4-2016

Rearward visibility issues related to agricultural machinery: Contributing factors, potential solutions

Shawn Gregory Ehlers
Purdue University

Recommended Citation

Ehlers, Shawn Gregory, "Rearward visibility issues related to agricultural machinery: Contributing factors, potential solutions" (2016). *Open Access Dissertations*. 643.
https://docs.lib.purdue.edu/open_access_dissertations/643

PURDUE UNIVERSITY
GRADUATE SCHOOL
Thesis/Dissertation Acceptance

This is to certify that the thesis/dissertation prepared

By Shawn G. Ehlers

Entitled
REARWARD VISIBILITY ISSUES RELATED TO AGRICULTURAL MACHINERY: CONTRIBUTING FACTORS, POTENTIAL SOLUTIONS

For the degree of Doctor of Philosophy

Is approved by the final examining committee:

William E. Field
Chair

Abigail S. Engelberth

Daniel R. Ess

Dennis R. Buckmaster

To the best of my knowledge and as understood by the student in the Thesis/Dissertation Agreement, Publication Delay, and Certification Disclaimer (Graduate School Form 32), this thesis/dissertation adheres to the provisions of Purdue University's "Policy of Integrity in Research" and the use of copyright material.

Approved by Major Professor(s): William E. Field

Approved by: Bernard Engel 4/19/2016
Head of the Departmental Graduate Program Date

REARWARD VISIBILITY ISSUES RELATED TO AGRICULTURAL MACHINERY: CONTRIBUTING FACTORS, POTENTIAL SOLUTIONS

A Dissertation
Submitted to the Faculty
of
Purdue University
by
Shawn Gregory Ehlers

In Partial Fulfillment of the
Requirements for the Degree
of
Doctor of Philosophy

May 2016
Purdue University
West Lafayette, Indiana

I dedicate this dissertation to my supportive family. I couldn’t have done this without your unwavering love and encouragement.

TABLE OF CONTENTS

Page

Page

Page

Page

APPENDICES

LIST OF TABLES

LIST OF FIGURES

Figure Page

Figure Page

Figure Page

Figure Page

Figure Page

Figure Page

LIST OF ABBREVIATIONS

ASABE: American Society of Agricultural and Biological Engineers

DOT: Department of Transportation

FACE: Fatality Assessment and Control Evaluation

MFWD: Mechanical Front Wheel Drive

NHTSA: National Highway Safety Transportation Administration

NIOSH: National Institute for Occupations Safety and Health

OEM: Original Equipment Manufacturer

OSHA: Occupational Safety and Health Administration

PTO: Power Take Off

RADAR: Radio Detection and Ranging

ROPS: Roll Over Protective Structure

RFID: Radio Frequency Identification

SCI: Special Crash Investigation

SCV: Selective Control Valve

UTV: Utility Vehicle

DISCLAIMER

The mention of any trade names do not imply an endorsement.

ABSTRACT

Ehlers, Shawn G. Ph.D., Purdue University, May, 2016. Rearward Visibility Issues Related to Agricultural Machinery: Contributing Factors, Potential Solutions. Major Professor: William Field.

As the size, complexity, and speed of tractors and other agricultural self-propelled machinery have increased, so have the visibility-related issues, placing significant importance on the visual skills, alertness, and reactive abilities of the operator. Rearward movement of large agricultural equipment has been identified in the literature as causing not only damage to both machine and stationary objects, but also injuries (even fatalities) to bystanders not visible to the operator. Fortunately, monitoring assistance, while not a new concept, has advanced significantly, offering operators today more options for increasing awareness of the area surrounding their machines. In this research, an attempt is made to (1) identify and describe the key contributors to agricultural machinery visibility issues (both operator and machine-related), and (2) enumerate and evaluate the potential solutions and technologies that address these issues via modifications of ISO, SAE, and DOT standardized visibility testing methods. Enhanced operator safety and efficiency should result from a better understanding of the visibility problems (especially with regard to rearward movement) inherent in large tractors and self-propelled agricultural machinery.

Used in this study were nine machines of different types that varied widely in size, horsepower rating, and operator station configuration to provide a broad representation of what is found on many U.S. farms/ranches. The two main rearward monitoring ‘technologies’ evaluated were the machines’ factory-equipped mirrors and cameras that the researchers affixed to these machines. A 58.06 m^2 (625 ft^2) testing grid was centered on the rear-most location of the tested machinery with height indicators centered in each of twenty-five grid cells. In general, the findings were consistent across all the machines tested—i.e., rather obstructed rearward visibility using mirrors alone versus considerably less obstructed rearward visibility with the addition of cameras. For example, having exterior extended-arm and interior mirrors only, a MFWD tractor with 1,100-bushel grain cart in tow measured, from the operator’s perspective, 68% obstructed view of the grid’s kneeling-worker-height markers and 100% throughout the midline of rearward travel; but when equipped with a rearview camera system, the obstructed area was decreased to only 4%. The visibility models created identified (1) a moderate-positive Pearson r correlation, indicating that many of the obstructed locations of the rearward area affected both mirrors and cameras similarly and (2) a strong-positive Pearson r correlation of kneeling worker height visibility, indicating that mirrors and camera systems share commonality of areas with high visibility (along the midline of travel and outward with greater distance from the rear of the machine, without implements in tow).

Of the recommendations coming from this research, the key one is for establishment of engineering standards aimed at (1) enhancing operator ability to identify those locations around agricultural machinery that are obstructed from view, (2) reducing the risk of runovers through improved monitoring capabilities of machine surroundings and components, and (3) alerting operators and co-workers of these hazardous locations.

CHAPTER 1. INTRODUCTION

[1]Historically, the operator station of most tractors and self-propelled agricultural machinery was open (i.e., not enclosed), which allowed a relatively unobstructed view of the area immediately around the machine and of attached implements (Figure 1.1). The operator station also was generally above the level of the implement and, on a number of makes and models, positioned off-center so that the operator could better observe the activity being performed. The overall footprint of most early self-propelled vehicles, with the exception of self-propelled combines and cotton pickers, was small enough to allow the operator a nearly 360° view around the base of the machine. In addition, the vehicle's field speed was usually less than 8 kph (5 mph), which typically allowed sufficient time for the operator to react to an incident, whether actual or potential.

---

[1] Publication: Ehlers, S., Field, W. 2016. Rearward Visibility Issues Related to Agricultural Tractors and Self-Propelled Machinery: Contributing Factors, Potential Solutions. Journal of Agricultural Safety and Health. 22(1): 47-59.

Figure 1.1. The open-frame design of the Allis Chalmers model G allows a nearly unobstructed view of the specific task (source: Delaware, 2010).

As machinery increased in size and enclosed ROPS-equipped operator stations were introduced (in response to demands for greater comfort and protection), visibility of the surrounding area markedly decreased. In addition, in earlier designs of operator enclosures, the operator began to be more isolated from the actions of the machine, including the ability to adequately monitor towed implements, especially when traveling in reverse. Hence, the need for monitoring assistance became apparent, with additional windows and rearview mirrors being incorporated into original equipment designs or offered as accessories as cost-effective solutions.

Today's tractors and self-propelled agricultural machines, now largely equipped with environmentally controlled cabs, extensive monitoring equipment, and often with mounted accessories (e.g., sprayer tanks), have significantly increased the occurrence of blind spots, i.e., areas around the machine that are completely out of the operator’s line of sight. Additionally, when towing an implement, adequately monitoring all aspects of a particular field operation is likely to become more challenging. The problem is further exacerbated if the operator has physical limitations (e.g., mobility, reaction time, vision, or hearing). This reduced monitoring ability can lead to personal injury, property damage, and productivity loss. The potential role that physical limitations, especially related to vision, can have on the operation of large, complex, and high-speed equipment has been given relatively little attention in the literature.

Blind spots are especially apparent directly in front of and behind the machine and at the base of the tires or tracks. In fact, there are apt to be locations within close proximity of the machine where a person standing on the ground is nearly, if not completely, out of the operator’s line of sight (Figure 1.2). This is especially true for areas immediately to the rear of large tractors and self-propelled machinery.

Figure 1.2. Driver's view of assistant at hitching point with full seat rotation in both directions.

This limitation of operator visibility has been documented for its contribution to injuries of co-workers or bystanders who were runover by rearward travel of equipment. However, the problem of blind spots has been difficult to adequately address due to the following:

- The lack of comprehensive documentation of incidents involving machine runovers.
- The difficulty of distinguishing, in the limited case studies available, between runovers involving falls from tractors and self-propelled machines, runovers in which the victim was standing near the machine, and runovers caused by attempting to jump start a tractor or equipment from ground level.
- The lack of consistent design standards regarding minimal operator visibility requirements for larger self-propelled machines.

1.1 Goal and Objectives

Currently, limited data are available on the economic impact that reduced visual monitoring on machinery, such as being able to monitor large tillage tools or high-capacity combines, has on agricultural operations. Also, little is known on the impact that impaired or obstructed vision has on the frequency or severity of agricultural workplace injuries. A fuller understanding of visibility-related problems could lead to improved work practices, equipment designs, and assistive aids, all of which would likely lead to increased production efficiency and reduced injuries and property damage.

The goal of this research was to improve the safety of agricultural machinery by which the operators' ability to assess the rearward area for hazards and implement monitoring. The objectives of this work were the following:

Objective 1. Complete a summary of a review of the literature related to operator vision including works associated with machine monitoring and methods for enhancing vision during rearward machine travel. Special consideration was given to research that addressed personal injuries and property damage occurring during rearward travel.

Objective 2. Summarize the types of incidents that occur due to the operators’ inability to view or monitor blind spots to the rear of agricultural machinery. This included documentation of actual case studies involving each type of incident.

Objective 3. Identify and document rearward blind spots associated with selected agricultural machinery with regard to the ability of the operator to observe and identify hazards of various heights within a constructed field of vision. Both enhanced vision technologies, such as mirrors and cameras, were assessed.

Objective 4. Evaluated key factors, including design characteristics and operator physical limitations, that impair rearward visibility on the selected agricultural machinery with known blind spots.

Objective 5. Develop recommendations for standards and best practices involving "Danger" labeling and its application, as well as methods for assessing rearward visibility of indirect viewing technologies.

1.2 Operator-related factors and potential solutions

Non-mechanical contributors to reduced visibility can relate to the operator's physical limitations and/or physical wellness at a particular time. Long durations of sedentary and habitually poor postures, combined with the inherent characteristics of an aging population, can significantly stress the operator and impair the operator's ability to continuously monitor the surrounding area. For example, fatigue can lead to delayed response time, and working at night can reduce the visual acuity of operators who need more light to see well.

1.2.1 Operator’s physical condition

Physical factors can affect an operator’s ability to adequately see and appropriately respond to events in the area immediately around the machine. Among these physical factors are stature, visual acuity, range of motion, mobility, eye-hand coordination, reaction time, fatigue, depth perception, use of multi-lens eyewear, and light sensitivity. The average age of U.S. farmers is 58 years (U.S. Census Bureau, 2011); and individuals that age or older may not possess the rapid eye movement and/or reflex action sufficient to properly monitor high-speed field operations.

While no data were found on the visual impairments specifically of individuals who operate agricultural machinery, the CDC (2009) has reported that as many as 21 million adult Americans have “vision problems” and 80 million have “potentially blinding eye diseases.” By extrapolation, this could mean that anywhere between 6% and 32% of farmers may have significantly reduced visual abilities. How such limitations would affect the performance and safety of agricultural equipment operators could not be documented. However, the issue is significant enough that nearly all states require that visual restrictions, such as the use of eyeglasses or contacts, be stated on the licenses of all highway motor vehicle operators. In most states, they are also required to pass a visual exam prior to renewal of their licenses. Impaired nighttime vision and visual acuity have been identified as significant causative factors in highway motor vehicle incidents involving older operators. No such assessments were identified in the literature specifically pertaining to agricultural equipment operation.

Operators with impaired or total vision loss in one eye (i.e., monocular vision) primarily suffer from a loss of stereopsis and reduction of the peripheral field of vision. "These will cause problems in eye-hand coordination, depth judgment, orientation, mobility and some activities" such as driving (Politzer, 2016). Optical aids recommended for those with monocular vision include technologies that offer wide fields of view and training to incorporate increased head movement to monitor peripheries of their task (Politzer, 2016).

1.2.2 Operator's seated posture

Proper seated posture is also an important component of quality of work and comfort (Sjøflot, 1980b). Since implements are located to the rear and/or side of a tractor, the driver is forced to spend a significant amount of time looking backward and is subject to poor posture, directly affecting the quality of work (Sjøflot, 1980b). In interviewing 1,706 farmers in New York, Gomez et al. (2003) found that, among those who drive tractors frequently, 35% suffered from neck and shoulder pain, and 41% experienced lower back discomfort. Rakhra and Mann (2013) reported that the "combination of driving and awkward postures together with whole-body vibration caused several types of musculoskeletal disorders in tractor drivers." Reducing exposure to awkward posture has been found to increase operator comfort and efficiency while lowering injury incidence.

As the operator's seat is important to comfort, so is it important to visibility. Sjøflot (1980b) found that turning the seat 30° to the right could be beneficial for the backward-looking posture, but problems arise in operating the clutch and brake pedals, which do not turn with the seat. Sjøflot's recommendation was that the operator alter direction of turning (one time to the right and the next time to the left) to reduce adverse effects of the twisted posture. However, operators may find this difficult, as twisting to the left could cause loss of contact with hydraulic, PTO, and electrical controls, which are commonly located on the driver's right side. This problem is alleviated in models that have controls attached to a swiveling seat structure.

Operator comfort is necessary for long, productive workdays. To help provide such comfort, the operator's anthropometric dimensions must be adapted through adjustments of the steering wheel and seat (Ferrari and Cavallo, 2013). By minimizing awkward postures and vibrations through assistive visibility technologies (e.g., cameras, mirrors, and vibration damping "smart seats"), the operator's workday longevity, comfort, work quality, and overall well-being can be markedly enhanced.

1.3 Machinery-related factors and potential solutions

Various machinery design changes continue to be made in an attempt to address visibility-related issues, including greater use of monitors, fewer visual distractions, and the relocation of impeding objects (e.g., air intake, exhaust stack, windshield framing, and ROPS components), and especially, more open cabs.

1.3.1 Cab design

The cab design of agricultural machinery is essential to the operability, efficiency, and ergonomic comfort of the operator. With the numerous, ever changing, and often complex tasks required during operation, cab design “creates new opportunity for innovative solutions in the operator’s environment,” allowing the operator to “intuitively manage the entire function being performed.” Thus, “the cab should be spacious enough to allow for comfortable movement, and the controls must not only be logically positioned, but also provide reference points for sightless access to them and, more importantly, provide control logic and functions that automate frequently used sequential controls” (Templeton et al., 1998). However, while functionality and ergonomics inside the cab are indeed important, adequate visibility of the surrounding area and entry-exit location is vital for operator and by-stander safety. Templeton et al. (1998) identified obstructions parallel to the eye plane to be most intrusive, while obstructions perpendicular to that plane are minimized when narrower than eye separation. Ideal cab design must incorporate clear sight lines to high-risk areas (e.g., entry-exit location) and full visibility of the drawbar and hitching points. For example, the drawbar hitch pin should be observable from the operator’s seat. In some designs, the drawbar can only be observed if the rear window is open and the operator rotates almost 180° to look between the window frame and the frame of the cab.

1.3.2 Cab accessories

In-cab accessories, such as equipment monitoring devices, should be evaluated for their effects on both the operator’s ability to manipulate controls and monitor field operations. In low-light situations, there needs to be enough illumination inside the cab to clearly identify the controls and monitor gauges while not creating distracting glare on the cab windows. Too much interior lighting at dusk or night can severely diminish visibility, while too little during the day can lead to visibility-related impairments, such as glare. Buildup of dust on the cab windows can have similar effects, especially during sunrise and sunset.

Many newer models of tractors and self-propelled agricultural machinery offer such vision-enhancing accessories as windshield wipers, window washers, and retractable mesh sunscreens, which are often located on both the front and rear windows. However, while their purpose is to enhance visibility by blocking light, Templeton et al. (1998) suggested that sunscreens can also block visibility.

1.3.3 Exterior lights

The technology involving exterior lighting for both field work and highway transport is ever changing. Today's agricultural machinery can be equipped with xenon, high-intensity discharge (HID), light emitting diode (LED), or less expensive sealed beam and halogen lighting options in a range of configurations of light output and up to 360° coverage of the area surrounding machinery (Figure 1.3) (Gaines, 2013). LED lights better withstand shock and vibration associated with agricultural machinery, and the white light associated with LEDs allows the operator to see better through dusty conditions (Gaines, 2013). Lumen output, color, and longevity differ greatly among those options. Color temperature, Kelvin, describes the relationship between white light to the other colors in the color spectrum. The recommended color temperature is about 6500k, which combines the most natural light with a touch of blue spectrum, allowing for easier focus on details and reduced eye strain (Draper, 2012).

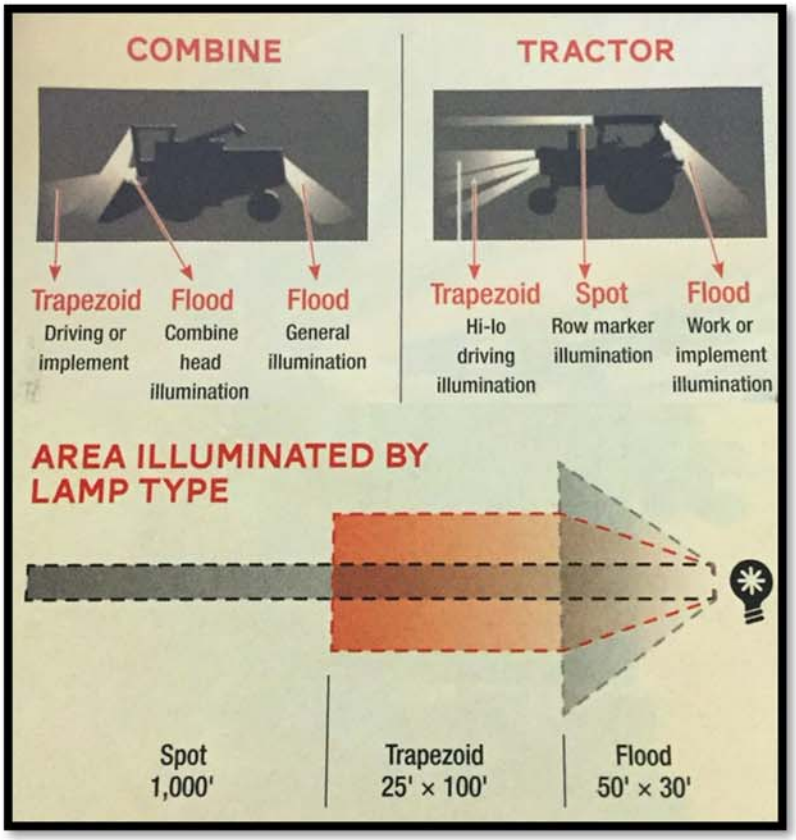


Figure 1.3. Lamp type placement (top) and area illuminated (bottom) by lamp type (source: Gaines, 2013).

As to the proper location and positioning of exterior lights, Templeton et al. (1998) found that lights positioned in line with one's line of sight create maximum illumination of dust particles from the operator's perspective. Thus, for best visibility, it is important that the lights be positioned above and/or below cab height. As Figure 1.3 illustrates, the area illuminated by light type falls into one of three categories—spot, trapezoid, and flood. Spotlights are intended for long-range viewing, allowing the operator to view down a long row since their patterns can reach out to 305 m (1,000 ft); thus, spots are often mounted on the roof of the tractor. Trapezoid lights are ideal general-purpose work lights that offer a narrow but long pattern for the immediate working area (typically 7.6 m [25 ft] wide and 30.5 m [100 ft] long). Floodlights are ideal for illuminating areas nearest the machinery since they cast a wide pattern (about 15.2 m [50 ft]), but only for a short distance (about 9.1 m [30 ft]) (Gaines, 2013).

1.3.4 Other factors influencing operator vision

Vision is a complex human attribute and rarely functions independent of other human senses. The relationship between knowledge and vision, such as estimating distances, and the role that hearing plays in enhancing visual recognition have been extensively studied in other settings but rarely in relation to agricultural machinery (Redlick et al., 2000). The difficulty that operators have in estimating clearances around a machine (i.e., trucks driving through underpasses) is one example.

The problem of foreign material on windows is well understood in auto racing, but the impact of accumulated dust on the windows of large tractors and other agricultural self-propelled machinery on the visual acuity and eye fatigue of the operator has been far less studied. The difficulties in attempting to reach and clean the glass surfaces plus the lack of window washing accessories on most agricultural equipment suggest that manufacturers may not fully recognize the correlation between visibility and safe, efficient operation of the equipment. Incidents that occur after dark or at dawn and dusk, when machines are operated into a rising or setting sun, have received little attention in published injury literature. The increased use of tinted glazing, sun visors, and retractable sun screens, however, suggests that the issues is not being completely ignored.

1.4 Devices that address visibility issues

1.4.1 Rearview mirrors

During the transition to larger tractors and self-propelled machinery with enclosed cabs, the operator's limited ability to adequately monitor both the machine and the trailing implement became apparent. For example, operators were no longer fully subjected to all the elements of field operation, including sun, dust, temperature extremes, and wind. As a result of being more shielded from the operation, operators became less engaged and required assistance in monitoring the intended task. This was especially true when operating equipment on roadways. As a result, interior and exterior extended-arm mirrors were adopted, with many variations in mounting locations and convex curvatures (Figure 1.4).

Figure 1.4. Modern combine harvester with exterior extended-arm mirrors.

1.4.2 Advantages of mirrors

Rearview mirrors (both in-cab and exterior) help in addressing rearward visibility problems and have also been shown to benefit operator performance and physical well-being, as Sjøflot (1980a, 1980b) documented. For instance, in one study, tractor operators who used mirrors were found to have higher working rates, better control their work, and more quickly detect faults in their equipment (Sjøflot, 1980a). Another study that included monitoring operators' heart rates found that proper application of mirrors measurably reduced perceived work load (Sjøflot, 1980b). A third study showed that without the use of mirrors a full rear view, such as when hitching, required turning the head 130° to 150°, twisting the back 40° to 50°, and rotating the neck 50° to 70°; whereas with external mirrors, twisting and turning were reduced to less than 8°, which is well within the comfort zone for a sitting posture (Sjøflot, 1980a). Comparing the benefits of operator comfort, implement fault detection, and surrounding area awareness (relating to bystander safety) to the relatively low cost of mirrors results in a low cost-to-benefit ratio.

1.4.3 Drawbacks of mirrors and potential solutions

Mirrors in general. While mirrors allow the operator to observe some objects to the rear while maintaining forward attention, seeing obstacles immediately behind the machine is difficult (if not impossible) without rotating or repositioning. Rakhra and Mann (2013) discovered that, while multiple mirrors offer increased rearward view, they may become distracting and cause excessive stress. In addition, Sjøflot (1980b) observed that mirrors smaller than 400 cm^2 (62 in^2) presented a limited field of view, even with convex glass, and concluded that the ideal size was 600 cm^2 (93 in^2), which reduced the time spent looking backward to less than 4%. Convex mirrors allow the operator to see a wider area in comparison to a flat-surface mirror but sometimes adversely distort images, making it difficult for the operator to interpret the image (Figure 1.5).

Figure 1.5. Distortion caused by convexity of the mirror surface.

Interior mirrors. Interior mirrors often demand a greater open area than is permitted by the cab design for the operator to realize the full benefit. For example, the mirror surface may be too close to the operator to maximize the viewing area. In many enclosed cabs, the operator's view in the interior mirror is obstructed by components mounted to the ceiling, such as a radio, climate controls, pull-down sunshades, and frequently the operator's own reflection (Figure 1.6).

Figure 1.6. Interior tractor mirror with cab component obstructions.

Exterior extended-arm mirrors. Improper location and mounting can significantly reduce the effectiveness of extended-arm mirrors. Extended-arm mirrors are also subject to image distortion as a result of excessive vibration, convexity, breakage, and limited viewing angles. Because they extend considerably (sometimes beyond the width of the machine), they can easily be struck by buildings, tree limbs, and other obstacles. In addition, Sap (2012) observed that, with some machines, if the extended-arm mirror bracket has been mounted on the cab corner, fully opening the cab door can cause the door to collide with the mirror, resulting in entry/exit problems. Even if the bracket has been attached to the door, similar problems are encountered, i.e., preventing the door from fully opening or rendering the mirror useless if the door is ajar, which is common in hitching situations. Lastly, manually adjusted mirrors can be very difficult to adjust, often requiring two people and a stepladder, and the adjustment must be repeated with changes in implements and/or field operations. Improper adjustment, due to the difficulty in making adjustments, can be a contributing factor to backup-related incidents, including running over a bystander.

Recommendations for extended-arm mirrors. Sjøflot (1980b) offered the following recommendations for maximizing the effectiveness, efficiency, safety, and ergonomic benefits of extended-arm mirrors on agricultural machinery: (1) the mirror size should be at least 20 X 30 cm (7.9 X 11.8 in), (2) the mirror should be rectangular with the glass properly framed and fixed, (3) convex glass should be used to give the widest field of view (to minimize image distortion, the convexity should have a radius of at least 1 m (39.4 in)), (4) to maintain a wide field of view, the distance from the mirror to the operator's eyes should be between 35 and 90 cm (13.8 and 35.4 in), (5) attachment to the machine should be firm but still allow easy adjustment of the mirror without tools, and (6) the mirror should be easy to remove or retract when not in use and should extend far enough to enable a broad towed equipment to be seen. More recent mirror recommendations for other off-highway vehicles appear to be consistent with Sjøflot's (1980b) findings, with many equipment manufacturers offering electronic adjustment of mirror position.

1.4.4 Camera monitoring systems

Camera monitoring systems offer advantages pertaining to flexibility, durability, and ease of use. At present in production agriculture, they are most commonly used for monitoring remote locations (e.g., livestock birthing barns) and on grain transport vehicles. However, camera systems have many potential applications on larger tractors and other self-propelled agricultural machinery where the operator's visibility (especially rearward) is often obstructed and blind spots exist. In addition, cameras can allow the operator to monitor the function of trailing implements during use.

Camera systems are currently in use and continue to expand in many industries, including mining, automotive and construction.

Mining industry. Machine operators in underground mining operations contend with having to maneuver of large machinery in extremely tight areas and in close proximity to coworkers. That challenge is further heightened as machine numbers, size, and payload capacity continue to increase. As with agricultural machinery, the operators of mining machinery are often isolated as well as drastically limited in terms of line of sight (Godwin et al., 2012). In their design evaluation case study of underground mining equipment in which four cameras were placed on an underground loader, the authors found that the cameras, in combination with moderate head, neck and trunk movement, essentially provided a 360° view around the machine to a standing pedestrian height.

Automotive industry. This industry is perhaps the one that's changing most rapidly relative to adoption of camera system technology. Camera are being used almost routinely for rearward object detection, full 360° view, pre-collision braking systems, adaptive cruise control, lane departure warning, pre-collision throttle management, lane sway warning, and lead vehicle movement alert. They often further assist by providing audible and visual alerts, along with automatic intervention in event of some detected hazard (Subaru, 2014; Brauer, 2014). Continued growth and development of camera system technology has the potential of completely automating transportation with fully self-driving vehicles (Google, 2016).

Construction industry. Similar to mining, this industry also often utilizes multiple large machines operated in close proximity to coworkers and other machines. Runovers and backovers account for nearly half of construction-related worker fatalities, with most incidents the result of the operator not seeing the on-foot worker or the worker being unaware of the moving equipment (Gambatese et al., 2016). The authors reported that in 55% of incident cases, the "visibility problem was due to blind spots, and in another 25% there were a variety of jobsite obstacles or visual obstructions." In a conversation with Dr. Jochen Teizer (2016) of RAPIDS Laboratory in Germany, he said that many insurers of construction operations in Europe require the use of camera and other technologies on jobsite machinery. Similar to the automotive industry, with automated intervention in response to hazard detection, camera-based 3D smart sensors are now available for direct connection to a machine's controller area network (CAN) in order to automate its reaction to detected hazards (ifm, 2016). Such smart sensors act as an extra set of eyes in monitoring blind spots by object detection and tracking in near proximity of the machinery. Continued development and improvement of such technologies are expected to markedly improve construction site working environment.

Flexibility. To allow the operator maximum visibility of difficult-to-observe areas, cameras can provide up to a 180° viewing angle, which is wider than both flat and convex mirrors. Because of easily adjusted placement, a camera monitoring system can be expanded to cover many areas of the machine simultaneously. When it comes to planting, camera systems can be used to monitor the pressure, flow, temperature, capacity, and seed levels in dill/planter hoppers or other trailing implements, as well as the functioning of spray tips and even workers on manual transplanters—all of which are typically located behind the operator (Hanson, 2016; Quinn, 2010). With regard to harvesting, a camera system can monitor simultaneously grain levels on both the harvester and the grain cart. It could also be used to monitor crop loss, presence of overheated components or fire.

Durability and small size. In general, cameras are more durable than extended-arm mirrors, which, because of their location, can easily be struck by buildings, tree limbs, and other obstacles. Cameras, on the other hand, are quite small and relatively protected where they are mounted (e.g., close to the cab or centered on a portion of the machine or accessory) and thus do not protrude. The camera housing typically provides protection from exposure to harsh field conditions.

Ease of use. Karimi et al. (2012) observed that, for rearward viewing, operators spend 33% of their time in an awkward posture, even when using auto-steer. However, if cameras are used to provide appropriate views of the machinery, it is expected that the need for turning to look rearward will be removed, or at least significantly reduced. In a study comparing direct observation, mirrors, and cameras for monitoring a rear-mounted implement (an air planter), Rakhra and Mann (2013) found the camera to have the least negative physical impact and thus was most preferred by the operators based on ease of use (97%), conveying of information (73%), mental workload (73%), and level of fatigue (97%) compared to direct observation and mirrors.

Drawbacks of camera systems and potential solutions. Common concerns regarding the use of cameras on agricultural machinery have to do with disorientation, image distortion, transmission, and cost.

Disorientation. One problem that operators have encountered when course correcting based on the video image from a rearview camera is the disorientation that can occur because “image mirroring” makes such correcting counter-intuitive. That is, similar to reading words in a mirror, correcting the course requires the opposite direction as viewed in the video image. To address these issues, some manufacturers include an option to turn mirroring on and off at the monitor, thus tailoring the video image to the demands of the application. This allows the operator to steer the machine in the same direction as the video image displayed on screen.

Depth perception. It is often difficult to estimate the distance to an object in the camera’s field of view due to the small lens, the “fish eye” effect, or the small display size. Some camera manufactures offer gridlines overlaid on the image (Figure 1.7). These gridlines allow the user to estimate the distance to objects and hazards in view. The grid lines are not necessarily calibrated distances, as the spacing between the lines changes with the mounting location, thus requiring the operator to establish a reference if the camera is positioned at a new location.

Figure 1.7. Rearview camera with a grid line depth reference mounted on UTV.

Image distortion. Image distortion can be the result of improper mounting of the camera(s), dust or contaminants, and/or signal interference. Similar to mirrors, mounting a camera on a rigid surface, stem, or arm can result in a shaky or distorted image due to vibration from the vehicle's engine or the terrain. Such distortion can be reduced by mounting the display on a surface that vibrates only at low amplitude/frequency or in sync with the driver (Mosely et al. 1986). Dust and contaminants can also distort images; however, they are relatively easy to remove. In fact, some cameras have a lens cover that automatically closes and wipes the lens clean on shutdown and/or startup. Image distortion due to signal interference is primarily an issue for cameras that feature wireless capability. Such cameras often use common radio frequencies, which are susceptible to interference from appliances, cordless phones, or items emitting radio waves (VSS, 2014). Some of the newer models of wireless cameras utilize digital transmission of data, which manufacturers claim reduces interference as compared to the analog systems of earlier models.

Wireless cameras have some unique advantages. For example, one camera can feed multiple monitors allowing, for instance, several grain cart operators to monitor the harvester’s grain tank level. However, wireless cameras generally do not have signal strength indicators, and they work best with a clear line-of-sight from transmitter to receiver (VSS, 2014). In addition, while the video signal is transmitted wirelessly, a wired power supply is needed for the transmitter, unless a battery-powered camera is used.

Cost. The cost of camera monitoring systems can vary greatly, from as little as $50 up to $500 or more. Generally, inexpensive systems (intended primarily for the automotive industry) do not have the durability required for harsh agricultural applications. Among the factors that influence cost are monitor screen size and picture quality, camera durability, and options such as night vision and wireless capability.

1.4.5 Camera and monitor mounting considerations

While permanent mounting of the camera with fasteners or adhesives is a suitable option, a temporary or movable mounting using high-powered magnets is a viable alternative for mobile applications. Many options also exist for placement of the in-cab monitor, such as window mounting with suction cups, bracket mounting, or using the monitor screens or tablet computers already present in many agricultural machines.

Many modern agricultural machines feature non-metallic body panels which limits the use of high-powered magnets for movable camera mounting. If a suitable mounting location is identified on such machinery, a small metallic plate can be adhered to the desired location with fasteners or adhesive for installation of a movable camera.

On combine harvesters, rearview cameras have been added by both dealers and operators on the unloading auger, allowing the operator to monitor unloading into the cart on the go while maintaining forward attention, even if the cart is too tall to be fully viewed from the cab. When the auger is folded back into transport mode, the camera is positioned to monitor the rear blind spots. However, no manufacturer currently provides cameras as standard equipment.

On skid-steer loaders, the best camera location appears to be above the rear engine compartment door or inside the door to monitor rearward activity through a small observation port (although this can decrease the viewing angle and expose the camera to engine compartment temperatures). This location reduces the likelihood of damaging the camera by preventing it from protruding beyond the body of the machine, as operations are often performed in tight quarters.

