend and stabilize movement of the ISO pole during dynamic testing. Monofilament line of 75 pound test was used to suspend objects from the boom. Figure 22 shows a photograph of this fixture with the 3-year-old ATD suspended from it.

Figure 22. Hoist and Boom Apparatus with 3-year-old ATD on Indoor Field of View Measurement Grid

3.5. INSTRUMENTATION

All tests were recorded in digital video format with sound. These video data documented the test object's position with respect to the vehicle as well as the system's response to the object's presence (if any). A Sony TRV-90 digital video camera was mounted on a tripod positioned approximately 30 feet behind the test vehicle to capture a wide-angle view of objects' positions behind the test vehicle. A second, identical camera was located inside each test vehicle to capture any visual and/or auditory warnings produced by the systems. System detection performance data were also recorded by hand.

3.6. APPARATUS FOR CONTROLLED-SPEED DYNAMIC TESTING

For controlled-speed dynamic sensor system object detection tests, a pulley system was used to tow the hoist and boom fixture (as described at the end of Section 3.4) with suspended test object laterally behind the vehicle. The hoist was positioned such that it was outside the range of detection of the sensor system. A pulley system used weights, which were dropped by remote control, to cause a steel-braided cable to pull the hoist with attached test objects. Using this method, objects were moved at specific speeds across lines of the grid parallel to the vehicle's rear bumper. Figure 23 shows a photograph of the pulley system.

Figure 23. Pulley System Used for Controlled Speed Dynamic Tests

3.7. APARATUS FOR SENSOR SYSTEM RESPONSE TIME TESTING

Sensor system detection response time was measured using a remote-controlled fixture containing an aluminum plate that would pop up from the ground. Testing was conducted indoors on a flat, level, concrete surface.

The dimensions of the plate were 20.25 by 35.5 inches. The plate was attached to a plywood board using hinge. The plywood board rested on the ground and provided weight to fix one end of the plate at ground level. The aluminum plate began in a horizontal position resting atop the plywood board, as shown in Figure 24. When released, the plate rotated about the hinge point to a vertical position at full deployment, as shown in Figure 25. Two springs were attached 14.0 inches up from the pivot point position one on each side of the aluminum plate and to the plywood 3.0 inches before the pivot point. A solenoid was triggered by wired remote control to release a cam type latch that held the plate down (with springs fully extended) prior to deployment. When the cam was released it pushed the bottom of the aluminum plate upward, initiating the movement. The springs provided the force to move the plate into its deployed vertical position. Braided stainless steel cables were attached from the plywood plate to the back side of the aluminum plate to limit its travel. The height of the fixture when deployed was 36.5 inches. The fixture was situated such that, when deployed, the plate was 3 feet from the vehicle's rear bumper.

Figure 24. Response Time Fixture (Down Position)

Figure 25. Response Time Fixture (Deployed Position)

3.8. MIRROR IMAGE QUALITY MEASUREMENT METHODOLOGY

The measurements of the quality of images visible in the rear cross-view mirror performed for this research was based upon a methodology originally published by Satoh, Yamanaka, Kondoh, Yamashita, Matsuzaki, and Akisuzuki in 1983 [2]. This methodology has been used for other NHTSA research that required the measurement of the quality of images seen in school bus cross-view mirrors and forms the basis for the school bus cross-view mirror test that is in S9 and S13 of FMVSS No. 111 (see Garrott, Rockwell, and Kiger [10]). It has also been used for NHTSA research on rear cross-view mirror performance (see Huey, Boyd, and Lerner [11]).

There are two parts to the measurement of the quality of images visible in the rear cross-view mirror: (1) quantification of the amount of image distortion and (2) determination of the minification of test objects that are viewed in the rear cross-view mirror. Distortion is defined as how apparent shapes of objects change when viewed in the rear cross-view mirror. Minification is defined as how large objects appear when viewed in the rear cross-view mirror.

Rear cross-view mirror image quality measurement was performed using a camera placed on a tripod in the vehicle at a selected driver eye position. The driver eye position selected was that of a 25th percentile adult female driver. This driver eye position was selected because it is the one used in FMVSS No. 111 for the school bus cross-view mirror compliance test. As specified in S13.4 of FMVSS No. 111 [12], the position of the image plane of the camera used to take the image quality determination photographs was determined by first adjusting the driver's seat of the 1996 Grumman-Olson 4x2 step van "to the midway point between the forward-most and rear-most positions, and if separately adjustable in the vertical direction [which the 1996 Grumman-Olson 4x2 step van's seat was], adjust to the lowest position." After making the necessary measurements, the seat was removed from the vehicle. The camera was mounted on a tripod with the center of the image plane laterally at the center of the seat, longitudinally at the intersection of the seat cushion and the seat back, and vertically 27 inches above the intersection of the seat cushion and the seat back.

3.8.1. Quantification of Image Distortion

For image distortion determination, a cube mounted on a metal stand was constructed. This cube is shown in Figure 26. Each face of the cube was 1-foot square in size. The top face of the cube, which was colored green, was parallel to, and 29.6 inches above (the average height of a 1-year-old child), the ground. The cube's front and rear faces, which were colored red, were parallel to the rear bumper of the test vehicle. The left and right faces of the cube were colored blue.

Figure 26. Cube Used for Image Distortion Determination

The cube was placed at a grid of 35 test locations behind the test vehicle. Laterally, the cube was positioned such that its center was on the center line of the test vehicle, ±2 feet from the center line, and ±4 feet from the center line (i.e., testing was performed at five lateral positions for each longitudinal position). Longitudinally, for each lateral position the cube was first positioned such that its center was 0.5 feet behind the test vehicle's rear bumper (i.e., the front face of the cube was against the bumper). Additional positions 2.5, 4.5, 6.5, 8.5, 10.5, and 12.5 behind the rear bumper were then used. A two foot grid was used to minimize the photograph analyzer's workload based on the belief that it was not important to know distortion ratings with a higher spatial granularity. Figure 27 shows all cube locations used during this testing.

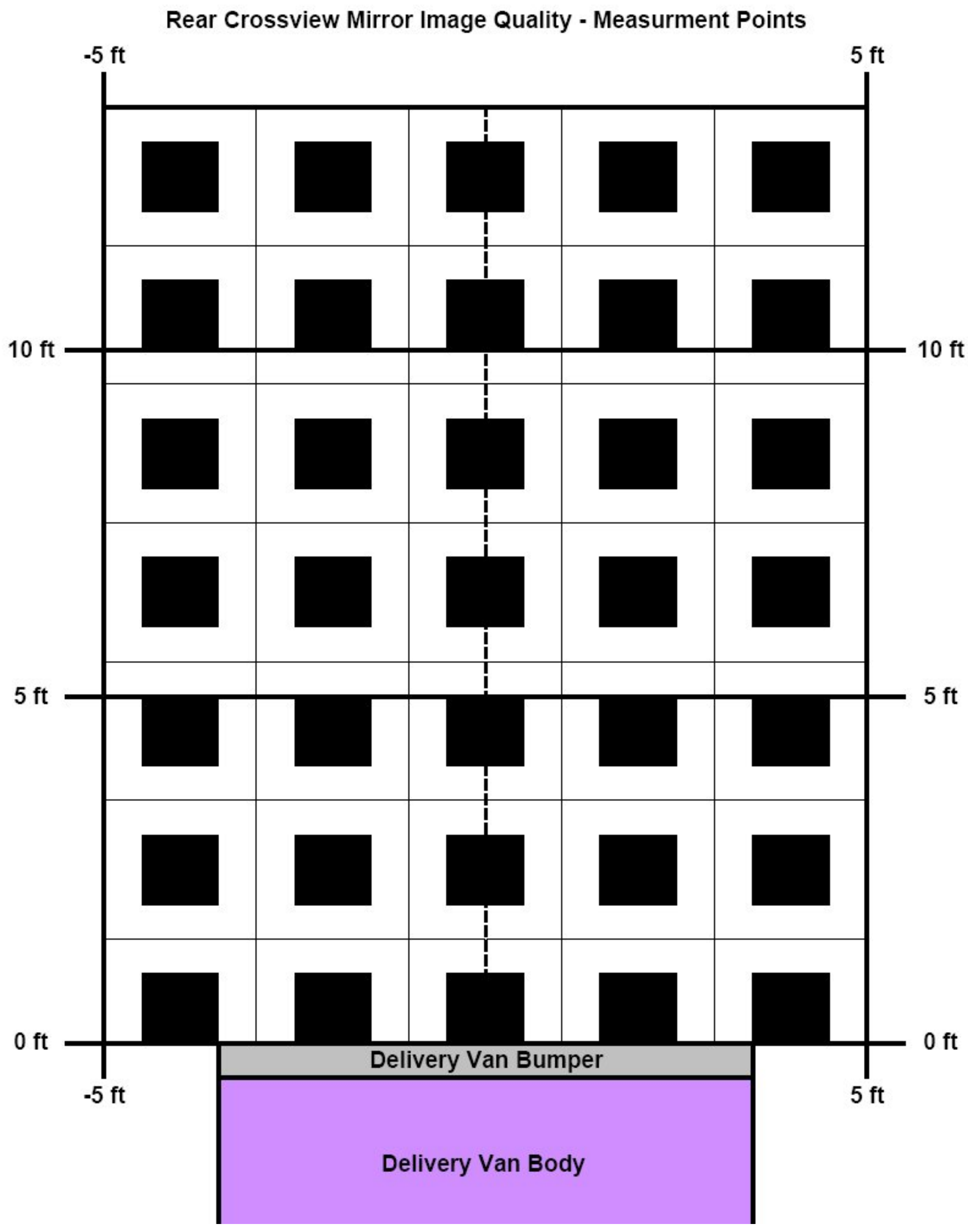

Figure 27. Grid of Locations Used for Image Quality Measurement

At each test location, the cube was photographed by a camera mounted on a tripod in the previously described driver eye position. Photographs were taken with a 5 megapixel Nikon Coolpix 5700 digital camera. To make it easier to measure the distortion, these photographs were taken using an 8x optical zoom. After the image had been transferred to a computer, digital zooming was used to further magnify the distortion measurement photographs. Figure 28 shows a typical, highly enlarged, picture of the cube that was used to measure image distortion.

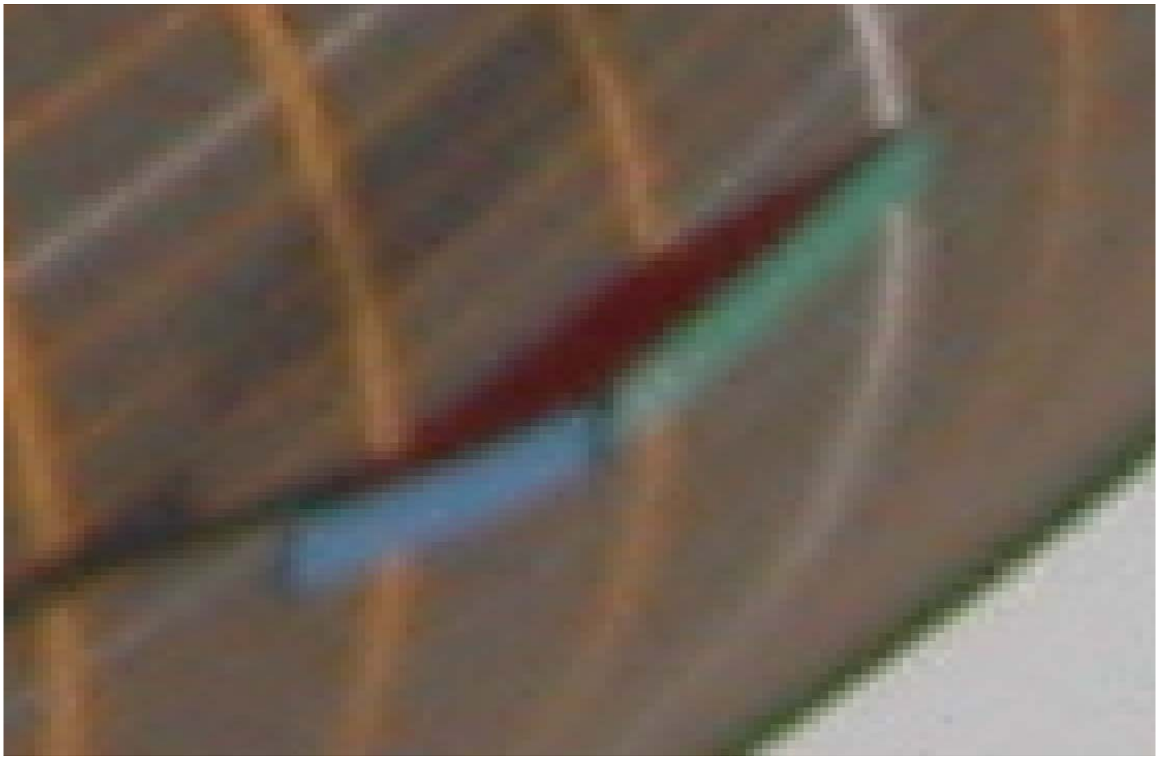

Figure 28. Typical, Highly Enlarged, Picture of the Cube that was Used to Measure Image Distortion

For each of the front, left, and top faces of the cube at each grid location (at some grid locations one of these faces could not be seen in the camera image), the distorted image of each face was approximated as a quadrilateral, i.e., a shape consisting of four straight lines. Although the analysts tried to be as objective as possible, due to the apparent curvature of the edges of the some of the distorted images, a small degree of subjectivity was introduced into the distortion determination process during this stage.

As shown in Figure 29, six measurements (the lengths of the four sides and of the two diagonals) were made for each distorted image of a cube face quadrilaterals. Each measurement was made under a lighted magnifying lens and is believed to be accurate to ±0.01 inches. Because the length of the top edge of the front face must be the same as that of the front edge of the top face, and other similar equivalences, in general, a total of 15 length measurements were made for each grid location. At the grid locations closest to the rear bumper of the test vehicle the front face of the cube could not be seen by the camera. Also, at the leftmost grid locations the left face of the cube could not be seen. At these locations fewer length measurements were made.

From the six measurements that were made for each distorted image of a cube face quadrilaterals, a four epsilons (called ε_1 through ε_4) were computed using the equations shown in Figure 29. The largest of ε_1 through ε_4 was then chosen as the overall epsilon for each distorted image of each cube face.

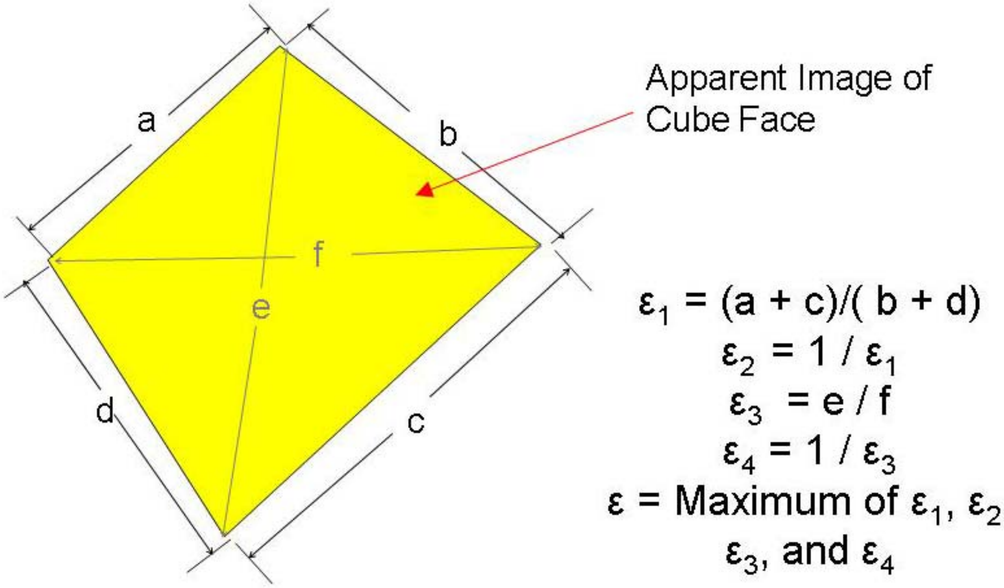

Figure 29. Measurements Made and Formulas Used for Determining Image Distortion

A weighted average of the overall epsilon values from the three visible faces, referred to as the cube's epsilon, was then computed for each cube test location. The cube's epsilon was calculated by weighting the overall epsilon value for each face by the apparent area of the face according to the formula

$$\varepsilon_{Ave} = \left(A_F \varepsilon_F + A_L \varepsilon_L + A_T \varepsilon_T\right) / \left(A_F + A_L + A_T\right)$$

where

A_F, A_L, and A_T are the apparent areas of the front, left, and top faces of the cube at each test location, respectively, and

ε_F, ε_L, and ε_T are the overall epsilons for the front, left, and top faces of the cube at each test location, respectively.

The apparent areas of the front, left, and top faces of the cube at each test location, A_F, A_L, and A_T were calculated using Bretschneider's formula for the area of a general quadrilateral, i.e.,

$$A_{F,L,T} = \frac{1}{2}\sqrt{4e^2 f^2 - \left(b^2 + d^2 - a^2 - c^2\right)^2}$$

where a, b, c, d, e, and f are as defined in Figure 29.

Once the weighted average epsilon had been computed for each grid location, Table 4 was used to determine a subjective degree of image distortion at each test location. Note that Table 4 is taken from Satoh [2] except for the lowest line. The final line was added by the authors so as to allow a subjective rating to be assigned at test locations for which the value of the weighted average epsilon exceeded ten.

Table 4. Relationship Between the Shape Change Factor, ε, and the Subjective Degree of Image Distortion

Level	**Degree of Image Form**	**Degree of Image Shape Change**	**Shape Change Factor ε**
5	Excellent	No Image Shape Change	<2
4	Good	Visible but no Problem	2-4
3	Fair	Visible but Possible to Judge	4-6
2	Poor	Large and Hinders Judgment	6-8
1	Very Poor	Impossible to Judge	8-10
0	Impossible	Impossible	>10

3.8.2. Image Minification Determination

The driver's expected ability to see child-size objects in the rear cross-view mirror was measured at each test location using both the Hybrid III 3-year-old ATD (H-III3C) and the Child Restraint/Air Bag Interaction (CRABI) 1-year-old ATD. Photographs of these ATDs were previously presented in Figure 21. Unlike for the previously described sensor testing, the crash dummies were not dressed for this testing. This was because for the sensor testing, there were concerns that the dummies polyurethane skins would reflect radar and ultrasonic waves differently than would the clothes worn by actual children. For the mirror testing, only the geometric size of the dummies affected the results while the higher contrast between the dummy skins and the asphalt pavement made the procedure easier.

The same grid of test locations, previously shown in Figure 27, were used for image minification determination. As was the case for the sensor testing, the ATD's were suspended from a hoist apparatus. The apparatus used was previously shown in Figure 22; however, for the image minification determination testing the long boom shown in Figure 22 was unnecessary and therefore not used.

Photographs were taken of each ATD at each test location. Figure 30 shows a typical photograph of a 3-year-old ATD behind the vehicle.

The visual angle at the driver's eyes that was subtended by both the 1- and the 3-year-old dummies was determined at each test location. While in principle measurements of apparent dummy size and optics could have been determined this, due to fears that the 8x optical zoom being used when the needed photographs were taken might not provide exactly a magnification of 8.0, a "Sizing Object" was used.

Figure 30. Photograph of Rear Cross-View Mirror Image, as Seen in the Left Side-View Mirror, Showing a 3-Year-Old ATD 4.5 Feet Behind the Rear Bumper of the Vehicle and 2.0 feet to the Left of the Vehicle's Centerline

(Note: Image in figure appears reversed because it is an image within the left side-view mirror.)

The Sizing Object consisted on a 12-inch square piece of styrofoam the front of which was covered with orange construction paper. Centered in the 12-inch square was a 6-inch square piece of blue construction paper. The Sizing Object was hung below the rear cross-view mirror perpendicular to the driver's line of sight from the flat side-view mirror. Figure 30 shows a portion of the Sizing Object hanging below the rear cross-view mirror. As is the case in Figure 30, only a portion of the Sizing Object was visible in the photographs that were taken to determine the subtended visual angles.

To determine the subtended visual angle for each ATD at each grid location, the analyst (working under a lighted, magnifying lens) first measured the longest dimension of the ATD image. This length was called the Measured Length - Longest Direction and gives the best (easiest) case for the driver to see the ATD. All measurements were made to the nearest 0.01 inch and had an estimated accuracy of ±0.01 inches. In the direction perpendicular to the longest dimension of the ATD image, the analyst then selected the point where the ATD image was the widest. The resulting length was called the Measured Length - Shortest Direction and gives the worst (hardest) case for the driver to see the ATD.