1.4.6 Other potential visibility enhancing systems

In addition to mirrors and cameras, other systems have potential to help solve some of the visibility-related problems of agricultural machinery. The four systems that appear to be the most applicable are auto-steer systems, back-up alarms, proximity sensors, and combination alert systems. The following are brief descriptions of these systems, their advantages and drawbacks, and why their use on agricultural machines has so far been limited:

Auto-steer systems. Comparing the use of auto-steer systems versus manual steering, Karimi et al. (2012) observed that, when monitoring an implement in tow with manual steering, the operators turned their heads (i.e., neck turn only) 28% of the time, compared to 13% when driving with auto-steer. In addition, with manual steering, the operators changed their visual focus almost every two seconds; with auto-steer, this duration was increased to four seconds. One of the largest drawbacks for many agricultural businesses considering this technology involves the cost of the hardware and/or the subscription fees associated with the service.

Back-up alarms. OSHA requires machinery back-up alarms in certain industries that qualify for oversight by the agency, including construction. Specifically, OSHA regulation 1926.602(a)(9)(ii) states that “no employer shall permit equipment which has an obstructed view to the rear to be used in reverse gear unless the equipment has in operation a reverse signal alarm distinguishable from the surrounding noise level or an employee signals that it is safe to do so" (OSHA, 2014). However, agricultural enterprises with fewer than eleven employees are exempt from compliance with this regulation. In addition, backup alarm systems are not generally required, either by legislation or engineering standard, on agricultural tractors and self-propelled equipment.

Proximity sensors. A common technology in the automotive industry, proximity sensors alert drivers of objects in the path of their vehicles. These systems could, if installed, alert agricultural machinery operators to objects (including people) that are within dangerous vicinity of their equipment. Proximity sensors function by emitting an electromagnetic field, infrared signal, or radio detection and ranging (RADAR). These systems 'sense' the presence of nearby objects as signals are reflected back to the sensor. Teizer (2015) fitted construction equipment with magnetic field proximity detection systems that required the workers to wear a calibrated tag, which allowed for a customized distance that the workers could be in relation to equipment, before alerting the operator.

Many proximity sensor systems emit a beeping tone inside the cab to indicate the distance to a detected object. As that object gets closer, the beeps get faster until becoming a continuous tone when the object is dangerously close. In some applications, a visual alert is coupled with the auditory alert. Another type of proximity sensor vibrates the operator's seat when a detected object is within a hazardous distance.

However, proximity sensors may have limited application for agricultural machinery because of the false alarms they would likely generate when hitching to implements; although they could be beneficial if located where implements are not commonly attached—e.g., immediately in front or to the sides of the machine. Currently, no known application of these systems are available on agricultural equipment.

Combination alert systems. Systems developed to reduce the noise associated with the back-up alarms of multiple vehicles operating simultaneously at one location, such as a construction site, combine the function of a back-up alarm with the object-detecting ability of a proximity sensor. These systems provide audible and visual feedback to the operator for detected objects. The back-up alarm is not activated whenever the vehicle is operating in reverse but only when the proximity sensor detects an object. Manufacturers suggest that combining these two technologies reduces confusion and disorientation for workers in close proximity of heavy machinery (Preco Electronics, 2014).

RFID systems. Radio Frequency Identification (RFID) systems are made up of a RFID tag and tag reader. The reader receives data from the RFID tag, which can be passive (without battery), semi-passive (battery assisted), or active (battery powered), wirelessly through radio waves without direct line of sight. Costin et al. (2015) equipped an 83,612 m^2 (900,000 ft^2) construction site with more than 1200 workers with RFID tags and 80 strategically placed tag readers. Worker safety was improved through the ability to detect and monitor worker movement within the construction site, especially in the event of an emergency. Reader range was recorded to be between 4 and 10 m (13 and 30 ft.), depending on the readers’ antenna. This technology is currently commercially available and utilized in industries such as underground mining. RFID technology could be utilized in the agricultural industry in detecting workers in near proximity of machinery who may be in a blind spot of the operator. However, limitations of this technology would be realized in the inability to detect an object/coworker not equipped with an RFID tag. (Costin et al., 2015)

1.5 Summary and conclusions

Given the size, complexity, and speed of today’s agricultural machinery, it has become extremely important that operators are aware of the issues involved in monitoring the critical aspects of their tasks, especially tasks impacted by limited visibility, as well as the potential solutions available for addressing these issues. The occurrence of blind spots is even more problematic for operators who have limited range of motion due to arthritis, injuries, or other physical limitations.

There is a need to better understand the role that visibility plays in the frequency and severity of agricultural machinery-related injuries, especially among co-workers and bystanders. This includes the visual limitations of the operator and the visual restrictions caused by machine design and operational requirements. To assist operators of tractors and self-propelled agricultural machinery, it is necessary to provide them with tools developed for increasing their visibility and reducing dangerous blind spots. Properly positioned mirrors and cameras were found to be most beneficial for rearward object and hazard detection and were most conforming to the needs of operators. Combining the two technologies has been found to provide the greatest benefit to operators and to the safety of co-workers and bystanders.

The agricultural industry can learn much from the successes in the automotive and construction industry regarding assistive visibility and alert systems. However, the need for expanded knowledge about the assistive technologies associated with visual awareness calls for further research.

CHAPTER 2. EXAMINATION OF REARWARD MOVEMENT INCIDENTS INVOLVING AGRICULTURAL MACHINERY

2.1 Introduction

Recent attention given to rearward motion-related fatal backovers of children located in blind spots behind motor vehicles has raised the question of the impact of similar events involving large, off-highway agricultural equipment not covered by current motor vehicle regulations or OSHA standards comparable to those enforced on construction sites. A review of the general agricultural injury data found few sources that specifically address incidents involving the backover of by-standers and co-workers located in the rearward path of agricultural equipment, especially with machine designs that limit the rearward vision of the operator. Examples of machines with substantial barriers to rearward visibility include large, high horsepower 4-wheel drive and track-type tractors, combines, skid-steer loaders, and large capacity sprayers. This chapter attempts to elucidate the risks associated with the rearward travel of these machines, identify similarities in documented incidents to aid in understanding contributing factors, and identify possible solutions to reduce future occurrences. Specific case studies are summarized and recommendations are provided, including the installation of rear-travel alarm systems, remote cameras and monitoring systems. The necessity of operator walk-arounds prior to moving large machinery is also addressed.

2.2 Background

An extensive review of the literature was conducted that included published data related to runover incidents involving motor vehicles, construction equipment, loading docks, and agricultural equipment. Key causative factors and recommended operator practices were identified that could have application to agricultural settings. Case studies were developed from documented incidents that reflected the most frequent type of incident. The following is a summary of what was found.

No publically accessible research was identified that specifically reported on the frequency and severity of injuries associated with rearward travel of agricultural equipment. A review of data sources that distinguished between types of agricultural machinery incidents found none that separated out rearward runovers from the broader category of "runovers".

Even though the problem of rearward runovers has been well understood in the mining and construction industry for several decades, this understanding cannot be documented as having transitioned to agricultural workplaces. For example, OSHA standards have for many years required backup alarms on equipment used at manufacturing and construction sites. However, agricultural equipment is generally exempt from those requirements. Almost no agricultural equipment currently being sold comes equipped with audible back up warning devices, even though similar equipment, even manufactured by the same manufacturer, sold in the European market is generally sold equipped with these devices due to European health and safety standards (Conversation with Dr. Teizer, 2016).

The agricultural industry ranks as having the highest fatal work injury rate with 22.2 people per 100,000 full-time equivalent workers by the U.S. Bureau of Labor Statistics (BLS, 2014). Exposure to agricultural equipment has been identified as the primary cause of most fatal farm work related fatalities (BLS, 2014). Of these incidents, runovers have been identified as the second most frequent type of fatal incidents preceded only by tractor rollovers (NIOSH, 2014). In most runovers, the victim fell from the machine and was runover by either the primary power source or the trailing implement. However, in some cases, it was documented that a co-worker or bystander was runover when the operator failed to see the victim before initiating movement of the machine.

2.3 Methods

Cases identified in this document were categorized to only contain rearward incidents that were not a result of mechanical malfunction (i.e., failing clutch, brakes, hydraulics). With these criteria, cases were isolated that identified operator error relating to poor visibility as the key contributor to the incident. A review of more than 100 runover incidents documented from online sources and farm-related injury data identified 27 cases that met the criteria for rearward runovers and were analyzed and categorized by incident type (Table 2.1).

Table 2.1. Summary of reviewed incident cases.

Industry	Machine type	Incident Description	Scenario # (1-3)
Agriculture	Tractor	Operator fell from tractor and was backed over	3
Agriculture	Tractor	Operator backed over embankment	3
Agriculture	Skid steer	Operator backed over victim while exiting building	2
Agriculture	Tractor	Operator backed over assistant	1
Logging	Tractor	Operator backed over unknown coworker	2
Industrial	Tractor	Operator unloading cargo backed over unknown coworker	2
Agriculture	Tractor	Operator using loader attachment backed into tree	3
--	Tractor	Operator backed over victim's leg	1 or 2
Industrial	Tractor	Operator backed over assistant while hitching implement	1
Construction	Tractor	Operator backed over unknown coworker	2
Agriculture	Tractor	Operator backed over assistant while hitching implement	1
Landfill	Compacting tractor	Operator backed over unknown victim	2
Agriculture	Tractor	Operator backed over unknown child	2
Agriculture	Tractor	Operator backed over embankment	3
Agriculture	Tractor	Operator backed over unknown child	2
Agriculture	Tractor	Operator backed over assistant while hitching implement	2
Agriculture	Tractor	Operator backed into stationary hazard	3
Agriculture	Cotton module transport	Operator backed over assistant while positioning equipment	2
Construction	Skid steer	Operator backed over embankment	3
Construction	Front loader	Operator backed over unknown coworker	2
Agriculture	Pickup truck	Operator crushed assistant while hitching wagon	1
Construction	Skid steer	Operator backed over unknown coworker	2
Landfill	Compacting tractor	Operator backed over unknown coworker	2
Construction	Front loader	Operator lost visual contact and backed over assistant	1
Construction	Grader	Operator backed over unknown coworker	2
Agriculture	Truck/trailer	Operator crushed assistant while positioning trailer	1
Agriculture	Tractor	Operator backed over coworker servicing implement	2

Though not by any means comprehensive, these cases provided sufficient data for analysis and to gain a better understanding of the issues. This review revealed that the cases documented could be generally categorized into one of three scenarios:

1. *Machinery operator losing visual contact with a known assistant during reverse motion, resulting in a runover or crushing incident*
2. *Machinery operator with no knowledge of a bystander to the rear resulting in an incident*
3. *Incidents involving only the machinery operator while traveling in reverse into a stationary hazard*

Of the cases reviewed, three were selected for inclusion that represented each of the most frequent types of incidents. Locations and identities of the victims were excluded for privacy reasons.

Scenario 1: Machinery operator losing visual contact with a known assistant during reverse motion, resulting in a runover or crushing incident.

On May 3rd 2013, an 81-year-old man died after being backed over by a tractor operated by a 68-year-old operator. The victim was assisting with the hitching of a mowing attachment when the operator lost visual contact as the assistant lost his balance and fell. The county coroner said, “He was crushed when the tractor backed over top of him. He died instantly.”

Scenario 2: Machinery operator with no knowledge of a bystander to the rear resulting in an incident.

On September 9th 2010, a 1-year old child died after being backed over by a tractor operated by his father. The victim was playing nearby with other children under supervision of their mother. The father was operating a tractor doing landscaping around their home. The victim’s mother briefly walked away and the victim, unbeknownst to the father, stepped in the space behind the tractor resulting in the incident.

Scenario 3: Incidents involving only the machinery operator while traveling in reverse into a stationary hazard.

On November 2nd 2014, a 65-year-old man was moving a round hay bale with a tractor in reverse and could not see an aluminum round-bale feeding ring behind him because of the bale obstructing his view. County sheriff spokesman said, "..when he backed up, he mistakenly rolled over it (the bale feeding ring). The pipe then sprang off the ground and struck him in the head." The individual's wife was present, but nothing could be done to revive him. He was pronounced dead at the scene.

2.4 Recommendations

Recommendations from Fatality Assessment and Control Evaluation (FACE) reports produced by the National Institute for Occupational Safety and Health (NIOSH) are generated during each incident investigated (a. FACE, 2015). The most prevalent recommendations made by the investigators of these case studies involved the notification of bystanders, information available to the operator, execution of proper safe working practices, and the use of barriers and technologies to reduce or eliminate runover incidents.

Of the three incident scenarios identified, recommendations were collected from FACE and PAMI that address causative factors. These recommendations were compiled based upon all cases reviewed in addition to the three studies documented in this paper.

Scenario 1 Recommendations:

1.) *Operator should <u>stop</u> immediately upon losing visual contact with assistant (e. FACE, 2002)*
2.) *Proper hitching methods should be followed; (PAMI, 2011)*
3.) *Assistant should maintain safe distance outside the path of the tractor/implement and direct operator using hand signals for proper alignment (a. ASAE, 2004)*
4.) *Tractor should be put into park and/or engine shut off when assistant approaches area to complete hitching (PAMI, 2011)*
5.) *Additional assistive viewing devices, such as mirrors and cameras, should be utilized to eliminate blind spots in dangerous proximity of machinery (a. FACE, 2015)*

Scenario 2 Recommendations:

1.) *All individuals in proximity of machinery should be informed of dangers associated (training, machine spotter, alarms) (c. OSHA, 2015)*
2.) *Additional assistive viewing devices, such as mirrors and cameras, should be utilized to eliminate blind spots in dangerous proximity of machinery (a. FACE, 2015)*
3.) *A backup alarm system would alert individuals of reversing machinery (a. OSHA, 2015)*

Scenario 3 Recommendations:

1.) *Additional assistive viewing devices, such as mirrors and cameras, should be utilized to eliminate blind spots in dangerous proximity of machinery (a. FACE, 2015)*
2.) *Tractors should be equipped with a roll over protective structure (ROPS). The addition of a canopy can protect operator from elements and offer additional structure of protection (b. ASAE, 2004)*

All three scenarios share the recommendation of increasing the ability to notify individuals involved with or nearby machinery processes. There are two groups of individuals who require notification of hazards in proximity of operating machinery: the operator and the bystanders. Notification of these two groups is generated via very different practices and technologies. Bystanders must remain alert at all times and are reminded of the dangers of operating machinery by backup alarms (if equipped). However, these alarms provide no benefit to the operator. They can actually be distracting or overpower sounds the operator needs to hear. Backup alarms are often disabled, not repaired if malfunctioned, or become overwhelming/disorienting in locations of multiple operating machines (d. FACE, 1998). However, they still remain the best option of notifying individuals in the area of operating machinery. OSHA standards requiring many of these safety devices and operating procedures are not enforceable on agricultural operations that employ 10 or fewer people currently or within the previous 12 months (b. OSHA, 1998).

Operators rely on multiple avenues of detecting hazards in the areas in close proximity to their machine. A FACE report of an incident involving a rearward runover in 1992 recommended the need to equip "machinery with devices to eliminate blind spots behind machinery"(b. FACE, 1992). While technology has advanced considerably since 1992, the application of devices to "eliminate blind spots behind machinery" has advanced very little. Current technology best suited to assist an operator in observing surrounding areas of the machinery are multiple mirrors (both internal and external extended arm models), proximity detectors, and cameras with a large display.

Mirrors are reliable, inexpensive, and relatively robust, when attached to breakaway mounting fixtures. They do possess multiple shortfalls such as image distortion, difficulty in proper adjustment (manually adjusted extended arm types) and the existence of blind spots within close proximity of the machinery. Image distortion is caused by one of three contributors: vibration, convexity, and foreign material collection (Sjøflot, 1980). Proper adjustment of external extended arm mirrors is often a time consuming difficult task requiring two individuals (or one while implementing a guess and check method). Improper adjustment of mirrors does not allow for sufficient view of critical areas and has been shown to be a key contributor to rearward travel incidents. Even with properly adjusted mirrors, the continued presence of blind spots is extremely hazardous, especially in close proximity to the vehicle and the hitching area of most self-propelled agricultural machines.

Lund (2011) found that “whilst the (tractor) driver can make allowances for the poor frontal vision, and possibly the rear visibility on either side of the tractor is close to zero, mirrors help but it is easy for a bicycle or motorcycle to be completely out of vision.”

Proximity detectors utilized in the automotive industry allow for the detection of an obstacle within a calibrated range of the sensor. These sensors can however offer false readings in applications of varying terrain and must be deactivated when an implement is in tow. While some industrial applications of proximity sensors are feasible, agricultural applications are limited and not likely the best avenue for preventing rearward travel incidents.

OSHA standard 1926.21(b)(2) says "The employer shall instruct each employee in the recognition and avoidance of unsafe conditions and the regulations applicable to his work environment to control or eliminate any hazards or other exposure to illness or injury". The training of employees to recognize hazards is crucial to the safe working conditions of himself and coworkers. Multiple FACE reports reviewed for this document indicated that employees were provided training and safety measures were reviewed on a regular basis. Despite training, incidents still occurred indicating a disconnect between reality and an ideal working situation.

Prior to ever moving a piece of equipment, it is recommended that the operator conduct a "walk-around" of his self-propelled machinery and any implement hitched, or in the process of hitching, to identify hazards that may not be visible from the operator’s station

(PAMI, 2011). Proper hitching methods involve the use of American Society of Agricultural and Biological Engineers (ASABE) hand signals for an assistant to guide the operator into position while the assistant is outside the path of the moving machinery (ASAE, 2004). When the vehicle reaches close proximity to the hitching point it should be put into park and/or shut off the engine and remove the key. The assistant then makes any adjustments necessary and returns to their position outside the path of the moving machinery and proceeds to direct the operator to finalize the hitching process. Hitching is a dangerous process. If proper procedures are not followed, assistants are put into harms way between the machinery and implement. Also, vital to the safety of individuals involved is the steadiness of the implement being hitched. If the implement is not stable, it can be bumped and become dangerous if it collapses. Wheels of the implement should be chocked or the brake set, if parking break is equipped, to prevent unintended movement of the implement. Lastly, it is recommended to equip implements with hitches that accommodate adjustments for misalignment to reduce the need of an assistant to stand in dangerous proximity between the vehicle and implement during hitching (FACE, 2005). These accommodations are available in many forms such as telescopic tongues on wagons/trailers, telescopic arms, as well as lateral and vertical adjustability on a 3-point hitch, and lastly tapered/wedge shaped guides often used on quick hitches to guide alignment of implements without intervention of an assistant. Utilizing accommodating technology to assist in hitching greatly reduces or eliminates the physical intervention of an assistant, assuring a safe hitching procedure.

2.5 Conclusion

Understanding incidents involving rearward travel of agricultural machinery is problematic due to broad categorical classification of "runover" incidents by recording agencies and the lack of reporting in general. However, investigation of identified incidents involving the rearward travel of agricultural machinery revealed common factors that contributed to fatalities resulting from the operator's inability to maintain visual contact with a known assistant, identify the presence of an unknown bystander in dangerous proximity, or identify a stationary hazard. All three scenarios share the commonality of the inability of the operator to visually recognize or maintain a visual connection with objects or persons in dangerous proximity of a reversing machine. More data is necessary to fully understand the complexity of rearward backover incidents. The reduction of future occurrences could involve modifications of equipment or the addition of aiding technologies such as properly positioned mirrors, cameras, proximity sensors and/or backup alarms, allowing the operator and bystanders to be more informed of hazards in close proximity of their location.

CHAPTER 3. GOAL AND OBJECTIVES

The goal of this research was to improve the safety of agricultural machinery by which the operators' ability to assess the rearward area for hazards and implement monitoring. The objectives of this work were the following:

Objective 1. Complete a summary of a review of the literature related to operator vision including works associated with machine monitoring and methods for enhancing vision during rearward machine travel. Special consideration was given to research that addressed personal injuries and property damage occurring during rearward travel.

Objective 2. Summarize the types of incidents that occur due to the operators’ inability to view or monitor blind spots to the rear of agricultural machinery. This included documentation of actual case studies involving each type of incident.

Objective 3. Identify and document rearward blind spots associated with selected agricultural machinery with regard to the ability of the operator to observe and identify hazards of various heights within a constructed field of vision. Both enhanced vision technologies, such as mirrors and cameras, were assessed.

Objective 4. Evaluated key factors, including design characteristics and operator physical limitations, that impair rearward visibility on the selected agricultural machinery with known blind-spots.

Objective 5. Develop recommendations for standards and best practices involving “Danger” labeling and its application, as well as methods for assessing rearward visibility of indirect viewing technologies.

CHAPTER 4. METHODS OF COLLECTING AND ANALYZING REARWARD VISIBILITY DATA FOR AGRICULTURAL MACHINERY: HAZARD AND/OR OBJECT DETECTABILITY[2]

4.1 Abstract

Recent interests in rearward visibility for private, construction, and commercial vehicles; and documentation of rearward runovers involving bystanders outside the field of vision of the operators of vehicles led to an investigation into the need for enhanced methods of rearward visibility for large, off-highway, agricultural equipment. A review of the literature found limited relevant research and minimal data on incidents involving rearward runovers of bystanders and co-workers. This article reviews the findings regarding the methods identified and tested to collect and analyze rearward visibility data, from the operator’s perspective, on large self-propelled agricultural equipment, including 4-wheel drive tractors, combines, and agricultural sprayers, and skid-steer loaders, increasingly found on agricultural production sites. The methods identified, largely drawn from research conducted on private and commercial vehicles, were tested to determine their application in identifying rearward blind spots. These methods are described and the findings from field-testing of specific machines are provided. Recommendations include the need to explore the benefits of establishing an appropriate engineering standard

---

[2] Submitted for publication January 2016 to Journal of Agricultural Safety and Health.

regarding rearward visibility of agricultural equipment with limited rearward vision and the use of rearward alarm systems for warning bystanders of rearward movement.

4.2 Introduction

In the early days of mechanized agricultural production, monitoring the area around one’s tractor and trailing implement was not too difficult. The equipment was relatively small, traveling speed slow, and width at most only a few feet to either side of the machine. In addition, on most tractors, the operator’s station was typically rather high up, open and unobstructed, often behind the rear axle, and on some models offset from its centerline (to aid in row-crop cultivation)—all of which helped maximize surrounding area visibility, including rearward, and allowed the operator to see, track, and quickly respond to individual tasks as they were being performed (Figure 4.1).

Figure 4.1. Farmall A featuring Culti-Vision; Offset frame design allowed for increased operator view of the specific task (Antique Farming, 2016).

While technological advances today allow the operator to monitor, diagnose, and automate many machine operations, which have contributed significantly to greater productive capacity requiring less manual labor, visibility issues related to agricultural machinery still rely almost entirely on the operator. For example, the standard modes of observing a machine's rearward area involve either the operator turning his head or body well more than 90° from a forward posture or relying on rear view mirrors located in front of the operator. Physical rotation of the operator, even with the use of rotary seats, is a distraction from the forward operation of the tractor, but may also be impaired due to being beyond the operator's physical limits (especially for operators with a limited range of motion). Physical rotation of the operator’s body may also not provide a sufficient field-of-view to assure complete observance of all obstacles that may be in close proximity. Such reduced monitoring capability has led to injury (even death) to operators or bystanders, damage to equipment and property, inefficient machine function, and reduced productivity (Rakhra & Mann, 2013; Karimi et al., 2012; CDC, 2002).

4.3 Research focus and objective

The focus of this study was to develop methods for collecting and analyzing rearward visibility data for agricultural machinery; creating a platform from which to identify problem areas of insufficient or completely unobservable locations in the immediate proximity of the machine. It was determined that the results of this research would contribute to development of more effective work practices, equipment design, and assistive aids that could enhance operator visibility and improve efficiency in addition to reducing the risk of injury.

One objective of this study was to identify and document rearward blind spots associated with selected agricultural machinery with regard to the ability of the operator to observe and identify hazards of various heights within a measured field of vision. Both normal vision and enhanced vision technologies, such as mirrors and cameras, were assessed.

4.4 Review of literature

A review of documented reports identified primarily bystanders but also operators as the ‘victims’ in incidents involving the rearward travel of agricultural machinery. Lund et al.

(2011), in an evaluation of modern tractor cabs, concluded that “The majority of the area around the modern tractor is a zone of invisibility creating a potential trap.” NIOSH FACE reports documented losses included injury, death, and property damage. It should be noted that the documentation of minor injuries and property damage are believed to be significantly under-reported, if reported at all. There are currently no reporting requirements for injuries occurring on farms exempt from OSHA standards. Thus, all case studies documented by the author involved severe injuries or death of the victim as primary outcomes (Ehlers et al., 2015).

Currently, there is no known published data on the economic impact that reduced visual monitoring has on agricultural operations or the contributions that impaired or obstructed operator vision has on the frequency or severity of agricultural workplace injuries. Nearly all incidents reviewed through case studies can be categorized into one of three scenarios described in Chapter 2—(1) machinery operator losing visual contact with a known assistant during reverse motion, resulting in a runover or crushing incident; (2) machinery operator with no knowledge of a bystander to the rear, resulting in a runover or crushing incident; and (3) incidents involving only the machinery operator while traveling in reverse into a stationary hazard.

Accessible agricultural industry-specific data related to the significance that impaired rearward visibility has on safety and productivity is limited or non-existent beyond being identified as a key contributor to rearward travel incident case studies. In some of these studies, the research findings appear to be considered proprietary. There are no engineering or mandatory safety standards pertaining to quantifiable values of acceptable rearward visibility for agricultural manufacturers to comply with, nor are there standardized methods for evaluating and collecting such data. However, ISO Standard 5721, “Agricultural Tractors—Requirements, Test Procedures, and Acceptance Criteria for the Operator’s Field of Vision, Part 2” does focus on testing procedures for rearward visibility, but does not evaluate the assistance that indirect viewing technologies provide (ISO. 2013). The American National Standard Institute (ANSI) is a member of the International Standards Organization (ISO) and may adopt identical or modified ISO standards into an American National Standard by following ANSI adoption procedures (ANSI, 2007). Advancements in both standards and technologies designed to reduce rearward runovers while operating on-highway motor vehicles are being rapidly adopted in the automotive industry. Fueled initially by public opinion and now by legislative action, automotive manufacturers must meet government standards of rearward visibility, employing numerous investments of visibility and object detection technology.

Common practice in nearly every industry involving self-propelled vehicles calls for evaluating the operator’s ability to detect nearby hazards, including and especially those to the rear. The U.S. Department of Labor’s Occupational Safety and Health Administration (OSHA), the U.S. Department of Transportation’s National Highway Traffic Safety Administration (NHTSA), and the Society of Automotive Engineers (SAE) all have—or have proposed—methods and standards of visibility evaluation for vehicles qualifying for oversight. However, agricultural businesses with 10 or fewer employees are not required to use equipment and practices that comply with any of the above agency/organization regulations (OSHA, 1998).

The American Society of Agricultural and Biological Engineers (ASABE), which is responsible for development of many agriculture industry standards, does not currently require a quantifiable level of visibility or have a standard mode of evaluating the area of visibility (including rearward) for agricultural machinery. Hence, modifying the modes of testing used in other industries in order to better understand the hazardous blind spots of agricultural machinery would at least lay the groundwork for improving the safety of agricultural workers and bystanders. SAE International has published a standard specific to earthmoving machinery (Standard J1091_201311, "Earthmoving Machinery—Operator's Field of View); however, this standard does not take into account the use of implements in tow or any "operational movements of working tools" (SAE, 2013). Similar to SAE's standard, ISO Standard 5721also utilized a 12-meter (39 foot) radius circle from the reference point of the operators seated position (ISO, 2013). Both SAE J1091 and ISO 5721 produce a 2D visibility schematic of which measured obstructed area must be within allowable tolerances set by the respective agency.

The Research, Development and Education for Leaders in Safety and Technology (RAPIDS) Laboratory developed a novel approach of 3D spot measurement, which computes 3D volumetric blind spot data (as opposed to the 2D data generated by ISO and SAE standards). Also utilizing a12-meter (39-foot) circular test area, the RAPIDS method eliminates the use of manually calculated shadow obstructions of the machinery though utilizing point cloud data (Teizer, 2013). The 3D data collected via the RAPIDS method allows for 2D analysis of SAE and ISO standards in addition to analyzing object detection dependent upon height.

4.5 NHTSA's on-highway vehicle rearward visibility test procedure: a potential model for agricultural machinery?

The NHTSA-crafted Cameron Gulbransen Kids Transportation Safety Act of 2007 proposed an expansion of rearward visibility for all passenger cars, trucks, minivans, buses, and low-speed vehicles with a gross weight of up to 10,000 pounds (motorcycles and trailers exempt). This directive was designed to ensure that drivers can see directly behind their vehicle when in reverse (2007, NHTSA). The act was signed into law on Feb. 28, 2008, with it taking full effect on May 1, 2018. In personal correspondence with NHTSA officials in Fall 2014, it was confirmed that, although procedures to validate qualifying vehicles were still in the testing phase, they will closely resemble those pertaining to vehicle mirrors, reported in FMVSS No. 111, Section 13, "School Bus Mirror Test Procedures—Rearview Mirrors (USDOT, 1999).

One portion of the new law that would be especially applicable to agricultural machinery is Federal Motor Vehicle Safety Standard 49 CFR Part 571, titled "Rearview Mirrors;"' and Part 585, titled "Low-Speed Vehicles Phase-In Reporting Requirements" (USDOT, 2011). Both 571 and 585 outline the proposed testing procedures for validating rearview cameras, which address the following:

4.5.1 Visibility relative to the operator

A reference point proposed is intended to simulate the location of a 50th percentile male driver's eyes when glancing at the rearview image (Figure 4.2).

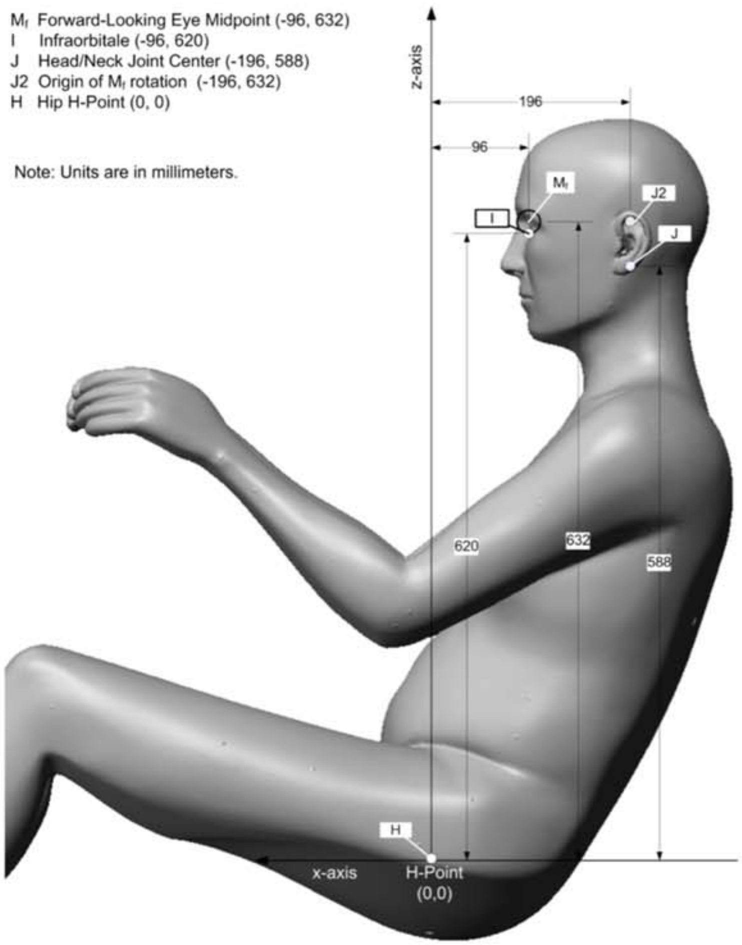


Figure 4.2. Coordinates of the forward looking eye midpoint (MF) and joint center (J) of neck/head rotation of a 50^{th} percentile male driver with respect to the H-point (H) in the Sagittal body plane (USDOT, 2011).

Based on observations of drivers using rearview video systems in NHTSA testing, it is assumed that, for visual displays located in the vicinity of the center console or interior rearview mirror, the driver will turn his head to look at the display with little or no lateral eye rotation. Anthropometric data from the NHTSA-sponsored study of the dimensions of the 50th percentile male drivers seated with a 25º seat-back angle give the longitudinal and vertical location with respect to the H point.

4.5.2 Visibility relative to the rearward grid

Through evaluation of rear pedestrian collisions, NHTSA determined that the highest risk is concentrated to a 10-foot-wide area centered to the rear of the vehicle; that the longitudinal range (i.e., length) was the distance a vehicle traveled before contacting a pedestrian (Figure 4.3). In this study the NHTSA determined that 77% of special crash investigation backover cases the vehicle traveled 20 feet or less (Figure 4.3). (USDOT, 2011)

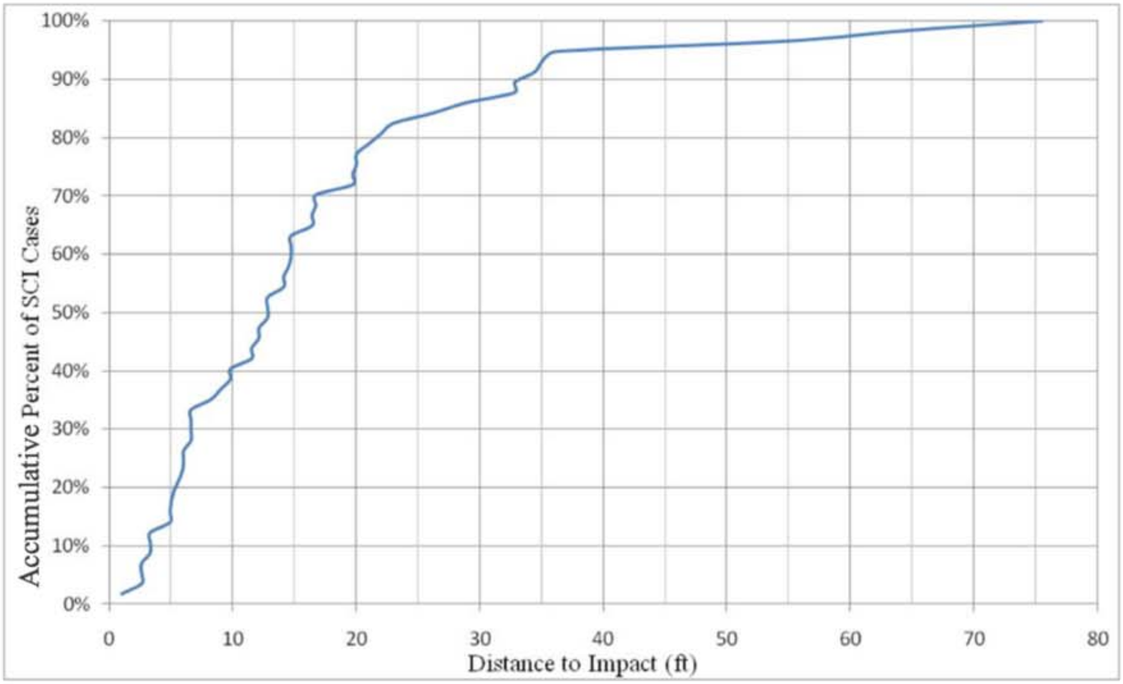


Figure 4.3. Percent of special-crash investigation (SCI) backover cases as a function of distance to impact (revised) (USDOT, 2011).