The known dimensions of the portion of the Sizing Object visible in each photograph were used to calculate the true values of each Measured Length - Longest Direction and Measured Length - Shortest Direction. For some photographs which were inadvertently taken with the Sizing Object not visible, an average scale factor was used to calculate these true values.

The following equation, obtained from geometric optics, was used to calculate the subtended visual angles:

$$\theta = 60\sin^{-1}\left(\frac{d}{(a+b)}\right)$$

where:

θ is the subtended visual angle in units of minutes of arc.

a is the distance from the driver eyepoint to the center of the flat side-view mirror. This is constant for all photographs and equal to 38.50 inches for this research.

b is the distance from the center of the flat side-view mirror to the surface of the rear cross-view mirror. This is constant for all photographs and equal to 187.50 inches for this research.

d is the measured ATD dimension. This will be either the Measured Length - Longest Direction or Measured Length - Shortest Direction.

and $\sin^{-1}$ is calculated in units of degrees.

Once the subtended visual angle had been determined for each grid location, Table 5 was used to determine a subjective degree of image visibility at each test location. Note that Table 5 is taken from Satoh [2] except for the last line, level 0. The last line was added by the authors so as to allow a subjective rating to be assigned at test locations for which the value of the subtended visual angle was less than 3 minutes of arc.

Table 5. Relationship Between the Subtended Visual Angle, θ, and the Subjective Degree of Image Visibility

Level	**Degree of Image Form**	**Degree of Image Size**	**Visual Angle ϴ (minutes)**
5	Excellent	No Image Small	>50
4	Good	Small, but no Problem	20-50
3	Fair	Small, but Possible to Judge	10-20
2	Poor	Small and Hinders Judgment	5-10
1	Very Poor	Impossible to Judge	3-5
0	Impossible	Impossible	<3

4.0 SYSTEM TESTING AND RESULTS

Tests were conducted to characterize the performance of available backover avoidance technologies in detecting objects and people. This section describes the details and procedures for individual test scenarios and summarizes the test results.

4.1. STATIC TESTS

Sensor-based systems were tested to measure their performance in detecting a set of objects in a static scenario, in which both the vehicle and the test object are stationary.

4.1.1. Sensor Detection Zone Area Tests

Sensor system detection zone area was measured by placing test objects in the center of individual grid squares behind the vehicle and recording the response of the system to the object. Test objects included 12-inch, 18-inch, 28-inch, and 36-inch traffic cones, 20-inch-tall PVC pole, 40-inch-tall PVC pole, 1-year-old ATD, 3-year-old ATD, 1-year-old child, a 3-year-old child, and an adult male. All objects were oriented in an upright (vertical) position for all grid locations aft of the bumper. The 12-inch cone (upright) and 1-year-old ATD (lying on the ground) were also positioned under the bumper in some cases. Results for the 28-inch cone, 40-inch PVC pole, and 3-year-old ATD are in Section 4.1.2, which addresses static repeatability.

Testing began with objects being placed in a grid square near a rear corner of the vehicle within the 12-inch area just aft of the vehicle's bumper. The object would be moved to the next square to the right or left until the system ceased to detect the test object. After completing one row of the grid, the object would be moved to the next row of grid squares further away from the rear of the vehicle and the process was repeated. This continued until the sensor system ceased to detect the object. Testing was also performed with the test object in front of the vehicle's bumper in a few locations.

For each location at which the test object was placed, a data point was manually recorded to reflect whether the system did or did not detect the presence of the object. To the extent possible, the level of warning emitted was also recorded. Some systems presented multiple stages of warnings, while others used continuously increasing frequency of audible beeps to indicate the imminence of contact. Thus, to simplify the presentation of sensor system object detection performance results the coding scheme shown in Table 6 was used for data presentation to indicate whether the object was detected in a particular location and to describe the approximate level of warning provided by the system. A system's response was considered an "inconsistent warning" if the system produced a sporadic or occasional visual or auditory alert in response to the object's presence.

Highest Level Warning	●
Intermediate Level Warning	◍
Lowest Level Warning	○
Inconsistent Warning	⊗
Location Tested But Object Not Detected	·

Table 6. Coding Scheme for Static Sensor System Detection Zone Area Data Plots

The results of the static sensor detection zone area trials, grouped by test object, are shown in Figures 31 through 37. Individual figures show the results for all sensor systems for a particular test object (system names are listed above each graph). These figures show an overhead view of the test grid with the rear bumper of the vehicle (not to scale) at the bottom of the graph. As mentioned, symbols in the grid squares indicate whether or not the location was tested and the result (i.e., system response).

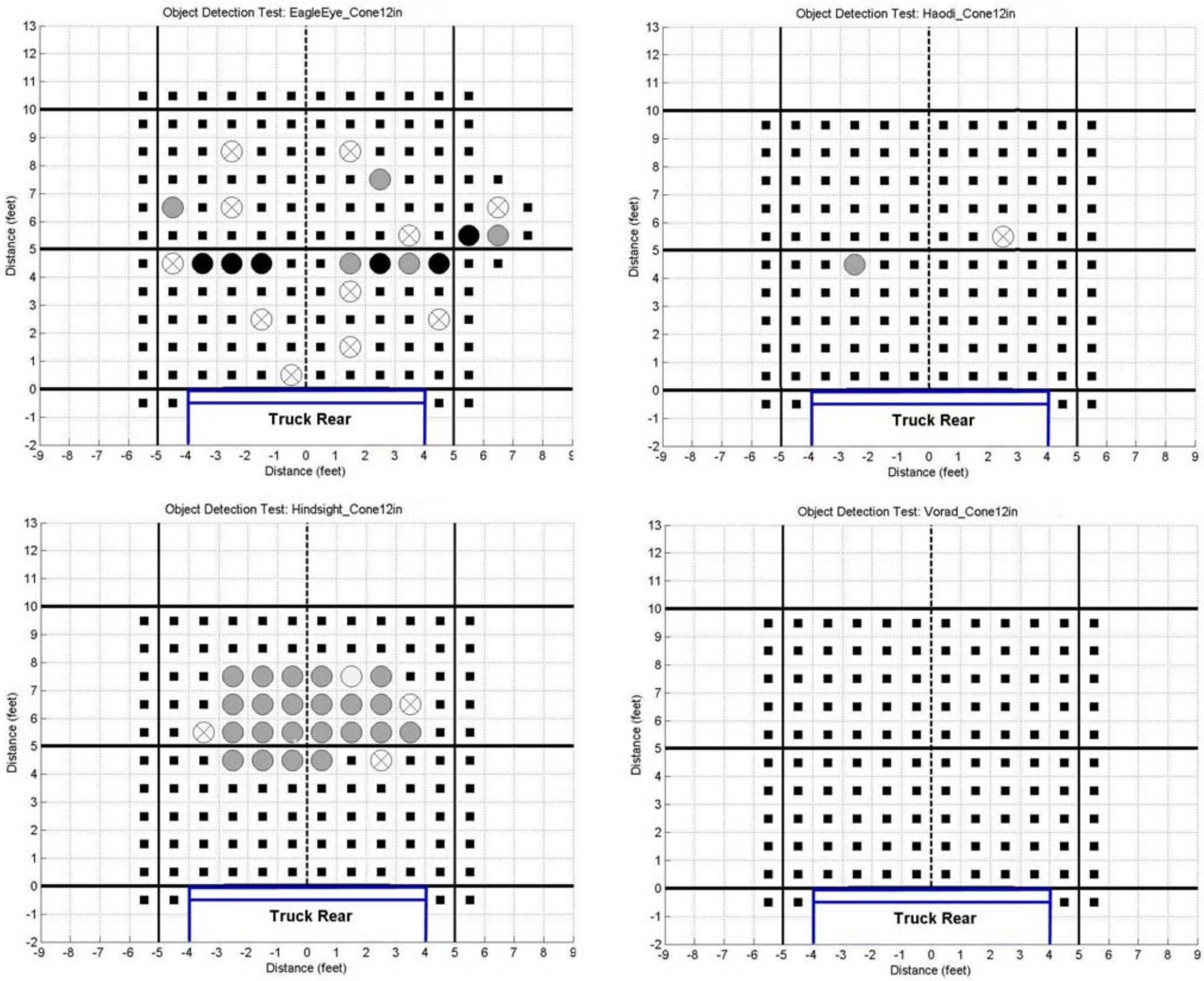

Figure 31. Detection Results for the 12-Inch-Tall Traffic Cone

The 12-inch traffic cone was not well detected. Only one system, the Hindsight 20/20 detected the cone consistently. However, this system did not detect the cone within 4 feet of the vehicle's bumper, showing that the lower boundary of the sensors' detection zone had a shallow slope that reached 12 inches from the ground at approximately 4.5 feet from the vehicle's rear bumper. The Eagle Eye system detected the object in several locations across the rear of the vehicle, but primarily at a distance of 4.5 feet from the bumper. This object was essentially not detected by the HaoDi and VORAD Backspotter systems.

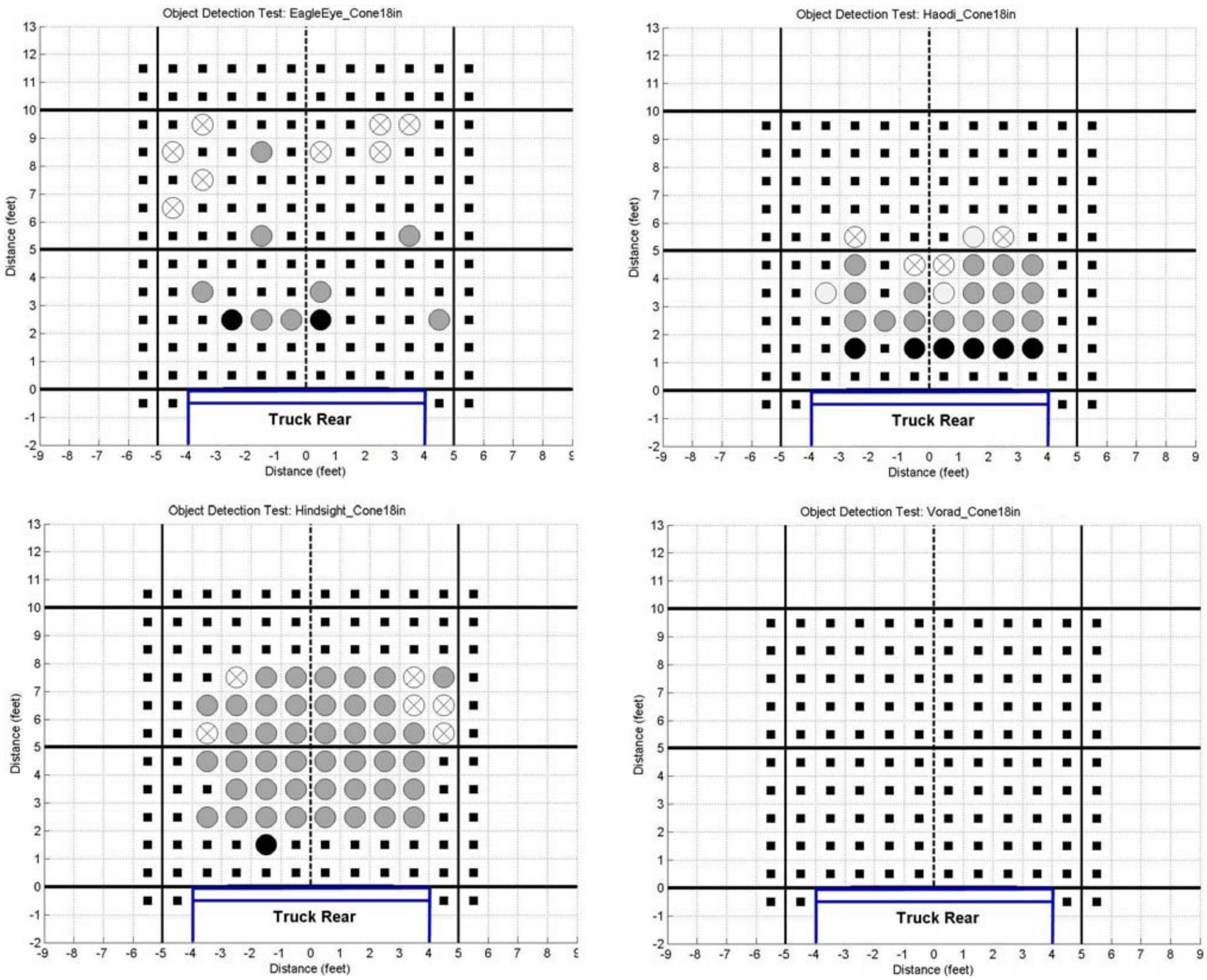

Figure 32. Detection Results for the 18-Inch-Tall Traffic Cone

Results for detection of the 18-inch traffic cone were only slightly better than those seen for the 12-inch cone. The Hindsight 20/20 system detected this object in the most locations, generally ranging from 2.5 to 7.5 feet from the vehicle's rear bumper. The HaoDi system detected the cone between 1.5 and 3.5 feet from the bumper. The Eagle Eye system detected the cone in several locations, but with no clear pattern. This object was not detected by the VORAD Backspotter system.

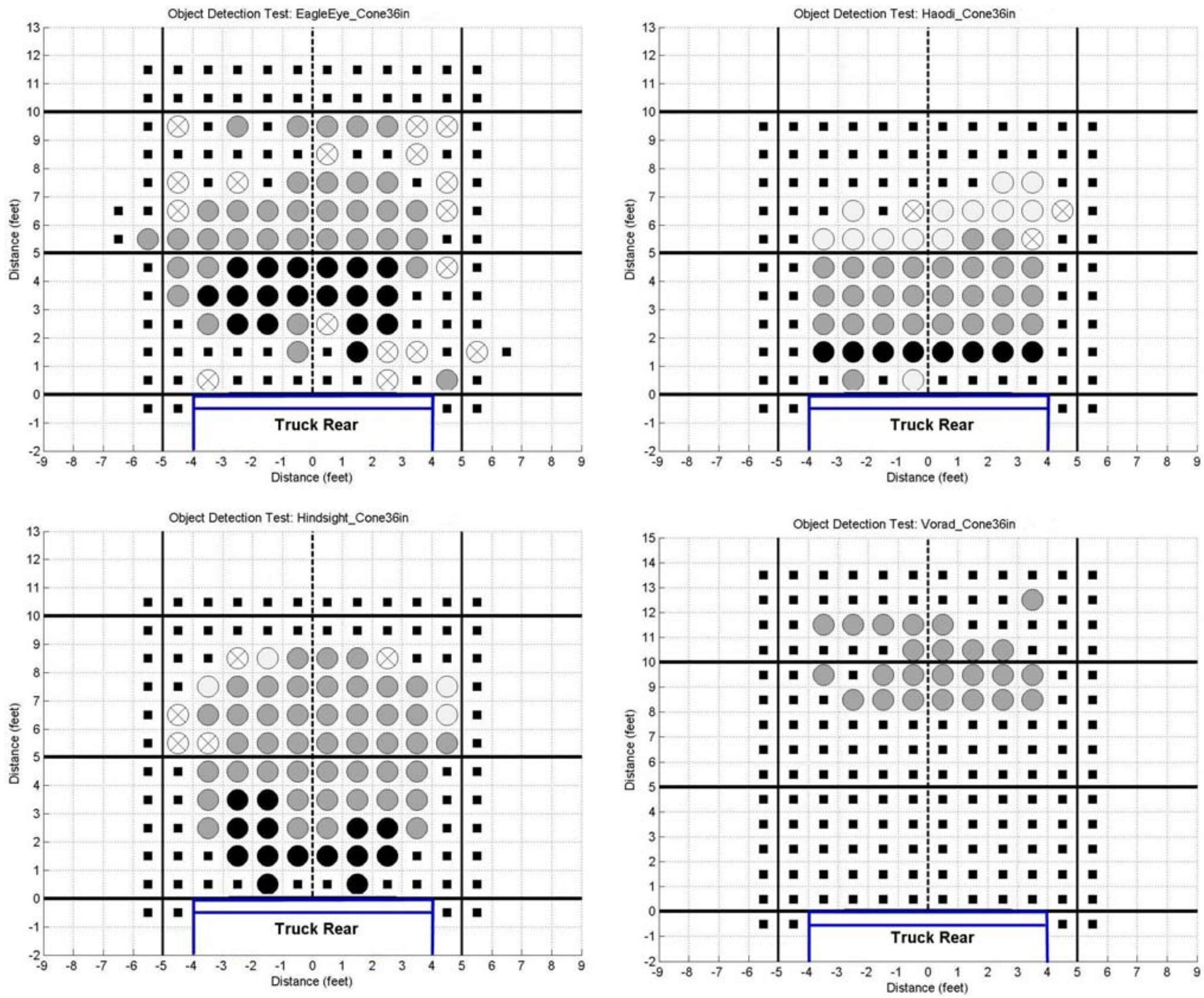

Figure 33. Detection Results for the 36-Inch-Tall Traffic Cone

The 36-inch traffic cone was detected well at short range by three systems tested, except within 1-foot of the vehicle's bumper. The VORAD Backspotter detected the cone at the greatest range from the bumper, 12.5 ft in one location, however it did not detect the cone within 8 feet from the vehicle's rear bumper.

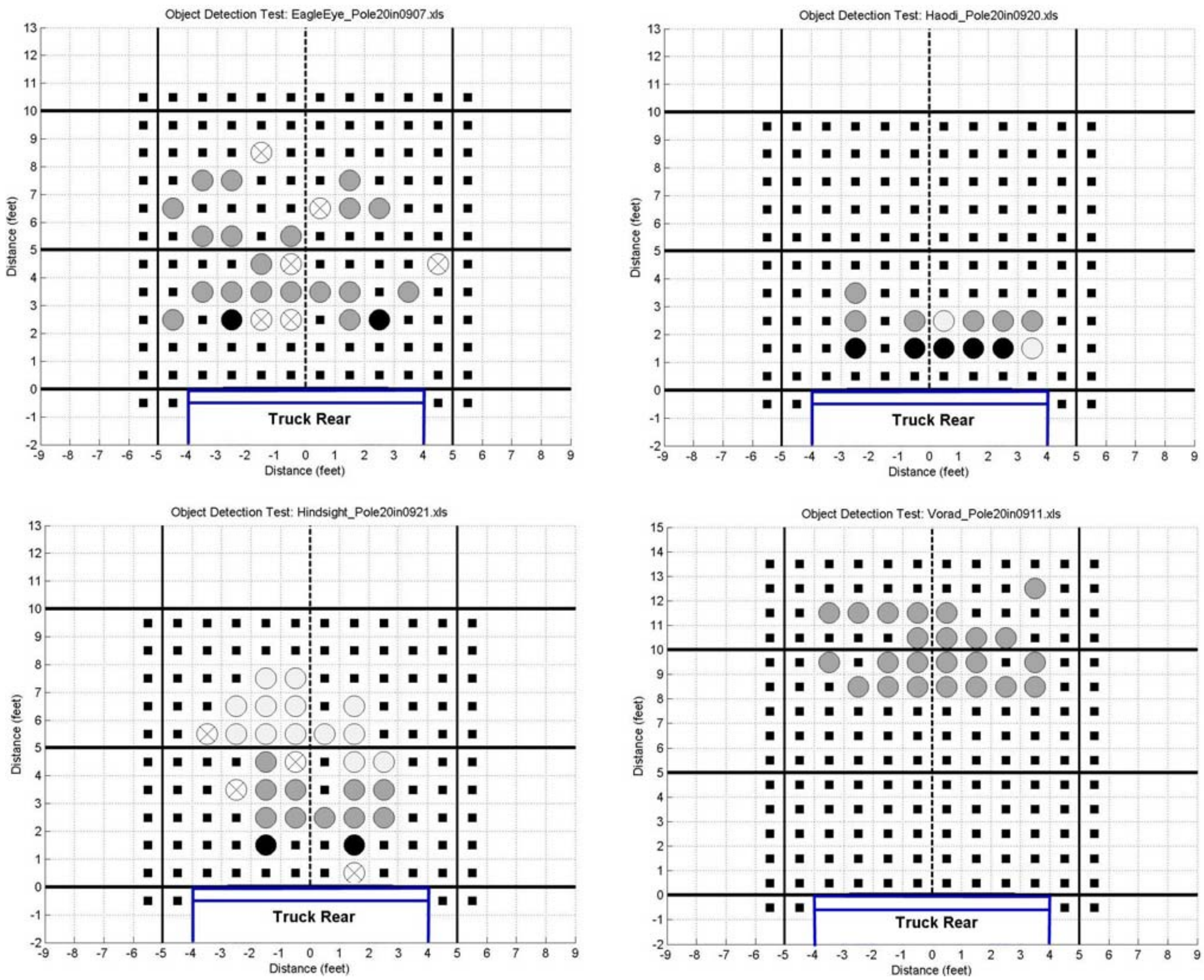

Figure 34. Detection Results for the 20-Inch-Tall PVC Pole

Two systems, the Hindsight 20/20 and the HaoDi, could not detectethe 20-inch-tall PVC pole as well as the shorter, 18-inch-tall traffic cone. The Eagle Eye system detected the cone in several locations, but with no clear pattern. The VORAD Backspotter did not detect the object within 8 feet from the bumper, but did detect it fairly well within the range of 8.5 to 11.5 feet.