Based on this case-study evaluation, to meet sufficient levels of visibility, a rear-viewing camera must allow for the operator to detect seven objects (indicated by letters A-G) that are placed on a grid 6.1 m (20 feet) long, 3 m (10 feet) wide and centered on the rear-most location of the vehicle (Figure 4.4).

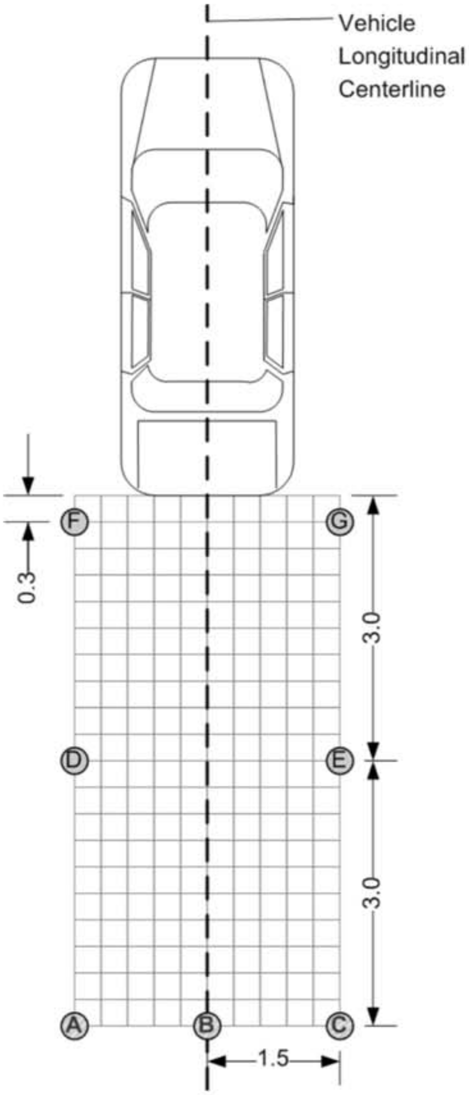


Figure 4.4. Countermeasure performance test area illustration and required test object locations (USDOT, 2011).

The seven objects are cylinders 32 inches tall and 12 inch in diameter. Those closest to the vehicle (Objects F and G) are to have 5.9-inch vertical stripes of different colors to represent the head size of an 18-month-old child, while Objects A-C are to have a 5.9-inch color-contrasting band surrounding the perimeter of the upper portion of the cylinder. (USDOT, 2011)

4.5.3 Visibility relative to the camera

The NHTSA recommends that a minimum of 130º horizontal-angle camera be installed on the rear of the vehicle to allow for sufficient viewing angle, although a 180º horizontal-angle camera was also tested and found to offer improved viewing angles close to the vehicle (Table 4.1). The NHTSA proposes that camera durability and performance meet current minimum requirements for exterior lamps of highway vehicles, tested in accordance with ASTM B117-73, Method of Salt Spray (Fog) Testing, for a total period of 50 hours. This test is comprised of two identical periods of 24 hours of exposure followed by 1 hour of drying time at high and low humidity levels and varying temperature ranges. At the conclusion of the test, all external components must meet the visibility and field-of-view requirements. (ASTM, 1979)

Table 4.1. Summary of overall effectiveness values by system type (USDOT, 2011).

System	F_A	F_S	F_{DR}	**Final Effectiveness $F_A x F_S x F_{DR}$=FE**
180º Camera	90%	100%	55%	**49%**
130º Camera	76%	100%	55%	**42%**
Ultrasonic	49%	70%	7%	**2.5%**
Radar	54%	70%	7%	**2.7%**
Mirrors	33%*	100%	0%**	**0%**

*F_A for mirrors is taken from separate source due to lack of inclusion in the SCI case review that generated F_A for cameras and sensors.

** F_{DR} for mirrors is taken from a small sample size of 20 tests. It is 0% because throughout testing, drivers did not take advantage of either cross-view or lookdown mirrors to avoid the obstacle in the test.

4.5.4 Visibility relative to image display

The NHTSA proposes a display capable of showing image sizes of at least 5 minutes of arc for Objects A, B, and C (Figure 4.4), and individually not less than 3 minutes of arc. Image size specifically relates to these three objects due to their farthest positioning from the rear of the vehicle, which are inherently perceived as the smallest in the display image. The NHTSA further proposes that ‘image lag time’ be limited to no more than two seconds, calculated from the time the vehicle's transmission is shifted into reverse gear to when a rear image is displayed on the monitor. It is believed that, given a longer lag time, drivers will be more likely to begin a backing maneuver before the image of the area behind the vehicle is displayed. ‘Image linger time’ refers to the period in which the rearview image continues to be displayed after the vehicle's transmission has been shifted out of reverse. There are two modes of determining image linger—(1) time based limit for a maximum of 10 seconds or (2) speed-based limit 8 kph (5 mph).

4.6 Agricultural machinery: rearward visibility testing methodology

Rearward visibility testing procedures for agricultural machinery were developed with strong emphasis on the NHTSA's proposed methods of validating on-highway rear-view cameras (OFR, 2014). Methods developed for agricultural machinery were utilized on numerous machines of varying configuration, size, and type. Rear view camera monitoring in agricultural applications is intended to remain functioning throughout the entire duration of operation, as opposed to being limited to the selection of reverse gear such as the automotive industry. A grid design was modified to be more conducive to agricultural applications, given the notably larger stature and comparatively lower travel speeds of agricultural equipment. Data was collected for the entire grid, however areas of most importance, identified to have the highest occurrence of runover incidents (Ehlers et al. 2015), were assigned a minimum threshold of visibility to receive a passing recommendation.

4.7 Machinery selected

From the largest agricultural equipment manufacturers in the U.S., the following nine self-propelled machines were selected as representatives of equipment with the potential of impaired rearward vision.

420-hp 4WD articulated-track tractor.

2. 360-hp MFWD row-crop tractor.
3. 310-hp MFWD row-crop tractor with 1,100-bushel grain cart.
4. 140-hp MFWD utility tractor.
5. 100-hp MFWD utility tractor.
6. 320-hp class 6 combine harvester.
7. 325-hp 1,200-gallon self-propelled sprayer (with 120-foot boom).
8. 60-hp skid-steer (with 1,850-pound operating-load).
9. 44-hp full-size side-by-side utility vehicle.

(4WD: Four Wheel Drive, MFWD: Mechanical Front Wheel Drive)

This broad representation of machine categories/types provided a sample that varied widely in size, horsepower rating, and model configuration to distinguish samples and allow for a broad representation. All nine, however, featured enclosed operator stations. A 1,100-bushel grain cart was added to the 310-hp row-crop tractor (#3) to represent implements in tow that, because of height and solid construction, completely block direct visibility—compared to implements (e.g., disks, cultivators, mowers) that permit at least some visibility.

4.8 Mirrors/Cameras utilized

4.8.1 Exterior mirrors

The components used to measure rearward visibility were the original equipment manufacturer (OEM) mirrors on machines 1,2,3,4,6,7; OEM rear-viewing camera on machine 6, VisionWorks camera kit affixed on machines 1,2,3,4,5,7,8, and a HDE camera on machine 9. The VisionWorks kit (model VWIC700) included a night-vision weatherproof camera, 7-inch color monitor, 30-foot video cable, and 12-volt power connections. The magnetic base fixture of the camera was mounted in several locations during testing, and would vary given the operation/implement in tow, however it was commonly mounted above the power take off (PTO) shield or in a central location approximately 0.9 m (3 feet) off the ground for machines without a PTO. For machine 6, the factory camera was mounted approximately 2.7 m (9 feet) off the ground centered on the rear panel. Given the operating environment of machine 6 (combine harvester), this location was necessary to reduce image distortion caused by excessive amounts of dust and debris. Machine 9 (side by side utility vehicle) was equipped with a HDE model E336 170° camera mounted centrally to the underside of the bed of the UTV, with a TFT 7-inch color display monitor. Machine 8 (skid-steer loader) was equipped with the same magnetically mounted camera utilized on all tractor tests, however camera mounting position was centered above the engine compartment door to provide shielding during machine operation.

4.8.2 Interior mirror(s)

In each machine’s enclosed cab, from the forward-facing position of the average height U.S. man, an indicator pendulum was suspended from the ceiling, marking the location of the midpoint of the operator's eyes (similar to point M_f of Figure 4.1). It was at this reference point that a 12.1 Mega Pixel Canon PowerShot model SX260 HS camera, with 20X optical and 4X digital zoom (80X combined zoom), was mounted to record the images from point M_f of all internal and external mirrors and the rearview camera *(*Figures 4.5 and 4.6*)*.

Figure 4.5. Right extended-arm mirror view of assessment grid from operators' forward facing positon.

Figure 4.6. Full view optical zoom of right extended-arm mirror from operators' forward facing positon.

4.8.3 Camera systems

A VisionWorks 17.8 cm (7 inch) color display paired with a wide angle (170°) weatherproof (Sony) camera was selected for use on all tested machines with exception of the S660 Combine, which was pre-installed with a camera system utilizing an existing monitor, and the Polaris UTV, that was paired with a 17.8 cm (7 inch) TFT dual input display and a HDE model E336 (170°) weatherproof camera. The VisionWorks system was selected as the main test system because it is an agricultural specific system designed to withstand conditions characteristic of production agriculture. The VisionWorks camera system also featured one of the highest resolutions of the advertised agricultural specific cameras systems at 700 TVL.

The display was positioned so not to impair forward visibility, and out of direct sun to reduce glare. Both the VisionWorks and TFT displays featured a sunshade to improve image clarity and were placed above or beside the steering column. Cameras utilized on all tested equipment were directly wired to the display (wireless camera systems were not tested). Power was supplied to the camera directly from the display with exception of the UTV, which was powered by a local power source available near the mounting location. Cameras were mounted in a low central location to allow for an outward view as opposed to a top down perspective, except when the function of the machine would reduce image clarity in this location i.e. combine, sprayer, and skid-steer.

4.9 Grid design/construction

Assessment of rearward visibility was achieved utilizing a grid design similar to the NHTSA proposal (Figure 4.4) but modified to make it more favorable to the characteristics of agricultural machinery. This involved altering grid dimensions to 7.62 m wide by 7.62 m deep (25 ft x 25 ft) and testing each grid cell individually, as opposed to the NHTSA method of pass/fail based upon visibility of seven key locations (Figure 4.7) (USDOT, 2011).

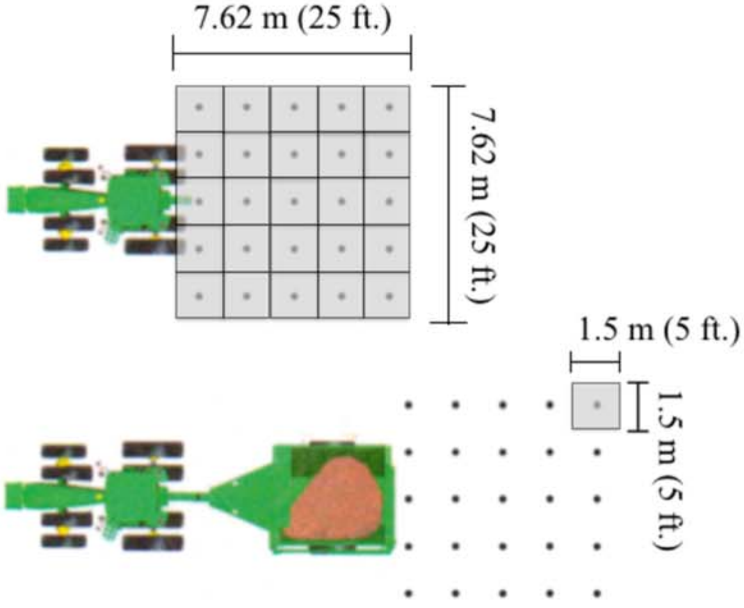


Figure 4.7. Agricultural visibility assessment grid.

Grid width was 2.5 times greater than the NHTSA grid, to accommodate the footprint of large off-road equipment; while the length was only 1.25 times greater to account for the length of some trailing implements

The grid was composed of 25 cells, each 1.52 m by 1.52 m (5 ft. x 5 ft.). At the center of every cell was a height indicator pole on which was affixed four different colored fluorescent marking flags indicating the average height of a U.S. man, woman, 10-year-old child, and kneeling worker—1.76 m (69.2 inches), 1.62 m (63.8 inches), 1.42 m (56.1 inches), and 0.61 m (24 inches), respectively (CDC, 2012) (Figure 4.8).

Figure 4.8. Agricultural machine rear visibility evaluation grid with height indicator flags.

These indicator poles were plastic fence posts with molded footsteps, and the 'flags' were 2.54 cm wide by 61 cm long (1" x 24"), florescent streamers. The precise height of each streamer was measured up from the top of the footstep and affixed at the corresponding height point. The poles at the grid's four corners were additionally identified with 183 cm (6') long brightly colored streamers. This was to reduce the difficulty in determining grid boundaries through sometimes limited views observed in mirror and display images during image analysis.

The grid was constructed beginning at Pole 3, which was positioned at the rearmost center of the tested machinery (Figure 4.9).

Machinery Side

1	2	3	4	5
6	7	8	9	10
11	12	13	14	15
16	17	18	19	20
21	22	23	24	25

Figure 4.9. Agricultural machinery rear visibility evaluation grid configuration with numbered indicator pole position.

Typically, on tractors, grid point three corresponded to the location of the drawbar. From there, a contractor's string was run perpendicular to the machine's rear tires, with the five poles positioned in 152.4 cm (5') spacing (two on either side of Post 3), forming Row 1 immediately behind the machine. To assure the grid was square, the positions of Pole 21 and Pole 25 were calculated using the Pythagorean theorem, and a string indicating the calculated hypotenuse was stretched diagonally from Pole 5 to Pole 21 and intersected with a 6.09 m (20') string stretched from Pole 1 to Pole 21 to insure proper placement of the corners. The identical procedure was followed to identify the position of Pole 25. With Row 1 and all four corner-poles in position, the contractor's string was used to insure straight alignment of all interior poles.

For every exterior-mounted mirror and camera, the visibility of all four streamers on each of the 25 indicator poles was recorded by the interior camera to be later evaluated for level of visibility from the forward-facing position of the operator. This generated 100 data points for each rear-viewing mirror and camera source.

4.10 Data collection procedure

The collected images were enlarged and analyzed using Mac iPhoto software. The lowest visible height (indicating the highest level of visibility) was recorded for each indicator pole and translated to a 5 x 5 table in Microsoft Excel, resembling the 5 x 5 grid used to collect data (Figure 4.9). A table was generated for every mirror and camera view for all nine machines. From the individual visibility-grid results, a master rearward visibility grid was generated to represent the area of visibility available to the operator utilizing all viewing modes. The Excel tables allowed for visual identification of limited or invisible locations to the rear of the tested machinery and immediate identification of hazardous area. Figures 4.10 & 4.11 represent the findings from tractor 2.

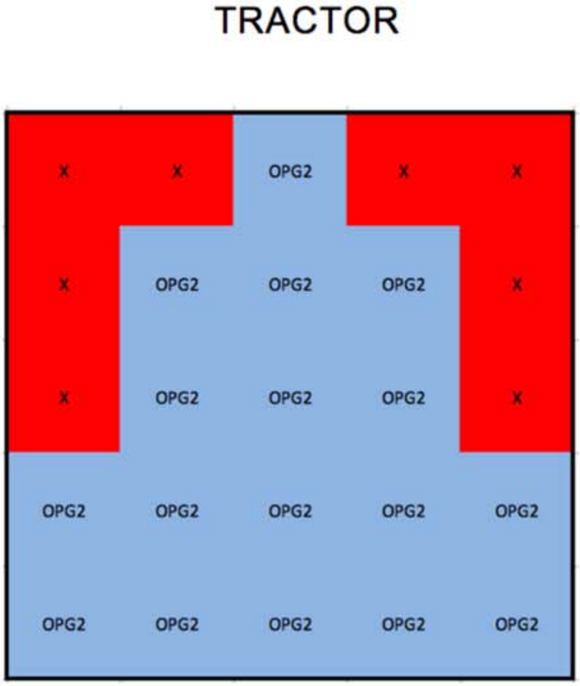
X	OP	X	X	X
X	OPG	X	X	X
X	OPG2	X	X	X
OPG2	OPG2	X	X	X
OPG2	OPG2	OPG	X	X

X	X	X	OP	X
X	X	X	OPG	X
X	X	X	OPG2	X
X	X	OPG	OPG2	X
X	X	OPG2	OPG2	OPG2

Figure 4.10. Tractor 2, left and right extended-arm mirrors.

Key for figures 10 & 11:

OPG2	**2ft** INDICATORS COULD BE SEEN
OPG	**10 YR OLD CHILD** INDICATOR FLAGS COULD BE SEEN
OP	**ONLY** MEN AND WOMEN COULD BE SEEN
O	**ONLY** MEN COULD BE SEEN
X	**NO** INDICATOR FLAG COULD BE SEEN



X	X	OPG2	X	X
X	OPG2	OPG2	OPG2	X
X	OPG2	OPG2	OPG2	X
OPG2	OPG2	OPG2	OPG2	OPG2
OPG2	OPG2	OPG2	OPG2	OPG2

Figure 4.11. Tractor 2, camera mounted above PTO shielding.

4.11 Results and analysis

Utilizing data collected, each machine received a pass/fail grade (based on the NHTSA's points A-G (Figure 4.4)) depending on the visibility of five highly hazardous locations identified through the case studies prepared by Ehlers et al. (2015). Machinery that received a passing score allowed the operator to visually monitor the 0.61 m (24") indicator of locations 2, 3, 4, 21, and 25 (Figure 4.9). Indicators 2, 3, and 4 correspond to the locations directly adjacent to the rear of the machine; with 2 and 4 in dangerous proximity of the rear tires, and location 3 corresponding to the hitching area. Locations 21 and 25 are the furthest corners from the rear of the machine. These areas did not pose immediate danger to bystanders, however requiring visibility of these locations assured viewing angles of the rear-monitoring equipment (e.g. should a camera be misaligned with an angle too vertical, locations 2, 3, and 4 could be visible, but not likely locations 21 and 25).

Statistical analysis was conducted on "fail points" of tested machinery. These non-parametric analyses represent the frequency of failure pertaining to the five pass/fail indicators and frequency of obstructed markers across all categories. Compilation of this data will assist in future monitoring technology and machine design by identifying high-risk areas with limited visibility.

4.11.1 Rearward visibility models

Visibility models were created for both tractors only and all self-propelled machinery tested. These models were composed of twenty-five pie charts overlaid on the rearward test grid corresponding to each of the twenty-five grid cells. For each grid cell, the highest level of visibility was recorded for both of the tested technologies (mirrors and cameras) for each tested machine. The incorporation of best achievable visibility of multiple tested machines of similar type allowed for rearward visibility modeling and comparison, allowing for evaluation of patterns and correlations.

4.12 Conclusion

The development of methods to collect and analyze rearward visibility data for agricultural machinery will serve as a basis for expanding the safety, productivity and wellbeing of operators and bystanders. The establishment of a standardized mode of identifying hazardous locations, and setting a standard level of acceptable visibility unilaterally adopted by machinery manufacturers will serve as a platform for advancing technologies generating un-foretold benefits.

4.13 Recommendation

It is recommended that the appropriate technical committee of ASABE or SAE review the findings and consider two standards.

1) A standard to allow for consistent objective assessment of rearward vision on self propelled agricultural equipment with the potential for blind spots. This could help identify risk factors that could be addressed in the operator's manual or warning decals on the machine.

2) A standard that would address the selection, testing, and installation of rearward travel warning systems and enhanced vision accessories including mirrors, and cameras.

CHAPTER 5. DATA COLLECTION RESULTS AND DISCUSSION

5.1 Introduction

Visibility testing procedures employed in this study focused specifically on the ability of the operator to visually identify objects and hazards within close proximity to the rear of the machine during operation. This procedure (outlined in Chapter 4) utilized methods similar to those adopted by the National Highway Transportation Safety Administration (NHTSA) to validate on-highway vehicles in compliance with visibility standards to be enforced, beginning in 2018, as well as the Society of Automotive Engineers (SAE) in standard J1091, Earthmoving Machinery- Operator's Field of View. It was intended that the data collected would identify not only common factors limiting rearward visibility, but also any changes that technological advancements in monitoring have on the operator's ability to observe objects and hazards.

5.2 Machinery tested

The agricultural machines tested included nine self-propelled vehicles—five tractors of varying sizes, a combine harvester, a sprayer, a skid-steer and a side-by-side utility vehicle (UTV). These machines were selected from 2015 dealer inventories of the largest agricultural machinery manufacturers in the U.S. Multiple self-propelled machines and tractors were not tested in the same class of vehicle due to indiscernible differences within “series” of machines, which did not affect operator station configuration with respect to rearward visibility. However, optional equipment, including various configurations of mirrors and cameras, were available in some instances and may not have been completely represented by the machines selected.

5.3 Grid labeling key

Rearward visibility was measured using an approach described in Chapter 4. Findings were recorded graphically using a 5 Cell X 5 Cell grid (Figure 5.1). Labeling of each of the 25 grid cells correlated to colors representing one of five levels of visibility and letter coded (Figure 5.2) to represent the recorded level of visibility for the specific location of the grid.

Machinery Side

1	2	3	4	5
6	7	8	9	10
11	12	13	14	15
16	17	18	19	20
21	22	23	24	25

Figure 5.1. Agricultural machinery rear visibility test grid configuration with numbered indicator position.

Indicator flags, positioned on a post at the center point of each grid cell, possessed four uniquely colored indicators of varying height representing the average size of an American male, female, 10-year-old child, and kneeling worker. Each flag was colored coded to correspond to the height indicator as coded below:

X = (Red) No flag could be seen in this grid cell

O = Orange, 1.76 m (69.2 in), representing the average height of an U.S. male

P = Pink,1.62 m (63.8 in), representing the average height of an U.S. female

G = Green, 1.42 m (56.1 in) representing an average height of an U.S. 10-year-old child

2 = Blue, 0.61 m (24 in), representing a kneeling worker

OPG2	**2ft** INDICATORS COULD BE SEEN
OPG	**10 YR OLD CHILD** INDICATOR FLAGS COULD BE SEEN
OP	**ONLY** MEN AND WOMEN COULD BE SEEN
O	**ONLY** MEN COULD BE SEEN
X	**NO** INDICATOR FLAG COULD BE SEEN

Figure 5.2. Indicator flag key representing the lowest marker visible of the measured height indicators.

5.4 1. Case Quadtrac 420 articulated track tractor

The largest of the machines tested in terms of size and horsepower, the Case Quadtrac 420 represented the broad category of articulated tractors. Basic specifications of the Quadtrac 420 are as follows (Table 5.1):

Table 5.1. Case Quadtrac 420 specifications.

Engine Power	kW (hp)	313 (420)
Trackbase	mm (in)	4064 (160)
Length (including hitch)	mm (in)	8001 (315)
Width (minimum and maximum)	mm (in)	2438-3658 (96-144)
Height	mm (in)	3843 (151)
Weight (un-ballasted, max ballast)	kg (lb)	19736-25877 (43510-57050)

The operator station is forward of the articulation point while the hitching point is located at the rear-most of the tractor (Figure 5.3). In comparison to non-articulated tractors, the operator station’s forward position introduced a lower sloped line of vision to the hitching points for direct view of the rearward area. Without the use of mirrors or camera, this presents obstacles for the operator to observe locations immediately behind the tractor.

Figure 5.3. Case IH Quadtrac 420 –Tractor positioned adjacent to rearward visibility test grid.

5.4.1 The mirrors

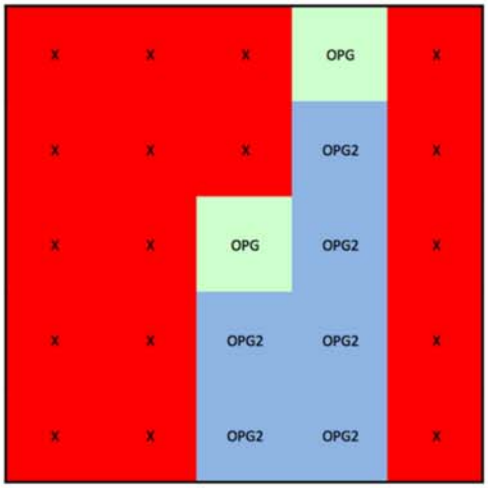
This tractor was factory equipped with two convex-curvature, external extended arm mirrors and one in-cab mirror. The mirrors for this tractor (and, in fact, all other tested machines) were positioned for maximum visibility of the grid indicators for the average sized male operator with respect to the forward looking eye midpoint (MF) as described in Chapter 4.

5.4.1.1 Right mirror

The right extended arm mirror had a convex curvature to allow for an increased field of view (Figure 5.4). Mounting hardware for in-cab monitors introduced a visibility obstruction of the left and lower sections of the mirror, preventing the operator to fully utilize the mirror without repositioning himself (Figure 5.4).

Figure 5.4. Case IH Quadtrac 420—Right extended-arm mirror view of rearward visibility test grid.

The right extended mirror of this articulated tractor allowed for a 68% obstructed view of the 58 m^2 (625 ft^2) test grid as seen by the X's (red) (Figure 5.5). Cells 3 and 8, which corresponded to the hitching location, were completely unobservable for all tested heights; and Cell 4 did not allow the operator to view the 0.61 m (2 ft.) kneeling indicator flag, which increases the likelihood of incidents in these areas.



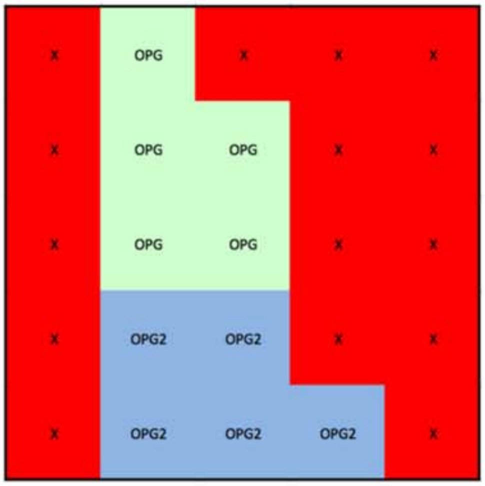
x	x	x	OPG	x
x	x	x	OPG2	x
x	x	OPG	OPG2	x
x	x	OPG2	OPG2	x
x	x	OPG2	OPG2	x

Figure 5.5. Case IH Quadtrac 420—Right extended-arm mirror rearward visibility test grid results.

5.4.1.2 Left mirror

The view of the left extended-arm mirror was unobstructed by in-cab components with the cab door closed (Figure 5.6). However, 60% of the 58 m^2 (625 ft^2) grid was completely obstructed. Cell 3 was undetectable, as so with the right extended arm mirror; and the 0.61 m (2 ft.) marker was not visible in any cell closer than 4.6 m (15 ft.) from the rear most point of the tractor (Figure 5.7).

Figure 5.6. Case IH Quadtrac 420—Left extended-arm mirror view of rearward visibility test grid.



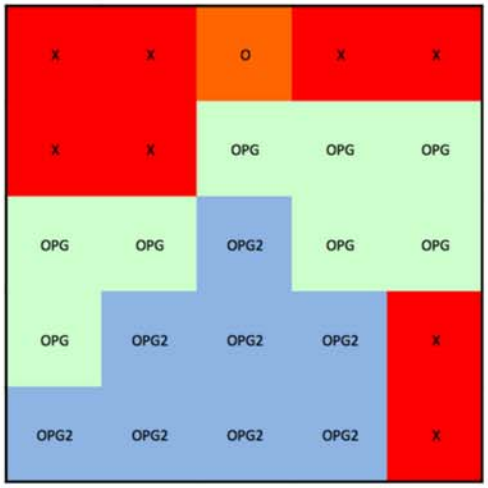
X	OPG	X	X	X
X	OPG	OPG	X	X
X	OPG	OPG	X	X
X	OPG2	OPG2	X	X
X	OPG2	OPG2	OPG2	X

Figure 5.7. Case IH Quadtrac 420—Left extended-arm mirror rearward visibility test grid results.

5.4.1.3 In-cab mirror

The convex curvature of the in-cab mirror had the highest level of visibility of the factory equipped mirrors (Figure 5.8). Nevertheless, an average sized man could be seen in Cell 3, but only if he was standing in a full upright position, while the height indicators of women, children, and kneeling markers were completely obstructed. During testing, 32% of the grid cells were obstructed. It should be noted that with both an operator, and assistant present in the cab, the level of visibility would be greatly reduced due to their silhouettes blocking part of the in-cab mirror. The in-cab mirror also did not provide any visibility for the kneeling indicator closer than 3 m (10 ft.) from the hitching point (Figure 5.9).

Figure 5.8. Case IH Quadtrac 420—Interior mirror view of rearward visibility test grid.

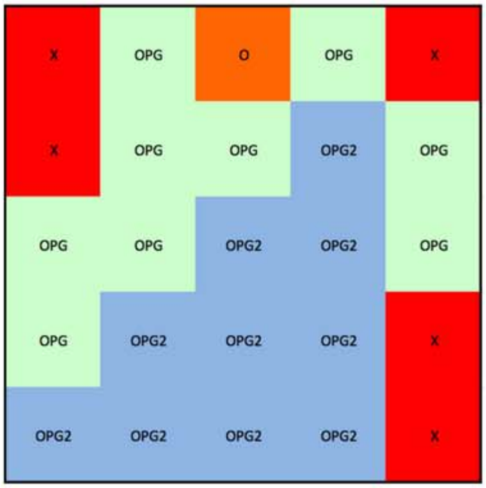


X	X	O	X	X
X	X	OPG	OPG	OPG
OPG	OPG	OPG2	OPG	OPG
OPG	OPG2	OPG2	OPG2	X
OPG2	OPG2	OPG2	OPG2	X

Figure 5.9. Case IH Quadtrac 420—Interior mirror rearward visibility test grid results.

5.4.1.4 Union of all mirrors

The overall operator visibility achieved though use of all equipped mirrors of the Quadtrac 420 was achieved via union of Figures 5.9, 5.7 and 5.5. This union depicts the potential overall visibility achieved by the factory equipped machine (Figure 5.10). However, due to limitations in the operator's field of vision, being able to view each mirror simultaneously is not possible. Obstructed view accounted for 20% of the test area with 40% of the area allowing view of the kneeling indicators.



X	OPG	O	OPG	X
X	OPG	OPG	OPG2	OPG
OPG	OPG	OPG2	OPG2	OPG
OPG	OPG2	OPG2	OPG2	X
OPG2	OPG2	OPG2	OPG2	X

Figure 5.10. Case IH Quadtrac 420—Union of all equipped mirrors rearward visibility test grid results.

5.4.2 The camera system

A VisionWorks 17.8 cm (7 inch) color display was positioned above the cab's center dash (Figure 5.11). A built-in sun shade helped reduce glare and improved the operators' ability to detect objects to the rear (Figure 5.12). A wide (170°) camera was positioned above the PTO shielding, which offered the highest level of un-obstructed visibility (Figure 5.13).

Figure 5.11. Case IH Quadtrac 420—Center dash camera monitor mounting position.

Figure 5.12. VisionWorks two input, 17.8 cm (7 in) color monitor with sunshade.

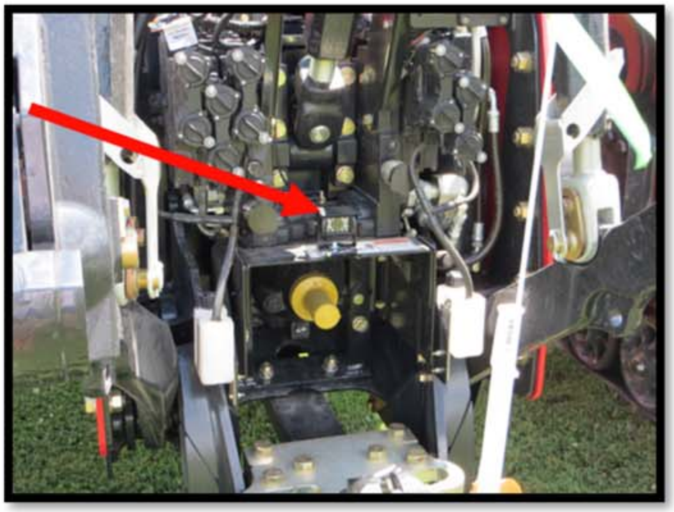
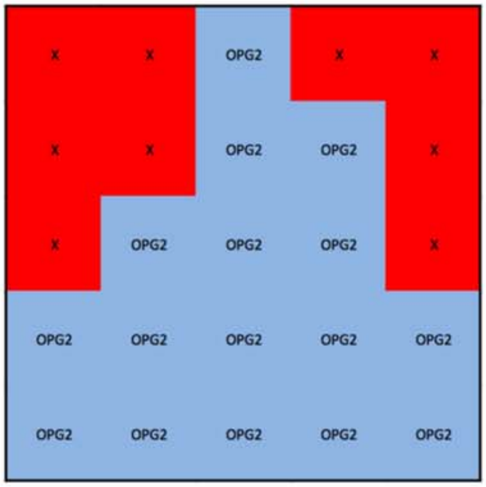


Figure 5.13. Case IH Quadtrac 420—Above PTO shield camera mounting location.