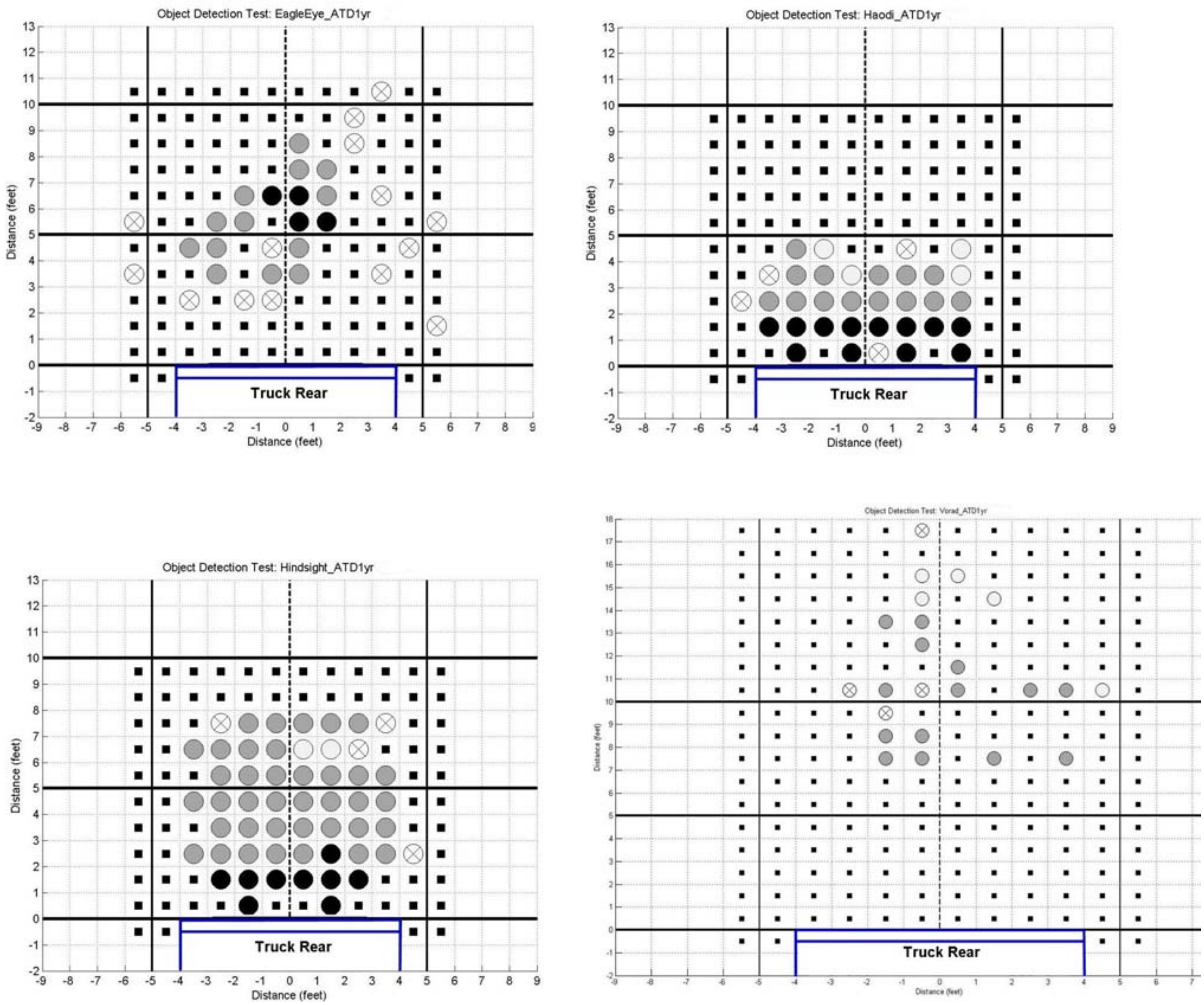

Figure 35. Detection Results for the 1-Year-Old ATD

The 1-year-old ATD was detected with some consistency by the Hingsight 20/20 and HaoDi systems within their exhibited detection ranges. The 1-year-old ATD was only sporadically detected by the Eagle Eye system. The 1-year-old ATD test object was the object of shortest height detected by the VORAD Backspotter system. Therefore it appears that the lower vertical limit of the Backspotter's detection zone was approximately 29 inches.

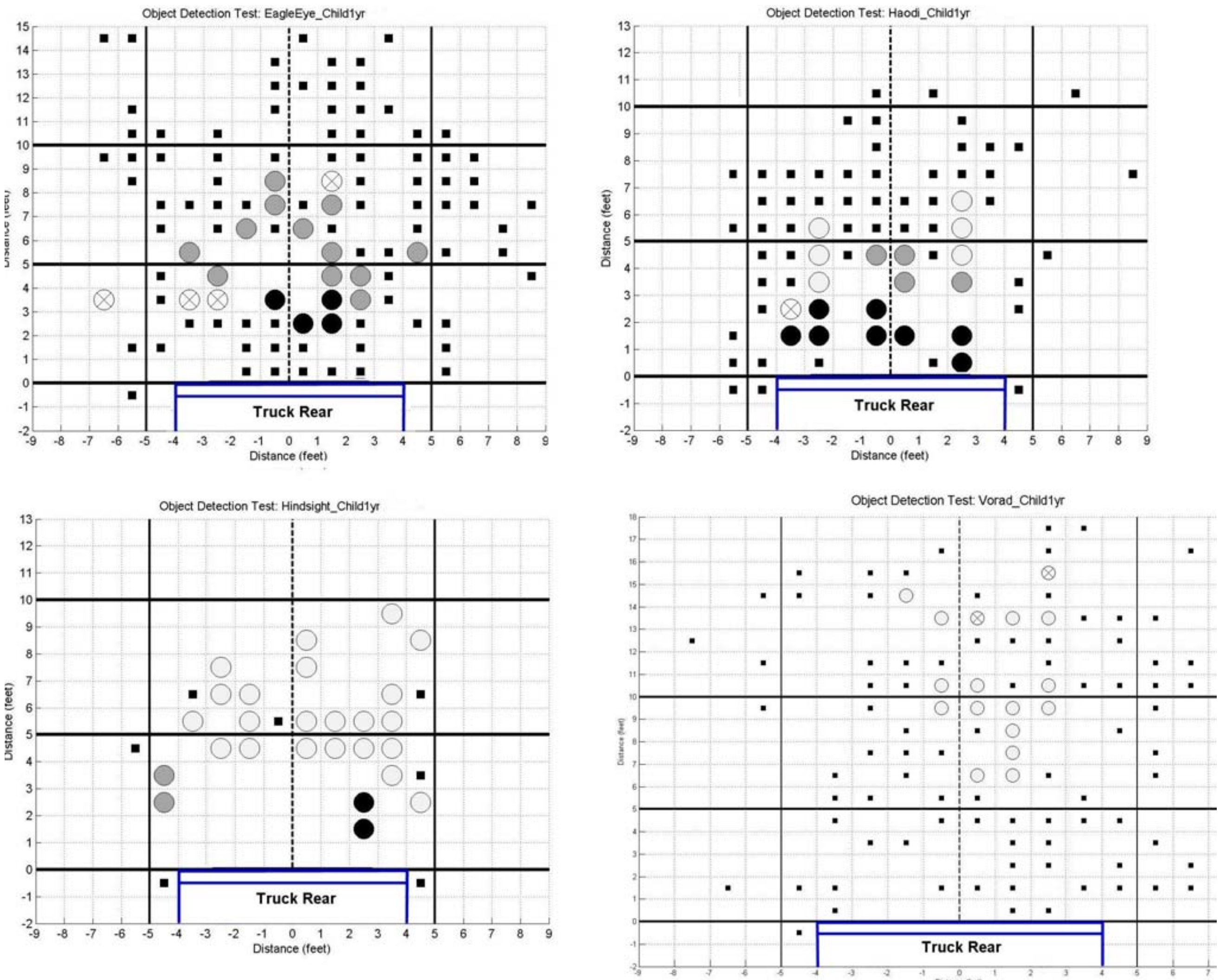

Figure 36. Detection Results for the 1-Year-Old Child

A complete field of data points was difficult to obtain with a 1-year-old child, as indicated by the numerous empty cell locations in Figure 36. The 1-year-old child subject was detected by all four systems in some locations, but with no clear pattern.

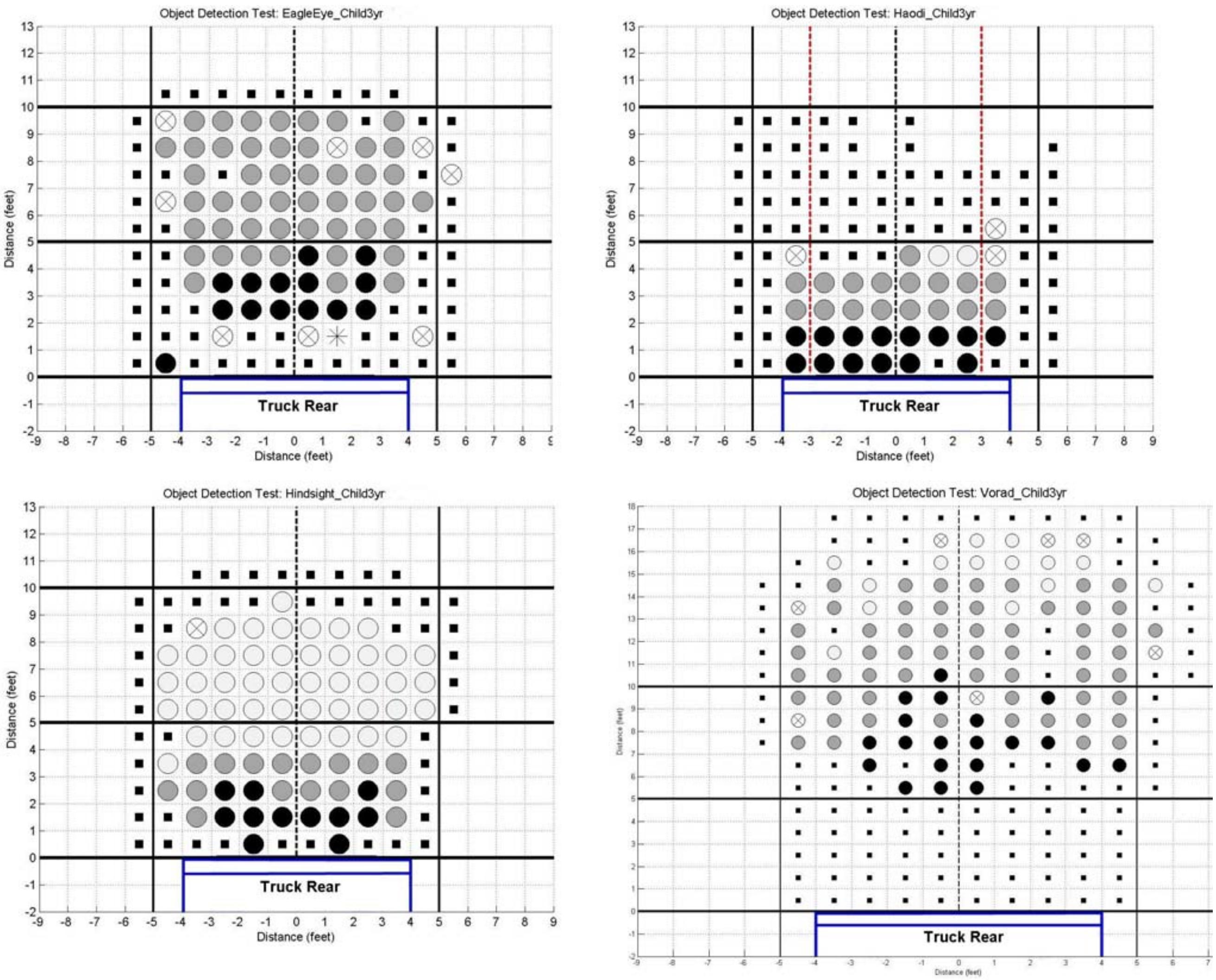

Figure 37. Detection Results for the 3-Year-Old Child

The 3-year-old child subject was detected somewhat better than the 1-year-old child, as indicated by the more solid field of detection locations shown in Figure 37. The Eagle Eye and Hindsight 20/20 systems exhibited difficulty in detecting the child close to the bumper (within 1-2 feet). The VORAD Backspotter did not detect the child within 5 feet of the bumper. This system exhibited similar performance when detecting other test objects.

Static detection results for the 28-inch traffic cone, 40-inch-tall pole, 3-year-old ATD, and the adult male are reported in detail the next section. In general, the detection results for these test objects reflect the objects' heights and reflectivity:

- The 28-inch cone was detected less well than the 36-inch cone for the Eagle Eye and VORAD Backspotter systems. The 28-inch cone produced similar patterns as seen for the 36-inch cone for the HaoDi and Hindsight 20/20 systems.

- The 36-inch cone was consistently better detected than the 34.2-inch-tall 3-year-old ATD for the Eagle Eye, HaoDi, and VORAD Backspotter systems, possibly due to both object height and surface differences (i.e., the ATD was clothed).

- The 40-inch-tall pole produced similar detection patterns to those of the 36-inch cone.

- The 3-year-old ATD was detected less well, to varying degrees, than a 3-year-old child for the VORAD Backspotter (largest difference), Eagle Eye, Hindsight, and HaoDi (smallest difference).

4.1.2. Sensor Detection Zone Area Repeatability Tests

Providing consistent, good object detection performance is important to ensure the detection of critical objects and to ensure that the driver will trust and therefore use and respond to the system. To assess repeatability, additional trials of static sensor system detection zone measurements were conducted with a subset of test objects to capture day-to-day variability in the detection performance of sensor systems. The degree of variability noted in these tests was whether or not an object was detected in a particular location (i.e., differences in level of warning provided were not noted) on a particular day. Systems' performance in detecting objects was measured on each of 3 consecutive days. The procedure used was the same as that used in the original static sensor system detection zone measurements. Objects used in these tests included the 28-inch cone, 40-inch-tall PVC pole, 3-year-old ATD, and an adult male human.

Figures 38 through 41 show the static detection zone repeatability test results. Each figure contains four graphs, one per test object as indicated by the label above the graph. Individual graphs illustrate the data for the three repetitions of an individual test object through a single graph. Each graph shows an overhead view of the test grid with the vehicle's rear bumper (not to scale) at the bottom of the graph positioned at the 0 longitudinal point on the grid. The numbers shown in grid squares indicate the number of trials, out of three, in which the system successfully detected the test object in that particular location.

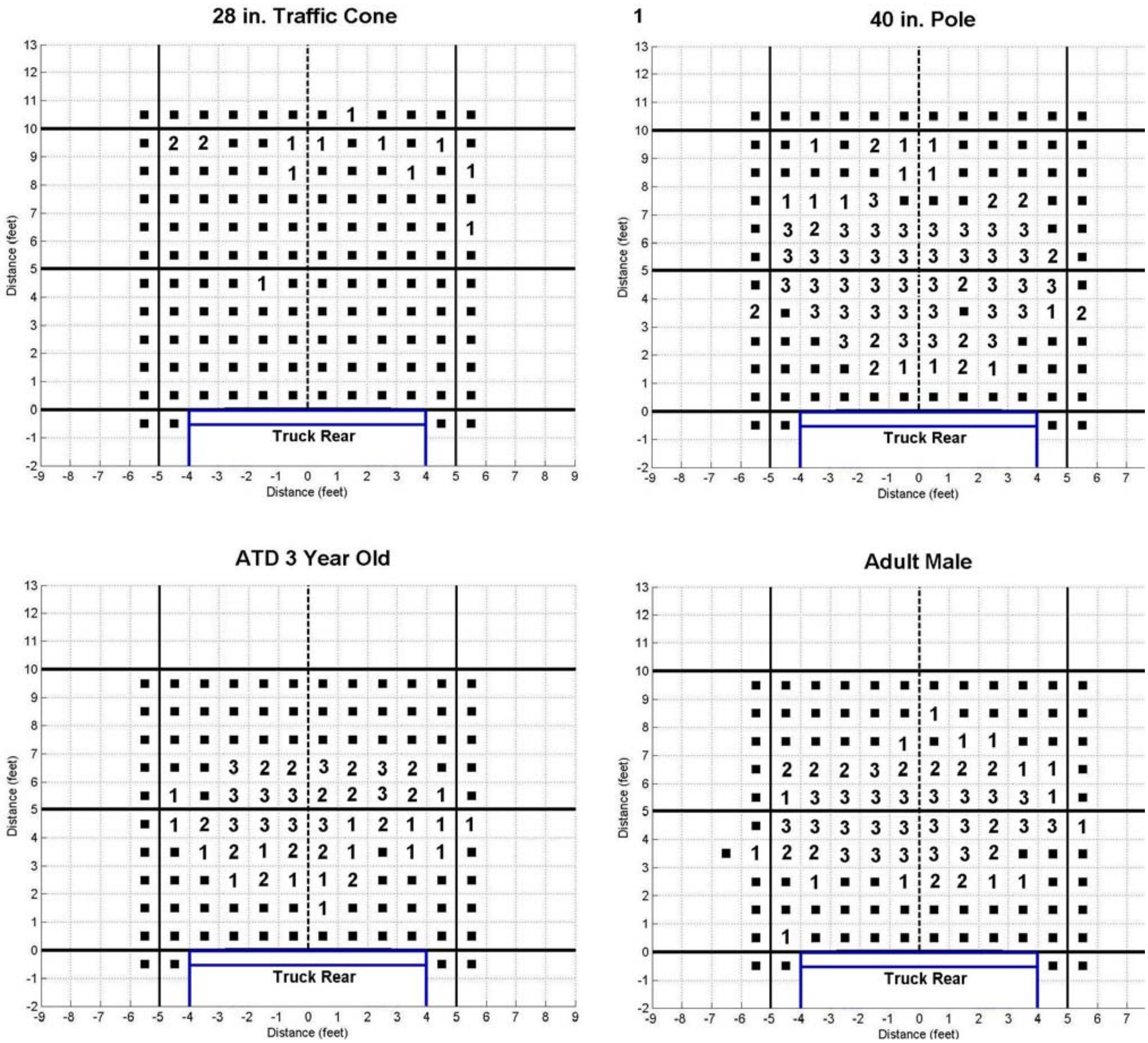

Figure 38.	Repeatability Test Results for the Eagle Eye System

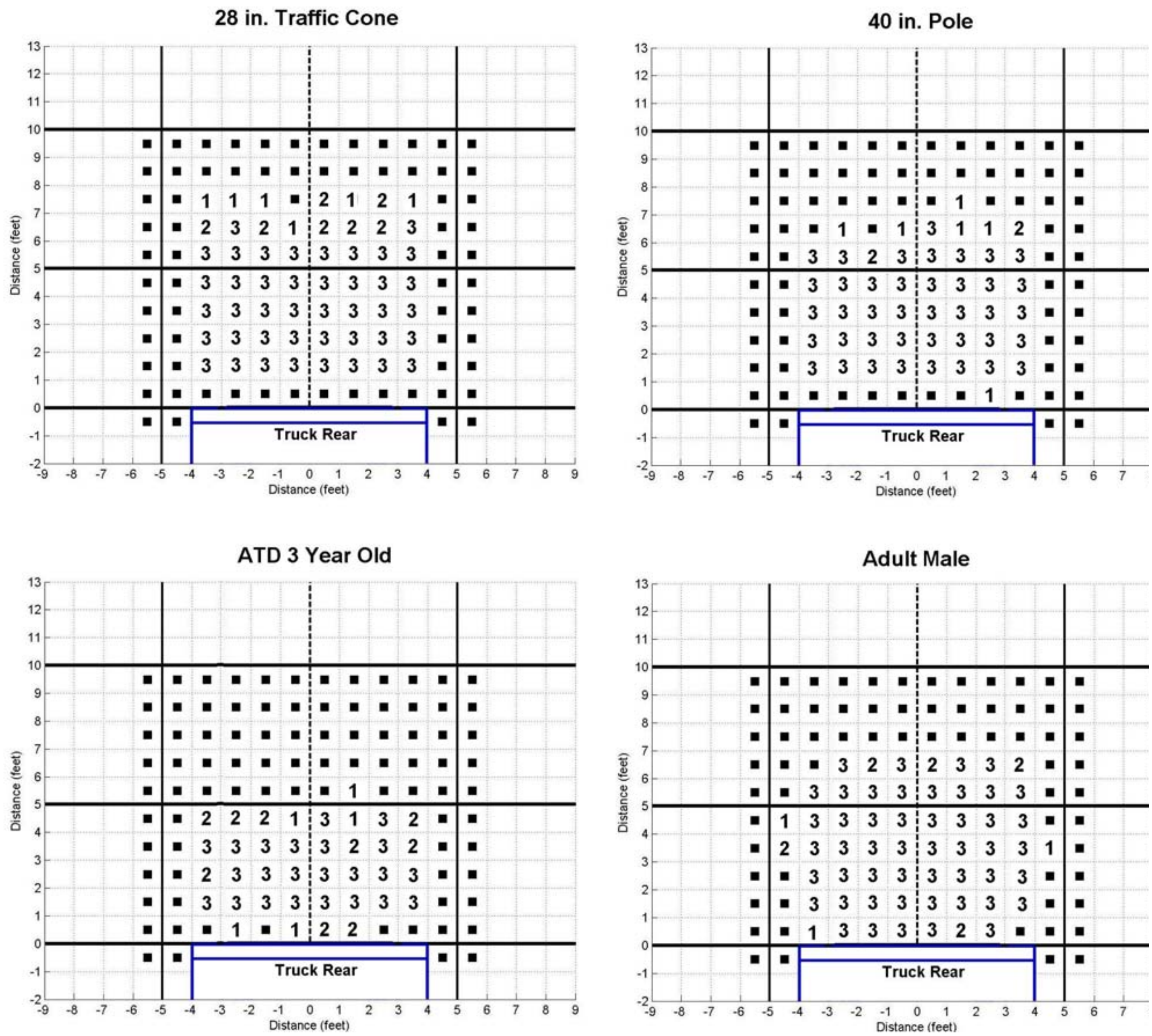

Figure 39. Repeatability Test Results for the HaoDi PAS-405 System

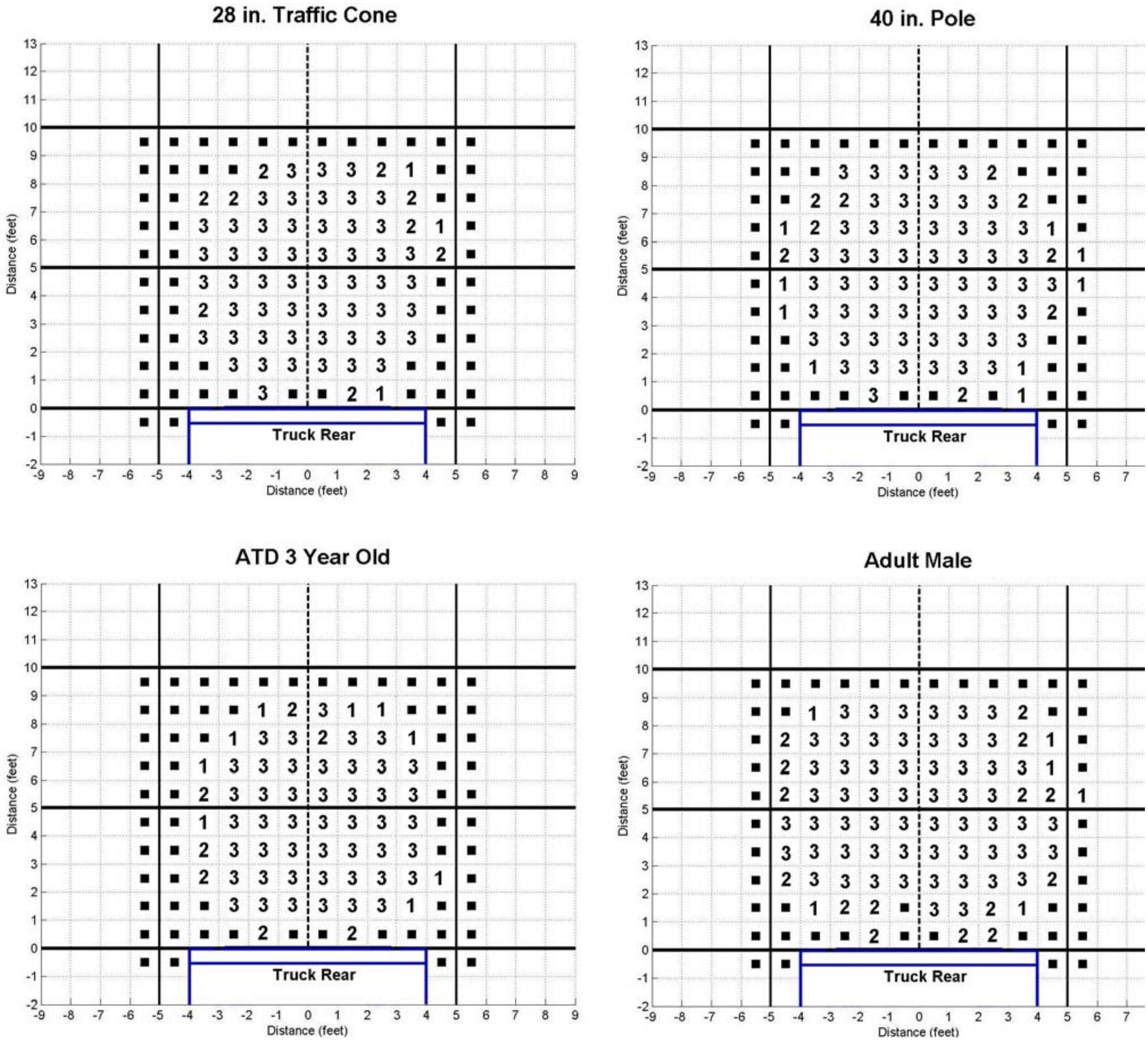

Figure 40.   Repeatability Test Results for the Hindsight 20/20 System

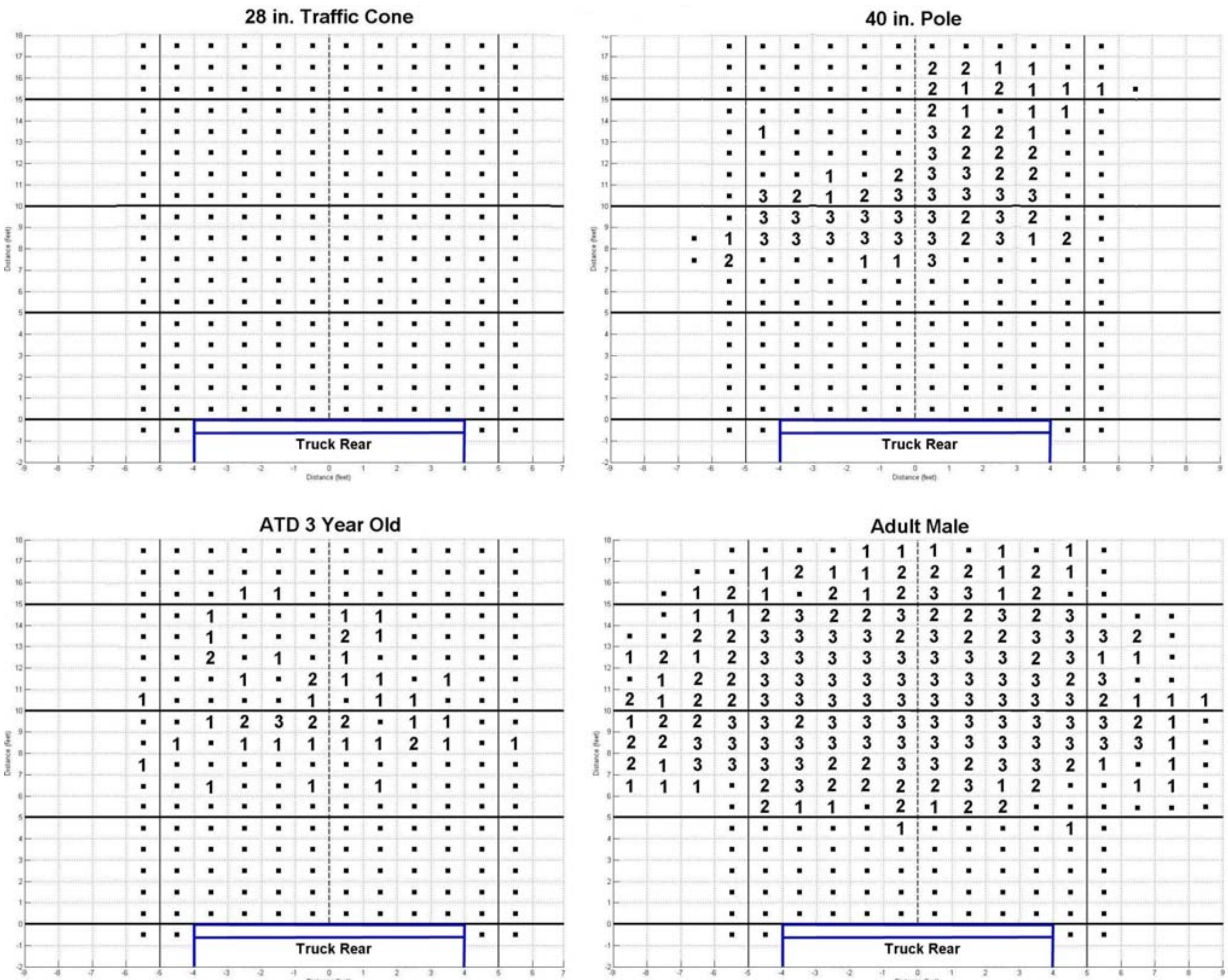

Figure 41. Repeatability Test Results for the VORAD Backspotter System

Results of static sensor system detection zone repeatability showed a range of performance quality. Repeatability results at close range from the vehicle's rear bumper were best for Hindsight 20/20 and HaoDi systems. Repeatability results for the VORAD Backspotter were good for the adult male, but not as good for the other three objects whose composition the system was less sensitive to. Inconsistency in detection, when present, was usually seen in the periphery of the detection zones.

4.1.3. Sensor Detection Zone Height Tests

For determining systems' performance in detecting objects based on their vertical position with respect to the ground, static hardware testing was also conducted using a 20 foot long section of PVC pipe that was oriented horizontally and parallel to the rear bumper (as in ISO 17386). This test simulated backing up to a fence or the bumper of another car.

The pole was supported at each end using 10-inch-tall plastic crates. The plastic crates were positioned such that they were outside the detection zone. Detection of the pole was performed beginning with the pole resting on the ground 1 foot behind the rear bumper. The pole was then raised in increments of 10 inches to determine the vertical extent of the detection zone. This procedure was repeated for additional 1 foot increments of the grid behind the vehicle until the sensor system ceased to detect the object. The pipe was moved iteratively through a vertical plane grid and system detection performance measured. System detection performance and the level of warning provided by the system were noted.

Figure 42 presents the results for this test for the four sensor-based systems. The Eagle Eye system detected the horizontal pole up to 80 inches in height over a nearly 10-foot range. The Hindsight 20/20 showed solid detection of the horizontal pole up to 70 inches in height over a 9-10 foot range. The HaoDi system detected the pole well out to 5 feet in range, but had a smaller detection zone height of 40 inches. The VORAD Backspotter did not detect the pole within 7 feet of the vehicle's bumper and showed only sporadic detection of the pole from 7 to 13 feet. However, it should be noted that radar sensors are expected to show less sensitivity in detecting an object such as a PVC pole due to its composition.

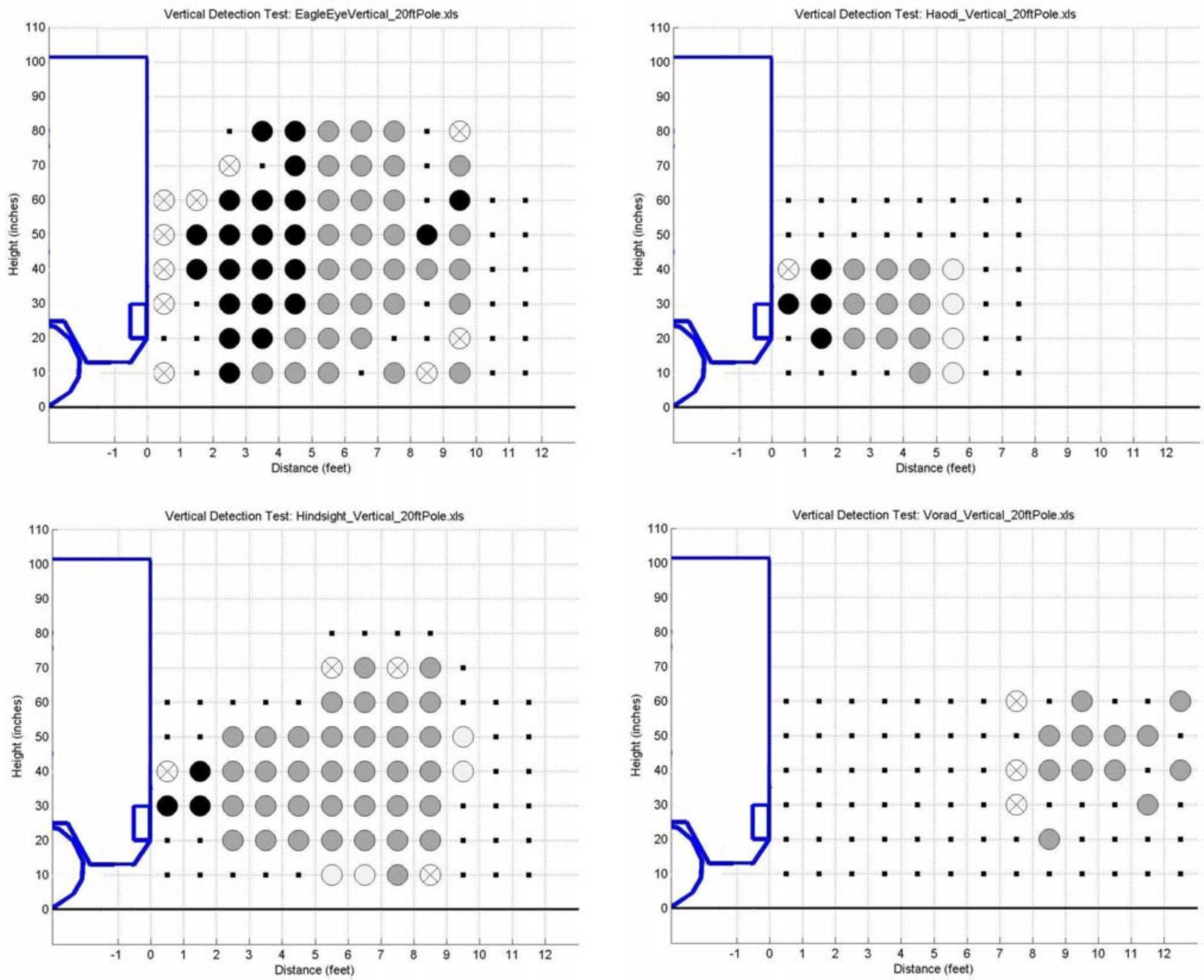

Figure 42. Sensor Detection Zone Height Test Results

4.1.4. Low Profile Test Object Detection Results

Sensor-based systems were tested to measure their performance in detecting low profile objects, such as a parking curb and an adult lying on the ground. This test scenario would provide information about whether parking curbs or other low to the ground objects, which some might consider a nuisance alarm since the driver should already be aware of its presence or not be too concerned with them, are typically detected by backing systems. This test scenario could also provide information about the detectability of children lying on the ground behind a vehicle, through the use of an adult as a surrogate test object.

The parking curb used was composed of plastic and had dimensions 70 inches long by 5 7/8 inches wide by 3 5/8 inches tall. The curb was placed on the ground parallel to the vehicle's rear bumper and centered on the vehicle's centerline. The curb was first placed 1 foot from the bumper, then moved back in 1 foot increments and the system's response to the curb in each location was noted. Figure 43 illustrates the results of the curb detection test.

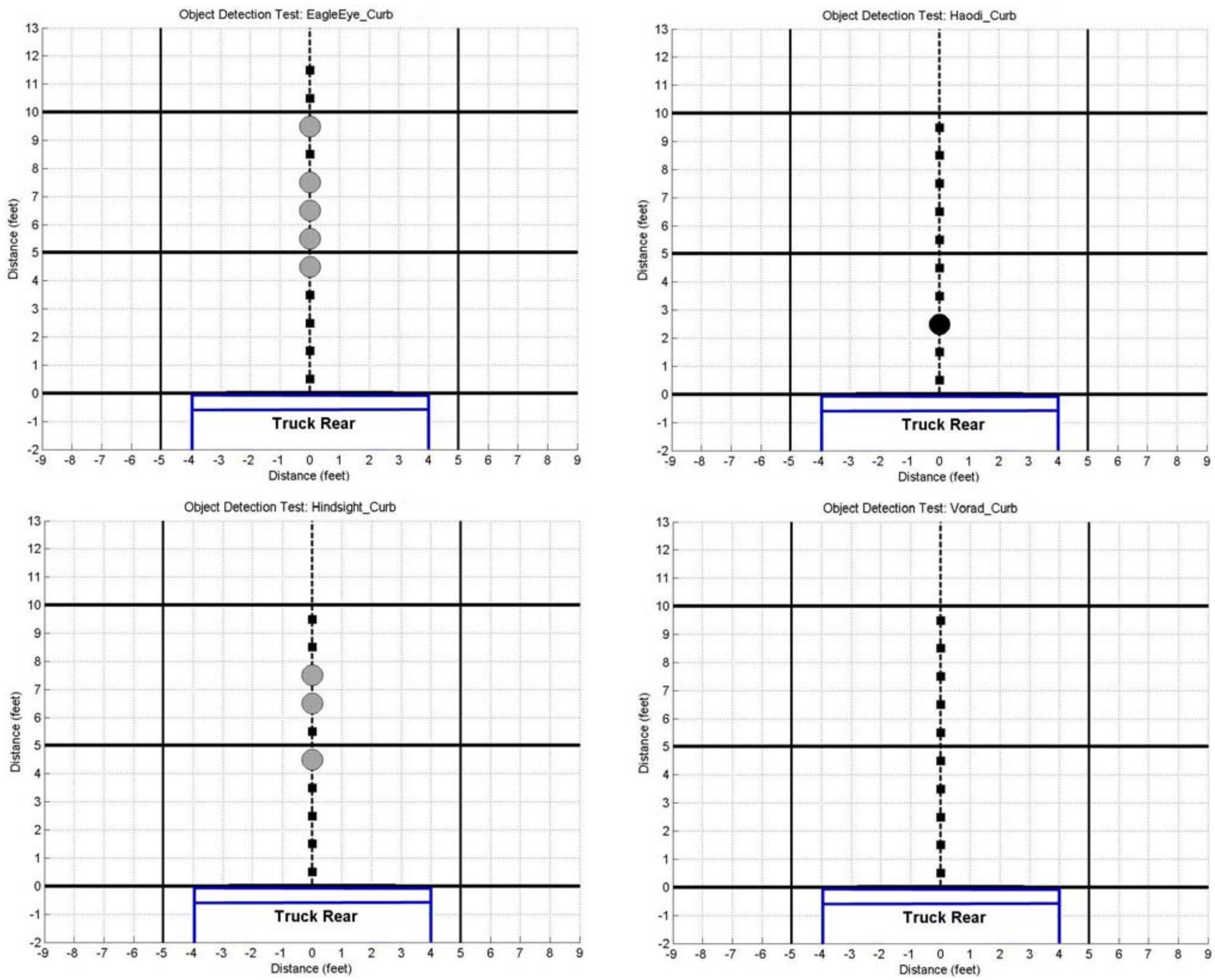

Figure 43. Parking Curb Detection Test Results

The Eagle Eye and Hindsight 20/20 systems detected the parking curb, but neither system detected the curb within a range of 4 feet from the vehicle's bumper. The HaoDi detected the parking curb in one location, 2.5 ft from the bumper; however, it is not clear why the system did not detect the curb at locations beyond that distance.