This location demonstrated the highest level of visibility achieved with the use of the camera on the Quadtrac 420, with a 36% obstructed view (Figure 5.14). The camera's low mounting height and wide lens allowed for 64% of the 0.61 m (2 ft.) indicators to be visible. Full visibility was achieved in Cell 3 which had not been obtainable with the factory installed mirrors. However, Cells 2 and 4 located behind each track were still completely obstructed.

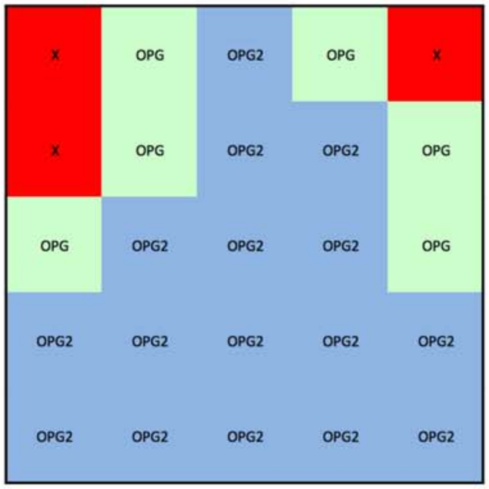


X	X	OPG2	X	X
X	X	OPG2	OPG2	X
X	OPG2	OPG2	OPG2	X
OPG2	OPG2	OPG2	OPG2	OPG2
OPG2	OPG2	OPG2	OPG2	OPG2

Figure 5.14. Case IH Quadtrac 420—Above PTO shield camera location rearward visibility test grid results.

5.4.3 Union of all mirrors and camera system

The optimum level of visibility was achieved via the union of all mirrors and camera system. This included two extend arm mirrors, one interior mirror, and one camera placed above the PTO master shield (Figures 5.5, 5.7, 5.9, 5.14). This combined affect resulted in a 12% obstructed view of the test area with 64% of the of the kneeling indicators visible (Figure 5.15). The midline of the test grid was completely visible to the kneeling level throughout the entire test area. By combining all mirrors and camera system, the width of the tractor (excluding columns 1 and 5) was visible at a minimum height of an average 10-year old child for the entire test area.

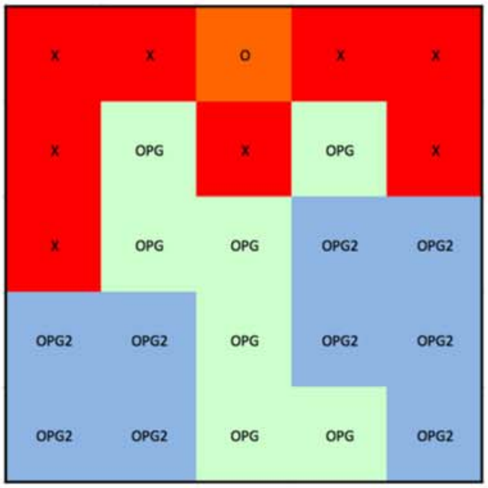


X	OPG	OPG2	OPG	X
X	OPG	OPG2	OPG2	OPG
OPG	OPG2	OPG2	OPG2	OPG
OPG2	OPG2	OPG2	OPG2	OPG2
OPG2	OPG2	OPG2	OPG2	OPG2

Figure 5.15. Case IH Quadtrac 420—Best union of all viewing mediums rearward visibility test grid results.

5.4.4 Discussion

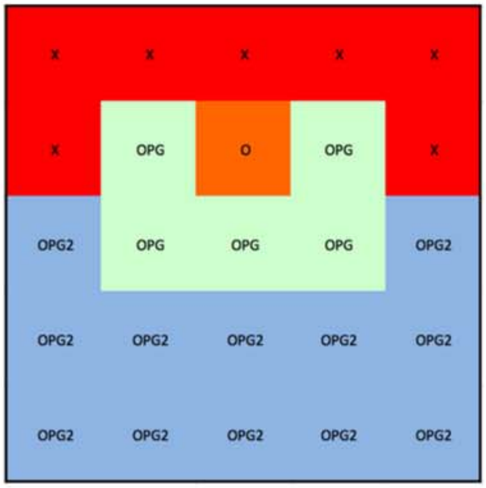
The mirrors and camera positions were evaluated individually due to the inability of the operator to look at two places at once. Multiple locations of camera placement were tested – one, atop the three-point hitch mount and the other on the rear flasher cross bar. The three-point hitch mount presented several obstacles, especially the three-point hitch top link bar, which obstructed view to areas directly adjacent to the rear of the tractor for Cells 1-5 with exception of the average-sized male indicator flag in Cell 3 (Figure 5.16). Also, there was a noteworthy difference between the three-point hitch and PTO shield locations in the kneeling indicators visible with 36% versus 64% respectively.



X	X	O	X	X
X	OPG	X	OPG	X
X	OPG	OPG	OPG2	OPG2
OPG2	OPG2	OPG	OPG2	OPG2
OPG2	OPG2	OPG	OPG	OPG2

Figure 5.16. Case IH Quadtrac 420—3-point hitch camera mount location rearward visibility test grid results.

Figure 5.17 represents the camera mounted to the rear flasher crossbar. This location provided the lowest percentage of completely obstructed view (28%), however was not selected as the best mounting location due to the inability of the operator to view Cells 1-5, which were directly adjacent to the rear of the machine.



x	x	x	x	x
x	OPG	O	OPG	x
OPG2	OPG	OPG	OPG	OPG2
OPG2	OPG2	OPG2	OPG2	OPG2
OPG2	OPG2	OPG2	OPG2	OPG2

Figure 5.17. Case IH Quadtrac 420—Flasher crossbar camera mount location rearward visibility test grid results.

5.5 2. John Deere 8360R MFWD row-crop tractor

This was the largest mechanical front wheel drive (MFWD) row-crop tractor selected in the study (Figure 5.18). Basic specifications of the 8360R are as follows (Table 5.2):

Table 5.2. John Deere 8360R specifications.

Engine Power	kW (hp)	268 (360)
Wheelbase	mm (in)	3080 (121)
Length (including hitch & weights)	mm (in)	6591 (259.5)
Width (warning lamp arms)	mm (in)	3488 (137.3)
Height	mm (in)	3285 (129.3)
Weight (un-ballasted, max ballast)	kg (lb)	14828-18000 (32691-39683)

The operator seating position proved more favorable for direct viewing (without assistance of a mirror or camera) than articulated tractor models due to a more rearward seat location and steeper viewing angles of the hitching area. Tests for this tractor included the two factory equipped extended arm mirrors and in-cab mirror, and the rear-mounted VisionWorks camera system mounted for test purposes.

Figure 5.18. John Deere 8360R—Positioned adjacent to rearward visibility test grid.

5.5.1 The mirrors

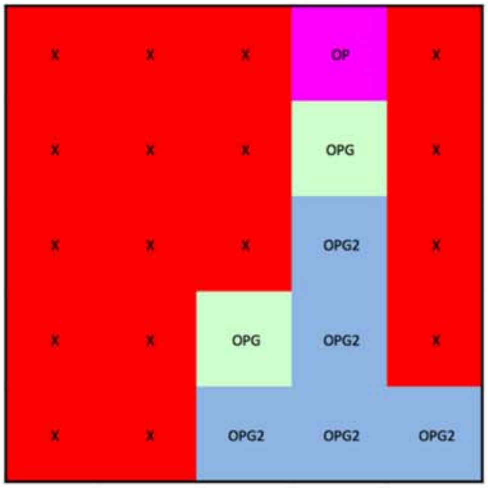
The external extended-arm mirrors of this model tractor featured electrically controlled mirror adjustments (Figure 5.19). This optional feature allowed the operator to adjust mirror positioning for the specific task being performed as manually adjusted mirrors may not be properly positioned due to the difficulty to access the mirrors or the need for an assistant to make adjustments.

Figure 5.19. John Deere 8360R—Electronically controlled external mirror adjustment.

5.5.1.1 Right exterior mirror

The right extended-arm mirror presented no obstruction from components or brackets inside the cab (Figure 5.20). However, a clear line of sight to the convex mirror offered limited rearward visibility, with 68% of the measured area obstructed (Figure 5.21) and with hazardous areas directly adjacent to hitching points (Cell 3) completely obstructed. The tractor's dual rear tires presented some obstruction of visibility at their base obstructing visibility of anything less than the average height of a woman. The mid-line of machine travel was completely obstructed from the right mirror's view as far back as 7.6 m (25 ft.) for the kneeling indicator (Figure 5.21).

Figure 5.20. John Deere 8360R—Right extended-arm mirror view of rearward visibility test grid.

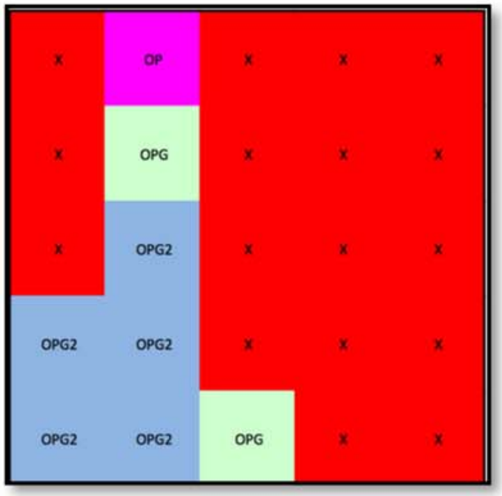


x	x	x	OP	x
x	x	x	OPG	x
x	x	x	OPG2	x
x	x	OPG	OPG2	x
x	x	OPG2	OPG2	OPG2

Figure 5.21. John Deere 8360R—Right extended-arm mirror rearward visibility test grid results.

5.5.1.2 Left exterior mirror

The left extended-arm mirror offered similar visibility levels as the right with obstructed views accounting for 68% of the 58 m^2 (625 ft^2) test area. Visibility of the mid-line of travel was completely obstructed with this mirror as far back as 7.6 m (25 ft.) with an average sized 10-year-old child being the lowest level visible (Figure 5.22). Due to this mirror's mounting location, the view of the mid-line of travel was limited due to obstruction caused by the rear cab corner post, however, relocating the mounting location of the mirror would be difficult as it would cause interference with the opening of the cab door or with operator ingress/egress.

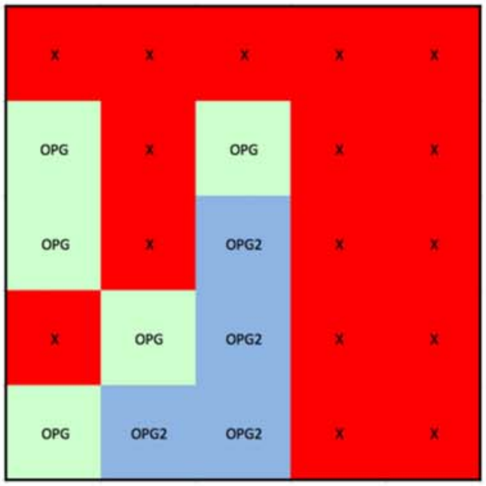


X	OP	X	X	X
X	OPG	X	X	X
X	OPG2	X	X	X
OPG2	OPG2	X	X	X
OPG2	OPG2	OPG	X	X

Figure 5.22. John Deere 8360R—Left extended-arm mirror rearward visibility test grid results.

5.5.1.3 In-cab mirror

Despite its convex curvature, this in-cab mirror provided the lowest level of operator visibility of the three factory equipped mirrors (Figure 5.23). Mid-line visibility was good at distances greater than 3 m (10 ft.) from the rear of the machine (Figure 5.23), an average sized child could be seen in Cell 8, but only standing in a full upright position. With 64% of the test grid cells completely obstructed during testing, it should be noted that with an operator and assistant seated in the in-cab instructor seat, the level of visibility would be greatly reduced by their silhouette due to the position of the in-cab mirror.

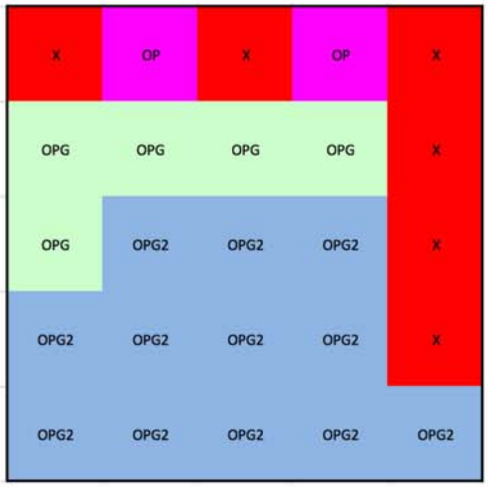


x	x	x	x	x
OPG	x	OPG	x	x
OPG	x	OPG2	x	x
x	OPG	OPG2	x	x
OPG	OPG2	OPG2	x	x

Figure 5.23. John Deere 8360R—Interior cab mirror rearward visibility test grid results.

5.5.1.4 Union of all mirrors

The overall visibility achieved though use of all equipped mirrors of the John Deere 8360R was achieved via union of the best achieved visibility levels from Figures 5.21, 5.22 and 5.23. This presented the overall visibility achieved by the factory equipped machine (Figure 5.24). Again, as noted earlier, the limited field of vision of an operator prevents full use of all mirrors simultaneously. Obstructed view accounted for 24% of the test area with 48% of the area allowing view of the kneeling indicators.

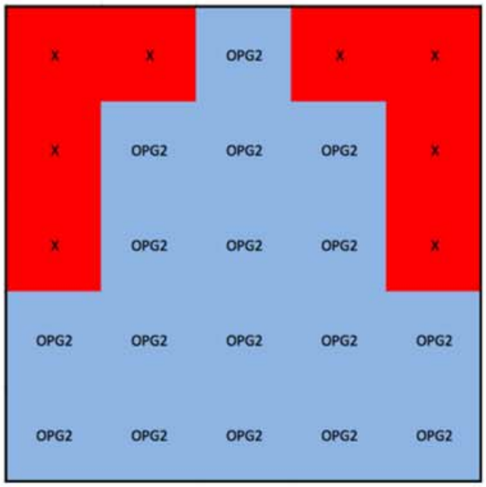


X	OP	X	OP	X
OPG	OPG	OPG	OPG	X
OPG	OPG2	OPG2	OPG2	X
OPG2	OPG2	OPG2	OPG2	X
OPG2	OPG2	OPG2	OPG2	OPG2

Figure 5.24. John Deere 8360R—Union of all mirrors rearward visibility test grid results.

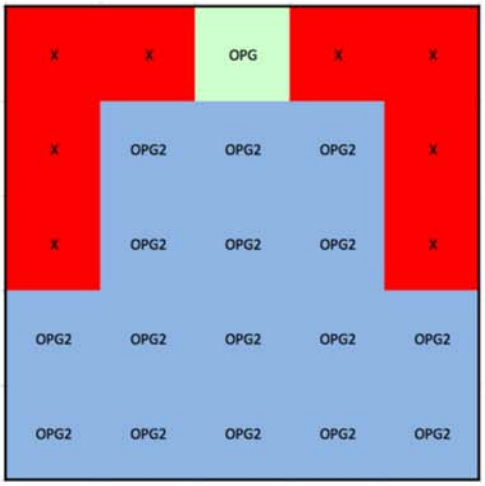
5.5.2 The camera system

A VisionWorks 17.8 cm (7 inch) color display was positioned above the cab's center dash paired with a wide (170°) camera which was tested in two locations (above the selective control valve (SCV) valve stack and above the PTO shield). The highest level of visibility was achieved with the camera located above the PTO shield (Figure 5.25). This location offered full view of the kneeling indicators over the full length of the test area with 32% of the test area being completely obstructed. However, the highest level of obstructed view associated with this camera position was Cells 2 and 4 at the base of the rear tires. In attempt to achieve a better view of areas located at the base of the rear wheels, a higher camera mounting position was selected above the SCV valve stack. Results of this location had the same level of completely obstructed view (32%). Cell 3 visibility was reduced so as to not include the kneeling indicator, and was thus deemed as not beneficial to the operator (Figure 5.26).



X	X	OPG2	X	X
X	OPG2	OPG2	OPG2	X
X	OPG2	OPG2	OPG2	X
OPG2	OPG2	OPG2	OPG2	OPG2
OPG2	OPG2	OPG2	OPG2	OPG2

Figure 5.25. John Deere 8360R—Above PTO shield camera mount rearward visibility test grid results.

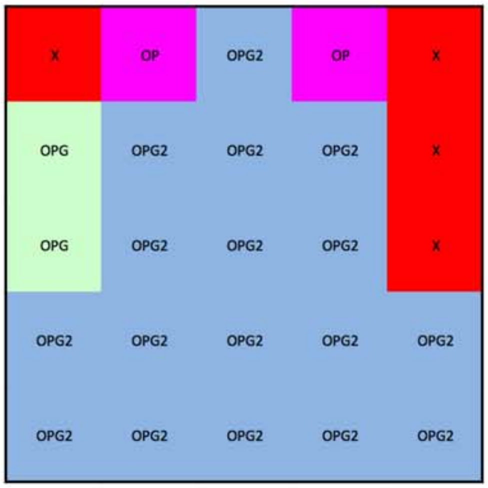


X	X	OPG	X	X
X	OPG2	OPG2	OPG2	X
X	OPG2	OPG2	OPG2	X
OPG2	OPG2	OPG2	OPG2	OPG2
OPG2	OPG2	OPG2	OPG2	OPG2

Figure 5.26. John Deere 8360R—Above hydraulic SCV camera mount rearward visibility test grid results.

5.5.3 Union of all mirrors and camera system

The optimum level of visibility was achieved via the union of all viewing mediums – i.e., the two extended-arm mirrors, the one interior mirror, and the one camera mounted above PTO master shield. Such a configuration resulted in a 16% obstructed view, with 68% of the of the kneeling indicators visible (Figure 5.27) and the midline of the test grid completely visible to the kneeling level throughout the entire test area. By combining the best of all viewing mediums, the width of the tractor (excluding Columns 1 and 5) was visible at a minimum of the height of an average woman.



X	OP	OPG2	OP	X
OPG	OPG2	OPG2	OPG2	X
OPG	OPG2	OPG2	OPG2	X
OPG2	OPG2	OPG2	OPG2	OPG2
OPG2	OPG2	OPG2	OPG2	OPG2

Figure 5.27. John Deere 8360R—Best union of all viewing mediums rearward visibility test grid results.

5.5.4 Discussion

It is possible to rotate the extended arm mirrors on this tractor, and most others, 90° to offer a wider field of view while reducing the ability to monitor objects at a greater distance from the rear of the machine as a means to correct limited width of the viewable areas (Figures 5.21 and 5.22). Another possible ‘corrective action’ could involve repositioning the external mirror mounting position to the mid-section of the cab as an alternative to the farthest forward corner of the cab. This allows for improved viewing angles to monitor locations closer to the tractors mid-line of travel, however caution would need to be given to the cab-door swing and ingress/egress ease of the operator.

Also, in an effort to reduce the number of monitors in the cab, the rearward viewing camera display could be incorporated into one of the factory-equipped monitors found in this tractor (Figure 5.28), instead of having an additional monitor (see Figure 5.12). Wiring harnesses are readily available for many makes and models of agricultural equipment that are compatible to use with cameras and existing monitors.

Figure 5.28. John Deere 8360R—OEM monitors mounted to control arm and front cab pillar.

5.6 3. Case Magnum 310 MFWD row-crop tractor with 1,100-bushel grain cart

To evaluate implements in tow, a Case Magnum 310 MFWD tractor was paired with a Brent 1082 grain cart. Basic specifications of the 310 Magnum are as follows (Table 5.3):

Table 5.3. Case Magnum 310 specifications.

Engine Power	kW (hp)	231 (310)
Wheelbase	mm (in)	3050 (120)
Length (including hitch & weights)	mm (in)	6275 (247)
Width (bar axle ends)	mm (in)	3048 (120)
Height	mm (in)	3339 (131.5)
Weight (un-ballasted, max ballast)	kg (lb)	13082-15680 (28800-34500)

Basic specifications of the Brent 1082 are as follows (Table 5.4):

Table 5.4. Brent 1082 grain cart specifications.

Capacity	m^3 (bu)	35.2+ (1000+)
Length (hitch to rear most point)	mm (in)	8992 (354)
Length (hitch to axle)	mm (in)	5054 (199)
Width (outside wheel to wheel)	mm (in)	4343 (171)
Height (folded auger)	mm (in)	3840 (151)
Weight (empty)	kg (lb)	5570 (12280)

As with the testing of the bare machine, flags were positioned at the farthest rearward point (Figure 5.29). A grain cart was selected to represent implements because of its solid construction, as opposed to a disk, toolbar or similar implement, which allows for windows of visibility, but also is highly variable as to configurations of individual types and models. In other words, an operator of a tractor towing a large grain cart has almost no ability to view what is behind the cart using factory equipped vision aids such as mirrors.

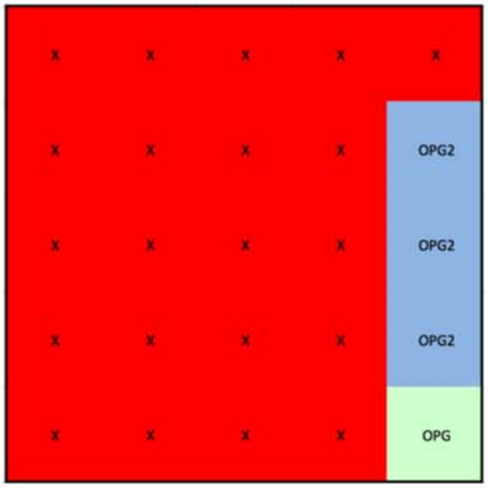
Figure 5.29. Case IH Magnum 310 with Brent 1082 grain cart in tow positioned adjacent to rearward visibility test grid.

5.6.1 The mirrors

Both right- and left-side extended-arm mirrors and the in-cab mirror were evaluated in their ability to assist the operator in observing the test grid with an implement in tow (i.e., grain cart), that posed substantial obstruction to rearward visibility.

5.6.1.1 Right exterior mirror

The right extended-arm mirror had an 84% obstructed view with the grain cart in tow. The solid construction of the cart obstructed the view of all but four flags that were outside the width of implement (Figure 5.30).

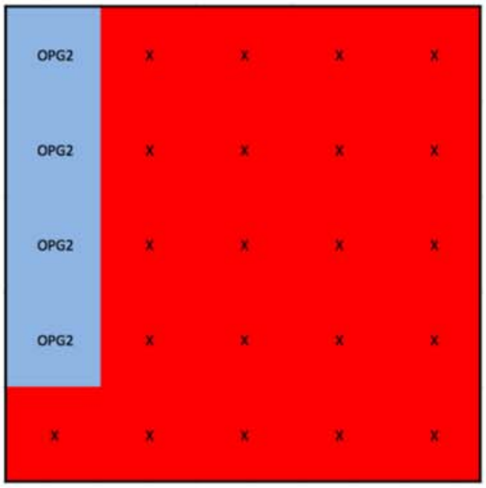


x	x	x	x	x
x	x	x	x	OPG2
x	x	x	x	OPG2
x	x	x	x	OPG2
x	x	x	x	OPG

Figure 5.30. Case IH Magnum 310 with Brent 1082 grain cart—Right extended-arm mirror rearward visibility test grid results.

5.6.1.2 Left exterior mirror

The left extended-arm mirror had identical results as the right with 84% of the 58 m^2 (625 ft^2) area completely obstructed, again the only visible areas were outside the implement's width (Figure 5.31).

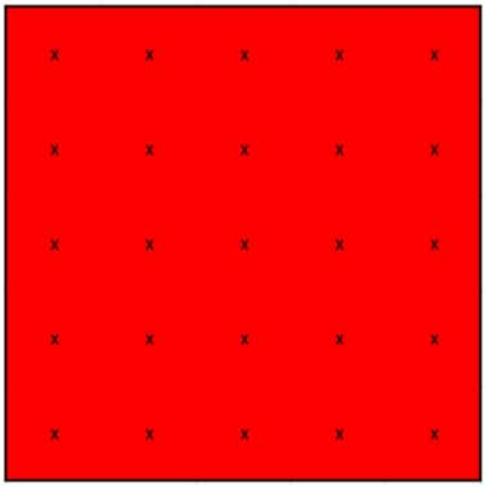


OPG2	x	x	x	x
OPG2	x	x	x	x
OPG2	x	x	x	x
OPG2	x	x	x	x
x	x	x	x	x

Figure 5.31. Case IH Magnum 310 with Brent 1082 grain cart—Left extended-arm mirror rearward visibility test grid results.

5.6.1.3 Interior mirror

The interior mirror of was 100% obstructed by the grain cart as seen in (Figure 5.32).

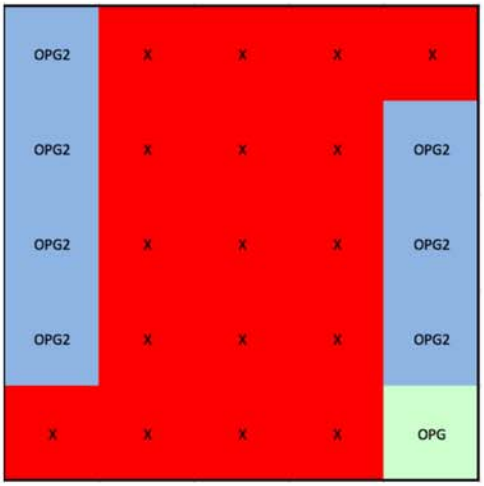


x	x	x	x	x
x	x	x	x	x
x	x	x	x	x
x	x	x	x	x
x	x	x	x	x

Figure 5.32. Case IH Magnum 310 with Brent 1082 grain cart—Interior cab mirror rearward visibility test grid results.

5.6.1.4 Union of all mirrors

The union of all factory-equipped mirrors on the Case Magnum 310 produced poor visibility (Figure 5.33). This union presented the overall visibility realized by the factory equipped machine. Obstructed views accounted for 68% of the test area, with 28% of the area allowing view of the kneeling indicators.



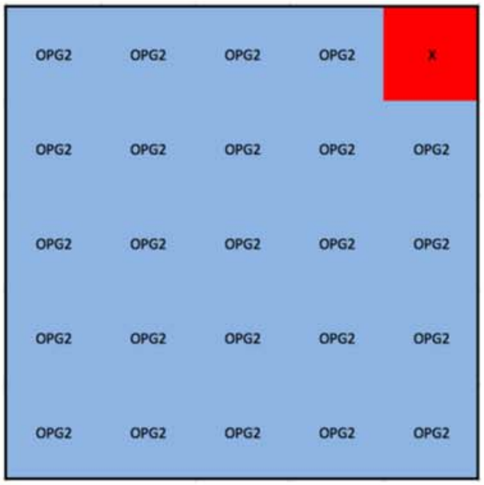
OPG2	X	X	X	X
OPG2	X	X	X	OPG2
OPG2	X	X	X	OPG2
OPG2	X	X	X	OPG2
X	X	X	X	OPG

Figure 5.33. Case IH Magnum 310 with Brent 1082 grain cart—Union of all mirrors rearward visibility test grid results.

5.6.2 The camera system

A VisionWorks 17.8 cm (7 inch) color display was positioned above the cab's center dash paired with a wide (170°) camera which was tested in two locations (beside the SMV sign and on the frame cross member). The most effective location was atop the frame cross member, which not only provided shielding from in-field hazards (e.g. corn stocks), but also provided the operator with only 4% obstructed view (Figure 5.34). This was the highest level of visibility achieved on any self-propelled machine or tractor and was not improved upon by the union of all mirrors (Figure 5.35).

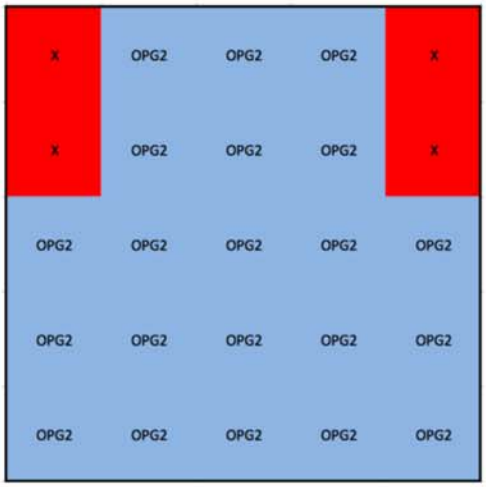
Figure 5.34. Case IH Magnum 310 with Brent 1082 grain cart, central frame cross member camera mount location.



OPG2	OPG2	OPG2	OPG2	X
OPG2	OPG2	OPG2	OPG2	OPG2
OPG2	OPG2	OPG2	OPG2	OPG2
OPG2	OPG2	OPG2	OPG2	OPG2
OPG2	OPG2	OPG2	OPG2	OPG2

Figure 5.35. Case IH Magnum 310 with Brent 1082 grain cart—Frame cross member camera mount rearward visibility test grid results.

The second location tested on the grain cart featured a higher mounting location with the camera positioned next to the SMV sign (see Figure 5.34). This location was further to the rear and did not offer the same level of visibility, as side obstructed views were recorded nearest the cart as seen (Figure 5.36). These obstructed views were caused due to the camera being located further back on the cart which did not allow for the view 170° angle to include areas on either side of the cart.



X	OPG2	OPG2	OPG2	X
X	OPG2	OPG2	OPG2	X
OPG2	OPG2	OPG2	OPG2	OPG2
OPG2	OPG2	OPG2	OPG2	OPG2
OPG2	OPG2	OPG2	OPG2	OPG2

Figure 5.36. Case IH Magnum 310 with Brent 1082 grain cart—SMV high camera mount rearward visibility test grid results.

5.6.3 Discussion

Each of the Case Magnum 310’s external extended-arm mirrors featured double-stacked convex mirrors in a single housing, which were electronically controlled. This design offered the operator a level of visibility superior to a single mirror configuration, allowing one to see behind the tractor as well as to the side of it’s rear tires – locations that were otherwise undetected in the other tested vehicles (Figure 5.37).

Figure 5.37. Case IH Magnum 310 dual stacked extended-arm mirror view of rearward visibility test grid.

Although perhaps best designed, these mirrors still did not provide sufficient view to the rear of the implement in tow, as seen in Figure 5.33. On the other hand, utilizing camera technology with implements in tow offered an un-paralleled level of visibility of the area directly behind the implement. However, with just a single camera mounted to the rear of the implement, the space between tractor and implement was neglected, allowing for a dangerous zone of obstructed visibility. This area could be easily monitored with two cameras feeding a dual-input monitor.

5.7 4. John Deere 6140D MFWD utility tractor

Selected to represent mid-sized row-crop tractors, the John Deere 6140D MFWD was factory equipped with two manually adjusted extended-arm mirrors mounted at the front two cab corners (Figure 5.38).

Figure 5.38. John Deere 6140D MFWD mid-sized tractor positioned adjacent to rearward visibility test grid.

Basic specifications of the 6140D are as follows (Table 5.5):

Table 5.5. John Deere 6140D specifications.

Engine Power	kW (hp)	104 (140)
Wheelbase	mm (in)	2450 (96.5)
Length (including hitch & weights)	mm (in)	4341 (171)
Width (to flanges)	mm (in)	2451 (96.5)
Height	mm (in)	2756 (108.5)
Weight (un-ballasted, max ballast)	kg (lb)	4536-6420 (10000-14374)

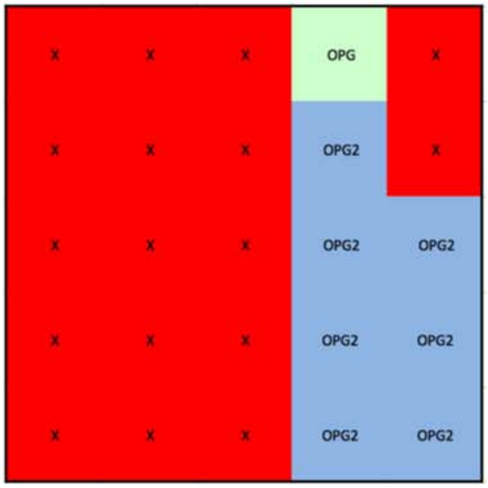
5.7.1 The mirrors

Although symmetrically positioned for visibility testing, the two extended-arm mirrors did not have a telescopic feature, which was found on some of the other models tested.

Such a feature would have allowed for improve views of the centerline of travel by permitting the operator to extend the mirrors further away from the machine. Also, these mirrors were not positioned at the furthest points possible (at a right angle with the cab corner) from the tractor due to potential ingress/egress interference of the left mirror.

5.7.1.1 Right mirror

A 68% obstructed view was recorded for the right extended-arm mirror for the 58 m^2 (625 ft^2) test area (Figure 5.39). Visibility of the kneeling indicator was achieved in all visible locations excluding Cell 4, which was adjacent to the tractors' right rear tire.

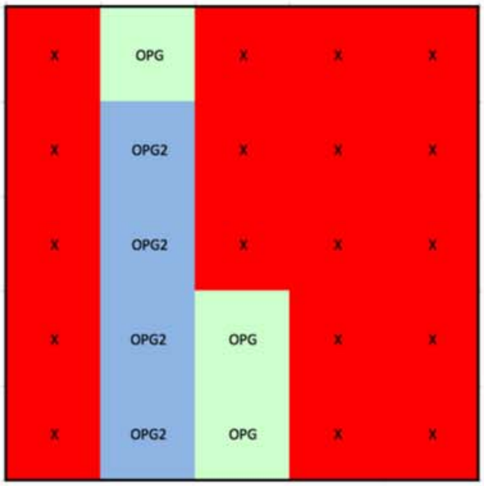


X	X	X	OPG	X
X	X	X	OPG2	X
X	X	X	OPG2	OPG2
X	X	X	OPG2	OPG2
X	X	X	OPG2	OPG2

Figure 5.39. John Deere 6140D—Right extended-arm mirror rearward visibility test grid results.

5.7.1.2 Left mirror

The left extended-arm mirror measured a 72% obstructed view. Also, similar to the right extended arm mirror, the left mirror could not view the kneeling indicator at the base of the left rear tire (Figure 5.40).