For the tests with an adult laying on the ground, a 74.75-inch-tall male was positioned in three locations across the width of the vehicle including the vehicle's centerline, and 4.5 feet from the centerline on either side. At each of these locations, the person was centered at that location, with his body parallel to the vehicle's bumper. Figure 44 illustrates the results of the test in which an adult male was lying on the ground.

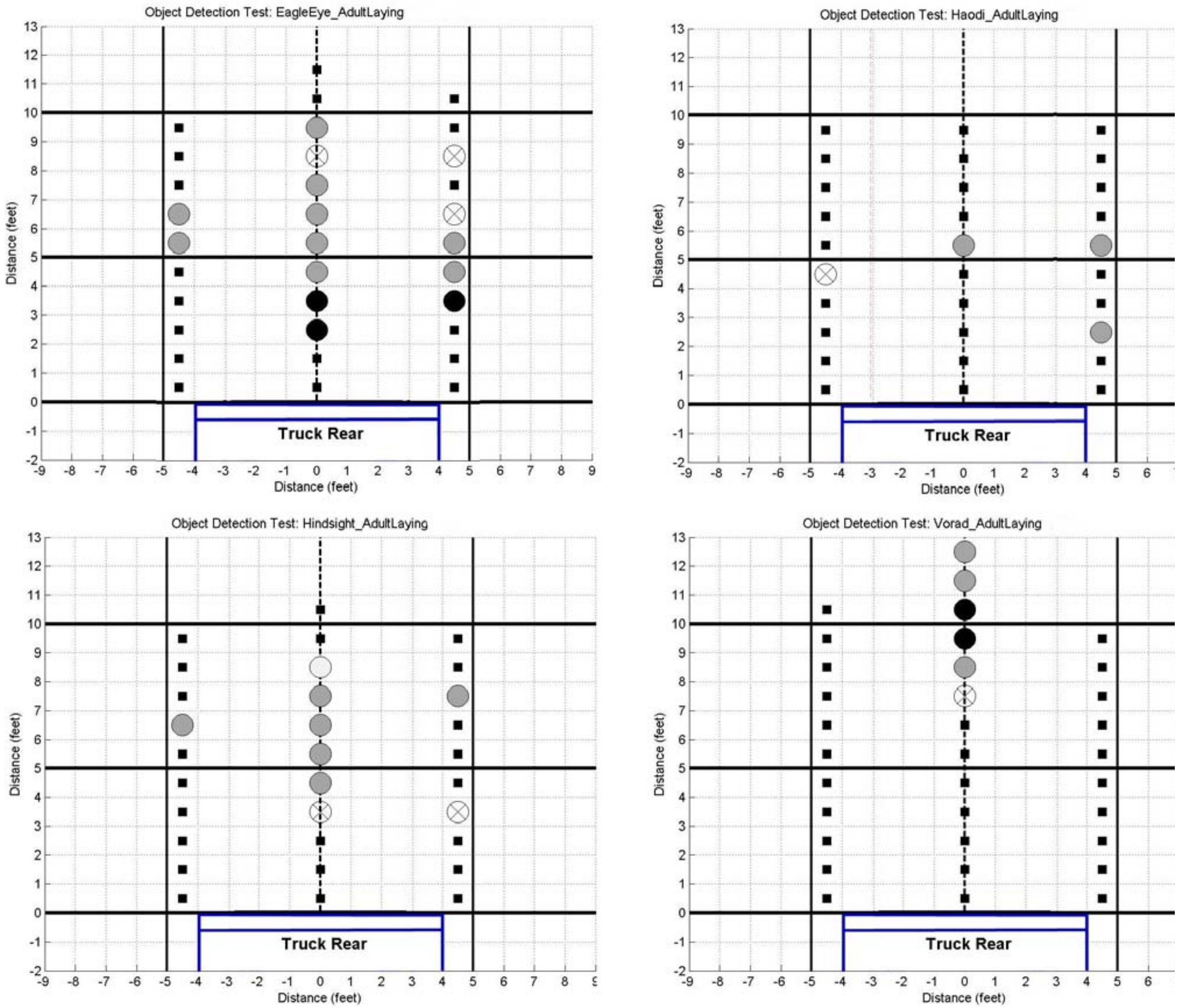

Figure 44. Detection Results for an Adult Male Laying on the Ground

The Eagle Eye, VORAD Backspotter, and Hindsight 20/20 detected the person well along the centerline of the vehicle within each system's particular detection range. The HaoDi detected the person in a few locations, but with some inconsistency in terms of pattern and detection.

4.2. DYNAMIC TESTS

Sensor system detection performance was also measured in controlled dynamic test scenarios. A majority of these tests were performed with the vehicle stationary and the test object moving, using a subset of test objects as well as human subjects. The remaining few tests involved the system-equipped vehicle backing at a slow speed toward a stationary test object.

4.2.1. Dynamic Tests with the Vehicle Stationary: Non-Human Test Objects

Test objects (non-human) included the 40-inch PVC pole, 1-year-old and 3-year-old crash dummies, and a toy car, called a "Cozy Coupe®" (made by the Little Tikes Company). Figure 45 shows a photograph of the toy car test scenario. Test objects were moved horizontally across the lines of the test grid, parallel to the vehicle's rear bumper, using the apparatus described in Section 3.3.

Figure 45. Photograph of Toy Car Outdoor Dynamic Test Trial

(Note: Photograph shows a light truck being tested; however, the procedure was identical for medium straight trucks.)

Dynamic test object speeds were chosen to span a range of pedestrian walking speeds. Information on average human walking speed was found to primarily relate to signalized intersection crosswalk timing. The Manual on Uniform Traffic Control Devices (MUTCD) [13] suggests 4 feet per second (2.73 mph) as a normal walking speed value for use in coordinating traffic signal timing. Another reference [14] noted average walking speeds at unsignalized intersections to be 5.7 feet per second (3.89 mph) for young pedestrians, 4.9 feet per second (3.34 mph) for middle-aged pedestrians, and 3.8 feet per second (2.59 mph) for elderly pedestrians. A laboratory research study by Chou et al [15] found the walking velocity of normal 5-year-old children was 101 cm/s, or 2.26 mph. Based on these references, tests were conducted with the objects moving at 2 and 3 mph for these test objects.

Table 7 summarizes the results of dynamic test trials for non-human test objects. Results for the VORAD Backspotter system are shown as ranges, since for each test object there was an area close to the vehicle's bumper over which the object was not detected. All other systems detected the objects from the test grid position closest to the vehicle's bumper out to the distance value listed in the table. All systems detected the 40-inch tall PVC pole well within their stated detection ranges. Dynamic detection ranges for the 40-inch pole generally matched those seen in static testing for all systems. Speed did not seem to noticeably affect detection range in a consistent manner for any test object. The toy car was well detected by all systems with detection ranges seen from 7 feet to 18 feet.

Table 7. Sensor System Detection Range (ft) – Dynamic: Non-Human Test Objects

	40-inch Pole		ATD 1 yr old		ATD 3 yr old		Toy car	
	2 mph	3 mph	2 mph	3 mph	2 mph	3 mph	2 mph	3 mph
Eagle Eye	6	7	ND	3	7	6	9	8
HaoDi	5	4	4	5	4	3	8	8
Hindsight 20/20	7	8	8	7	8	8	9	9
Vorad Backspotter	6-17	7-16	7-15	7-15	6-15	8-14	9-18	7-18

Note: ND indicates "Not Detected"; N/A indicates that the test was not run for that system.

4.2.2. Dynamic Tests with the Vehicle Stationary: Human Subjects

Results for dynamic test trials with human subjects are presented in Table 8. The adult involved in the test trials was in 74.75 inches in height (with shoes).

Table 8. Sensor System Detection Range (ft) – Dynamic: Human Subjects

	Child, 1-yr-old		Child, 3-yr-old			Adult Walking
	Walk	Towed Ride-On	Walk	Run	Pedaled Ride-On Toy	(Outdoors)
Eagle Eye	3-7	3-9	4-10	2-4, 6	2-11	4-6
HaoDi	5	8	4	4-5	7	7
Hindsight 20/20	8	8	8	8	9	9
Vorad Backspotter	8-11	9-12	8-14, 16	9-12, 14-15	8-11, 13-14	5-18

Results for trials with the 74.75-inch-tall (in shoes) adult walking longitudinally with respect to the rear bumper are presented in Table 9. This table gives the distance from the centerline of the vehicle over which the sensor system successfully detected the adult male subject.

Table 9. Sensor System Detection Area Width for Adult Walking Longitudinally

	Distance Left (L) or Right (R) of Vehicle Centerline
Eagle Eye	8R, 4R-6R, 1R - 3L
HaoDi	3R - 4L
Hindsight 20/20	5R - 4L
Vorad Backspotter	9R - 11L

Results for the longitudinal walking tests show the widest range of lateral detection, 20 feet, was exhibited by the VORAD Backspotter system. The range of lateral detection exhibited by the HaoDi and Hindsight systems were smaller, at 7 and 9 feet, respectively. The detection pattern exhibited by the Eagle Eye system for the longitudinal walking test was discontinuous and asymmetrical.

Trials with the adult walking diagonally with respect to the rear bumper were conducted using the paths illustrated in Figure 46. In this figure, the numbers mark the origin of the walking path arrow. The rear bumper of the system-equipped test vehicle (not to scale) is shown at the bottom of the figure with the walking paths behind it indicated with arrows and labeled with numbers. The subject performed two trials for each path, one walking toward the vehicle and one walking away from it. Results for this test are presented in Table 10.

Table 10. Sensor System Detection Area for Adult Walking Diagonally

	Numbered Paths Upon Which Adult was Detected
Eagle Eye	3-8, 12-19
HaoDi	2-6, 15-19
Hindsight 20/20	2-8, 12-19
Vorad Backspotter	3-18

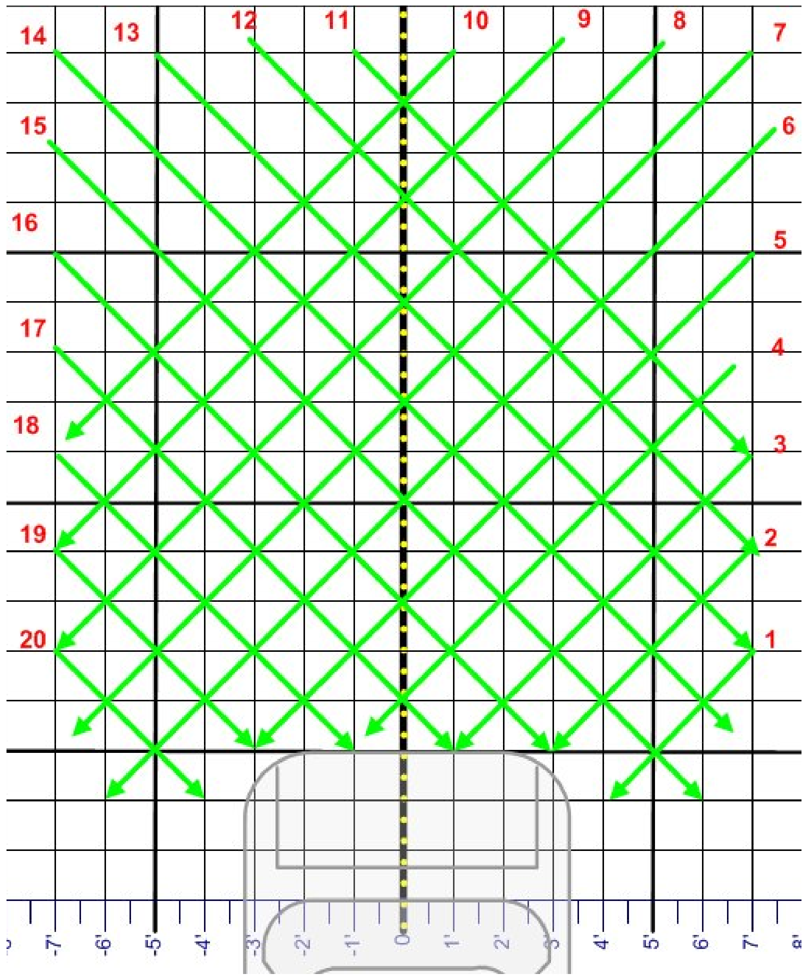

Figure 46. Numbered Walking Paths for “Adult Waking Diagonally” Trials

Paths 1 and 20 were out of the range of detection for all four systems. Paths 9 through 11 were out of the detection range for all systems except the VORAD Backspotter. The greatest number of undetected paths was associated with the HaoDi system. The walking adult was not detected along paths 7, 8, 13, and 14, despite that these paths cross locations that were detected by the system in static tests with the same adult male.

4.2.3. Dynamic Tests with the Vehicle in Motion

Tests were conducted in which each system-equipped vehicle was backed up to another vehicle (a Toyota Camry, as pictured in Figure 45) and a 36-inch-tall traffic cone. All systems detected the vehicle.

Table 11 gives the approximate distance at which the warning was first presented.

Table 11. Sensor System Detection Range – Outdoor Tests with Vehicle Moving

	Backing to Car: Distance from Rear Bumper (ft)	Backing to 36-inch Traffic Cone: Distance from Rear Bumper (ft)
Eagle Eye	8	4
HaoDi	7	4.5
Hindsight 20/20	7	7.5
Vorad Backspotter	14	ND

Results of dynamic tests with the vehicle in motion and the 36-inch tall traffic cone stationary show that the cone was detected at greater range for all systems in static detection zone tests (i.e., vehicle stationary). The VORAD Backspotter first detected the car at approximately twice the initial detection distance exhibited by the other three systems.

4.3. SYSTEM RESPONSE TIME

Since the timing of warning presentation is crucial to preventing a crash, sensor system object detection response time was measured. Response time testing was conducted for all systems indoors using a remote-controlled aluminum plate fixture, as described in Section 3.7. Calculations that estimate the effectiveness of the sensor systems given these measured response times are outlined in Section 5.2.

Five response time test trials were conducted for each sensor system. The sensor system response time results presented in the following table were determined based on five test trials. Mean response times across all trials are presented in Table 12.

Table 12. Sensor System Response Time Results

Vehicle or System	Mean Response Time (s)	Median Response Time (s)	Minimum Response Time (s)	Maximum Response Time (s)
Eagle Eye	0.43	0.37	0.33	0.63
HaoDi	0.49	0.47	0.40	0.60
Hindsight 20/20	0.51	0.53	0.37	0.63
Vorad Backspotter	0.27	0.27	0.20	0.40

ISO 17386 [9] contains a recommended maximum system response time of 0.35 seconds (measured using a different procedure). Only the VORAD Backspotter system met the ISO limit.

4.4. VIDEO SYSTEM VIEWABLE AREA

Two video-based backing systems were examined. The systems' viewable areas were measured using the indoor grid test area and the 28-inch-tall traffic cone with a reflector on top (total height of 29.4 inches, to simulate the height of a standing 1-year-old child). Figures 47 and 49 show the viewable areas for each system. Figures 48 and 50 contain photographs of the rearview video systems' visual displays.

Both systems provided a large area of coverage. The range of coverage for the Hindsight 20/20, 53 ft along the vehicle's centerline, was approximately twice that of the Audiovox system. However, the most appropriate range of video coverage is yet to be determined, so it is not clear which systems' may be most beneficial.

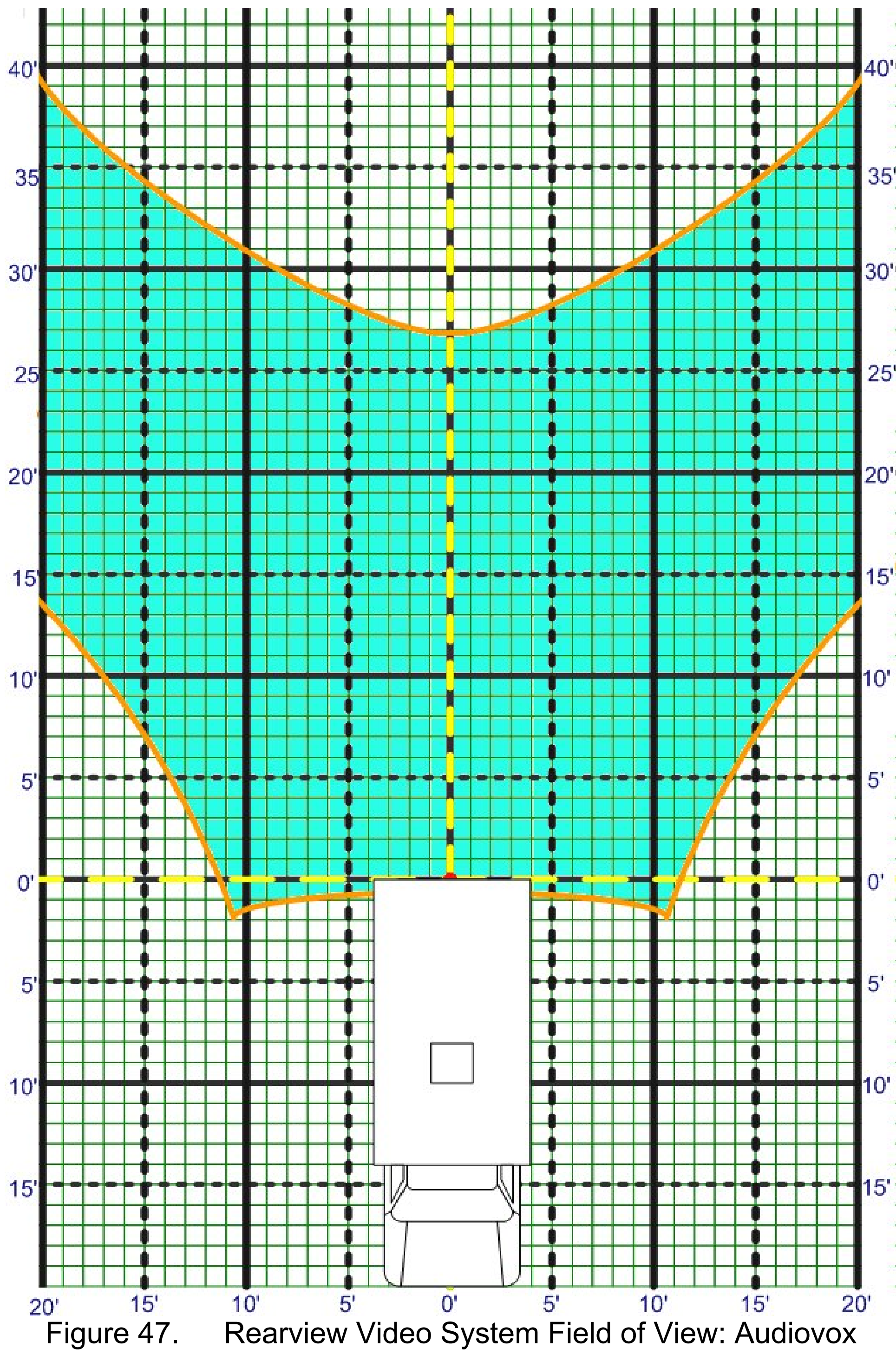

Figure 47. Rearview Video System Field of View: Audiovox

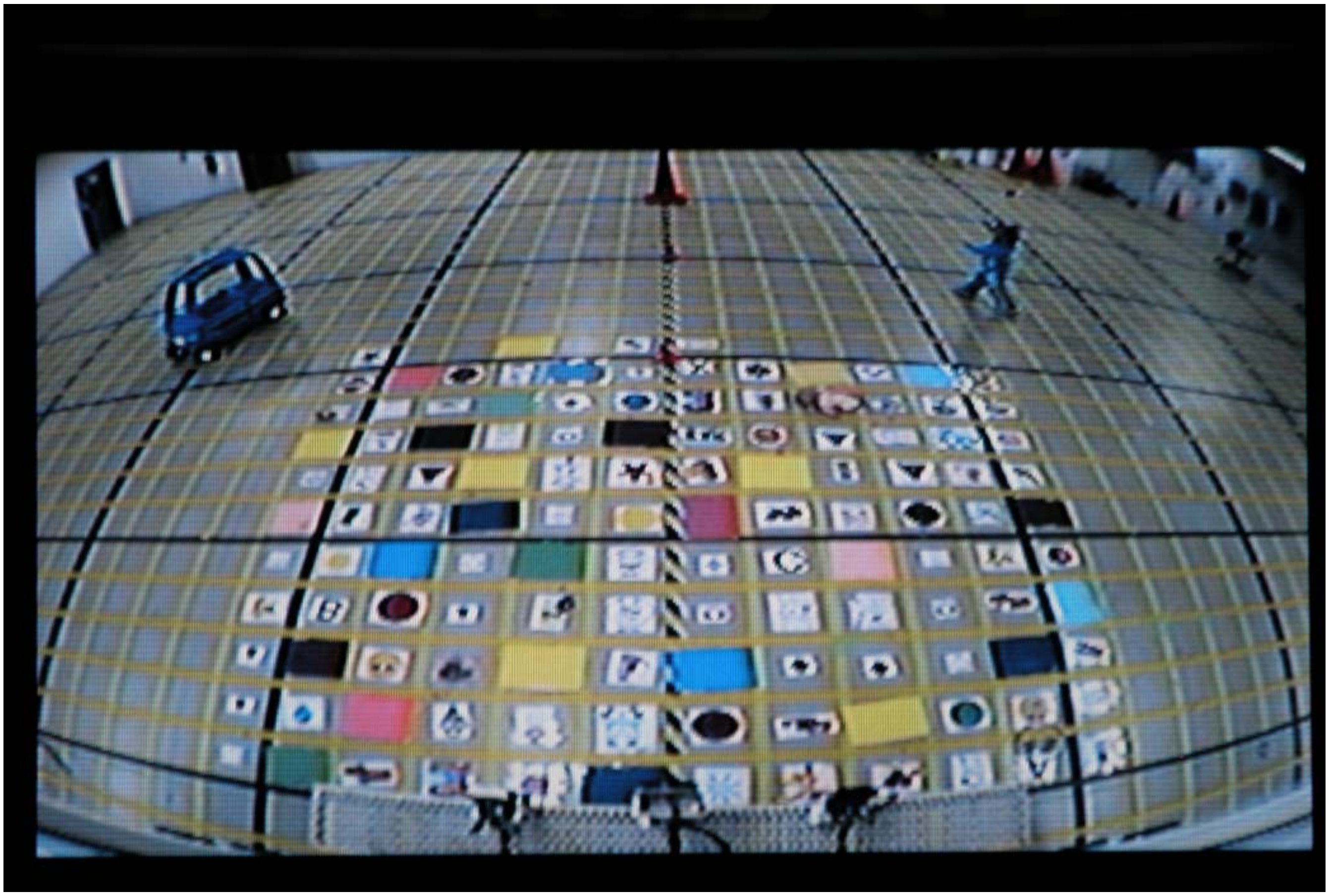

Figure 48. Photograph of Audiovox System Visual Display (Showing Child in Upper Right Quadrant)

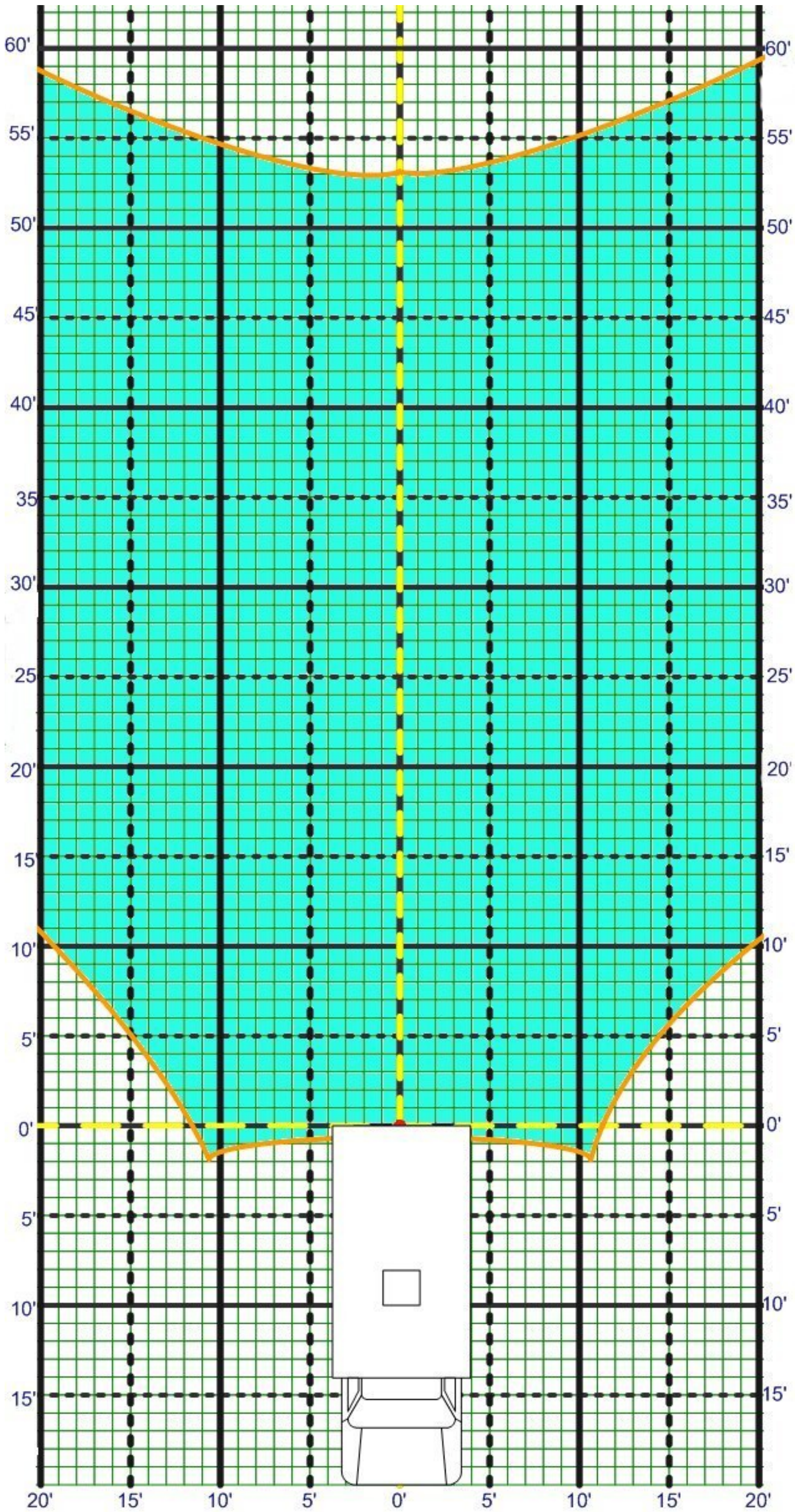

Figure 49. Rearview Video System Field of View: Hindsight 20/20

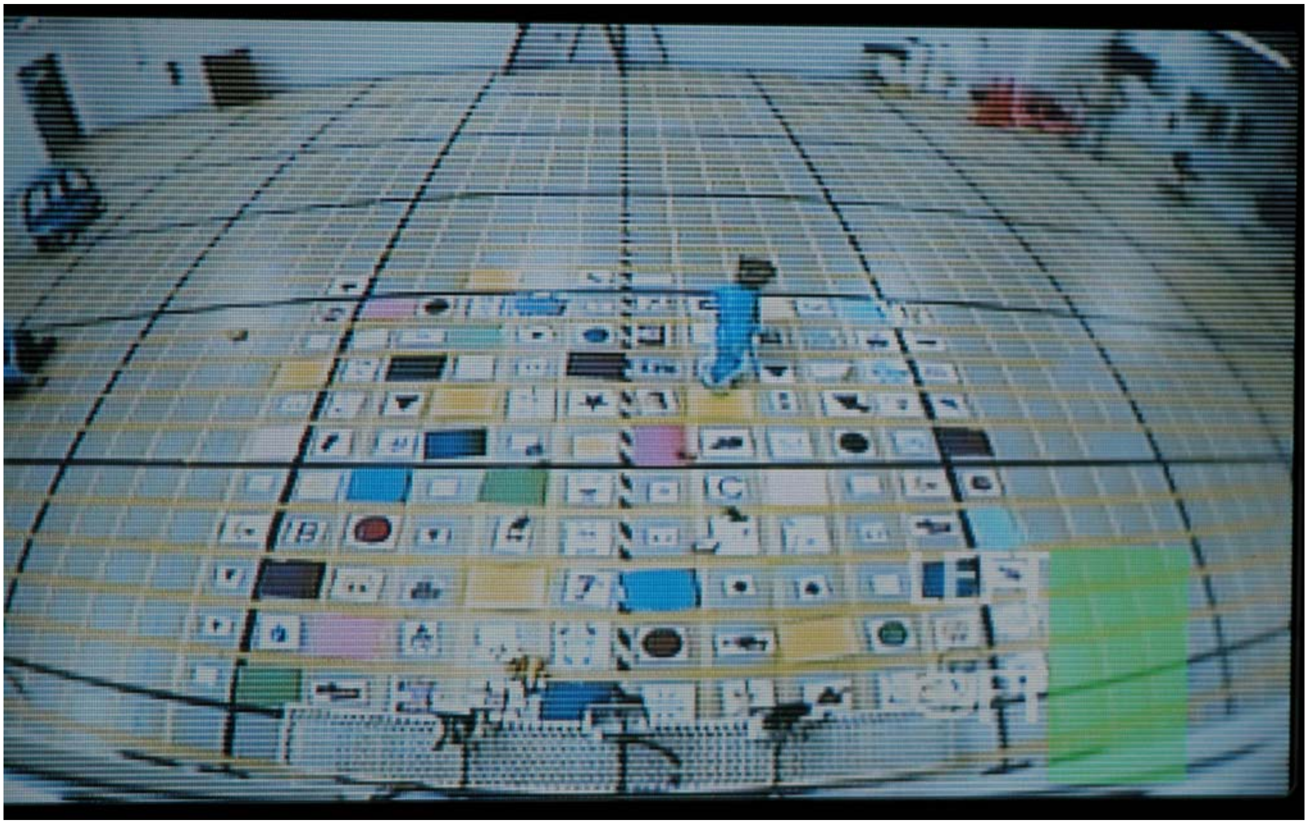

Figure 50. Photograph of Hindsight 20/20 System Visual Display (Showing Child in Upper Right Quadrant)

4.5. REAR FIELD OF VIEW WITH SIDE-VIEW AND REAR CROSS-VIEW MIRRORS

The rear field of view for the 1996 Grumman-Olson 4x2 step van test vehicle was assessed for areas visible by direct glance, side-view mirrors, and the rear cross-view mirror. The assessment used a visual target consisting of a 28-inch-tall traffic cone with a 3-inch in diameter red, circular reflector sitting atop it. The combined height of the cone and reflector was 29.4 inches to simulate that of a standing 1-year-old child. The area over which this object was visually detectable was mapped using a 50th percentile (i.e., 69-inch-tall) male as the driver. These data are presented in the Figure 51. The illustration shows the areas visible with direct glances with mirror visible areas overlaid in areas not visible with direct glances. The vehicle had a small window in each of its rear doors, making it possible for the driver to see behind the vehicle in some areas using direct glances through those windows.

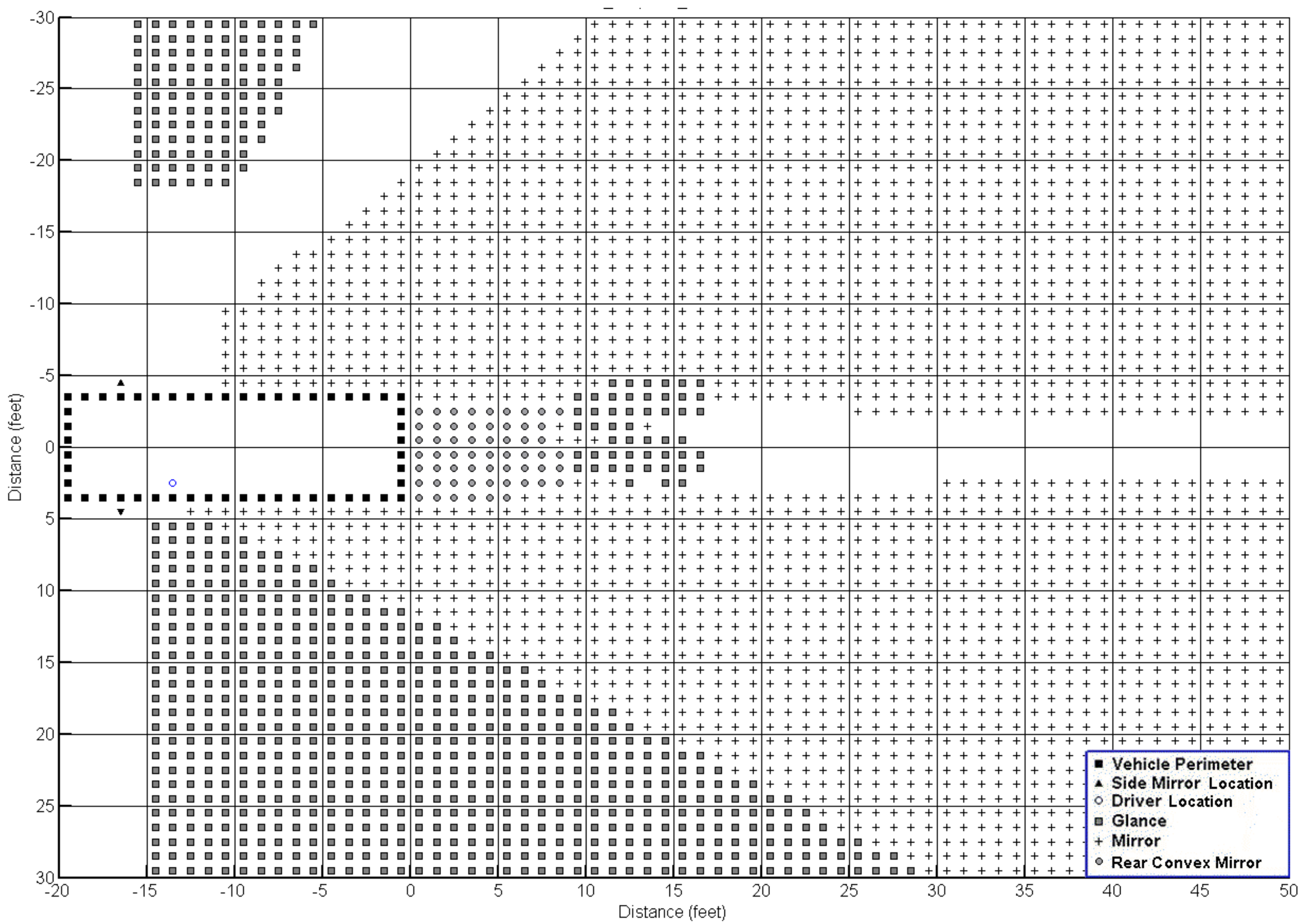

Figure 51. Rear Field of View for the Step Van Test Vehicle

Figure 52 illustrates the field of view for the rear cross-view mirror measured with a 69-inch-tall male driver. Note that rear cross-view mirror image distortion and visibility ratings (see the following section) were generated for some areas that are not indicated as being in the rear cross-view mirror's field-of-view in Figure 52. This happened because data for Figure 52 was collected by having a driver indicate whether he could see a traffic cone at each location. In other words, the test object had to be visible to the human eye for a location to be considered in the rear cross-view mirror's field-of-view. In contrast, the rear cross-view mirror image distortion and minification ratings were generated from photographs generated by a camera with an 8x optical zoom lens. Use of the 8x optical zoom made test objects visible in some regions with high image distortion and minification where the objects would not have been visible to the human eye.

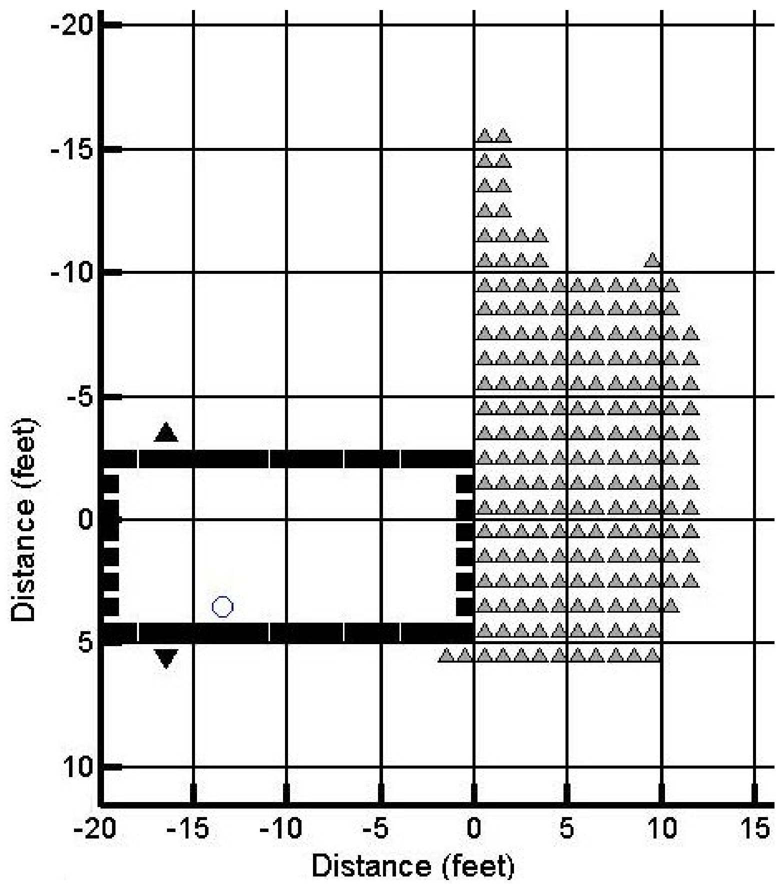

Figure 52. Rear Field of View for the Rear Cross-view Mirror as Mounted on the Step Van Test Vehicle

4.6. REAR CROSS-VIEW MIRROR IMAGE QUALITY

The coding scheme shown in Figure 53 is used in Figures 54 through 56 to show the image quality ratings at each measurement grid point (see Figure 27 for the measurement grid points used).

Figure 53. Key for Scheme Used to Display Rear Cross-view Mirror Image Quality Ratings

Figure 54 shows the rear-cross view mirror image distortion ratings at each of the image quality measurement points. As can be seen, the distortion ratings range from Excellent (minimal distortion) to Impossible (extreme distortion). As might be expected, the least distortion ratings occurred near the step van's bumper. Image distortion becomes worse as the test object is moved back from the bumper and from the right to the left side of the vehicle. (Note that Figures 54 through 56 are drawn from the vehicle bumper looking backwards. Therefore, somewhat confusingly, the left side of the vehicle is on the right side of these figures.) The highest distortion ratings occurred on the left side of the vehicle well back from the bumper. Generally acceptable image distortion ratings (ratings of Fair of better) were measured for distances up to 5.0 feet behind the bumper except for one Poor rating on the extreme left edge of the measurement grid.