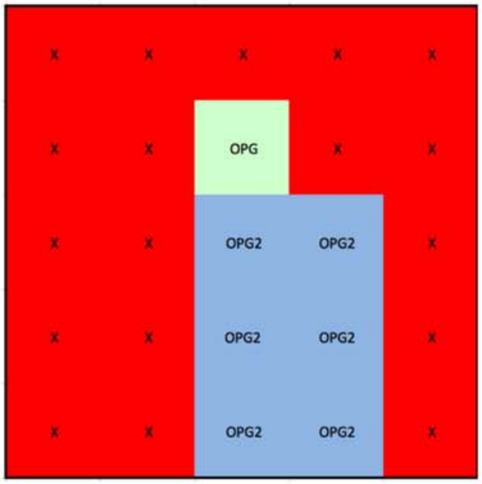


X	OPG	X	X	X
X	OPG2	X	X	X
X	OPG2	X	X	X
X	OPG2	OPG	X	X
X	OPG2	OPG	X	X

Figure 5.40. John Deere 6140D—Left extended-arm mirror rearward visibility test grid results.

5.7.1.3 Interior mirror

The interior cab mirror yielded a 72% obstructed view of the test area. The visible areas were primarily in the midline of the test grid (Figure 5.41). The kneeling indicator was visible in every observable cell with exception of Cell 8. Cell 3, which is directly adjacent to the tractor's hitching area, was complete obstructed at all tested heights.

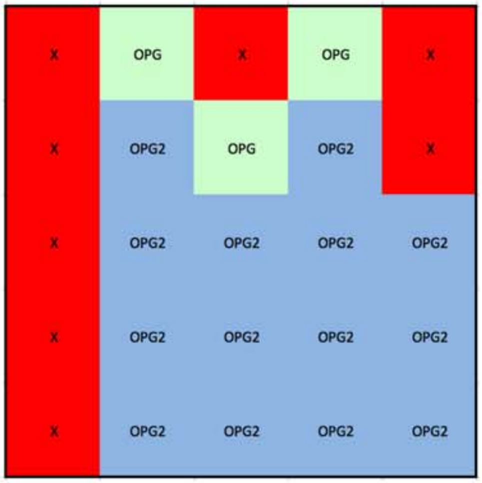


X	X	X	X	X
X	X	OPG	X	X
X	X	OPG2	OPG2	X
X	X	OPG2	OPG2	X
X	X	OPG2	OPG2	X

Figure 5.41. John Deere 6140D—Interior cab mirror rearward visibility test grid results.

5.7.1.4 Union of all mirrors

The union of all the factory-equipped mirrors on the John Deere 6140D produced the best achieved visibility levels (Figure 5.42). Obstructed views accounted for 32% of the test area, with view of the kneeling indicators possible in only 56% of the test area. with 56% of the area allowing view of the kneeling indicators.

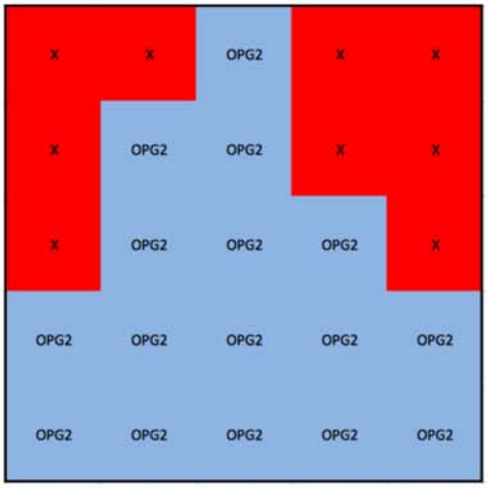


X	OPG	X	OPG	X
X	OPG2	OPG	OPG2	X
X	OPG2	OPG2	OPG2	OPG2
X	OPG2	OPG2	OPG2	OPG2
X	OPG2	OPG2	OPG2	OPG2

Figure 5.42. John Deere 6140D—Union of all mirrors rearward visibility test grid results.

5.7.2 The camera system

A VisionWorks 17.8 cm (7 inch) color display was positioned above the cab's center dash paired with a wide (170°) camera which was positioned above the PTO master shield. This configuration yielded a 36% obstructed view and was the only viewing medium which permitted the operator to view the locations adjacent to the hitching area (Cells 3 and 8) at the kneeling worker level (Figure 5.43). However, similar to all three mirror views, with the camera positioned above the PTO shielding areas adjacent to the rear tires (Cells 2 and 4) were unobservable.

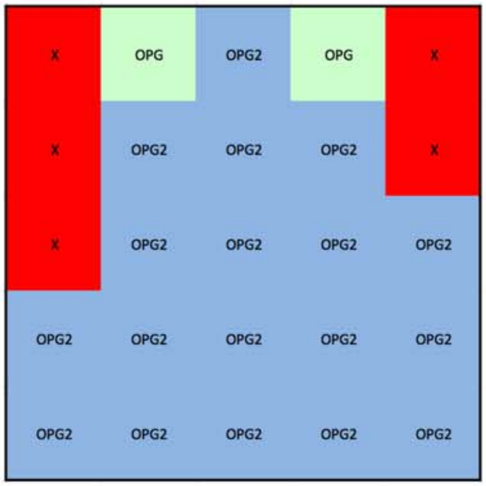


X	X	OPG2	X	X
X	OPG2	OPG2	X	X
X	OPG2	OPG2	OPG2	X
OPG2	OPG2	OPG2	OPG2	OPG2
OPG2	OPG2	OPG2	OPG2	OPG2

Figure 5.43. John Deere 6140D—Above PTO shield camera mount rearward visibility test grid results.

5.7.3 Union of all mirrors and camera system

The optimum level of visibility was achieved via the union of all viewing mediums – i.e., the two exterior extended-arm mirrors, the one interior mirror, and one camera mounted above the PTO shielding. This configuration allowed for a 20% obstructed view of the test area, with 72% of the of the kneeling indicators visible (Figure 5.44). The midline of the test grid was completely visible to the kneeling level throughout the entire test area; and by combining the best of all viewing mediums, the width of the tractor (excluding Columns 1 and 5) was visible at a minimum of the height of the average 10-year old child.



X	OPG	OPG2	OPG	X
X	OPG2	OPG2	OPG2	X
X	OPG2	OPG2	OPG2	OPG2
OPG2	OPG2	OPG2	OPG2	OPG2
OPG2	OPG2	OPG2	OPG2	OPG2

Figure 5.44. John Deere 6140D—Best union of all viewing mediums rearward visibility test grid results.

5.7.4 Discussion

Operators of many models of row-crop tractors often open the rear window to allow for a less obstructed view of the hitching area and/or for better communication with an assistant during hitching. While opening the rear window may enhance a direct view of the tractor's rearmost area, this movement requires almost 180° rotation of the operator's upper body. Physical limitations of some operators can reduce their ability to rotate sufficiently to acquire this direct view. Cab design of the 6140D incorporated an additional window to allow for improved direct view of the rear area (Figure 5.45). This cab design can be found on other makes and models of tractors, but not all.

Figure 5.45. John Deere 6140D—Low rear cab window for improved direct viewing of hitch area.

5.8 5. John Deere 5100E MFWD utility tractor

The John Deere 5100E was selected as a 100 horsepower utility tractor, and was the only tractor tested that did not have extended arm mirrors (Figure 5.46).

Figure 5.46. John Deere 5100E utility sized tractor positioned adjacent to rear visibility test grid.

Basic specifications of the 5100E are as follows (Table 5.6):

Table 5.6. John Deere 5100E specifications.

Engine Power	kW (hp)	74.6 (100)
Wheelbase	mm (in)	2300 (90.6)
Length (including hitch & weights)	mm (in)	3925 (154.5)
Width (to flanges)	mm (in)	1793 (70.6)
Height	mm (in)	2570 (101.2)
Weight (un-ballasted, max ballast)	kg (lb)	3700-4400 (8157-9700)

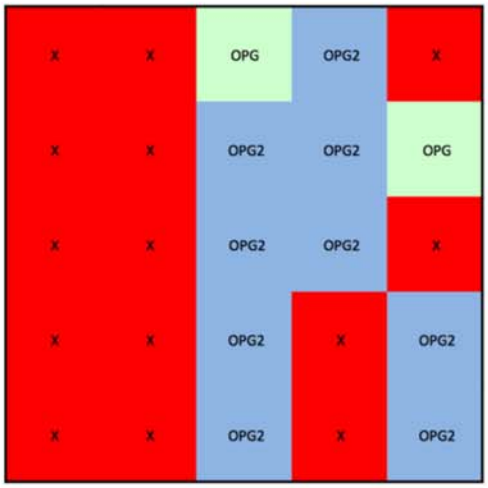
5.8.1 The mirrors

5.8.1.1 Interior mirror

The John Deere 5100E did feature one interior mirror to assist with rearward visibility (Figure 5.47). However, the tractor's smaller cab limited optimal placement of the interior mirror, which due to other interior components (e.g. radio, climate control venting, silhouette of the operator himself) contributed to rearward view obstructions (Figure 5.47).

Figure 5.47. John Deere 5100E—Interior mirror with impeading cab components view of rearward visibility test grid.

Rearward view of the John Deere 5100E was limited with a 56% obstructed view (Figure 5.48). The left side of the rearward area was disproportionately obstructed due to mirror placement in the upper right corner of the cab interior. View of the mid-line of the tractor was good with the kneeling indicators visible in all locations, with exception of Cell 3, where the lowest indicator visible was that of the average 10-year-old child.

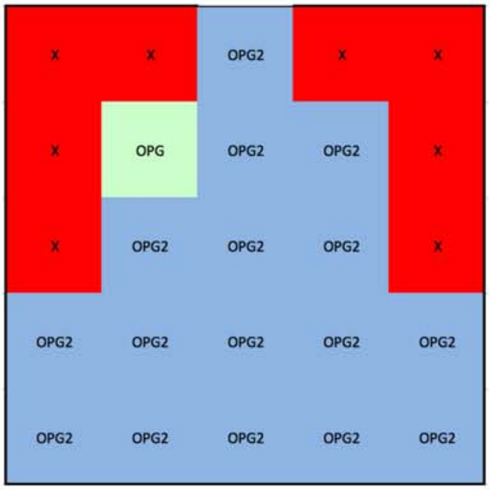


X	X	OPG	OPG2	X
X	X	OPG2	OPG2	OPG
X	X	OPG2	OPG2	X
X	X	OPG2	X	OPG2
X	X	OPG2	X	OPG2

Figure 5.48. John Deere 5100E—Interior cab mirror rearward visibility test grid results.

5.8.2 The camera system

A VisionWorks 17.8 cm (7 inch) color display was positioned above the cab's center dash paired with a wide (170°) camera which was positioned above the PTO master shield. This system provided a balanced view of the rearward test area, with 32% obstructed, a 24% improvement over the use of the mirror alone (Figure 5.49). However, the locations adjacent to the rear of the tires (Cells 2 & 4) were not observable utilizing the camera in its' tested location.

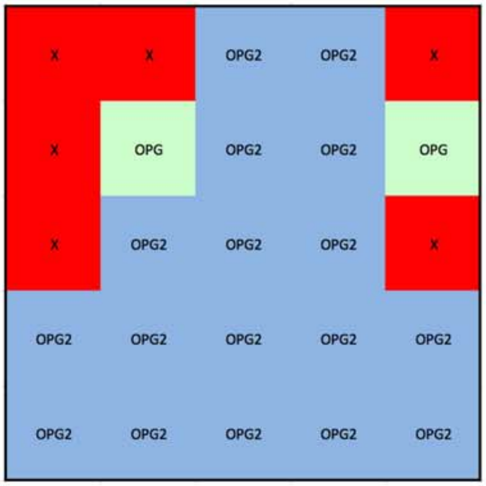


X	X	OPG2	X	X
X	OPG	OPG2	OPG2	X
X	OPG2	OPG2	OPG2	X
OPG2	OPG2	OPG2	OPG2	OPG2
OPG2	OPG2	OPG2	OPG2	OPG2

Figure 5.49. John Deere 5100E—Above PTO shield camera mount rearward visibility test grid results.

5.8.3 Union of all mirrors and camera system

The optimum level of visibility was achieved via the union of all viewing mediums i.e., the one interior mirror, and one camera placed above the PTO master shield. This configuration allowed for a 24% obstructed view of the test area, with 68% of the of the kneeling indicators visible (Figure 5.50). The midline of the test grid was completely visible to the kneeling level throughout the entire test area. By combining the best of all viewing mediums, the width of the tractor (excluding Columns 1 and 5) was visible at a minimum of the height of the average 10-year old child (excluding test Cell 2, which was completely obstructed).



X	X	OPG2	OPG2	X
X	OPG	OPG2	OPG2	OPG
X	OPG2	OPG2	OPG2	X
OPG2	OPG2	OPG2	OPG2	OPG2
OPG2	OPG2	OPG2	OPG2	OPG2

Figure 5.50. John Deere 5100E—Best union of all viewing mediums rearward visibility test grid results.

5.8.4 Discussion

While the John Deere 5100 E was not factory equipped with exterior extended-arm mirrors, due to its smaller size, the operator’s direct view was better than that of the larger framed row-crop tractors. Although many utility sized tractors feature an open operator station, which tends to allow for good direct rearward visibility, it must be considered that the ability of each individual operator to maneuver to monitor these areas varies greatly by the physical limitations. This tractor would benefit from the addition of exterior extended-arm mirrors allowing the operator to achieve a better awareness of the rearward area, especially in concert with a rear mounted camera.

5.9 6. John Deere S660 combine harvester

Combine harvesters of varying size, make, and generation were examined regarding their rearward visibility. For documentation of visibility, a John Deere S660 combine was selected. These machines appear to be designed with the assumption that rearward operator vision is greatly limited and cannot be enhanced with mirrors or windows. Tests below were conducted on a John Deere S660 combine, however similar results were noted on all models evaluated. Basic specifications of the S660 are as follows (Table 5.7):

Table 5.7. John Deere S660 combine harvester specifications.

Engine Power	kW (hp)	249 (333)
Length (not including auger or head)	mm (in)	8583 (338)
Width (up to depending on tires)	mm (in)	4877 (192)
Height (unfolded bin auger)	mm (in)	4800 (189)
Weight (dry)	kg (lb)	16650 (36706)

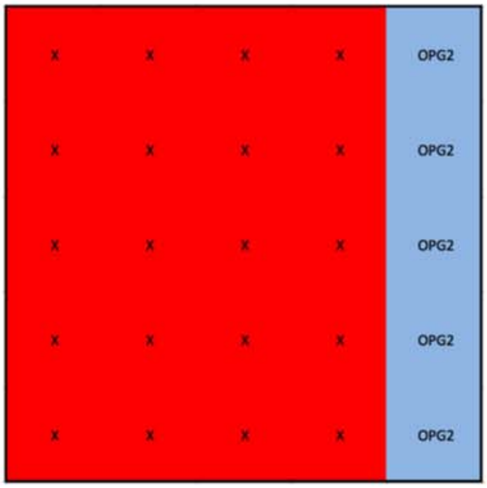
As described in the methods of testing, the test grid was centered on the rear most location of the self propelled vehicle. For tractors, this location correlated with the drawbar. However, the rear most location of a combine is the unloading auger, which does not pose an immediate threat to a bystander as it is located more than 3 m (10 ft.) off the ground (Figure 5.51). This location also neglects nearly 4.6 m (15 ft.) between the rear of the machine and the rear of the unloading spout. For this reason, the test grid was centered on the rear most location of the body of the combine, not the unloading spout. The inability of the operator to determine, in some cases, the position of the auger could result in machine damage.

Figure 5.51. John Deere S660 combine—Adjacent to rearward visibility test grid.

5.9.1 The mirrors

This combine featured two large extended arm mirrors that were electrically adjusted with in-cab controls. Rearward visibility testing for the S660 combine was consistent with other makes, models, and generations of combines tested as the exterior mirrors allow for a view along each side of the machine and beyond the rear. All kneeling visibility markers were identifiable beyond the width of the machine (Columns 1 and 5), however each mirror featured an 80% obstructed view of the test grid (Figures 5.52 and 5.53).

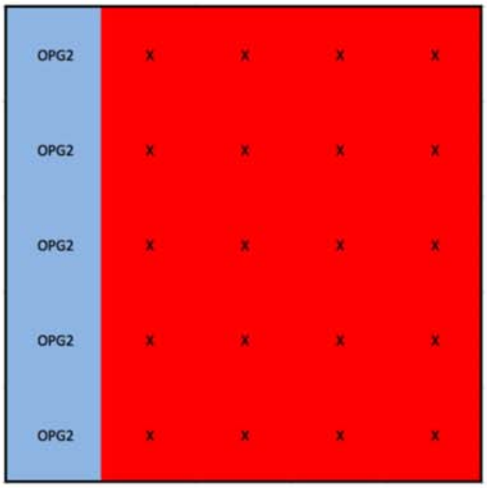
5.9.1.1 Right mirror



x	x	x	x	OPG2
x	x	x	x	OPG2
x	x	x	x	OPG2
x	x	x	x	OPG2
x	x	x	x	OPG2

Figure 5.52. John Deere S660 combine—Right extended-arm mirror rearward visibility test grid results.

5.9.1.2 Left mirror

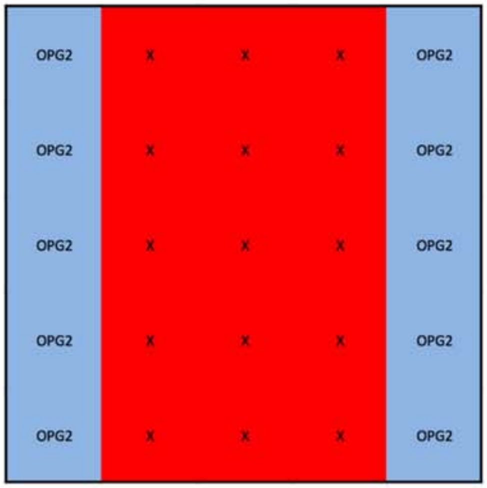


OPG2	x	x	x	x
OPG2	x	x	x	x
OPG2	x	x	x	x
OPG2	x	x	x	x
OPG2	x	x	x	x

Figure 5.53. John Deere S660 combine—Left extended-arm mirror rearward visibility test grid results.

5.9.1.3 Union of all mirrors

Of these obstructed locations, 100% of the points in the direct track of the machine were unidentifiable by the operator, causing potentially hazardous situations in the field, during on-highway transport and during movement in storage locations. The best overall visibility achieved though use of all equipped mirrors of the S660 combine was achieved via union of Figures 5.52 and 5.53. This union presented the best overall visibility achieved by the factory equipped machine (Figure 5.54). Obstructed view accounted for 60% of the test area with 40% of the area allowing view of the kneeling indicators. Again, as noted earlier, the operator's position midway between the mirror locations prevent the operator from viewing both mirrors simultaneously.



OPG2	x	x	x	OPG2
OPG2	x	x	x	OPG2
OPG2	x	x	x	OPG2
OPG2	x	x	x	OPG2
OPG2	x	x	x	OPG2

Figure 5.54. John Deere S660 combine—Best union of exterior mirrors rearward visibility test grid results.

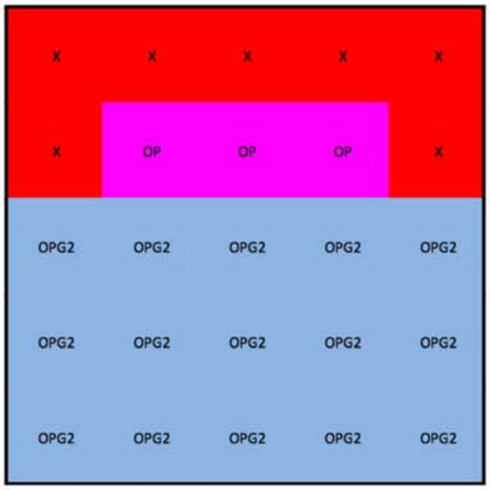
5.9.2 The camera system

This S660 featured an optional factory installed camera package located in a high central location, as seen in (Figure 5.55). This was one of two machines tested which did not utilize the VisionWorks camera kit. However, this was the only combine evaluated that came equipped with the camera and monitor.

Figure 5.55. John Deere S660 combine—Optional camera locaiton.

This mounting height affected the visibility of locations in close proximity to the base of the machine, however it did provide increased protection of the camera from ejected crop material and dust.

The mounting location of the factory equipped camera did not improve visibility of locations in close proximity of the machine (Cells 7,8 and 9), but provided a greatly improved view of the test area with a 28% obstructed view in comparison to the 80% obstructed view while using each mirror (Figure 5.56).

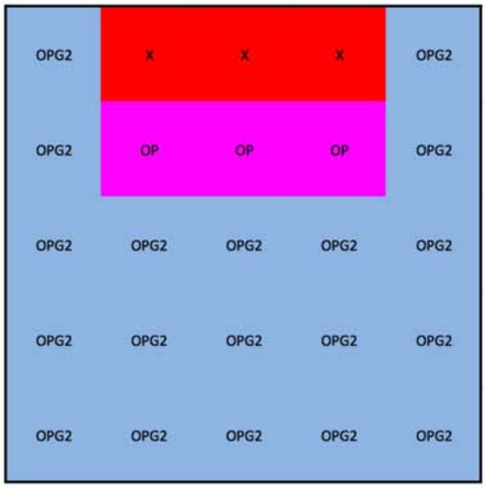


X	X	X	X	X
X	OP	OP	OP	X
OPG2	OPG2	OPG2	OPG2	OPG2
OPG2	OPG2	OPG2	OPG2	OPG2
OPG2	OPG2	OPG2	OPG2	OPG2

Figure 5.56. John Deere S660 combine—Camera mounted high on rear panel rearward visibility test grid results.

5.9.3 Union of all mirrors and camera system

The optimum level of visibility was achieved via the union of all viewing mediums – i.e., the two exterior extended-arm mirrors, and one camera mounted on the combine's upper rear panel. This configuration allowed for a 12% obstructed view of the test area, with 76% of the of the kneeling indicators visible (Figure 5.57).



OPG2	X	X	X	OPG2
OPG2	OP	OP	OP	OPG2
OPG2	OPG2	OPG2	OPG2	OPG2
OPG2	OPG2	OPG2	OPG2	OPG2
OPG2	OPG2	OPG2	OPG2	OPG2

Figure 5.57: John Deere S660 combine—Union of all viewing mediums rearward visibility test grid results.

Another camera mounting location observed on some combines is on the unloading spout (Figure 5.58). This location provides the operator a rearward view while the auger is folded back for transport or a direct view of the unload locations, such as a semi-truck or grain cart. This allows the operator to maintain forward attention while unloading ‘on the go’, or the ability to see the grain levels and stream positioning when the unloading location is too high for direct view.

Figure 5.58. Case IH combine with optional unloading auger camera mount.

While providing two tasks with the camera mounted in this location, rearward visibility is reduced as the camera is mounted more than 3 m (10 ft.) from the rear of the machine with a rearward orientation. No rearward observation is possible when the combine auger is in the unloading position.

5.9.4 Discussion

Cameras provide valuable assistance on combine harvesters, which inherently have large unobservable areas around the base of the machine. While two common mounting locations (i.e., rear of the machine and end of the unloading spout) provides increased visibility. To achieve optimal efficiency during operation and rearward visibility it would be advised to employ a dual camera configuration with a split-screen monitor, which would allow for simultaneous observation of two important locations.

For the John Deere S660 combine used here, the factory-equipped monitor doubled as the camera monitor (Figure 5.59). As technology advances, these monitors are becoming common on most self-propelled machines and tractors. In fact, currently many factory and third party providers allow operators to utilize existing monitors in coordination with camera technology to avoid the need for multiple displays inside the cab.

Figure 5.59. Factory montior utilized for camera display.

5.10 7. Case Patriot 4430 self-propelled sprayer

A Case Patriot 4430 self-propelled sprayer with a 36.6 m (120 ft.) boom was tested with the boom in both transport and field operation position (Figure 5.60). Basic specifications of the 4430 are as follows (Table 5.8):

Table 5.8. Case Patriot 4430 self-propelled sprayer specifications.

Engine Power	kW (hp)	250 (335)
Capacity	l (gal)	4542 (1200)
Wheelbase	mm (in)	4060 (160)
Length	mm (in)	9083 (358)
Width (retracted, extended wheels)	mm (in)	3505-4480 (138-176)
Height (boom)	mm (in)	480-2130 (19-84)
Weight (dry)	kg (lb)	13109 (28900)
Ground Clearance	mm (in)	1350 (53)
Cab glass area	m^2 (ft^2)	8.32 (90.1)

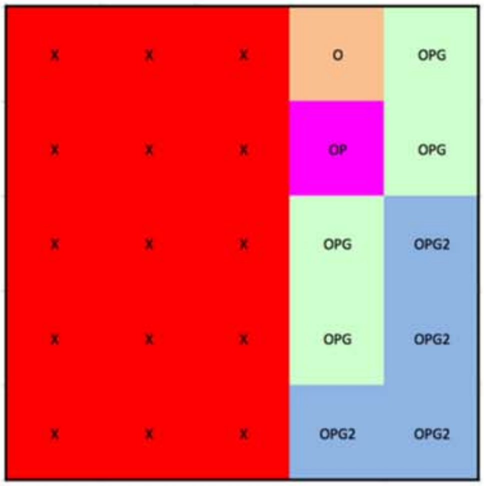
This sprayer featured two sets of left and right exterior extended-arm mirrors (no in-cab mirror). The first set of extended arm mirrors were attached to the cab corners similar to other tested agricultural machinery. The second set was only visible when the spray booms were folded into transport mode, as they were attached to the mid-section of the booms.

Figure 5.60. Case Patriot 4430 Self-Propelled Sprayer with 36.6 m (120 ft.) booms adjacent to rearward visibility test grid.

5.10.1 The mirrors

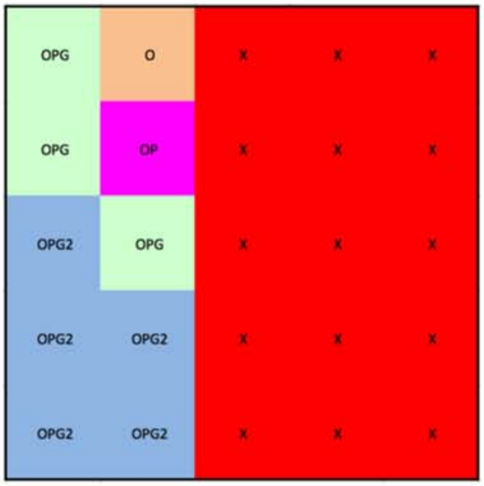
5.10.1.1 Exterior mirrors with unfolded booms:

With the booms unfolded, the right and left extended-arm mirrors had a 60% obstructed view (Figures 5.61 & 5.62). Similar to a combine with a forward-positioned cab and large obstructions to the rear, visibility is restricted to the areas along the side of the machine.



X	X	X	O	OPG
X	X	X	OP	OPG
X	X	X	OPG	OPG2
X	X	X	OPG	OPG2
X	X	X	OPG2	OPG2

Figure 5.61. Case Patriot Sprayer—Right extended-arm mirror (unfolded booms) rearward visibility test grid results.

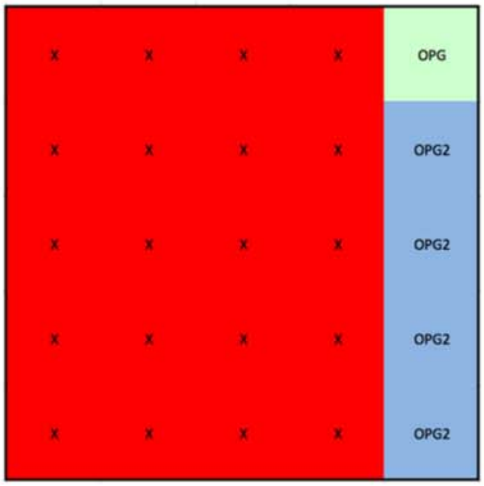


OPG	O	X	X	X
OPG	OP	X	X	X
OPG2	OPG	X	X	X
OPG2	OPG2	X	X	X
OPG2	OPG2	X	X	X

Figure 5.62. Case Patriot Sprayer—Left extended-arm mirror (unfolded booms) rearward visibility test grid results.

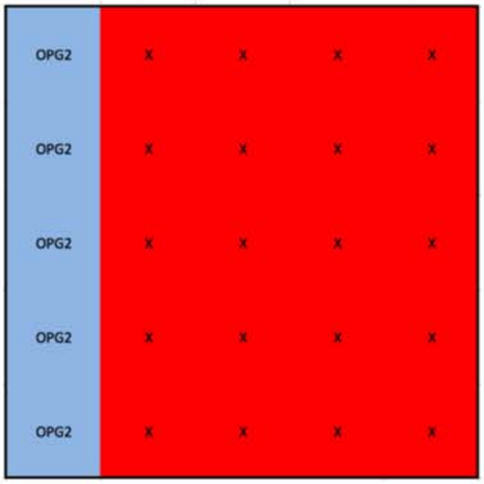
5.10.1.2 Exterior mirrors with folded booms

When the booms were folded, the right and left cab-mounted extended-arm mirrors were obstructed, so the operator had to rely on the boom-mounted mirrors (Figures 5.63 and 5.64). Since these mirrors were mounted further away from the cab, the obstructed view of the test area increased to 80% for each side, a percentage identical to the combine tested.



x	x	x	x	OPG
x	x	x	x	OPG2
x	x	x	x	OPG2
x	x	x	x	OPG2
x	x	x	x	OPG2

Figure 5.63. Case Patriot Sprayer—Right extended-arm mirror (booms folded) rearward visibility test grid results.

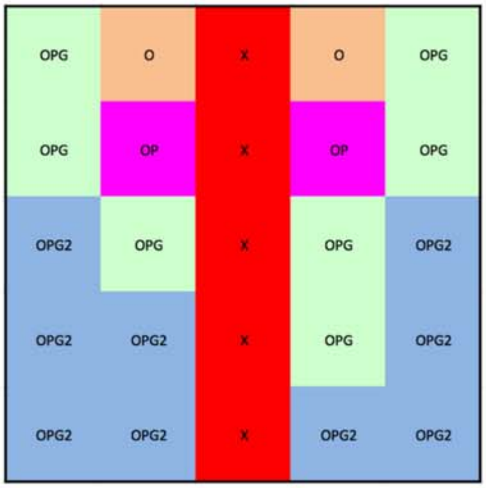


OPG2	x	x	x	x
OPG2	x	x	x	x
OPG2	x	x	x	x
OPG2	x	x	x	x
OPG2	x	x	x	x

Figure 5.64. Case Patriot Sprayer—Left extended-arm mirror (booms folded) rearward visibility test grid results.

5.10.1.3 Union mirrors (unfolded)

The best overall visibility achieved though use of all factory-equipped mirrors on the Case Patriot sprayer was realized via union of the best achieved visibility from Figures 5.61 and 5.62. This union presented the best overall visibility attained by the factory equipped machine (Figure 5.65). Obstructed views accounted for 20% of the test area, with 36% of the area allowing view of the kneeling indicators.



OPG	O	X	O	OPG
OPG	OP	X	OP	OPG
OPG2	OPG	X	OPG	OPG2
OPG2	OPG2	X	OPG	OPG2
OPG2	OPG2	X	OPG2	OPG2

Figure 5.65.Case Patriot Sprayer—Union of cab mounted exterior mirrors (booms unfolded) rearward visibility test grid results.

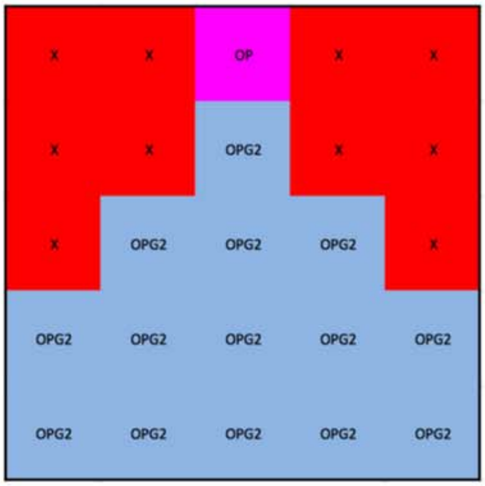
5.10.2 The camera system

A VisionWorks 17.8 cm (7 inch) color display was positioned above the cab's center dash paired with a wide (170°) camera which was positioned in several locations, with the least obstructed view found to be the center of the upper portion of the boom near the rear-facing field light (Figure 5.66). Placement on the machines' body created unpredictable obstructions as boom height position was adjusted during operation.

Figure 5.66. Case Patriot Sprayer—Center boom frame camera mount location.

A weakness associated with mounting the camera on the boom was seen as the boom height was adjusted during operation and transport. The adjustment of the camera height during operation changed the operator's perspective of the camera view, which made it difficult to see the low-height indicators and thus eliminated a consistent frame of reference for estimating the distance to an object.

Tests were conducted with the lower portion of the boom approximately 0.61 m (2 ft.) off the ground. From this perspective, a 40% obstructed view of the test area was recorded (Figure 5.67). Attributed to the camera mounting height and rear-most location on the boom, view angles were limited within close proximity to the boom.

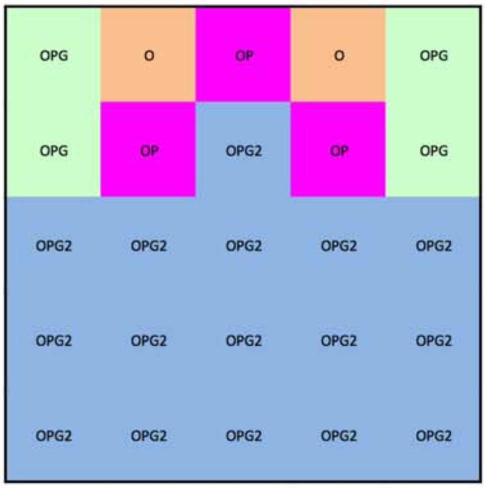


X	X	OP	X	X
X	X	OPG2	X	X
X	OPG2	OPG2	OPG2	X
OPG2	OPG2	OPG2	OPG2	OPG2
OPG2	OPG2	OPG2	OPG2	OPG2

Figure 5.67. Case Patriot Sprayer—Center boom frame camera mount rearward visibility test grid results.

5.10.3 Union of all mirrors and camera system (unfolded)

The optimum level of visibility was achieved via the union of all viewing mediums- i.e., the two exterior extended-arm mirrors and the one camera centrally placed on the upper sprayer boom. This configuration allowed for a completely unobstructed view of the test area with 64% of the of the kneeling indicators visible (Figure 5.68). Some obstruction of the test area occurred at lower indicator heights, which was caused by the sprayer boom and varied by the chosen operating height.