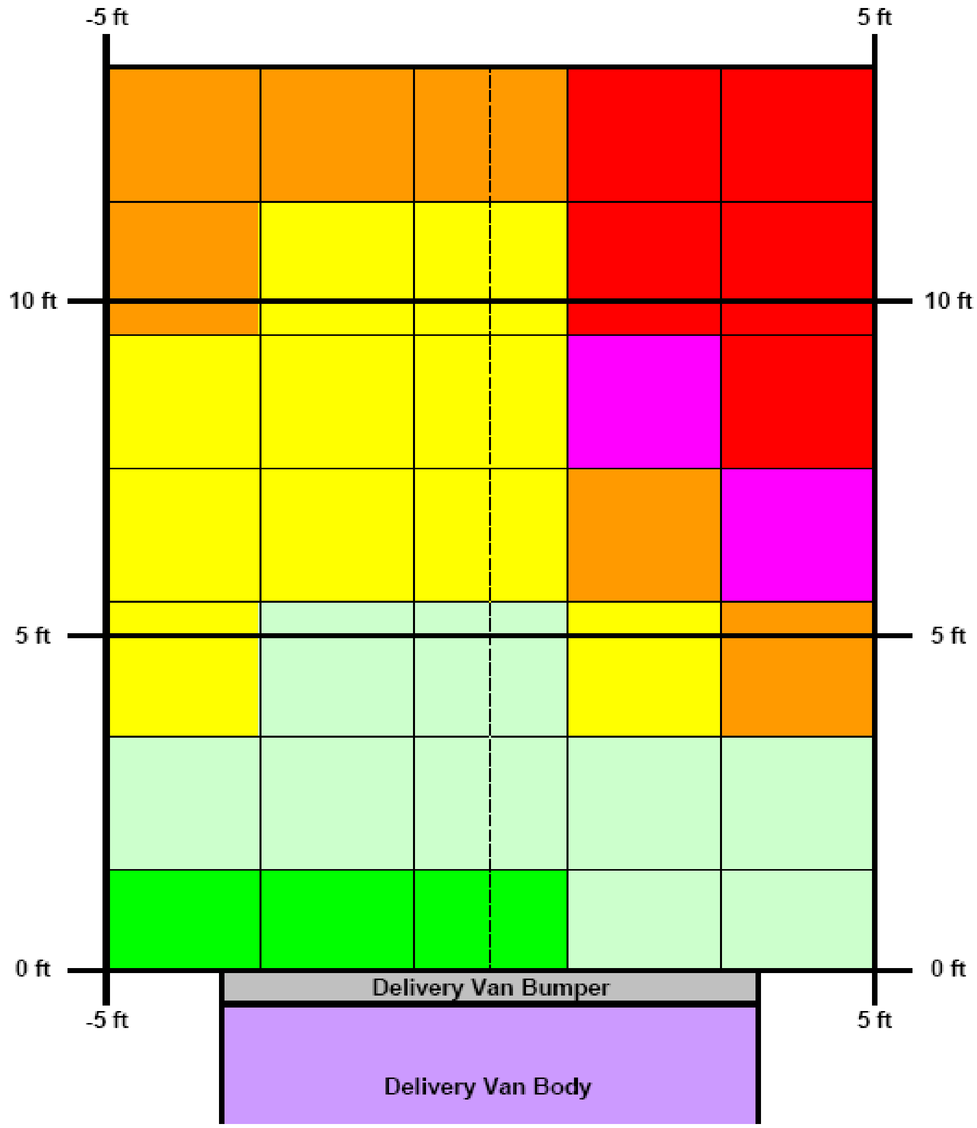

Figure 54. Distortion Ratings by Grid Location of Images Seen in the Rear Cross-view Mirror

Figure 55 shows the rear-cross view mirror 3-year-old ATD minification ratings at each of the image quality measurement points. As can be seen, the minification ratings range from Poor to Impossible. The best minification ratings occurred on the left side of the measurement grid. (Note that due to the way this figure is drawn the left side of the vehicle is on the right side of the figure.) Minification becomes worse as the test object is moved from the left to the right side of the vehicle. The worst minification ratings occurred on the right side of the vehicle well back from the bumper. Generally acceptable image minification ratings (ratings of Fair of better) did not occur anywhere for this test object.

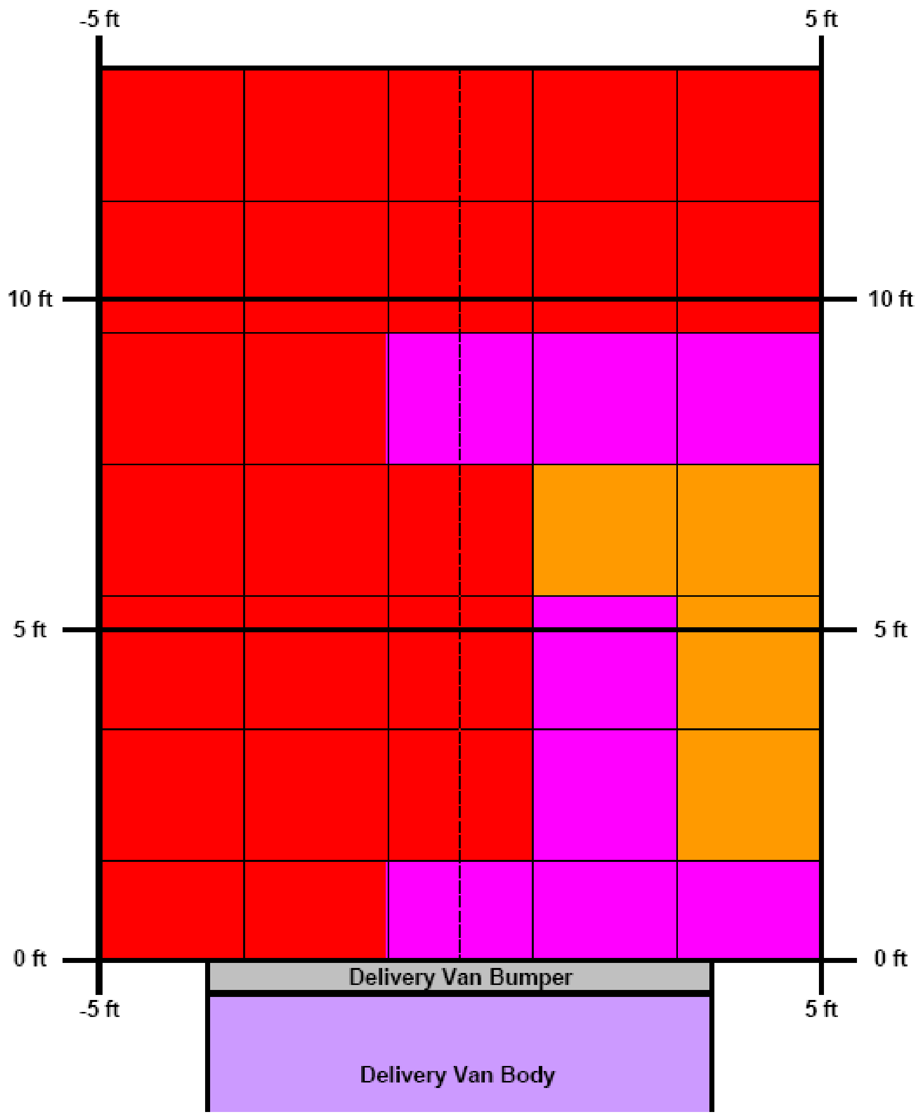

Figure 55. Minification Ratings of Images by Location for the 3-Year-Old ATD Seen in the Rear Cross-view Mirror

Figure 56 shows the rear-cross view mirror 1-year-old ATD minification ratings at each of the image quality measurement points. As can be seen, the minification ratings range from Poor to Impossible. The best minification ratings occurred on the left side of the measurement grid. (Note that due to the way this figure is drawn the left side of the vehicle is on the right side of the figure.) Visibility becomes worse as the test object is moved from the left to the right side of the vehicle. The worst minification ratings occurred on the right side of the vehicle well back from the bumper. Generally acceptable image minification ratings (ratings of Fair of better) did not occur anywhere for this test object.

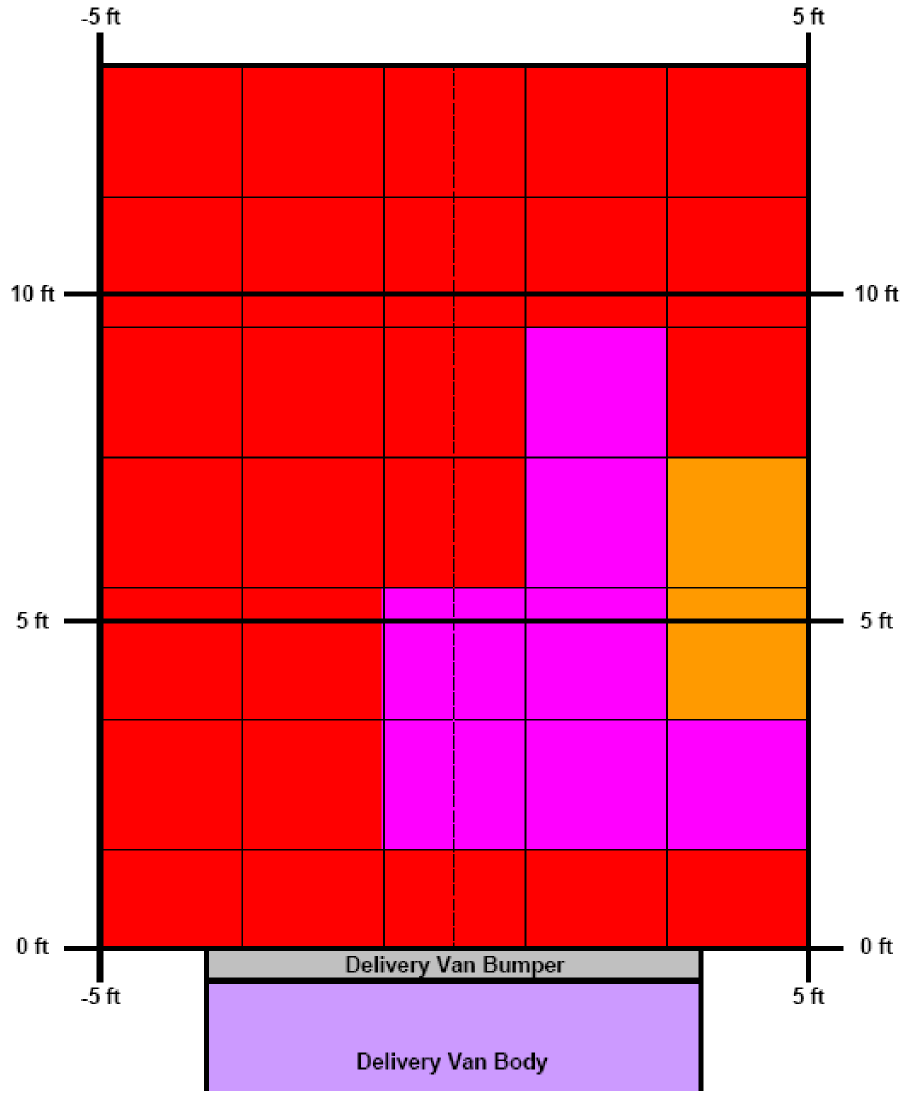

Figure 56. Minification Ratings of Images by Location for the 1-Year-Old ATD Seen in the Rear Cross-view Mirror

S13.7 of FMVSS No. 111 (the school bus cross-view mirror compliance test) imposes two requirements to ensure the visibility of a test object approximating the size and shape of a 3-year-old child in the cross-view mirror's field of view. Applying these requirements to the current situation, the subtended visual angle associated with the Measured Length - Longest Direction exceeded 9.0 minutes of arc at all image quality measurement points for the 3-year-old ATD. The subtended visual angle associated with the Measured Length - Shortest Direction exceeded 3.0 minutes of arc at some image quality measurement points but not at others. Figure 57 shows, for the 3-year-old ATD, how many of the FMVSS 111 visibility requirements were met at each of the image quality measurement points by the rear cross-view mirror. Figure 58 is the key for Figure 57 (and Figure 59). As can be seen from this figure, for the 3-year-old ATD, both FMVSS No. 111 visibility requirements are met in a region on the left side of the measurement area from the step van's bumper back to almost ten feet behind the bumper. One FMVSS No. 111 visibility requirement was met at all points for the 3-year-old ATD.

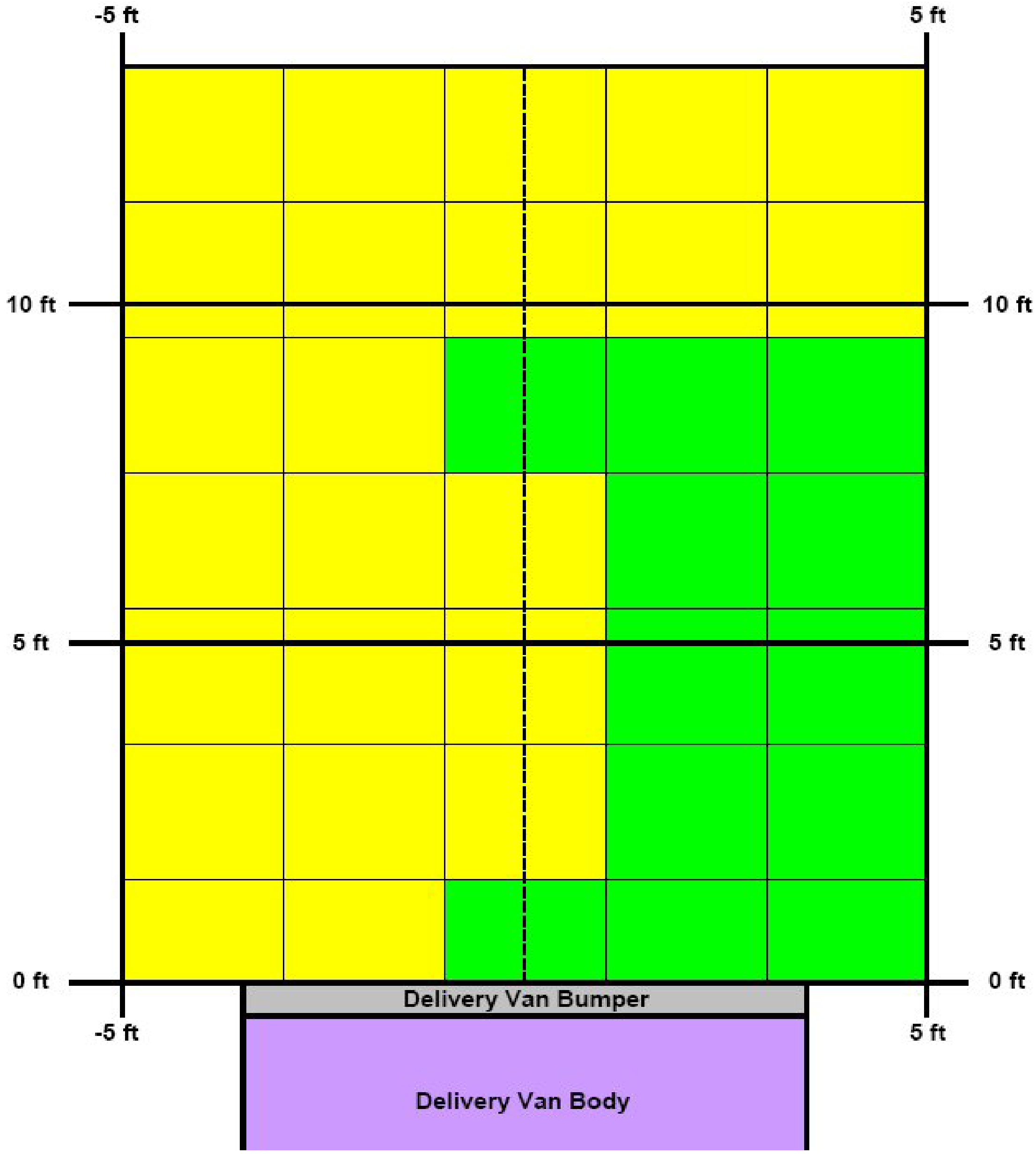

Figure 57. Number of FMVSS No. 111 (S13.7) Visibility Requirements Passed at Each Location for the 3-Year-Old ATD Seen in the Rear Cross-view Mirror

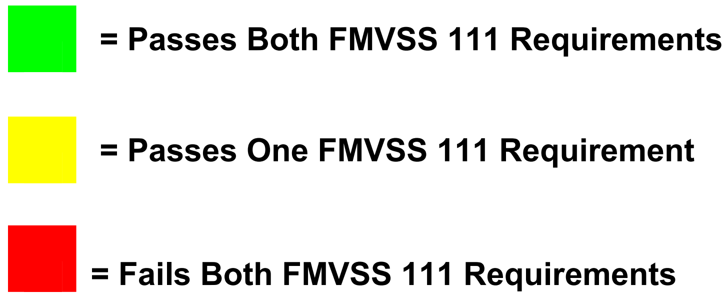

Figure 58. Key for Scheme Used to Indicate Number of FMVSS No. 111 Visibility Requirements Passed

While the FMVSS No. 111 visibility requirements were originally intended for a test object closer to the size of the 3-year-old ATD, they can also be applied using the 1-year-old ATD as the test object. When this is done, both test requirements are met at some image quality measurement points and not at others. Figure 59 shows, for the 1-year-old ATD, how many of the FMVSS 111 visibility requirements were met at each of the image quality measurement points by the rear cross-view mirror. Figure 56 is, again, the key for Figure 59. As can be seen from this figure, for the 1-year-old ATD, both FMVSS No. 111 visibility requirements are met at most measurement point in a region on the left side of the measurement area from the step van's bumper back to 7.5 feet behind the bumper.

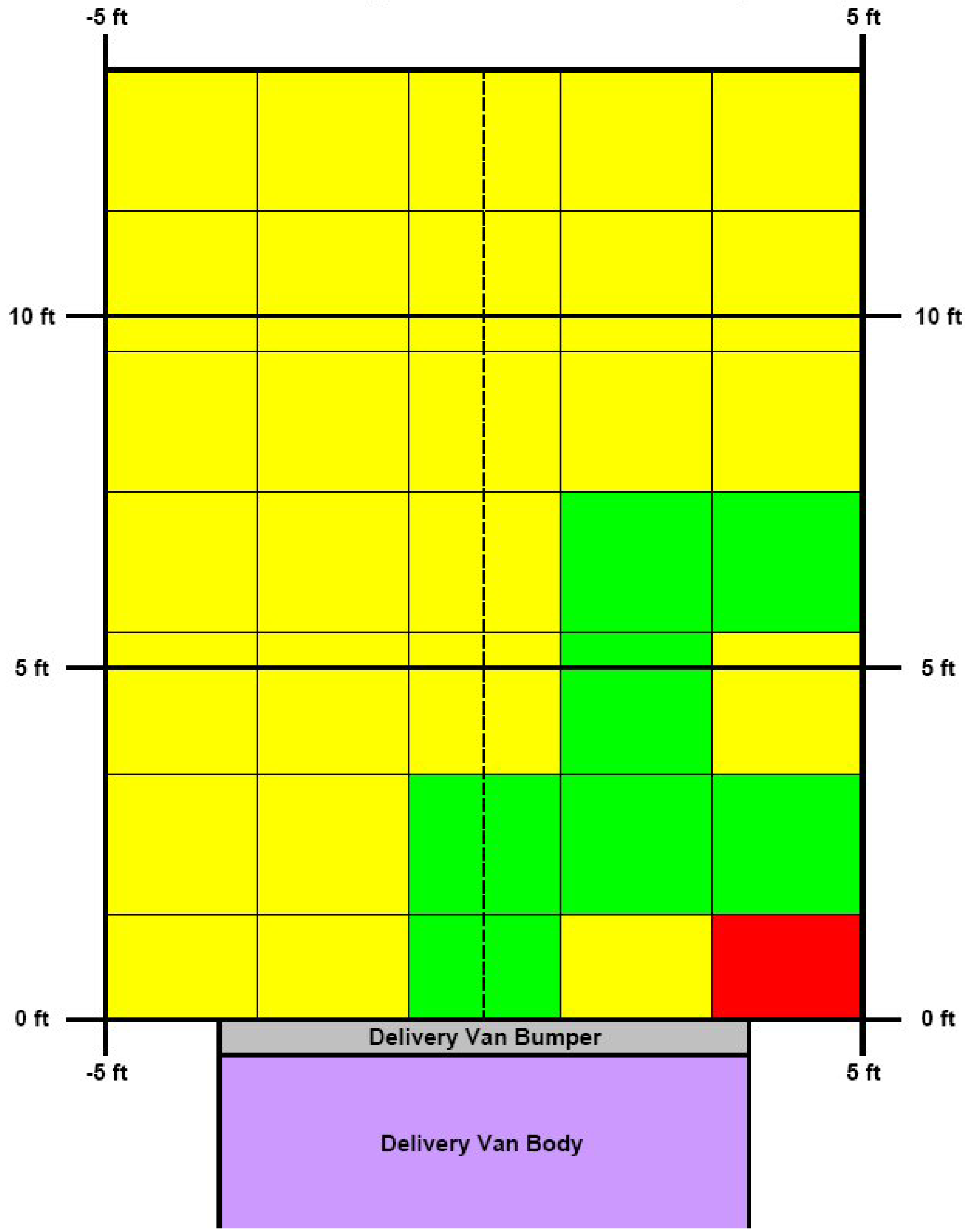

Figure 59. Number of FMVSS No. 111 Visibility Requirements Passed at Each Grid Location for the 1-Year-old ATD Seen in the Rear Cross-view Mirror

As Figures 56 and 59 show, 1-year-old children are too small to see over nearly the entire field of view of the mirror. One FMVSS No. 111 visibility requirement was only met for 20 percent (7 of 35) of image quality measurement points. Based on Figures 55 and 57, 3-year-old children are too small to see in right half of the field of view of the mirror. While no testing was performed with adult-sized test objects, based on the improvement in visibility from 1 to 3-year-old children, the authors expect the adults will be visible in the rear cross-view mirror anywhere in the rear cross-view mirrors field of view behind the step van (see Figure 50). However, even for adults the combination of high image distortion plus much image minification will reduce the driver's detection likelihood.