OPG	O	OP	O	OPG
OPG	OP	OPG2	OP	OPG
OPG2	OPG2	OPG2	OPG2	OPG2
OPG2	OPG2	OPG2	OPG2	OPG2
OPG2	OPG2	OPG2	OPG2	OPG2

Figure 5.68. Case Patriot Sprayer—Best union of mirrors and camera (booms unfolded) rearward visibility test grid results.

5.10.4 Discussion

Two things likely to increase a self-propelled sprayer's field of view would be a wider-angle camera or different camera angle. Some machines are equipped with cameras to achieve an overhead view which increases the width of visible area, but hinders depth. Due to the large area associated with this machine type, multiple cameras may be required to achieve desired visibility.

Secondary to increased safety associated with improved visibility is also increased awareness of machine function. Cameras utilized on sprayers, or any other type of implement, can allow the operator to monitor proper functionality (e.g. detection of impaired spray patterns, clogged nozzles, tangled weeds), otherwise undetectable by the operator in many locations during operation.

5.11 8. Case SV185 skid-steer

While more often associated with construction applications, the use of skid-steer loaders is commonly utilized on farming operations with handling materials, cleaning animal waste from confined spaces, animal feeding, light earth-moving/repairs, as well as paired with countless attachments. One of the most noted characteristics associated with operating a skid-steer is the abundance of blind spots for the operator. Due to the design of these machines, external mirrors are not possible due to the movement arc of the loader booms. Interior mirrors are also not found on many models as well. The area immediately behind these highly maneuverable machine is especially invisible to the operator. Incidents involving runovers of bystanders, including children have been documented.

Operator vision tests were conducted on a Case SV185, a mid-sized machine equipped with a quick attach bucket. Basic specifications of the SV185 are as follows (Table 5.9):

Table 5.9. Case SV185 skid-steer specifications.

Engine Power	kW (hp)	44.7 (60)
Length (with bucket)	mm (in)	3350 (131.7)
Width (standard tires)	mm (in)	1630 (64)
Height	mm (in)	1970 (77.7)
Weight	kg (lb)	2980 (6570)
Rated Operating Load	kg (lb)	840 (1850)

Figure 5.69. Case SV185 skid-steer, mid-sized 840 kg (1,850 lb.) operating load positioned adjacent to rearward visibility test grid.

5.11.1 The mirrors

This model skid-steer did not feature mirrors (interior or exterior) causing a 100% obstructed view to the rear of the machine (Figure 5.70).

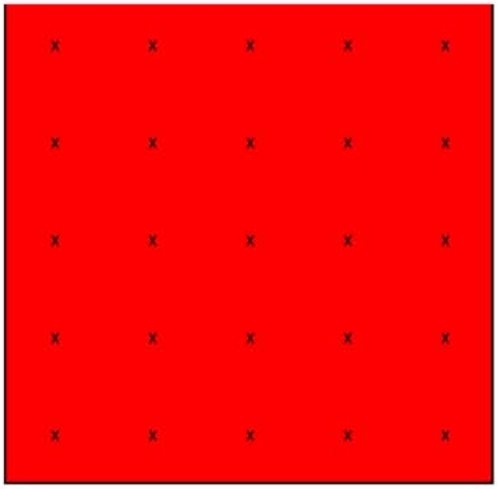
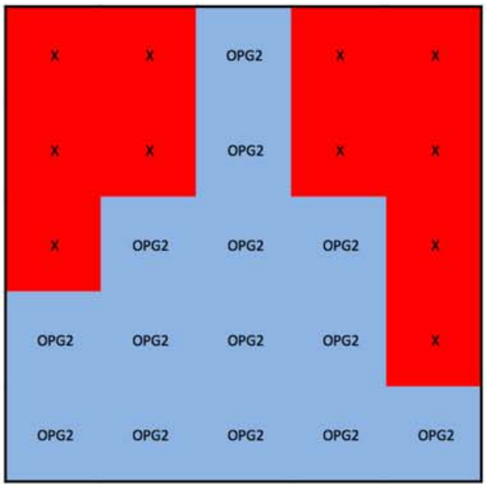


Figure 5.70. Case SV 185 Skid-Steer—Rearward visibility test grid results.

5.11.2 The camera system

A VisionWorks 17.8 cm (7 inch) color display was positioned beside the cab's upper instrument panel, and paired with a wide angle (170°) camera which was positioned above the engine compartment door. This location was chosen to protect the camera from damage during normal machine operation by not being outside the perimeter of the machine. With this placement, a 44% obstructed view was documented with limitations to the peripheral views of the camera (Figure 5.71).



X	X	OPG2	X	X
X	X	OPG2	X	X
X	OPG2	OPG2	OPG2	X
OPG2	OPG2	OPG2	OPG2	X
OPG2	OPG2	OPG2	OPG2	OPG2

Figure 5.71. Case SV185 Skid-Steer—Above rear engine compartment door camera mount location rearward visibility test grid results.

5.11.3 Discussion

Mirrors are generally not found on most skid-steer machines; however, interior mirrors are potentially more beneficial than none at all. During operation of models not included in the testing, some were found to be equipped with large convex mirrors mounted to the interior roof of the machine. While objects in near proximity remained undetectable, tall objects (e.g., other equipment, buildings, trees) were detectable.

Due to the zero-turning radius of a skid-steer, and minimum working clearances, proper camera placement was necessary to prevent damage. A camera can easily be mounted atop the engine compartment or roll cage with no modification, however some cameras could be placed on the inside of the rear engine compartment door to be fully shielded. In this location, a small opening could be added to the door for the camera to attain a rearward view, however, this mounting method can impair peripheral views.

5.12 9. Polaris Ranger UTV

The side-by-side utility vehicles (UTV) are commonly used in farming operations for a variety of tasks and their use continues to grow. Providing off-road transportation to check crops and livestock or utilized for production purposed such as spraying, seeding, tilling, planting, and mowing, provides a service much like a small utility tractor for small plots of land.

A Polaris Ranger was chosen as the representative for this category (Figure 5.72). This UTV did not feature factory-equipped mirrors in its factory original configuration, however they were added after purchased.

Figure 5.72. Polaris Ranger UTV positoned adjacent to rearward visibilty test gird.

Basic specifications of the Ranger are as follows (Table 5.10):

Table 5.10. Polaris Ranger UTV specifications.

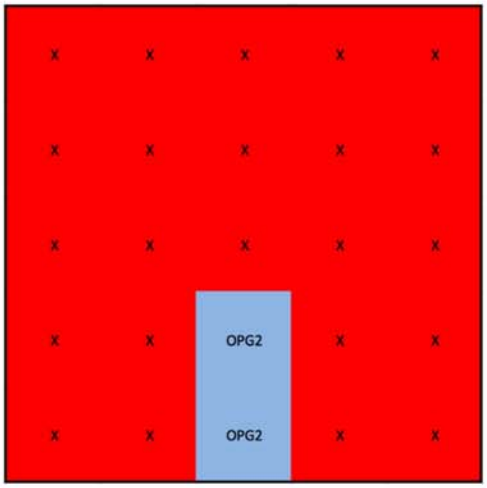
Engine Power	kW (hp)	34 (46)
Wheelbase	mm (in)	2060 (81)
Length	mm (in)	2960 (116.5)
Width	mm (in)	1520 (60)
Height	mm (in)	1930 (76)
Weight (dry)	kg (lb)	599 (1320)

5.12.1 The mirrors

The aftermarket mirrors attached outside the A-posts of the roll-bar frame of the UTV and featured a convex curvature. The mirrors added to increase visibility along the bedsides of the UTV, but did not improve rearward visibility to a satisfactory level.

5.12.1.1 Right mirror

The right mirror was adjusted to allow for a partial view of of the UTV's bed and rearward area. This was done to monitor bed-mounted attachments of the UTV. With this configuration, however, rearward visibility of the right mirror was reduced greatly to a 92% obstructed area (Figure 5.73).

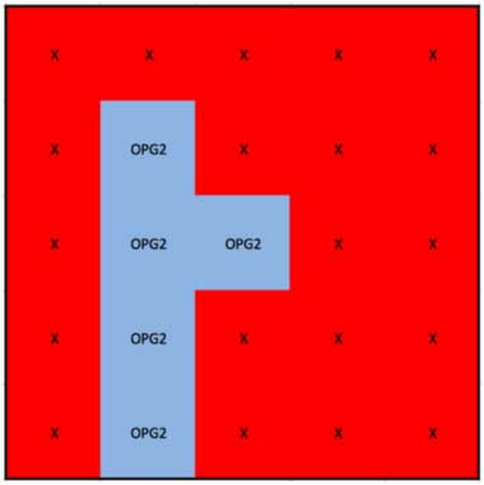


x	x	x	x	x
x	x	x	x	x
x	x	x	x	x
x	x	OPG2	x	x
x	x	OPG2	x	x

Figure 5.73. Polaris Ranger UTV—Right mirror rearward visibility test grid results.

5.12.1.2 Left mirror

Figure 5.74 depicts the visibility of the left mirror of the UTV. The obstructed area accounted for 80% of the test 58 m^2 (625 ft^2) grid. Grid Cell 3 directly adjacent to the hitching area of the UTV was completely obstructed with this mirror.

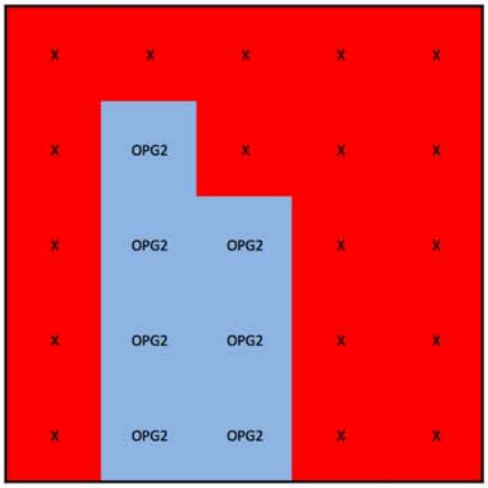


x	x	x	x	x
x	OPG2	x	x	x
x	OPG2	OPG2	x	x
x	OPG2	x	x	x
x	OPG2	x	x	x

Figure 5.74. Polaris Ranger UTV—Left mirror rearward visibility test grid results.

5.12.1.3 Union of all mirrors

The best overall visibility was achieved though union of the after-market right and left exterior mirrors on the Ranger UTV. This presented the best overall visibility achieved by the aftermarket mirrors (Figure 5.75). Obstructed view accounted for 72% of the test area, with 28% of the area allowing view of the kneeling indicators.



x	x	x	x	x
x	OPG2	x	x	x
x	OPG2	OPG2	x	x
x	OPG2	OPG2	x	x
x	OPG2	OPG2	x	x

Figure 5.75. Polaris Ranger UTV—Union of all mirrors rearward visibility test grid results.

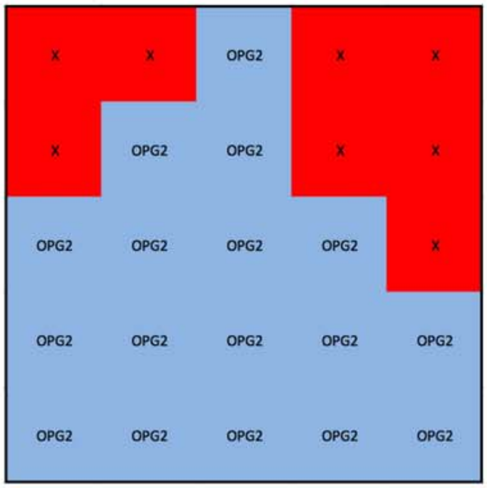
5.12.2 The camera system

The camera system chosen for the UTV consisted of an aftermarket, automotive grade HDE model E336 camera with 170° view and a dual input TFT 17.8 cm (7 in) color display monitor.

The camera mounting location for the UTV was chosen to be centrally located to the underside of the utility bed (Figure 5.76). This location provided ample shielding from encountered hazards.

Figure 5.76. Polaris Ranger UTV—Under utility bed camera mount location.

Measured visibility resulted in a reduction of obstructed views to 32% of the test area (Figure 5.77), with full visibility of the UTV’s centerline achieved throughout the entire test grid at the kneeling indicator level. Obstructed views were measured to be beyond the vehicle width on both sides, most notably Cells 2, 4, and 9.



X	X	OPG2	X	X
X	OPG2	OPG2	X	X
OPG2	OPG2	OPG2	OPG2	X
OPG2	OPG2	OPG2	OPG2	OPG2
OPG2	OPG2	OPG2	OPG2	OPG2

Figure 5.77. Polaris Ranger UTV—Under utility bed camera mount rearward visibility test grid results.

5.12.3 Union of all mirrors and camera system

The optimum level of visibility was achieved via the union of all viewing mediums (i.e., the two exterior external mirrors, and the one camera centrally placed under the utility bed); however, the level of visibility was not improved from that of the camera alone (Figure 5.77). The additional visibility achieved with the exterior mirrors were beyond scope of the testing grid; that is, they provided additional views along side of the machine that were not obtainable with the camera alone. Of the test area, this configuration resulted in a 32% completely obstructed view, with 68% of the of the kneeling indicators visible (Figure 5.77). The kneeling indicators were visible throughout the midline of the entire test grid, which corresponded with the UTVs' width.

5.12.4 Discussion

While the camera system components selected were automotive-grade, which are not necessarily manufactured to the durability tolerances as found in agricultural application camera kits, there has not been any malfunctions in more than two years of regular operation. A benefit of the automotive-grade camera system was the reduced financial investment by nearly 90% in comparison to some agricultural grade components. The HDE Model E336 camera had a distance grid overlaid on the display image to allow the operator to better estimate the distance to an object (Figure 5.78). This grid, although it must be measured each time the camera position is moved, remains constant once the permanent camera placement is achieved.

Figure 5.78. TFT dual input, 17.8 cm (7 in) color monitor paired with 170° waterproof camera with overlaid distance estimating grid.

CHAPTER 6. ANALYSIS OF RESULTS AND RECOMMENDATIONS

6.1 Introduction

There were 125 data points collected for each mirror view and camera position for each of the nine tested machines, with the compilation of these data identifying the common ones of limited visibility for all of them. The results were separated into two categories – (1) the four tractors only (without implements in tow) and (2) all nine of the tested machines. This allowed for creation of a ‘predictive model’ to compare rearward visibility in agricultural tractors and in the most commonly used self-propelled agricultural machine types by depicting the frequency of occurrence for visible area. Utilizing color-plus-letter key (Figure 6.1), each of the 25 cells in the test grid (Figure 5.2) contained a pie chart representing the overall union of the tested machines and the percentage of the best achievable level of visibility.

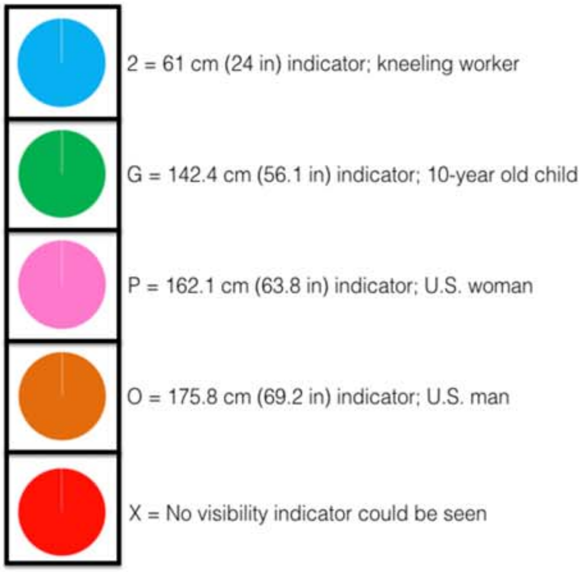


Figure 6.1. Color and letter key for grid results.

6.2 Analysis of results – The tractors only

6.2.1 Rearward visibility via the mirrors only

The visibility model for all tested tractors equipped with factor-installed and/or after-market mirrors are shown in Figure 6.2. Specific findings include:

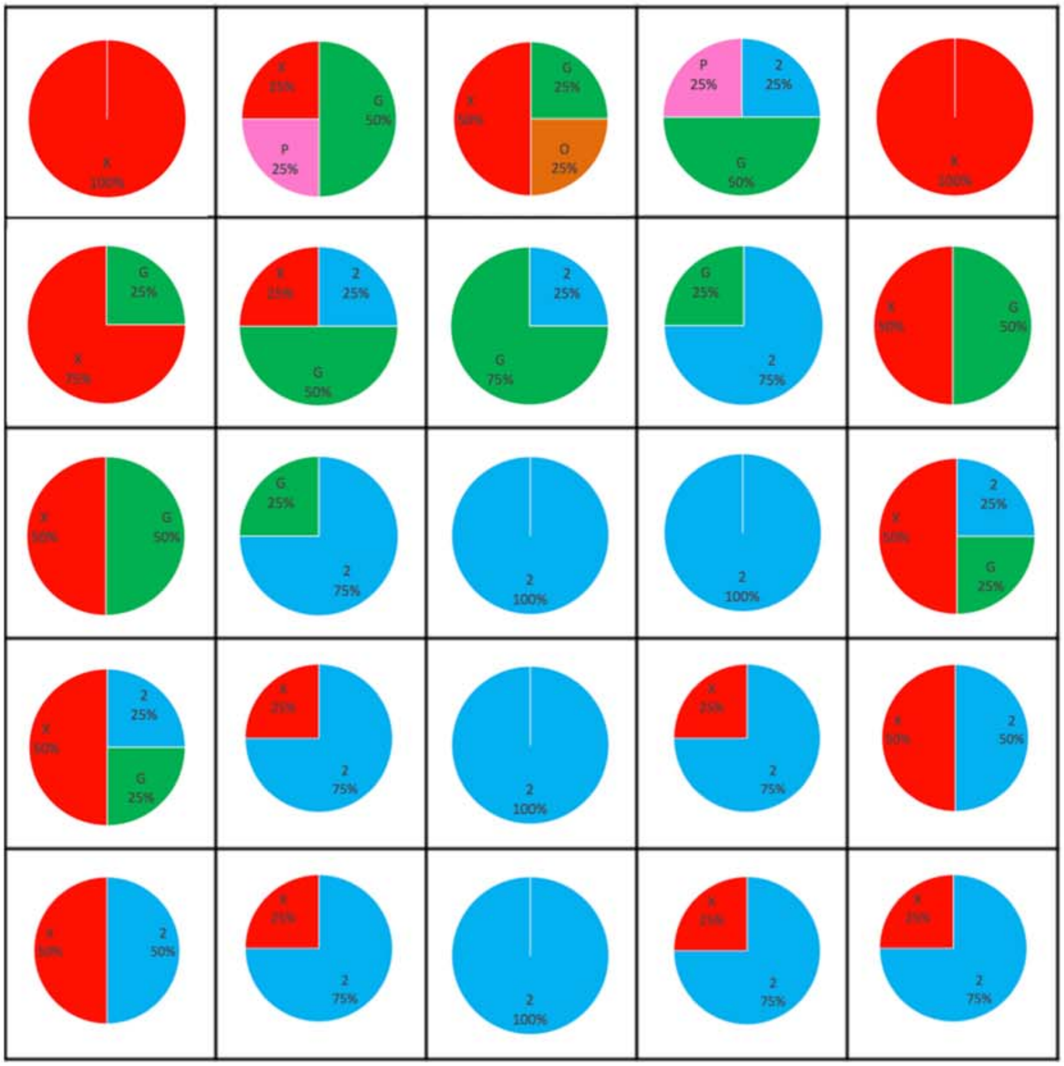


Figure 6.2. Tractor only visibility model of all mirrors tested.

- No mirrors-only-equipped tractor attained a kneeling visibility level directly adjacent to the hitching area (Cell 3)
- The best recorded level of visibility in Cell 3 – found in 25% of the tested tractors via the union of all mirrors – was the height of the average 10-year-old child; whereas 50% of the tested tractors found that Cell 3 was completely obstructed.

- Obstacles in the areas adjacent to the tractors’ rear tires (Cells 2 and 4) allowed for, at best, the view of an average child standing fully upright.
- Level of visibility greatly increased as distance from the tractor increased, as seen in Rows 4 and 5.
- Midline test cells 3 m (10 ft.) or more from the rear of the tractor (Cells 13, 18, and 23) achieved 100% visibility of the kneeling indicator level for all tractors tested. This allowed for excellent monitoring of implement-in-tow throughout the midline. However, depending on implement width and mirror positioning to view implement extremities, middling visibility would likely decrease.

6.2.2 Rearward visibility via cameras only

The four tractors tested utilizing cameras only, the camera mounting location uniformly selected was above the PTO master shield, which provided a superior viewing angle of the hitching area. The visibility models for these four tractors (Figure 6.3) revealed the following:

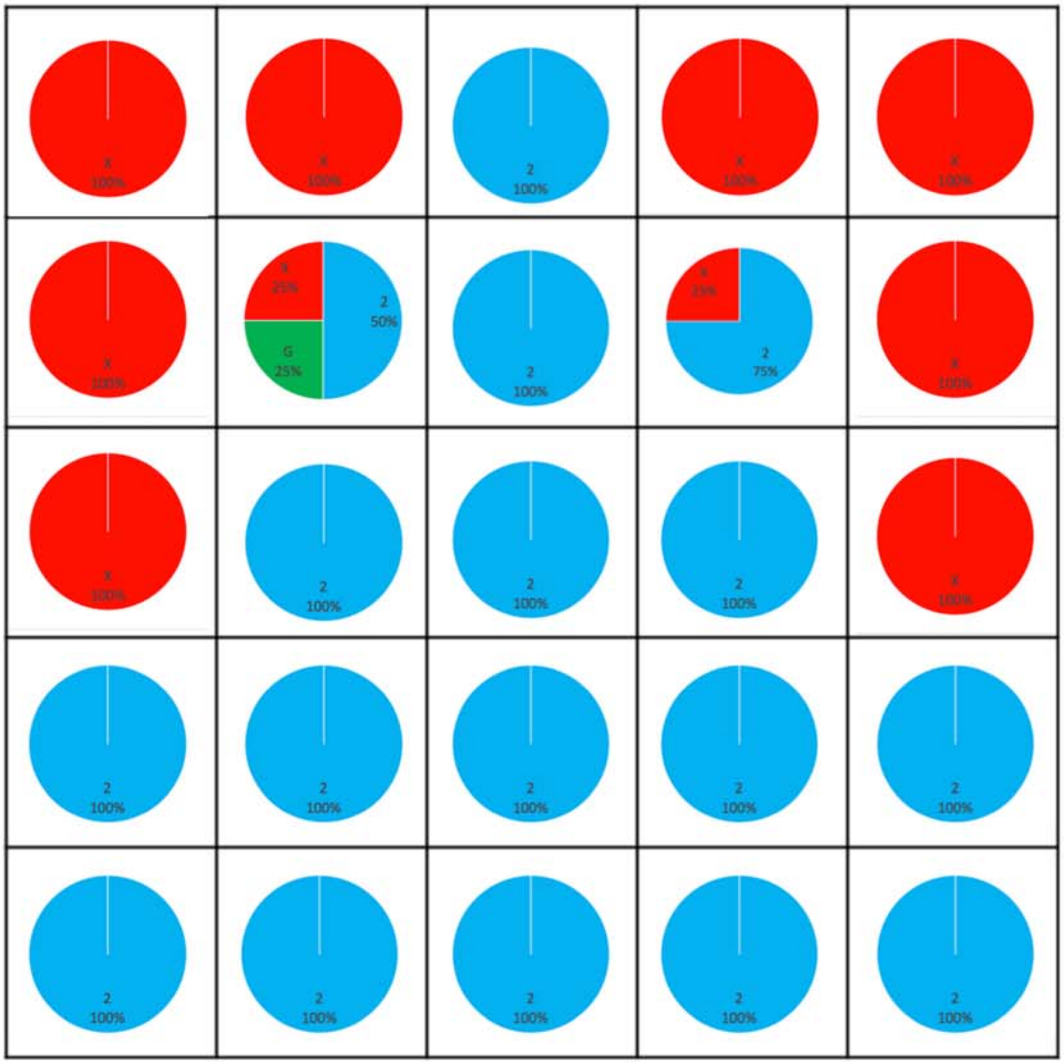


Figure 6.3. Tractor visibility model of all cameras tested.

- The midline of all tested tractors having a camera provided 100% visibility of the kneeling indicators for the test area – a visibility level not attainable with the tested mirrors.
- Due to the camera's wide (170°) lens angle, the visible areas resembled a funnel-shaped formation, with Cells 1, 2, 4, and 5 uniformly identified to be completely obstructed from camera view.

- Extremity points of the first three rows of the grid (i.e., Cells 1, 6, 11, 5, 10, and 15) were not visible in any camera test; however, these points were beyond the width of all the tested tractors.

6.3 Pearson r correlation between mirrors and cameras

A Pearson r correlation test was utilized to further examine the relationships between viewable areas of the test grid. The results were as follow:

- The Pearson r of obstructed visibility areas between the tractor mirrors and cameras yielded a moderate positive value of r = 0.54, indicating that many of the obstructed locations of the test grid affected both mirror and camera modes of viewing similarly. Such was visually detectable in Figures 6.3 and 6.4, which showed obstructed areas prevalent nearest the tractor and reduced to zero along the midline outward to the extremities of the test grid as distance from the tractor was increased.
- A strong positive correlation of r = 0.75 was recorded among those areas with visibility of kneeling indicators for both the tractor cameras and mirrors. This correlation indicates that mirrors and cameras share commonality of areas of high visibility of the area tested.

6.4 Rearward visibility via union of mirrors and cameras

Testing individual viewpoints was important in identifying area for visual improvement. Thus, a visibility model of the union of all mirrors and cameras was created to represent the full capacity of the operator to view the test area (Figure 6.4) and revealed the following:

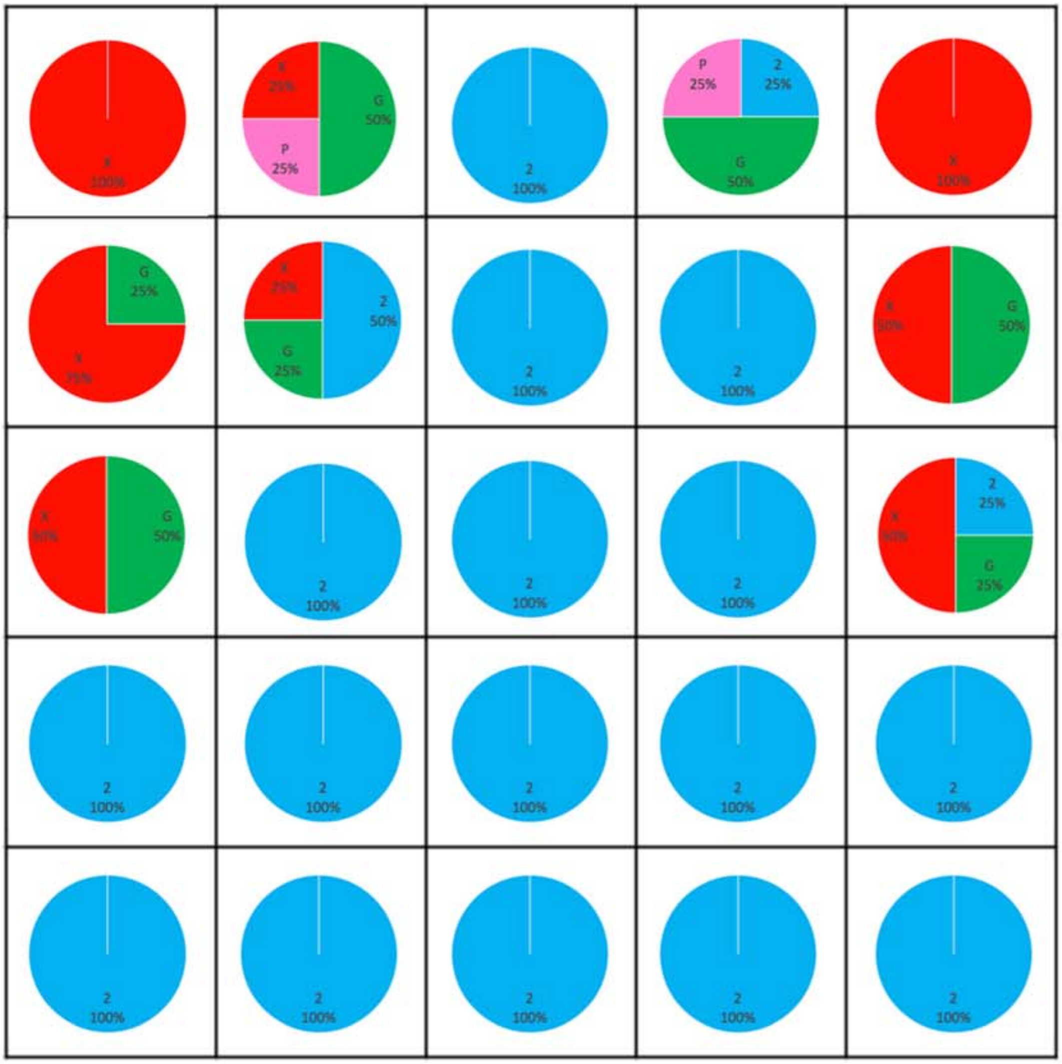


Figure 6.4. Tractor visibility model of all tested viewing mediums.

- The union of mirrors and cameras allowed for a 100% midline view for kneeling indicators as well as extremity views customizable to the rearward implement tasks.

- Despite this union, the locations adjacent to the tractors’ rear tires (Cells 2 and 4) suffered viewing impairments, with only 25% of tractors achieving the kneeling indicator level in Cell 4.
- Extremity locations nearest the tractor (Cells 1 and 5) were 100% unobservable and no greater than 50% observable as far away as 4.6 m (15 ft.) from the rear of the machine.

6.5 Analysis of results – All tested machines

Similar results were seen for all agricultural tractors and other self-propelled machines tested as with the tractors only – i.e., less visibility nearest the rear of the machines and improving with greater distance.

6.5.1 Rearward visibility via mirrors only

The visibility model for all nine tested machines equipped with factory-installed and/or after-market mirrors (Figure 6.5) revealed the following:

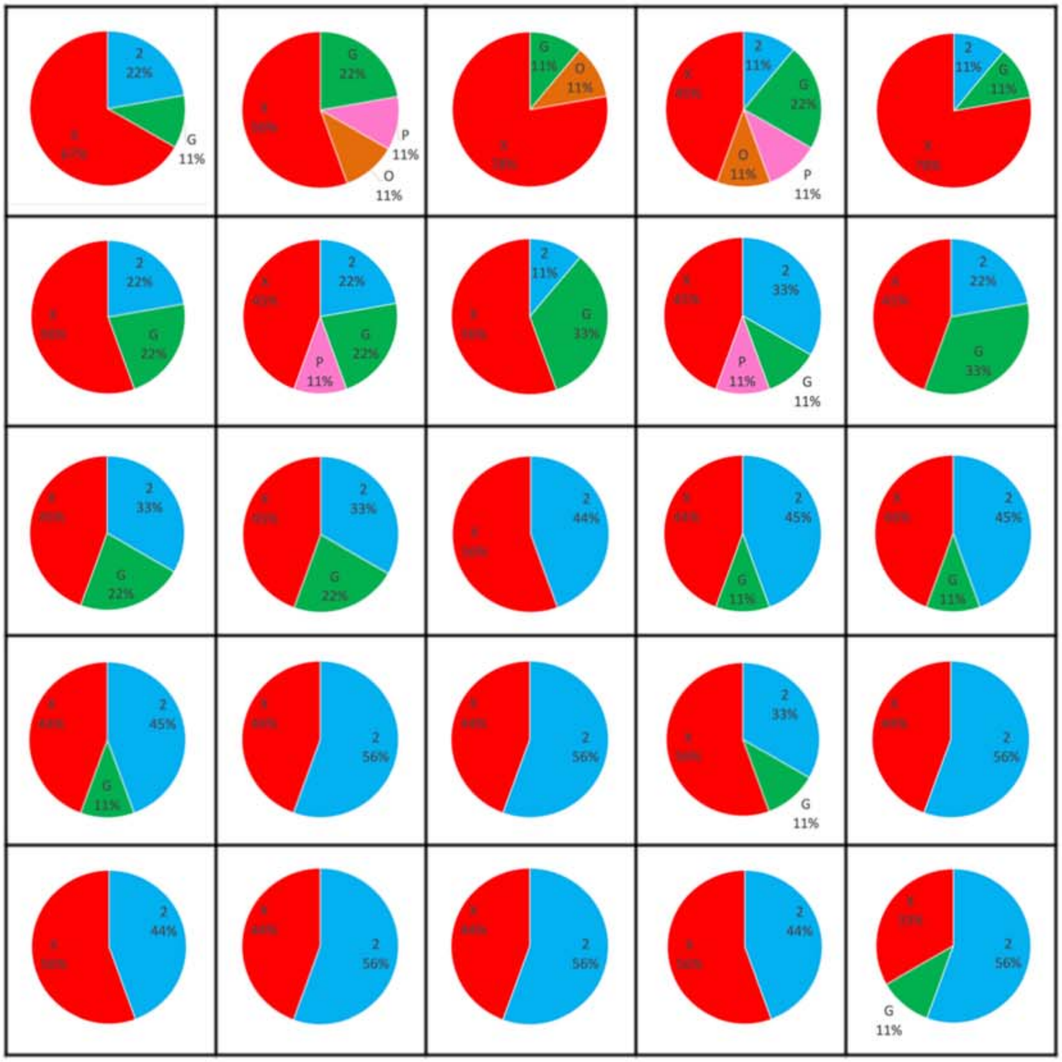


Figure 6.5. Visibility model for mirrors on all nine tested machines.

- An average of 65% completely obstructed view was recorded for the area directly adjacent o the rear of the machine (Row 1).
- The test grid located at the midline/hitching point (Cell 3) averaged 78% completely obstructed view, which was also the highest level of obstructed view recorded in Figure 6.5
- The level of obstructed view associated with Cells 2, 3, and 4 was closely linked the location of runover incidents discussed in Chapter 2.

- The greatest distance tested from the rear of the machine (Row 5) averaged 47% completely obstructed view.
- An average of 51% of the kneeling indicators in Row 5 were visible, compared to only 9% in Row 1.

6.6 Rearward visibility via cameras only

Unlike the uniformity of visible areas measured from the identical placement of the tractors only, the other self-propelled machines utilized multiple cameras of various makes, models and mounting locations. The visibility model for all the tested machines to which were added cameras (Figure 6.6) revealed the following:

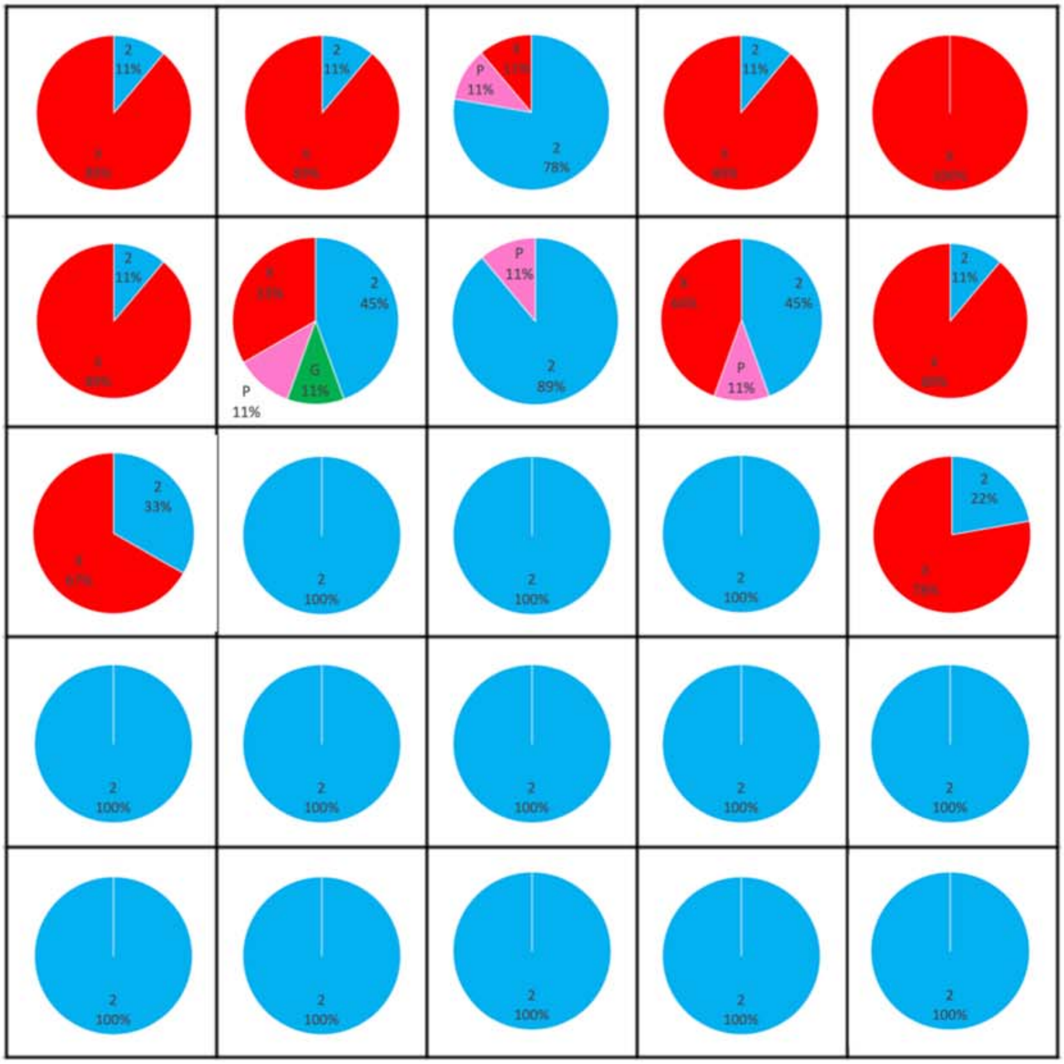


Figure 6.6. Visibility model for cameras on all nine tested machines.

- The level of consistency of the visibility grid was similar to that found for the tractors only as seen in Figure 6.3.
- The Pearson r test yielded a high value of r = 0.97, which indicated a strong positive correlation of visibility for the kneeling indicators utilizing camera technology for tractors only compared to all the machines tested.

- Minor variances were recorded in those areas nearest the rear of machines versus the uniform results generated by the consistent PTO shielding location for cameras in the tractors-only tests.
- These minor variances can be attributed to the different camera mounting locations on the other self-propelled machines, as their design and function limited the ability to consistently mount the camera in a low and central location.

6.7 Rearview visibility via union of mirrors and cameras

The visibility model that included a diverse pool of tractors and other self-propelled machinery with multiple variations of operator stations, cameras and both interior and exterior mirror positioning (Figure 6.7) revealed the following:

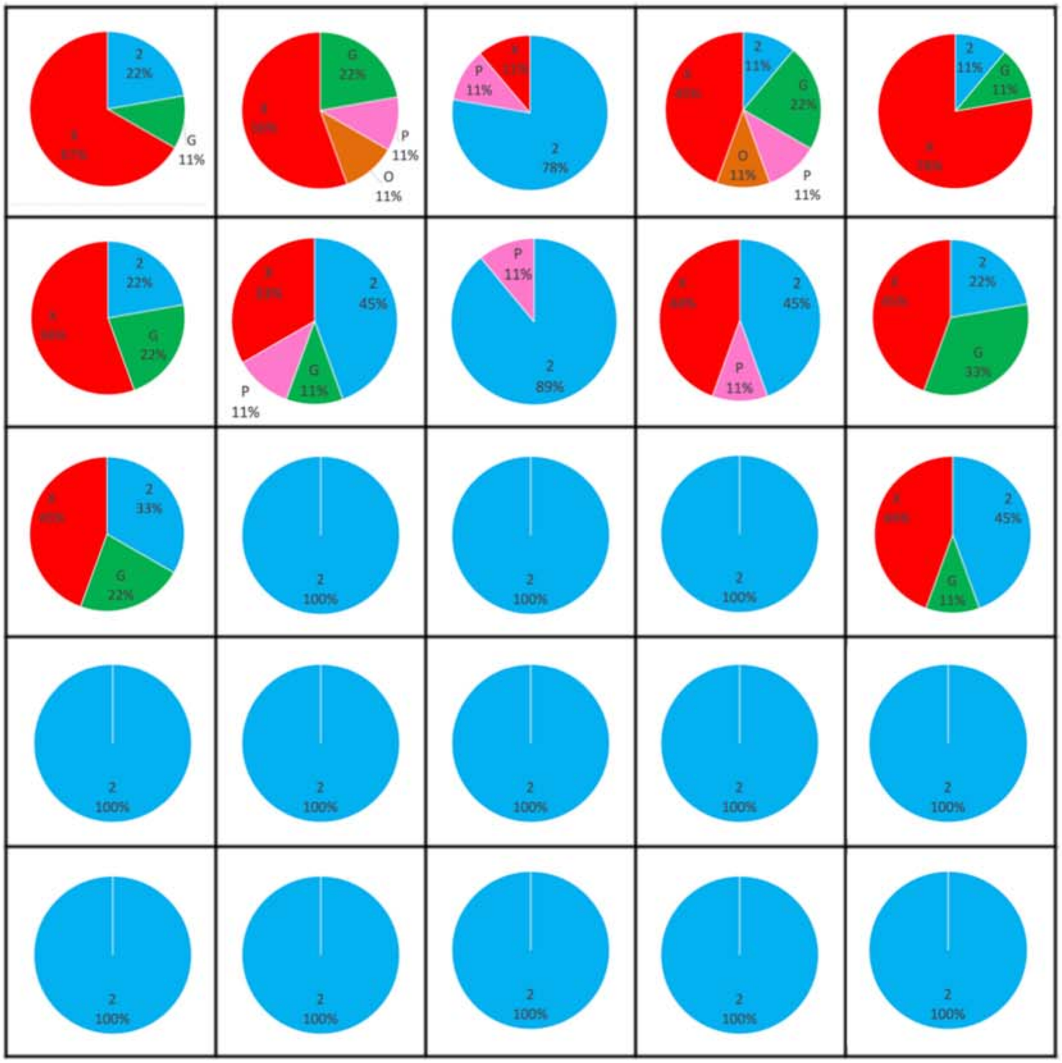


Figure 6.7. Visibility model of union of all testing mediums on all nine tested machines.

- Although many differences can be realized among the test sample, 100% visibility of the kneeling indicators were achieved in Rows 4 and 5.
- Overall midline visibility was unyielding, with minor infringements in Cells 3 and 8 averaging 93% visibility of the kneeling indicators along the entire midline of Cells 3, 8, 13, 18, and 23).

- Similar to the previous graphs, visibility increased as distance from the rear of the machine increased, with the grid extremities offering the highest level of obstructed views.

6.8 Recommendations based on the analyzed results

There are various elements/items that can impact the level of visibility (rearward and/or forward) of agricultural machinery. They involve operator station design and configuration, seat height, operation station optional accessories, machine exterior lighting, mirrors, camera systems, types of implements in tow, and methods of hitching. Following are some of the issues and recommendations related to each.

6.8.1 Recommendations regarding operator station design/configuration

In carrying out this study, subtle differences were noted among the various machines relative to the design features and configuration of their operator stations, some of which played a significant role in maximizing visibility, thus leading to the following recommendations:

(1) Operator stations should offer as clear a line of sight as possible of the areas immediately surrounding the machine by aligning unavoidable obstructions to minimize their impact. This is seen where the manufacturers have aligned displays, control panels, and external components with the machines' cab structural supports/ROPS.

(2) An under-utilized location in the operator station of all tractors tested was the area above the central steering wheel console. Aligning this area of forward obstruction of

the tractor’s hood with a monitor to display camera input offered no addition to forward obstructed areas while increasing the operators’ awareness of rearward areas greatly.

6.8.2 Recommendations regarding operator station accessories

Sun Blinds. A rather common in-cab component of most newer machines today, sun binds can be located in both front and rear windows and are usually made of a mesh material, which allows the operator to extend and retract them from the cab’s headliner. Although they may somewhat restrict visibility, the benefit of reducing glare and direct sunlight far outweighs any possible hindrances.

Windshield Wipers. These are another increasingly standard accessory, many of which have window-cleaning capability. The particulates that collect on the external surface of cab glass can significantly affect one’s ability to see clearly the surrounding area and even to carry out an intended task. Depending on cab location and style, configuration of the windshield wipers is important. For self-propelled vehicles with forward-positioned cab (e.g., combine harvester, sprayer, forage cutter), the front windshield often extends from roof to floor. If such is the case, it is recommended that the dual front wipers have washing capability to improve both outward and downward observations angles. If the machine is intended for extensive field work with towed or mounted implements, the capacity to clear rear-facing windows would be beneficial, especially under dusty conditions. Lastly, it is recommended for manufactures to place windshield wipers with washing capabilities on the cab’s side windows as well to allow for less obstructed view of exterior extended-arm mirrors for machine types of which this area is difficult to access, such as a combine.

Interior Lighting. Control panels and display monitors can produce interior glare during operation. Thus, it is recommended that all displays have the capability of being manually or automatically dimmed/brightened with changing light levels plus have an adjustable background color to reduce potential for creating glare as well as maximize contrast of the displayed information. In some situations, it may be necessary to provide a sun visor or shielding so the operator can better ‘read’ the displayed information.

Radio Controls: Machinery equipped with radios can impair the operators’ ability to audibly recognize hazardous situations, despite being equipped with assistive technology. Some types of hazard detection technology alert the operator not only visually but with an audible alarm, as well as vocal commands by co-workers. Operator recognition of audible hazard alerts and vocal commands can be undetected if radio volume level surpasses that of the alerting tone. It is recommended that machinery equipped with factory radio systems to be overridden by safety alert tones, and also set a maximum allowable decibel level when the machinery is in reverse. It is also recommended that placement of radio controls not impair the operators’ ability to utilize any viewing medium.

6.8.3 Recommendations regarding machine exterior lighting

The recommended color temperature is about 6500k, which allows easier focus for one with reduced eye strain (Draper, 2012). With recent improvements to xenon, HID, and LED capabilities, more of the surrounding area can now be illuminated (up to 360° around the machine) with the proper selection and placement of lamp type—i.e., flood, trapezoid, and spot (Gaines, 2013). According to Templeton et al. (1998), proper placement of exterior lights is important to prevent unwanted illumination of suspended particles (i.e., dust, debris) surrounding the machinery. That ‘proper placement’ is above and/or below the operator’s line of sight, whereas placement in his line of sight will maximize the illumination of suspended particles.

6.8.4 Recommendations regarding mirrors

A wide variety of mirrors were examined during this study, with multiple differentiations observed relative to their placement, size, shape, and curvature in relationship to their overall effectiveness.

Exterior mirrors. Exterior extended-arm mirrors were found to be highly beneficial when it comes to an implement in tow. Most often mounted on the forward most corners of the cab, they provided viewing angles otherwise unobtainable from the operator’s seated location. However, adjustability was the single most important asset or hindrance to level of visibility. In the case of manually adjusted mirrors, operators often neglect to position (or re-position) them to the proper viewing angles because of their out-of-reach location. Furthermore, one’s ability to vary the distance of exterior mirrors from the machine’s midline greatly affects the viewable area by broadening the angle of view. The highest level of visibility is acquired with mirrors that allow the greatest amount of ‘tailoring’ to accommodate specific tasks. The most commonly encountered adjustable variables include mirror angles and distance from the midline of the cab.

Through evaluation of multiple exterior extended-arm mirrors in this research, it is recommended that they possess the following characteristics – (1) have enough surface area to sufficiently view the intended areas as outlined by Sjøflot (1980b); (2) are electronically adjustable from the seated operating position; (3) are telescopic to allow for change in distance from the machine’s midline; (4) are durable and retractable with a breakaway feature as so to minimize damage by trees, buildings, and other machines; (5) have a multiple mirror surface within a single house (as seen on Case Magnum 310 Figure 5.37); and (6) are located so as not to impair ingress/egress and cab door arc.

Interior Mirrors. Interior mirrors can be beneficial to the operator’s ability to detect hazards toward the rear of the machine, provided the mirrors are properly placed. In this study, the most commonly encountered ‘hindrance’ to their effectiveness were such things as operator controls (e.g., radio, climate control vents), cab structural components, and even the operator himself. While not all of these hindrances can be removed, their impediments to rearward visibility can be reduced by mounting a mirror in each forward corner of the cab.

6.9 Recommendations regarding camera systems

At this point in time, utilization of camera technology in the agricultural industry (compared to other industries) has been rather limited. Yet it can be easily adapted to many facets of agricultural productions, such as monitoring machine functions; insuring proper alignment (during hitching, unloading, storage facility navigations); gauging input/output levels in grain tanks, seeding bins/compartments, liquid and dry applications; detecting fault; bystanders; and enhancing safety and security. As verified in this research, cameras properly placed on tractors and other self-propelled machinery can provide a level of visual data previously unattainable by the operator.

In this study, on conventional row-crop tractors, hitching and midline visibility was best achieved with the camera placed above the PTO master shield. At that location, it was not only largely protected from damage, but was also easily accessible should it have to be removed or repositioned. The 170° angle lens equipped cameras utilized in testing provided a wide angle of visibility but neglected some areas close to the rear tires. To improve the visibility these areas, it is recommended that a second camera be mounted high off the rear of the cab in order to provide a top-down orientation. Negatives with this location include poor depth perception and reduced rearward view as the distances from the rear of the tractor increase. On other self-propelled machinery, best results were realized with the camera in a low, central location, except where machine functions, such as generation of large amounts of dust or airborne materials would hinder image clarity, such as with a combine.

Two more crucial components when selecting a camera system for agricultural applications are image quality and display size. The operator’s ability to make decisions about obstructed areas in close proximity of his machine depends on correctly interpreting the visual data. High-definition camera images and a display that’s large and clear enough to convey the information are key to success of the system. The recommended characteristics of a camera systems are as follows:

Camera- (1) wide angle (170°), high definition, color camera; (2) waterproof or at least water resistant; (3) appropriate mounting capability for intended applications (e.g., magnetic, fasteners, adhesive); (4) water-printed (overlaid) distance grid to assist in gauging proximity to objects; (5) meets NHTSA standards; and (6) some level of low light assistance (LED lighting, night-vision)

Monitor- (1) minimum 17.8 cm (7 in.) color display, with resolution levels equal to or greater than the capacities of the camera; (2) at least two video inputs to allow for simultaneous viewing; (3) mirroring option to allow for proper orientation selection for the particular job; (4) 100% on time (unlike automotive backup cameras that only operate when the vehicle is in reverse); and (5) proper wiring harness to utilize existing display components.

6.10 Recommendations regarding implements in tow

Agricultural machines that tow implements require additional attention to ensure the detection of nearby or following hazards, such as overtaking traffic. Utilizing mirrors and cameras in unison will assist in achieving that increased level of visibility as well as maximizing safety and operation monitoring. When used in concert with rearview cameras (one on the machine’s PTO shield, the other at the rear of the implement), exterior extended-arm mirrors should be focused on the extremities of the trailing implement. This allows the operator to quickly see the furthest points of the implement’s footprint, while utilizing the camera technology to monitor midline and rear-most areas. Such a mirror-camera configuration, of course, calls for use of a dual-input monitor so the operator can see both the space between tractor and implement and the area behind the implement. This configuration can also be utilized in fault and implement status monitoring. Being relatively small, cameras can be positioned appropriately to allow the operator to see tank/bin levels, implement mounted gauges, in addition to their obvious safety benefits.

6.11 Recommendations regarding hitching

Case studies, cited in Chapter 2, have revealed that incidents involving co-workers are often encountered during the hitching of implements, resulting in injury or death from being crushed or pinned between the tractor and implement. A primarily reason is that the operator loses visual connection with a co-worker. Having the highest tested level of midline visibility of the kneeling indicators, camera technology provided the greatest capability of visual connection with a co-worker during hitching procedures. Safety is also increased due to better transmission of visual signals from co-worker to operator. Although not tested in visibility studies, the addition of an externally mounted microphone to allow verbal communication as well as increased visibility would also likely make the hitching process safer.

Adjustable hitching components also increase safety during hitching. While not a contributor to operator visibility, adjustable hitching components (telescopic lift arms on the three-point-hitch with sway control, telescopic tongue design on implements, external manipulation of three-point-hitch height from outside the machine, quick hitches, and spring assisted tongue height) allow for co-workers to maintain a safe distance from the hitch points while machinery is in motion during the hitching process (Figure 6.8).

Figure 6.8. Hitching assistive devices—A. spring assisted tongue, B. telescoping tongue, C. telescoping tractor lift arms, D. fender mounted lift arm controller.

6.12 Recommendations regarding highway transport

The safe transport of agricultural equipment on highways can be difficult and potentially dangerous due to its size and obstructed visibility. (In fact, for many implements, being in highway transport mode reduces visibility more than being in field-operation mode.) Exterior extended-arm mirrors are especially important during highway transport because they allow the operator to see beyond the extremities of both machine and trailing implement.

An on-highway vehicle passing an agricultural machinery is dangerous enough, but even more so if the machine operator is in the process of making a left-hand turn. Because large blind spots exist to the rear of machinery, detection of automotive traffic is difficult at best. In this study, the addition of camera technology was shown to increase midline visibility in all tests. If utilized during on-highway transport, it would provide the operator a level of awareness of automotive hazard otherwise unattainable, as seen with the tested implement in tow (see Figure 5.35)

6.13 Suggestions for future developing evidence-based standards

It is recommended that consideration be given to the establishment of an ASABE or SAE committee to develop a standard method of testing tractor and other self-propelled agricultural machine visibility, and for determining minimal levels of accepted visibility for particular machine types. This process should also include the development of standardized labeling or safety messages for obstructed areas. It is further recommended that prior-established methods of measuring visibility by

NHTSA for on-highway vehicles and SAE for construction equipment be utilized, as was done in this research. Combining SAE’s methods of determining obstructed areas created by machine components and NHTSA’s methods of examining visibility acquired by assistive technology (e.g., cameras and mirrors), would ensure a standard designed to improve one of the most dangerous industries in the world—agriculture. Attached as Appendix A is a draft letter to ASABE recommending the consideration of a consensus standard of operator visibility, with special consideration given to rearward travel. Appendix B is a preliminary draft of a standard related to safety signage based upon the findings of this study. Appendix C is a preliminary draft of a consensus standard designed to develop consistent methods for measuring the rearward visibility of agricultural machinery.

LIST OF REFERENCES

LIST OF REFERENCES

American Society of Agricultural Engineers Standards [ASAE]. (2004 a). S351: Hand Signals for Use in Agriculture. St. Joseph, MI.: American Society of Agricultural Engineers. Retrieved from: http://www.asabe.org/.

American Society of Agricultural Engineers Standards [ASAE]. (2004 b). S383.1: Roll-over Protective Structures (ROPS) for Wheeled Agriculture Tractors. St. Joseph, MI.: American Society of Agricultural Engineers. Retrieved from http://www.asabe.org/.

American Society for Testing and Materials [ASTM]. (1979). Standard Method of Salt Spray (Fog) Testing. Designation B 117-73. ASTM International. West Conshohocken, PA

American National Standards Institute [ANSI]. (2007). ANSI procedures for the national adoption of ISO and IEC standards as American National Standards. American National Standards Institute. New York, NY.

Antique Farming. (2016). International Harvester announces the Farmall A, January 14, 2016, http://www.antiquefarming.com/farmall-A.html

Brauer, K. (2014). 2015 Ford F-150: Top 10 innovative features on Ford's best selling truck. Forbs Autos. http://www.forbes.com/sites/sap/2016/04/07/lean-innovation-design-thinking-meets-lean-startup-for-the-enterprise/#7d051fe22faa

Centers for Disease Control and Prevention [CDC]. (1999). Deaths among children aged less than or equal to 5 years from farm machinery runovers – Iowa, Kentucky, and Wisconsin, 1995-1998, and United States 1990-1995. MMWR 48(28): 605-608. Atlanta, GA.

Centers for Disease Control and Prevention [CDC]. (2012). Anthropometric Reference Data for Children and Adults: United States, 2007-2010. National Center for Health Statistics. Vital Health Stat 11 (252)

Chang, JH., Fathallah, FA., Pickett, W., Miller, BJ., Marlenga, B. (2010). Limitations in fields of vision for simulated young farm tractor operators. Ergonomics. June; 53(6):758-766

Costin, A.M., Teizer, J., Schoner, B. (2015). RFID and BIM-enabled worker location tracking to support real-time building protocol control and data visualization", ITcon, 20, 495-517, http://www.itcon.org/2015/29.

de Leon, J. (2010). Airlift called for man injured in Snoqualmie tractor accident. The Seattle Times, Seattle WA. http://old.seattletimes.com/html/theblotter/2013609351_airlift_called_for_man_injured.html

Delaware. (2010). Delaware 2018 occupation and industry projections. Wilmington, Del.: Delaware Department of Labor, Office of Occupational and Labor Market Information.

Draper, T. (2012). Are higher cost LED work lamps worth the money? OEM off highway, November/December 2012. oemoffhighway.com/10055668

Ehlers, S. G., Field, W. E. (2015). Examination of Rearward Movement Incidents Involving Agricultural Machinery. International Society for Agricultural Safety and Health. Paper # 15-07

Ferrari, E., Cavallo, E. (2013). Operators' perception of comfort in two tractor cabs. J. Agric. Saf. Health, 19(1), 3-18. http://dx.doi.org/10.13031/2013.42539.

Fresno Bee. (2008). Tractor runs over worker. Fresno Bee. Fresno, California. http://www.fresnobee.com/2008/07/07/715675/news-briefs.html#storylink=cpy

Gaines, T. (2013) Lighting the way: Once restricted to incandescent lamps, today's equipment can be fitted with a far wider array of light types. Successful Farming Magazine, August 2013. Des Moines, IA.

Gambatese, J., Hyun Woo, L. (2016) 16-018 Prevention of equipment run-over/back over incidents in work zones. ODOT Research Section, Salem, OR.

Godwin, A., Eger, T. (2012). Evaluating underground mining equipment line-of-sight and augmented vision. EMERST Design Evaluation Case Study 12-02. Laurentian University, Sudbury, ON Canada.

Gomez, M., Hwang, S., Stark, A., May, J., Hallman, E., & Pantea, C. (2003). An analysis of self-reported joint pain among New York farmers. J. Agric. Saf. Health, 9(2), 143-157. http://dx.doi.org/10.13031/2013.13004.

Google. (2016). Google self-driving car project. Google. Mountain View, CA https://www.google.com/selfdrivingcar/

ifm. (2016). 3D smart sensor – your assistant on mobile machines. ifm USA. Malvern, PA. http://www.ifm.com/ifmus/web/mobile-3d.htm

Illinois Extension. (2012). Illinois Farm Relate Fatalities 1986-2012. Illinois Extension, University of Illinois, Champaign, Illinois. https://my.extension.illinois.edu/documents/2377131107130713/Illinois%20Farm%20Related%20Fatalities%201986.pdf

ISO. (2013). ISO 5721-1 Agricultural tractors – Requirements, test procedures and acceptance criteria for the operator's field of vision. Geneva, Switzerland: ISO/IEC

Hanson, B. (2016) Easily view the seed level. Successful Farming Magazine, January 2016. p 74. Des Moines, IA.

Hendricks, L. (2011). Child run over, killed by tractor. Arizona Daily Sun. Flagstaff, AZ. http://azdailysun.com/news/local/child-run-over-killed-by-tractor/article_dd9e19be-ca37-5488-9b4a-9c098b801665.html

Horswell, C. (2014). Freak tractor accident kills Liberty County man. Huston Chronicle. http://www.chron.com/news/houston-texas/houston/article/Freak-tractor-accident-kills-Liberty-County-man-5865257.php

Karimi, D., Henry, J., & Mann, D. D. (2012). Effect of using GPS autosteer guidance systems on the eye-glance behavior and posture of tractor operators. J. Agric. Saf. Health, 18(4), 309-318. http://dx.doi.org/10.13031/2013.42332.

KMBC. (2014). Marshall man dies in tractor accident. KMBC.com. Kansas City, MO. http://www.kmbc.com/news/marshall-man-dies-in-tractor-accident/27927770

KRCG. (2014). Missouri man dies in tractor accident. New Bloomfield, MO. http://krcgtv.com/news/local/missouri-man-dies-in-tractor-accident?id=1093578

KXRA. (2014) Man seriously injured in farm accident near Underwood. Kxra's Voice of Alexandria. Alexandria, MN. http://www.voiceofalexandria.com/news/local/man-seriously-injured-in-farm-accident-near-underwood/article_d71d328e-0e79-11e4-8b2b-001a4bcf6878.html?TNNoMobile

Lund, M., Butters, L. (2011). An investigation and comparison into operator field of vision for modern tractor cabs. Scientific papers, UASVM Buncharest, Series A. Vol. LIV, 2011.

Mosely, MJ., Griffin, MJ. (1986) Effects of display vibration and whole-body vibration of visual performance. Ergonomics Volume 29, Issue 8: 977-983.

National Highway Traffic Safety Administration [NHTSA]. (2007). Cameron Gulbransen Kids Transportation Safety Act of 2007. Public Law 110-189. 110th Congress. Washington D.C.

Nolan, D. (2014). Man injured under tractor. Independent House, Dublin, Ireland. http://www.independent.ie/regionals/kerryman/news/man-injured-under-tractor-30106121.html

Office of the Federal Register [OFR]. (2014). Federal Motor Vehicle Safety Standards; Rearward Visibility. Retrieved from: https://federalregister.gov/a/2014-07469

Occupational Safety and Health Administration [OSHA]. (2014). Standard 1926.602(a)(9)(ii): Safety and health regulations for construction. Subpart title: Motor vehicles, mechanized equipment, and marine operations. Washington, D.C.: Occupational Safety and Health Administration. Retrieved from https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10769.

Otago Daily Times. (2013). Wife backed over, killed near Christchurch. Otago Daily Times, Dunedin, New Zealand. http://www.odt.co.nz/news/national/278363/wife-backed-over-killed-near-christchurch

PAMI. (2011). Safe Implement Hitching, A Guide for Safe Connection ofAgricultural Tractors to Implements. Saskatchewan, Canada. Retrieved from http://www.wsps.ca/WSPS/media/Site/Resources/Downloads/Safe_Implement_Hitching_Guide.pdf?ext=.pdf

Politzer, T. (2016). Implications of acquired monocular vision (loss of one eye). Neuro-Optometric Rehabilitation Association. https://nora.cc/for-patients-mainmenu-34/loss-of-one-eye-mainmenu-70.html

Preco Electronics. (2014). PreView SAS: Safety alert system. Boise, Idaho: Preco Electronics, Inc. Retrieved from http://preco.com/safety-alert-system-sas/.

Quinn, R. (2010). The eyes have it – Versatile video cameras see where farmers cannot. The Progressive Farmer, Mid-November 2010 : 32-33 Birmingham, AL.

Rakhra, A. K., & Mann, D. D. (2013). Evaluation of implement monitoring systems. J. Agric. Saf. Health, 19(1), 51-67. http://dx.doi.org/10.13031/2013.42542.

Rapid City Journal. (2010). Tractor backs over Buffalo man. Rapid City Journal, Rapid City, SD. http://rapidcityjournal.com/news/tractor-backs-over-buffalo-man/article_6368f6ee-8f97-11df-a1ed-001cc4c03286.html

Redlick, F. P., Jenkin, M., & Harris, L. R. (2000). Humans can use optic flow to estimate distance of travel. Vision Res., 41(2), 213-219. http://dx.doi.org/10.1016/S00426989(00)00243-1.

Robinson, R. (2013). Man, 81, run over, killed by tractor in East Hempfield Township. Lancaster Online. http://lancasteronline.com/news/man-run-over-killed-by-tractor-in-east-hempfield-township/article_d6831866-c441-57ea-9027-4231f76cdf05.html

SAE International. (1994). Describing and measuring the driver’s field of view. SAE Standard J-1050.

SAE International. (1997 a). Measuring the radius of curvature of convex mirrors. SAE Standard J-1246.

SAE International. (1997 b). Motor vehicle driver’s eye locations. SAE Standard J 941.

SAE International. (1998). Vision glossary. SAE Standard J-264.

SAE International. (2009). Describing and Measuring the Driver's Field of View. SAE Standard J-1050. Revised 2009

SAE International. (2013). Earthmoving machinery – Operator’s field of view. SAE Standard J-1091.

Sap, B. (2012). Utility vehicle rear-view mirror. European Patent Specification EP.2.441.621.B1.

Sjøflot, L. (1980a). Big mirrors to improve tractor driver’s posture and quality of work. British Soc. Res. Agric. Eng. 25(1), 47-55.

Sjøflot, L. (1980b). Means of improving a tractor driver’s working posture, ergonomics. Norwegian Inst. Agric. Eng., 23(8), 751-761.

SnoValley Star. (2010). Logger taken by helicopter to Harborview after tractor crushes his leg. SnoValley Star, Issaquah, WA. http://snovalleystar.com/2010/12/07/logger-taken-by-helicopter-to-harborview-after-tractor-crushes-his-leg

Subaru of America. (2014). Forester EyeSight Owner’s Manual. Fuji Heavy Industries LTD. Tokyo Japan.

Suzuki, R. (2013). Construction worker killed after being run over by tractor. Suzuki Law Offices L.L.C. Phoenix, AZ. http://www.suzukilawoffices.com/Blog/2013/March/Construction-Worker-Killed-After-Being-Run-Over-.aspx

Teizer, J. (2013). Computing 3D blind spots of construction equipment: implementation and evaluation of an automated measurement and visualization method utilizing range point cloud data. Elsevier, 36, 95-107, http://dx.doi.org/10.1016/j.autcon.2013.08.007

Teizer, J. (2015). Magnetic Field Proximity Detection and Alert Technology for Safe Heavy Construction Equipment Operation. RAPIDS Construction Safety and Technology, Germany.

Teizer, J. (2016). Personal conversation. February 22, 2016.

Templeton, D. J., & Strong, R. W. (1998). Essential design considerations for today’s tractor cab and a challenge for the future. ASABE Distinguished Lecture No. 22. St. Joseph, Mich.: ASAE.

Todd, M. (2011). Tractor crushes man to death at landfill. Virgin Islands Daily News. St. Thomas, VI. http://virginislandsdailynews.com/news/tractor-crushes-man to-death-at-landfill-1.1248624

U.S. Deparment of Transportation [USDOT]. (1999). Laboratory Test Procedure for FMVSS - School Bus Rearview Mirrors. TP111SB-00. Office of Vehicle Safety Compliance. Washington D.C.