To try to give a better understanding of the difficulty of detecting small children in the rear cross view mirror, Figure 60 is a picture (taken with a camera with no optical zoom) of a 1-year-old ATD as seen in the rear cross-view mirror and the left side-view mirror of the step van.

Note that this Figure 60 is a "best case" picture in that the ATD is positioned at a location where the image distortion and the image minification ratings are both "Poor." From Figures 54 and 56, there were only two image quality measurement points that had image minification ratings of "Poor" for the 1-year-old ATD. All other points had a worse image minification rating. One of the "Poor" image minification points had a image distortion rating of "Poor," the other one had a distortion rating of "Very Poor." So the picture shown had the best image minification rating measured for the 1-year-old ATD and the best image distortion rating that was obtained at the best image minification rating.

Figure 60. Picture of 1-Year-Old ATD as Seen in the Rear Cross-view Mirror and the Left Side-view Mirror of the Step Van

The authors can only locate the 1-year-old ATD because they know where it appears in the picture. To help other readers, Figure 61 shows a highly enlarged portion of Figure 60 showing just the rear cross-view mirror image (as seen in the side-view mirror). The image of the 1-year-old ATD, in the lower left portion of the mirror image, is still quite small.

Figure 61. Magnified Picture of 1-Year-Old ATD as Seen in the Rear Cross-view Mirror and the Left Side-view Mirror of the Step Van

This testing found that the image quality of the rear cross-view mirror is greatly degraded by rain. One day during mirror image quality testing a light rain began to fall. Figure 62 shows the driver's view of the rear cross-view mirror in the side-view mirror when light rain is falling. As can be seen, it is no longer possible to see anything in the rear cross-view mirror in this weather condition.

Figure 62. Driver's View of the Rear Cross-view Mirror in the Side-view Mirror During Light Rainfall

In summary, the quality of the rear cross-view mirror image is insufficient to allow drivers to resolve small objects behind the vehicle. It is very hard to impossible to see small children over much of blind zone behind the vehicle. Identifying larger children and adults is somewhat easier, although there are still concerns that the combination of high distortion plus much minification will reduce detection likelihood in certain portions of the blind zone. Precipitation accumulation on the surface of the mirror or darkness will obscure the driver's view of images in the rear cross-view mirror.

Based on these concerns, the authors do not believe that rear cross-view mirrors are an effective means of allowing the driver to see behind the vehicle. All of NHTSA's human factors concerns for rearview video (which are currently being researched) also apply to rear cross-view mirrors.

The authors' original intention was to, after completing the above described testing, move the rear cross-view mirror further back from the side-view mirror. This would simulate using the rear cross-view mirror on a longer vehicle than the 1996 Grumman-Olson 4x2 step van. However, the measured image visibility was so bad using the actual vehicle's length that it did not seem worthwhile to perform testing with a simulated larger vehicle (which would have further degraded image quality).

Rear cross-view mirrors are not a good means of seeing behind the vehicle but they are better than nothing. They are expected to prevent some backover crashes. In comparison, school bus cross-view mirrors on the front and right side of the vehicle have been shown; by comparing crash data from before better cross-view mirrors were required with data from the improved mirrors, to have 60% effectiveness. School bus cross-view mirrors have less minification because the driver is closer to the convex mirror and because school children are larger than the 1 to 3-year-olds that are the focus for backover crash prevention and less distortion than the rear cross-view mirror studied. Based upon worse minification and distortion, NHTSA researchers expect the rear cross-view mirror evaluated to prevent 15 to 30 percent of backover crashes.

5.0 DISCUSSION

For a backover avoidance system to aid drivers in avoiding a collision with an obstacle present behind the vehicle, a number of steps must occur with favorable results:

- The system must:
  - *Sensor-based systems*: accurately detect the obstacle
  - *Visual systems*: clearly display the obstacle on an in-vehicle visual display
- The system must present the warning signal or obstacle presence information early enough that the vehicle can be braked to a stop before a collision occurs
- The driver's attention must be drawn to the warning or information the system is providing:
  - *Sensor-based systems*: presentation of an effective warning signal
  - *Visual systems*: driver chooses to look at the visual display
- The driver must perceive the warning, and
- The driver must make an appropriate crash avoidance response (apply the brakes hard and quickly) to stop the vehicle before reaching the obstacle

The three main variables in these steps include the system, the driver, and the physics of the situation. This section outlines aspects of each variable that can impact the outcome of a crash avoidance situation.

5.1. ADEQUACY OF SENSOR SYSTEM DETECTION RANGES

For a sensor-based backing system's warning to be effective, it must be presented early enough that the driver has time in which to stop the vehicle before colliding with the obstacle. Calculations were made to determine what conditions must be met in order for collision avoidance to be possible. The parameters included in these calculations and related assumptions used are as follows.

Driver Reaction Time – The time it takes a driver to initiate brake application in response to a stimulus. The stimulus in this scenario is warning signal presented by an object detect system. A mean driver reaction time of 1.17 seconds was used based on the mean value for dry pavement given in Table 4 of [16]. This driver reaction time was used instead of the mean driver reaction time in response to warnings presented during backing (0.54 s) given in [17] because that study used alerted drivers while the driver reaction time in [16] was for unalerted drivers; a situation that is more typical of the situation in which backover avoidance technology is needed. For the uncertainty calculations, a normal distribution of driver reaction times was used with a standard deviation of 0.31 seconds. Again, this standard deviation was taken from Table 4 of [16].

System Response Time – The elapsed time between presentation of a test object and the sensor-based system's delivery of a warning signal, as measured in this testing (see Table 12). For the uncertainty calculations, a uniform distribution of system response times ranging from the maximum to the minimum response time in Table 12 was used.

Brake Application Time – The elapsed time between the initiation of brake application to the point when maximum deceleration of the vehicle is reached. This parameter includes both the time for the driver to apply the brake and the time for the brake system to respond to this input. A mean time of 0.25 seconds was used based on one author's past research experience. For the uncertainty calculations, a uniform distribution of brake application times ranging from 0.20 to 0.30 seconds was used.

Maximum Deceleration – The maximum deceleration level attainable when braking the vehicle. The vehicle is assumed to decelerate at a constant rate after the initial brake application period. From the "stopping time" regression equation (Equation 2) of [17], a mean maximum deceleration of 0.32 g was calculated. For the uncertainty calculations, a uniform distribution of maximum decelerations ranging from 0.17 g to 0.47 g was used.

The first set of calculations estimated the distance in which a driver could reasonably be expected to brake to a stop from a range of initial speeds in response to a warning signal presented by a sensor-based backing system. This calculation used mean values of each of the parameters listed above. Table 13 shows the calculated distances given the assumptions noted above for system response time, driver reaction time, brake application time, and maximum deceleration.

Table 13. Distance in Which Drivers Could Brake To A Stop in Response to Backing System Warning

Vehicle or System	From 1.0 mph (ft)	From 2.0 mph (ft)	From 3.0 mph (ft)	From 5.0 mph (ft)	From 7.0 mph (ft)	From 10.0 mph (ft)
Eagle Eye	2.6	5.5	8.5	15.2	22.8	35.7
HaoDi PAS-405	2.7	5.6	8.8	15.7	23.4	36.6
Hindsight 20/20	2.7	5.7	8.9	15.8	23.6	36.9
Vorad Backspotter	2.4	5.0	7.8	14.1	21.2	33.4

Paine and Henderson concluded in [18] that a 4 meter (13.1 feet) detection distance would be sufficient (95% avoidance probability) for a vehicle traveling 8 kph (approximately 5.0 mph). The current results are somewhat pessimistic, giving calculated stopping distances from 5.0 mph that range from 4.3 meters (14.1 feet) to 4.8 meters (15.8 feet).

The second set of calculations estimated the maximum speed from which a driver could reasonably be expected to brake to a stop in response to a system's warning for an obstacle present at the system's maximum detection range. For this set of calculations, Crystal Ball® software was used to perform Monte Carlo simulation while the parameters listed below were varied over reasonable ranges. The results provide both the median maximum speed and the tenth and ninetieth percentile limits for this speed.

Monte Carlo simulation was performed to quantify the range of maximum speeds from which a driver could reasonably be expected to brake to a stop without striking an obstacle. The distances shown in Table 13 were calculated based upon one Driver Reaction Time, one System Reaction Time, one Brake Application Time, and one Maximum Deceleration. However, in real life the values of these parameters will vary from stop-to-stop over a range of values. This variation in these parameters will, of course, change the maximum speed for braking to a stop. Monte Carlo simulation quantifies the range of maximum speeds.

For this calculation to be made, sensor system detection range values were needed. The decision was made to use the maximum detection range values for a walking 3-year-old child for each system, as reported in Table 8 of this report. For the reader's convenience, Table 14 repeats these maximum detection range values.

Table 14 summarizes, for each system and its corresponding maximum detection range for a walking 3-year-old child, the maximum speed from which a driver could reasonably be expected to brake to a stop if warned by the system of the child's presence behind the vehicle.

Table 14. Maximum Speeds For Braking To A Stop – 3-year-old Child

Vehicle or System	Maximum Range (ft)	Maximum Speed for Braking to a Stop 10th Percentile (mph)	Median (mph)	90th Percentile (mph)
Eagle Eye	10.0	2.8	3.4	4.1
HaoDi PAS-405	4.0	1.2	1.4	1.8
Hindsight 20/20	8.0	2.3	2.7	3.3
Vorad Backspotter	16.0	4.6	5.4	6.6

As this table shows, for average driver parameters, the combination of system response time and detection range result in successful crash avoidance being unlikely except for fairly low vehicle backing speeds. For systems tested, the median speeds ranged from a low of 1.4 mph to a high of 5.4 mph.

To obtain a better idea of the significance of these speeds, testing was performed to determine the "natural" backing speed of vehicles. "Natural" backing speed here refers to the steady-state speed that is attained when a vehicle is placed in reverse and allowed to go backwards for a substantial period of time without throttle or brake application. Testing was performed on a flat, level surface, and going both up and down a 1 percent grade. (These cases correspond to backing in different directions on the Transportation Research Center's Vehicle Dynamics Area.) The 2002 Mack MV222L 4x2 medium straight truck was tested.

Table 15 summarizes the values obtained for natural backing speeds. As this table shows, for the HaoDi system the natural backing speed is above the median maximum speed for braking to a stop without striking the object (3-year-old child). For the Eagle Eye and the Hindsight 20/20 systems, the median maximum speeds for braking are slightly above (less than 1.0 mph) the natural backing speed. For the Vorad Backspotter, the median maximum speed for braking is well above (3.0 mph) the natural backing speed.

Table 15. Natural Backing Speeds for Selected Vehicles

Vehicle	Slope	Steady State Speed (mph)	Steady State Speed (kph)
2002 Mack MV222L 4x2 medium straight truck	Zero Slope	2.4	3.9
	Up 1% Slope	2.4	3.9
	Down 1% Slope	2.4	3.9

Additional information about vehicles speeds during backing can be found in the literature. Two studies have measured typical backing speeds. Huey et al. [11] found in a study of naturalistic backing behavior that "typical parking lot types of tasks all had slow maximum backing speeds (less than 7.0 mph, 10.3 feet per second). The mean maximum backing speed for those tasks was around 3.0 mph (4.4 feet per second)." In a 1996 study of driver reaction time to warnings during backing [17], mean backing speed for alerted drivers was 2.6 mph (SD 2.2).

A study sponsored by NHTSA [19] examined approximately 200 police accident reports corresponding to backing crash entries in the 1992 GES database. Fifty of these reports were for crashes in which the backing vehicle struck a pedestrian. Backing speed distributions were extracted from the available data. This analysis found that in approximately 90 percent of the fifty backing crashes with pedestrians, the striking vehicle was traveling at 5 mph or slower.

Based on these points, the combination of system response times and detection range values result in successful crash avoidance being unlikely except for fairly low vehicle backing speeds. For one of the ultrasonic sensor-based systems tested (the HaoDi PAS-405), the calculated median maximum speed for braking to a stop for a 3-year-old child was below 2.0 mph. This indicates that the maximum detection range for this sensor-based system was insufficient to prevent a backover situation in which the obstacle is a 3-year-old child. Based on the analysis in [19], only about 50 percent of the vehicles that back into pedestrians are traveling at speeds below 2.0 mph. The situation for the other sensor systems tested is slightly better, but still poor. Again, based on the analysis in [19], a system should have a maximum detection range that facilitates warning the driver in time for them to brake to a stop from at least 5 mph to avoid colliding with a 3-year-old child. Of the systems tested, only the Vorad Backspotter meets this criterion, and it has a close to the bumper non-detection zone that may cause problems in detecting children.

5.2. FACTORS AFFECTING SYSTEM PERFORMANCE

The testing documented in this report assessed the current state of sensor technology performance in the detection of objects, particularly children, at short range behind vehicles. The testing was conducted in a controlled, laboratory setting. However, in everyday driving, a variety of factors can impact sensor performance and system effectiveness. Some of these factors are described below.

The degree and quality of coverage provided by sensor or video systems is critical in accurately informing the driver of rear obstacles that may present a collision threat. Sensor systems detect certain objects better than others and some objects at closer range than others. Drivers may have difficulty realizing that a system may detect another vehicle at a range of 10 feet, but can only detect a small child to a distance of 3 feet. To complicate matters, some systems may detect a child at a certain distance in one location behind the vehicle, but not detect the child at the same distance if they take a step to one side. Care must be taken to ensure that the backover system's object detection strategy is understandable to drivers.

Sensor-based systems typically can only detect pedestrians or objects that are directly behind the vehicle. For the sensor-based systems tested, detection zones typically covered only a small amount of the non-visible (via direct glance or center rearview mirror glance) area behind the vehicles. None of the systems tested had large enough detection zones to completely cover the blind zone behind the vehicle on which they were mounted.

The degree of motion of the obstacle also affects sensor systems' ability to detect it. Sensor systems appear more likely to detect slowly moving objects than stationary ones. Even small motions, such as a young child standing still but moving a hand, can impact detection. Fast motion, such as a child running behind the vehicle, presented a detection challenge to some systems.

The permutations of possible scenarios in which a backover avoidance system could not assist in preventing a collision are numerous. Sensor systems typically only detect objects positioned directly behind the vehicle. Designing sensor-based systems to detect a wider area than that directly behind the vehicle could lead to problems such as nuisance alarms due to detection of adjacent vehicle when parking. While rearview video and convex mirror systems do provide some view of the areas diagonally to the rear of the vehicle on both sides, those views tend to be somewhat distorted due to mirror convexity or video image nonlinearities inherent in wide-angle camera lenses. A child standing to the rear of the vehicle, but a short distance to the side will probably not be detected by a sensor system, but may be within the field of view of a visual system. A child standing to the side of a vehicle that is backing in a curved path would not be detected by a rear sensor system or displayed by a rearview video system and could be struck by the front tires of the vehicle during the backing maneuver. A child crawling on the ground beside the vehicle between the front and rear wheels would not be detected by a rear sensor system or displayed by a rearview video system. A child positioned under the vehicle's rear bumper would also not be detected in many cases.

False alarms are warning signals emitted by the system when no threat is present. False alarms cause the driver annoyance and erode the driver's trust in the system. While false alarms were observed to be a significant problem in past NHTSA testing, only one of the current systems tested exhibited a false alarm problem. False alarms that appeared to be caused by wind gusts were seen with one ultrasonic sensor system.

Weather conditions can impact backing system performance. Dirt and dust can decrease the performance of ultrasonic sensors. Rain is a problem for rear cross-view mirrors. The accumulation of snow or ice on the camera may also provided

While it may be possible that a well-designed backover avoidance system could reduce the occurrence of backing crashes, it is important to realize that such a system would not be a panacea for every vehicle backing maneuver conflict situation.

6.0 FINDINGS

For this study, NHTSA tested three sensor-based rear object detection systems, one rear object detection system that combined sensors with rearview video, one rearview video (only) rear object detection system and one rear cross-view mirror. Since the sensor and rearview video portions of the combined systems were tested separately, NHTSA effectively tested four sensor-based systems, two rearview video systems, and one rear cross-view mirror. Three of the sensor-based systems used ultrasonic sensors; the fourth used frequency modulated continuous wave radar.

Testing of the sensor-based and rearview video-based rear object detection systems was conducted using the same methodology [1] as used by NHTSA for testing these systems for light vehicles. The rear cross-view mirror testing, which was only tested statically, was based on a method developed by Satoh.

The results found for the four sensor-based rear object detection systems were similar to those previously found for light vehicles [1]. Three of the four systems tested had longer ranges than those tested for light vehicles. All sensor-based systems still had erratic detection of children, particularly for 1-year-olds. One ultrasonic system had many false alarms. The gap in coverage near vehicle bumpers for two sensor-based systems is of concern. Overall, based on the test results, the performance of sensor-based systems in detecting children was poor and inconsistent.

Both rearview video systems tested provided detailed images of the area behind a vehicle in well lit conditions. The images were of good quality making it easy to see even small children behind a vehicle. However, in wet or wintery conditions, the camera view could be obstructed by water droplets, ice or snow on the lens. Depending upon the lighting provided, darkness may also prevent video systems from clearly showing people behind a vehicle. Overall, rearview video systems are an effective means of allowing the driver to see behind the vehicle. NHTSA has a human factors study in progress that will assess the degree to which typical, non-commercial drivers effectively use image information provided by rearview video systems to avoid backover crashes.

The quality of the images displayed by the rear cross-view mirror was evaluated using a 1996 Grumman-Olsen step van with a 12-foot long box. The side-view mirror to rear cross-view mirror distance was 190 inches, slightly shorter than the maximum 197 inches that NHTSA is considering. Two aspects of image quality, distortion and minification (how small an object appears to be in the mirror) were measured.

Rear cross-view mirror image quality distortion ratings ranged from Excellent (minimal distortion) to Impossible (extreme distortion). The least distortion was near the step van's bumper; the worst on the step van's left side well away from (9 feet or more behind) the bumper.

Measurements of image size in the rear cross-view mirror found that 1-year-old children are too small to be distinguished over nearly the entire field of view of the mirror. Three-year-old children are too small to see in the right half of the field of view of the mirror.

Adults can be seen anywhere in the blind zone. However, there are concerns that the combination of high distortion plus much minification will reduce detection likelihood in certain portions of the blind zone behind the step van.

Overall, the quality of the rear cross-view mirror image was insufficiently clear to allow drivers to resolve small objects behind the step van (or other vehicles of this length). It was found to be very hard, to impossible to see small children over much of blind zone behind the vehicle. Identifying larger children and adults is somewhat easier, although there are still concerns that the combination of high distortion plus much minification will reduce detection likelihood in certain portions of the blind zone. Water, ice, or snow on the mirror's surface will obscure the view in the rear cross-view mirror. Depending upon the lighting provided, darkness may also prevent rear cross-view mirrors from being visible to the driver using the mirror.

This study found that rear cross-view mirrors are not a very effective means of allowing the driver to see behind a vehicle. Additionally, as with rearview video, NHTSA has concerns that drivers may not use rear cross-view mirrors effectively.

Rear cross-view mirrors are not a good means of seeing behind much of the vehicle but do provide some aid, although minimal. They are expected to prevent some backover crashes. In comparison, school bus cross-view mirrors on the front and right side of the vehicle have been shown, by comparing crash data from before better cross-view mirrors were required with data from the improved mirrors, to have 60% effectiveness. School bus cross-view mirrors have less minification because the driver is closer to the convex mirror and because school children are larger than the 1 to 3-year-olds that are the focus for backover crash prevention and less distortion than the rear cross-view mirror studied. Based upon worse minification and distortion, NHTSA researchers expect the rear cross-view mirror evaluated to have lower effectiveness than a school bus cross-view mirror.

In conclusion, in the opinion of NHTSA researchers, sensor-based systems do not perform well enough to effectively prevent backover crashes. We worry that they may lead to a reduction in driver vigilance and do more harm than good. Rearview video systems are an effective means of seeing behind the vehicle. NHTSA has a human factors study in progress to examine the extent to which drivers use rearview video systems during backing maneuvers.

7.0 REFERENCES

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