U.S. Census Bureau. (2011). Statistical abstract of the United States: 2012. Washington, D.C.: U.S. Census Bureau. Retrieved from www.census.gov/library/publications/2011/compendia/statab/131ed.html

U.S. Department of Labor, Bureau of Labor Statistics [BLS]. (2014). National Census of Fatal Occupational Injuries in 2013 (Preliminary Results). Retrieved from http://www.bls.gov/news.release/pdf/cfoi.pdf

U.S. Centers for Disease Control and Prevention [CDC], Fatality Assessment and Control Evaluation [FACE]. (1992). NIOSH FACE Report 9307

U.S. Centers for Disease Control and Prevention [CDC], Fatality Assessment and Control Evaluation [FACE]. (1996). NIOSH FACE Report 96MO082

U.S. Centers for Disease Control and Prevention [CDC], Fatality Assessment and Control Evaluation [FACE]. (1998 a). NIOSH FACE Report 98IA037

U.S. Centers for Disease Control and Prevention [CDC], Fatality Assessment and Control Evaluation [FACE]. (1998 b). NIOSH FACE Report Minnesota Case 98MN030

U.S. Centers for Disease Control and Prevention [CDC], Fatality Assessment and Control Evaluation [FACE]. (1999). NIOSH FACE Report 99TX38101

U.S. Centers for Disease Control and Prevention [CDC], Fatality Assessment and Control Evaluation [FACE]. (2001). NIOSH FACE Report 01CA008

U.S. Centers for Disease Control and Prevention [CDC], Fatality Assessment and Control Evaluation [FACE]. (2002). NIOSH FACE Report California Case 02CA010

U.S. Centers for Disease Control and Prevention [CDC], Fatality Assessment and Control Evaluation [FACE]. (2005). NIOSH FACE Report Iowa Case 04IA017

U.S. Centers for Disease Control and Prevention [CDC], Fatality Assessment and Control Evaluation [FACE]. (2009). NIOSH FACE Report 2008-01

U.S. Centers for Disease Control and Prevention [CDC], Fatality Assessment and Control Evaluation [FACE]. (2015). NIOSH FACE Reports: Agriculture. Retrieved from http://wwwn.cdc.gov/NIOSHFACE/Default.cshtml?state=ALL&Incident_Year=ALL&Category2=0001&Submit=Submit

U.S. Centers for Disease Control and Prevention [CDC], National Institute for Occupational Safety and Health [NIOSH]. (2014). Agricultural Safety. Retrieved from http://www.cdc.gov/niosh/topics/aginjury/

U.S. Department of Labor [DOL], Occupational Safety & Health Administration [OSHA]. (1998). Enforcement Exemptions and Limitations under Appropriations Act. Retrieved from https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=DIRECTIVES&p_id=1519

U.S. Department of Labor [DOL], Occupational Safety & Health Administration [OSHA]. (2015 a). Regulations (Standards - 29 CFR 1926.601(b)(4)) Retrieved from: https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10768#1926.601(b)(4)

U.S. Department of Labor [DOL], Occupational Safety & Health Administration [OSHA]. (2015 b). Regulations (Standards - 29 CFR 1926.21(b)(2)) Retrieved from https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10607

U.S. Department of Transportation [DOT], National Highway Traffic Safety Administration [NHTSA]. (2010). 49 CFR Parts 571 and 585, Federal Motor Vehicle Safety Standard, Rearview Mirrors; Federal Motor Vehicle Safety Standard, Low Speed Vehicles Phase-in Reporting Requirements. Washington D.C.

U.S. Deparment of Transportation [DOT] National Highway Traffic Safety Administration [NHTSA]. (2011). Vehicle Rearview Image Field of View and Quality Measurement. Washington D.C.

VSS. (2014). TxRx wireless series. Oto, Iowa: Video Surveillance Solutions. Retrieved from www.vss911.com/products/wireless/txrx-info.

WLFI. (2016). Fatal tractor accident in Newton County. WLFI.com. West Lafayette, IN. http://wlfi.com/2016/02/26/fatal-tractor-accident-in-newton-county/

WMC-TV. (2010). Man accidently backs over one-year-old child with tractor. Memphis, TN. http://www.wbtv.com/story/13123088/man-accidentally-backs-over-one-year-old-child-with-tractor

Young-Joo, K., Sun-Ok, C., Mingzhang, S., Md Shasha Nur, K., Jong-Kyou, H. (2015). Visibility evaluation for agricultural tractor operators according to ISO 5006 and 5721-1 standards. Journal of Biosystems Engineering. 40(1): 19-27

APPENDICES

Appendix A Letter to ASABE director of standards & technical activities

Mr. Scott Cedarquist
Director, Standards & Technical Activities
American Society of Agricultural and Biological Engineers
2950 Niles Road
St. Joseph, MI 49085

I am writing you to recommend that voluntary consensus standards be developed by the appropriate ASABE committee to address issues pertaining to the limited visibility in near proximity to the rear of large frame agricultural machinery. The purpose of these standards would be to enhance operator capacity to identify potential locations around the machine that are obstructed from view, reduce the risk of runovers of co-workers located out of the field of vision of the operator through improved monitoring capabilities of machine surroundings and components, and to alert operators and co-workers of these hazardous locations. Specific issues that should be addressed include:

1) Need to conduct an operator field of vision assessment and include results in the operator's manual as a means of warning the operator of obstructed areas around the machine (i.e., establish a standard method of measuring machine visibility).
2) Provide clear warnings both on the machine and in the operator's manual for the potential of co-workers being out of the field of view of the operator; therefore, at risk of runover or making contact with energized components of the machine.
3) A means by which the operator can alert bystander and co-workers of machine movement, specifically in the directions outside of the operator's field of vision. This could include an audible or visual alarm indicating rearward movement of the machine.
4) Appropriate mounting and wiring configurations for the installation of camera mounting systems. This could include factory mounting brackets and wiring harnesses that meet current standards per electrical safety.

It is acknowledged that advancements of modern agricultural machinery have allowed farmers/ranchers to realize production levels that were previously unobtainable. The combination of greater speed, higher capacity and increased precision plus operator stations that provide high levels of comfort, have contributed to extremely efficient operators. However, there are some unfavorable consequences tied to these advancements. For example, (a) operators are increasingly isolated from the tasks they are performing relative to their ability to monitor machine components both visually and audibly; (b) some machine designs impair the rearward view of interior and exterior mirrors; (c) external components, (i.e., flasher bar, SMV sign, fuel tank) to the rear of some large articulated tractors are placed in direct viewing angles of the drawbar, making it nearly impossible to see a co-worker or bystander in the hitching area; and (d) when implements are in tow, the operator’s view of the area to the rear of those implements may be entirely obstructed.

With the average age of U.S. farmers/ranchers being 58 years old, the ability of many to simultaneously monitor both the multiple functions of complex machinery and the high-risk areas to the rear of that machinery can be diminished. Some of the more common age-related contributors are loss of visual and/or audible acuity and physical limitations such as arthritis, which hinders one’s ability to maneuver into a position that offers a direct rearward view without assistive technologies.

There are numerous documented incidents with regard to the unmonitored rearward travel of agricultural machinery. Some of these involved the operator reversing the machine without knowledge of an individual to the rear. Others involved the operator being aware of someone behind the machine (often co-worker attaching an implement) but failing to maintain visual contact, which resulted in the co-worker’s injury or death. Still, many cases concerned the operator him/herself failing to monitor rearward areas while backing the machine into a hazard, such as an embankment or structure, causing serious damage and/or personal injury or death. All of these identified scenarios can be substantially reduced, or eliminated, via the improvement of monitoring abilities of the operator.

Efforts are being made across the U.S. to increase the safety of motorized vehicles traveling in reverse. A recent National Highway Traffic Safety Administration (NHTSA) regulation will require, by May 2018, the installation of backup cameras on all highway vehicles weighing less than 10,000 pounds. While this regulation will not affect off-road agricultural vehicles, those engaged in the agricultural community should take note of the advancements in rearward visibility technology with minor incursion of costs. Prior to this backup camera mandate, all highway vehicles were required to attain a certain level of visibility utilizing mirrors. Again, this mandate did not apply to off-highway equipment.

Currently, agricultural machinery belonging to family farms in the U.S. do not fall under either NHTSA or Occupational Safety and Health Administration (OSHA) regulations, including 1926.602(a)(9)(ii), which states that "No employer shall permit equipment which has an obstructed view to the rear to be used in reverse gear unless the equipment has in operation a reverse signal alarm distinguishable from the surrounding noise level or an employee signals that it is safe to do so." To be subject to this regulation, the farm must have more than 10 employees. Failure to comply with these regulations can result in substantial financial penalties and/or large awards made as the result of civil litigation. This proposal seeks to pursue the development of a voluntary consensus standard that enables applicable to all new agricultural machinery, regardless of the number of employees. Such a proactive step should reduce the need for regulatory response that may not be easily applied in all circumstances.

Today's mechanized agriculture has the technology to better monitor the areas surrounding machinery that will result in fewer injuries and/or deaths. While not a new problem, new solutions are available to address the key causes of rearward travel incidents that are currently not being fully utilized by manufacturers. Our research has allowed us to gain a better perspective of both the causes and potential solutions pertaining to the rearward visibility of agricultural machinery. Thus our recommendation for the establishment of a technical committee to explore the need for standards that address the hazards present during the rearward operation of agricultural machinery as a necessary step to making agricultural production safer and more efficient.

Sincerely,

Shawn G. Ehlers, Ph.D. Candidate

William E. Field, Ed.D.

Purdue University,
Department of Agricultural and Biological Engineering
225 South University Street
West Lafayette, IN 47907

Appendix B Standard proposal: Backover-alert safety symbol for agricultural equipment

1. PURPOSE

1.1. The purpose of this standard is to establish a Backover-Alert Symbol for use on agricultural equipment, and to provide a symbol which clearly communicates the message that: YOU CANNOT BE SEEN! OBSTRUCTED VISIBILITY! BACKOVER HAZARD!

2. SCOPE

2.1. This standard presents the general uses, limitations on use, and appearance of the Backover-Alert Symbol on agricultural equipment that includes areas in the immediate vicinity of the equipment that cannot be seen prior to or during operation.

3. DESCRIPTION

3.1. The Backover-Alert Symbol shall be an equilateral square with rounded corners with black border. Interior of the symbol shall include a tractor in reverse motion in the direction of a silhouette of a person lying on the ground (in a blind spot of

3.2.the operator), with “Danger” in white uppercased bold letters overtop a red background (Figure B.1).

3.3. The tractor and person lying on the ground shall be in contrasting colors (black) with fill color of the triangular shape (yellow).

3.4. The symbol should meet the ASAE S441.3 standards for safety signs.

4. APPLICATION

4.1. The symbol should be used:

4.1.1. In conjunction with warning statements and signs found on agricultural equipment that has been identified to have areas around the equipment that cannot be observed by the operator while seated in the operator station.

4.1.2. In instruction manuals that accompany agricultural equipment where the risk of runover is present.

4.1.3. On communications which concern agricultural equipment safety.

4.1.4. In measured blind spots of agricultural machinery and implements to notify individuals that they cannot be seen by the operator.

4.2.The Symbol should *not* be used:

4.2.1. To indicate safety compliance or safety characteristic.

Figure B.1. Backover Alert Symbol.

Appendix C Standard proposal: Measuring rearward visibility for agricultural machinery

1. PURPOSE AND SCOPE

1.1. The purpose of this standard is to establish specifications which define a unique grid system to measure the operator's capacity to view rearward areas in the immediate proximity of the machine and implement while being operated.

1.2. This standard establishes 7.62 m (25 ft.) longitudinal and 7.62 m (25 ft.) latitudinal range-grid (centered and extended backward from the rearmost point of tested agricultural machinery) with indicator located in the center-point of each 1.5 m X 1.5 m (5 ft. X 5 ft.) grid cell.

1.3.Each indicator is uniquely marked utilizing the DOT method of pass/fail visibility of a single indicator (12" diameter, 32" tall cylinder) as outlined in DOT HS 811 512, section 3.3.

1.4. Tested technologies (i.e., mirrors, cameras, proximity detectors) should compliment but not replace operator direct contact (visual and audible) with intended tasks.

2. NORMATIVE REFERENCES

2.1. Agricultural equipment and other terms: Refer to ASAE Standard S390, Classifications and Definitions of Agricultural Equipment.

2.2. Vision glossary terms – Refer to SAE J264, VISION GLOSSARY

2.3. Anthropometry of Motor Vehicle Occupants: Schneider, L. W., Robbins, D. H., Pflüg, M. A. and Snyder, R. G., *Anthropometry of Motor Vehicle Occupants; Volume 1 – Procedures, Summary Findings and Appendices,* National Highway Traffic Safety Administration, DOT 806 715, 1985

2.4. Describing and Measuring the Driver's Field of View – Refer to SAE J1050

2.5. Earthmoving Machinery – Operator's Field of View – Refer to SAE J1091

2.6. Convex Mirrors – Refer to SAE J1246, Measuring the Radius of Curvature of Convex Mirrors

2.7. Agricultural Mirrors – SjOflot, L., 'Big Mirrors to Improve Tractor Driver's Posture and Quality of Work'. 1980. The British Society of Research in Agricultural Engineering

2.8. Determining Rearview Image Field of View Size, DOT 811 512, section 2.2

2.9. Establishing Rearview Image Quality Criteria, DOT 811 512, section 2.3

2.10. Rearview Image Field of View Test Procedure, DOT 811 512, section 3.3

2.11. Salt Spray (Fog) Testing, American National Standard Institute, B117-73

3. DESCRIPTION OF TEST GRID

Grid width was 2.5 times greater than the NHTSA grid, to accommodate the footprint of large off-road equipment; while the length was only 1.25 times greater to account for the length of some trailing implements (Figure C.1).

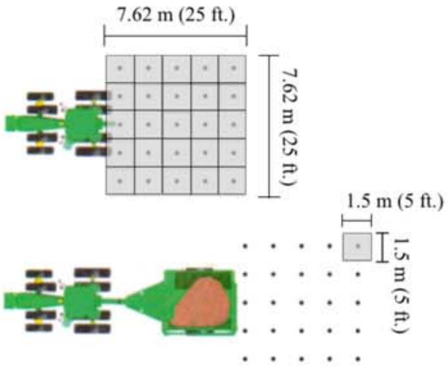


Figure C.1. Rearward agricultural test grid dimensions.

Grid cell indicators (cylinders), represented by black circles in were used to measure visibility at the center of each cell of the test area. Each test indicator was a cylinder 305 mm (12.0 inches) in diameter and 813 mm (32.00) inches tall (Figure C.2).

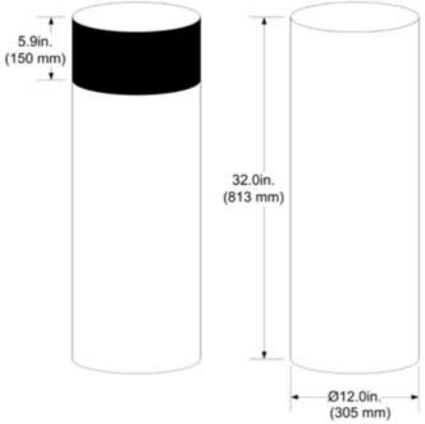


Figure C.2. Grid cell test indicator (source: DOT 811 512, 2011).

4. TEST PROCEDURE

4.1. **Equipment positioning.** Agricultural equipment tested is positioned with the rearmost protruding part (less than 2 m off the ground) centered directly adjacent to the forward-most indicator of the mid-line of the test grid. Machinery with rear-most protrusion **greater** than 2 m off the ground (i.e., combine unloading auger in the transport positon) shall be positioned with the rear-most protrusion **less** than 2 m adjacent the first mid-line indicator (see Figure C.1).

4.2. **Tested technologies positioning.** Tested technologies (i.e., in-cab mirrors, external mirrors, camera systems, proximity sensors) shall be positioned to provide the greatest level of visibility of indicators within the test grid from the operating position of the 50th percentile male driver as described by Robbins (1985), and utilized by DOT (2011) in reference to forward-looking eye midpoint (MF) point of the operator (Figure C.3).

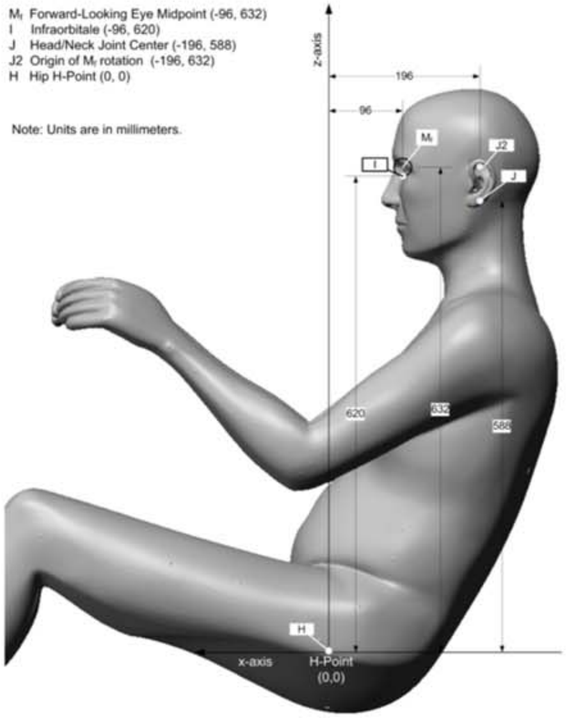


Figure C.3. Forward-looking eye midpoint (source DOT, 2011).

4.3. **Testing technologies mounting locations**. Tested technologies shall be securely mounted to machinery in accordance to manufacturer suggested method. Mounting locations must not impair equipment ingress/egress of the operator's cab, obstruct direct-view sight lines of areas in near proximity of the machine, or be placed in locations where normal operation of machinery will interfere with function or data quality of the device.

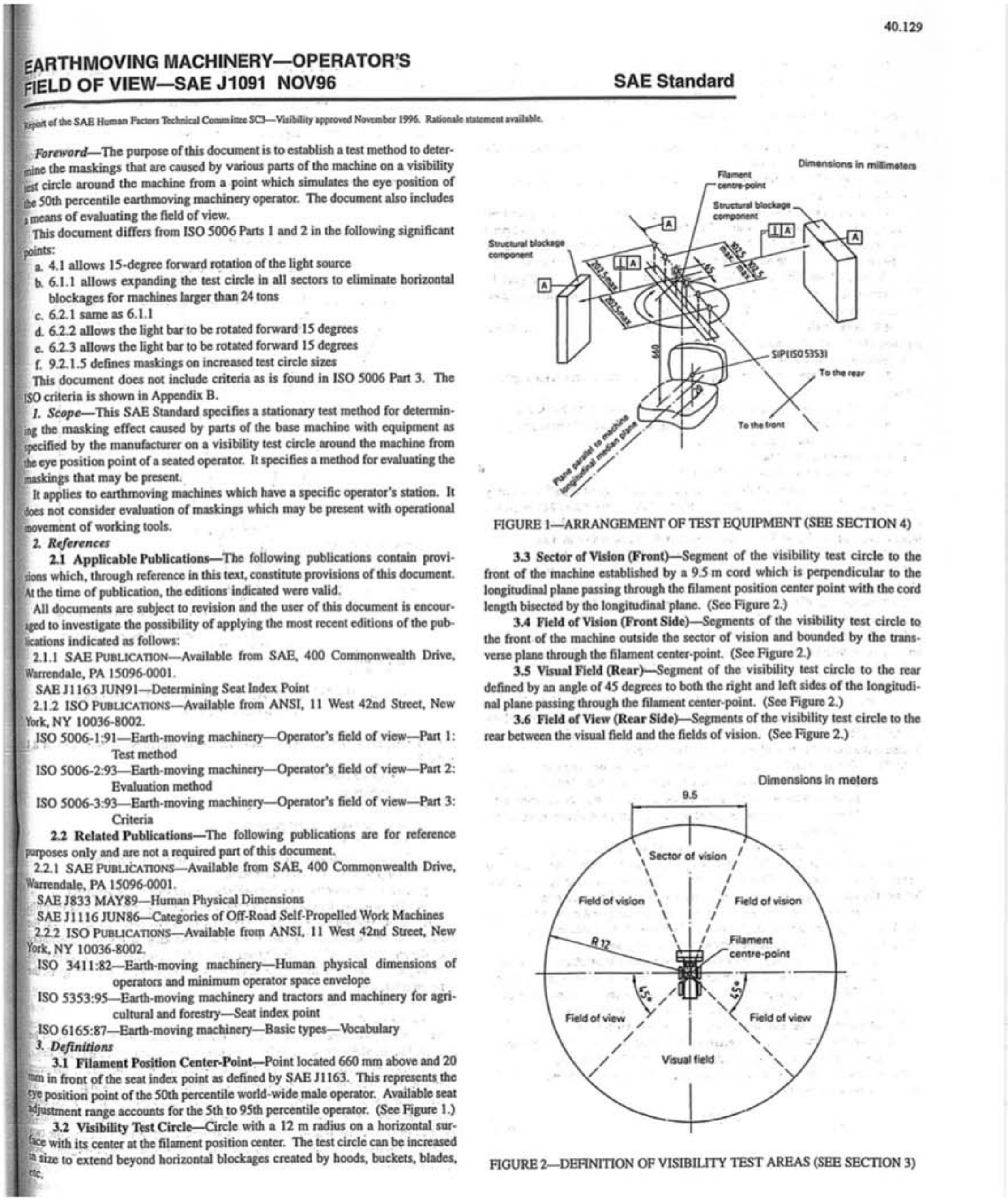
4.4. **Data acquisition.** Each of the tested technologies will be assessed individually for each of the twenty-five grid cells in accordance to the 50th percentile operator's ability to detect the indicator positioned at each cell center-point. A union of all results will display overall rearward visibility of the agricultural machine.

4.5. **Camera system requirements.** Camera systems selected for use with agricultural machinery shall meet the minimal requirements for cameras and displays as recommended by the NHTSA (DOT 811 512, 2011)

4.6. **Durability test.** Each of the tested technologies shall retain full functionality after being submitted to the ASTM B117: Standard Practice for Operating Salt Spray (Fog) Apparatus.

4.7. **Operating interval.** Each of the tested technologies shall remain in full operation while machinery ignition switch is in the “On” position.

Appendix D Earthmoving machinery – Operator's field of view – SAE J1091



EARTHMOVING MACHINERY—OPERATOR'S FIELD OF VIEW—SAE J1091 NOV96

SAE Standard

Report of the SAE Human Factors Technical Committee SC3—Visibility approved November 1996. Rationale statement available.

Foreword—The purpose of this document is to establish a test method to determine the maskings that are caused by various parts of the machine on a visibility test circle around the machine from a point which simulates the eye position of the 50th percentile earthmoving machinery operator. The document also includes a means of evaluating the field of view.

This document differs from ISO 5006 Parts 1 and 2 in the following significant points:

a. 4.1 allows 15-degree forward rotation of the light source
b. 6.1.1 allows expanding the test circle in all sectors to eliminate horizontal blockages for machines larger than 24 tons
c. 6.2.1 same as 6.1.1
d. 6.2.2 allows the light bar to be rotated forward 15 degrees
e. 6.2.3 allows the light bar to be rotated forward 15 degrees
f. 9.2.1.5 defines maskings on increased test circle sizes

This document does not include criteria as is found in ISO 5006 Part 3. The ISO criteria is shown in Appendix B.

1. Scope—This SAE Standard specifies a stationary test method for determining the masking effect caused by parts of the base machine with equipment as specified by the manufacturer on a visibility test circle around the machine from the eye position point of a seated operator. It specifies a method for evaluating the maskings that may be present.

It applies to earthmoving machines which have a specific operator's station. It does not consider evaluation of maskings which may be present with operational movement of working tools.

2. References

2.1 Applicable Publications—The following publications contain provisions which, through reference in this text, constitute provisions of this document. At the time of publication, the editions indicated were valid.

All documents are subject to revision and the user of this document is encouraged to investigate the possibility of applying the most recent editions of the publications indicated as follows:

2.1.1 SAE PUBLICATION—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J1163 JUN91—Determining Seat Index Point

2.1.2 ISO PUBLICATIONS—Available from ANSI, 11 West 42nd Street, New York, NY 10036-8002.

ISO 5006-1:91—Earth-moving machinery—Operator's field of view—Part 1: Test method
ISO 5006-2:93—Earth-moving machinery—Operator's field of view—Part 2: Evaluation method
ISO 5006-3:93—Earth-moving machinery—Operator's field of view—Part 3: Criteria

2.2 Related Publications—The following publications are for reference purposes only and are not a required part of this document.

2.2.1 SAE PUBLICATIONS—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J833 MAY89—Human Physical Dimensions
SAE J1116 JUN86—Categories of Off-Road Self-Propelled Work Machines

2.2.2 ISO PUBLICATIONS—Available from ANSI, 11 West 42nd Street, New York, NY 10036-8002.

ISO 3411:82—Earth-moving machinery—Human physical dimensions of operators and minimum operator space envelope
ISO 5353:95—Earth-moving machinery and tractors and machinery for agricultural and forestry—Seat index point
ISO 6165:87—Earth-moving machinery—Basic types—Vocabulary

3. Definitions

3.1 Filament Position Center-Point—Point located 660 mm above and 20 mm in front of the seat index point as defined by SAE J1163. This represents the eye position point of the 50th percentile world-wide male operator. Available seat adjustment range accounts for the 5th to 95th percentile operator. (See Figure 1.)

3.2 Visibility Test Circle—Circle with a 12 m radius on a horizontal surface with its center at the filament position center. The test circle can be increased in size to extend beyond horizontal blockages created by hoods, buckets, blades, etc.

FIGURE 1—ARRANGEMENT OF TEST EQUIPMENT (SEE SECTION 4)

3.3 Sector of Vision (Front)—Segment of the visibility test circle to the front of the machine established by a 9.5 m cord which is perpendicular to the longitudinal plane passing through the filament position center point with the cord length bisected by the longitudinal plane. (See Figure 2.)

3.4 Field of Vision (Front Side)—Segments of the visibility test circle to the front of the machine outside the sector of vision and bounded by the transverse plane through the filament center-point. (See Figure 2.)

3.5 Visual Field (Rear)—Segment of the visibility test circle to the rear defined by an angle of 45 degrees to both the right and left sides of the longitudinal plane passing through the filament center-point. (See Figure 2.)

3.6 Field of View (Rear Side)—Segments of the visibility test circle to the rear between the visual field and the fields of vision. (See Figure 2.)

FIGURE 2—DEFINITION OF VISIBILITY TEST AREAS (SEE SECTION 3)

3.7 Masking Effect—Segments of the visibility test circle on which a shadow is created because a part(s) of the base machine and/or its equipment block(s) the light rays from both of the filaments. For example, masking could be caused by ROPS, window and door frames, exhaust pipes, the hood and equipment components such as bucket, boom, etc.

3.8 Horizontal Blockage—Light source is above the blockage and the light can be seen on the ground.

3.9 Vertical Blockage—A blockage that extends above the light source.

4. Test Apparatus

4.1 Light Source—Consisting of two halogen bulbs (or equivalent) mounted with the filaments vertical. The fixture shall be such that the mid-point of the filaments is at the height of the filament position center-point defined in 3.1. Each filament should be horizontally movable from 32.5 mm up to 202.5 mm on each side of the filament position center-point and rotatable (see Figure 1). The fixture may be capable of 15-degree forward rotation (parallel to the centerline of the machine) from the SIP perpendicular to the light bar.

4.2 Test Surface—An area of compacted earth or paved surface which has no more than a 3% gradient in any direction.

5. Machine Test Configuration

5.1 The machine shall be equipped according to the manufacturer's specification.

5.2 All machine openings such as doors and windows shall be closed.

5.3 The machine shall be set up according to the specific information given in Appendix A for each type of machine.

6. Measurement Procedure

6.1 Machine and Filament Placement

6.1.1 Place the machine on the test surface and mark the 12 m radius visibility test circle on the test surface. In addition for machines greater than 24 tons, mark a larger radius, if required, to eliminate horizontal blockages from hoods, buckets, blades, etc., as needed if the maskings exceed the 12 m radius in a sector when tested in accordance with 6.2.4. The larger radius shall not exceed 30 m.

The filament position center-point defined in 3.1 shall be vertically above the visibility circle center-point.

6.1.2 Mount the filaments so that they are equally spaced around the filament position center-point defined in 3.1.

6.1.3 To take measurements, rotate the light bar so that the line between the filaments is perpendicular to the line between the filament position center-point defined in 3.1 and the center of the visibility blockage components.

6.2 Determination of Masking

6.2.1 Place the light-bulbs so that they are 32.5 mm either side of the filament center-point defined in 3.1. Rotate the light bar for one revolution and record the masking effect of each visibility blockage created on the visibility test circle. Measure the maskings in millimeters as a chord-length.

> NOTE—The test can be carried out in a dark environment where the masking effects can be directly noted on the visibility test circle or a mirror located on the test surface can be used to develop a line of sight to the filament to determine the point on the visibility test circle where masking occurs.

6.2.2 If maskings are recorded in the sectors of vision and field of vision, conduct a second test with the filament spacing up to 202.5 mm to either side of the filament center-point. The light bar may also be rotated forward up to 15 degrees. Record the remaining masking effect, if any, on the visibility test circle.

6.2.3 If maskings are recorded in the field of view, carry out a second test with the filament spacing up to 102.5 mm to either side of the filament center-point. The light bar may also be rotated forward up to 15 degrees.

6.2.4 If maskings recorded are caused by a horizontal blockage, carry out a second test with a radius of visibility test circle increased to exceed the horizontal blockage. Using the appropriate filament spacing for the segment being measured, record the maskings on the larger visibility test circle, if any.

Record the remaining masking effect, if any, on the visibility test circle.

7. Calculation Procedure for Determination of Maskings—The calculation procedure provides an alternative to the test method. (See Figure 3.)

For binocular vision with an eye spacing of s, the masking, expressed in millimeters, is given by Equation 1:

$$x = \left(\frac{b-s}{a}\right)r + s \qquad \text{(Eq. 1)}$$

where:

r is the radius from the filament center-point on the test surface to the visibility test circle on the test surface, in millimeters

b is the width of the component causing the maskings measured horizontally, and perpendicular to the radius from the filament position center-point and the center of the component, in millimeters

s is the distance between the filaments, used to represent binocular vision with this eye spacing, in millimeters

x is the width of the masking calculation of the masking and becomes less accurate as the length of the masking increases

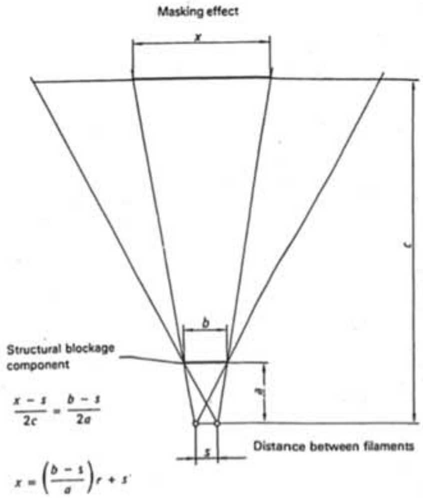


FIGURE 3—MATHEMATICAL DETERMINATION OF MASKING EFFECTS (SEE SECTION 7)

8. Test Report—The test report shall include the information indicated in 8.1 and 8.2.

8.1 Machine Details

a. Manufacturer
b. Model
c. Machine mass or rated payload
d. Serial number
e. Operator enclosure and/or ROPS description or identification
f. Equipment installed on the machine
g. Any other information which affects the masking measurements

8.2 Drawing—The drawing shall show the maskings (dimensions in millimeters) on the visibility test circle by the designated visibility test area with the specific filament spacing. The distance between maskings and also the distance from the end of the specific visibility test area shall be provided (see Figure 4 for an example). In lieu of a drawing, a tabulation can also be provided if it gives the required information.

9. Evaluation Method

9.1 General

9.1.1 When maskings overlap adjacent visibility areas, the masking shall be evaluated in the visibility test area in which the greatest part of the masking lies.

9.1.2 Adjacent narrow maskings may be combined with the space between them and treated as one larger masking to reduce the count of maskings.

9.1.3 The space between any two adjacent maskings in the visibility test area being evaluated and the space with adjacent maskings in the adjoining visibility test area shall be equal to or greater than 1 300 mm. If this is not the case, the two maskings and the space shall be combined to result in one reported masking. See Figures 5 to 7.

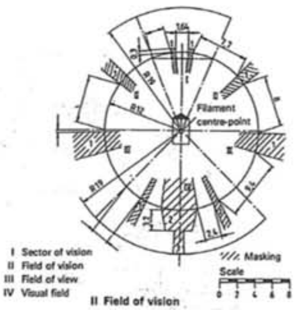
Machine type

Manufacturer: ....
Machine type and model: Wheel loader /704........
Mass: ....22 605.....kg
Serial No.: ..377510301..............................

Type of cab (indicate)

ROPS and cab ☒
ROPS and canopy ☐
Cab without ROPS ☐
Without cab ☐

Equipment fitted on machine: ..Standard...bucket....



I Sector of vision

Radius		12 m		19 m	
Filament position, i.e, cumulative distance of filaments from filament centre-point		mm		mm	
		65	405	65	405
Masking (indicate cause and width in millimetres)	Cause	Width		Width	
	No. 1 Tilt [illegible]	600	-		
	No. 2				
	No. 3				
	No. 4				

II Field of vision

Radius		12 m	
Filament position, i.e. cumulative distance of filaments from filament centre-point		mm	
		65	405
Masking (indicate cause and width in millimetres)	Cause	Width[1]	
	No. 1 Cab post	1600	+(230)
	No. 2		
	No. 3		
	No. 4		
	No. 5		
	No. 6		

[1] Measurement in parentheses is bulb distance.

III Field of view

Radius		12 m	
Filament position, i.e, cumulative distance of filaments from filament centre-point		mm	
		65	205
Masking (indicate cause and width in millimetres)	Cause	Width	
	No. 1 Cab/ROPS post	3 200	890
	No. 2		
	No. 3		
	No. 4		
	No. 5		
	No. 6		

IV Visual field

Radius		12 m	19 m
Filament position, i.e. cumulative distance of filaments from filament centre-point		mm	
		65	
Masking (indicate cause and width in millimetres)	Cause	Width	
	No. 1 Window frame	700	
	No. 2 Engine bonnet	5 600	
	No. 3 Exhaust pipe and pre-cleaner		1600
	No. 4		

FIGURE 4—EXAMPLE OF COMPLETED TEST REPORT

9.1.4 A masking under 100 mm may be neglected when it is not covered by the requirements in 9.1.3.

9.1.5 When a radius greater than 12 m is used, the allowable maskings are increased by the ratio of the new radius to the 12 m radius. For example, with a radius of 19 m, the blockage width would increase X1.58.

9.2 Maskings at Sector of Vision

9.2.1 VISIBILITY CATEGORY I—The visibility is evaluated as Category I, if, where measured in accordance with 6.2.1, there are no more than two maskings each with a masking chord length of 700 mm or less. (See Figure 5.)

9.2.2 VISIBILITY CATEGORY II—The visibility is evaluated as Category II, if, when measured in accordance with 6.2.2, the masking conditions in 9.2.1 are met. (See Figure 6.)

9.2.3 VISIBILITY CATEGORY III—The visibility is evaluated as Category III, if, when measured in accordance with 6.2.2, there are no more than two maskings with a masking chord length of 700 mm or less and two maskings with a masking chord length of 1 300 mm or less. (See Figure 7.)

9.3 Field of Vision

9.3.1 VISIBILITY CATEGORY I—The visibility is evaluated as Category I, if, when measured in accordance with 6.2.1, there are no more than one masking with a masking chord length of 700 mm or less and no more than one masking chord length of 5 000 mm or less in either the left or right field of view. (See Fig-

with a masking chord length of 1 300 mm or less in each of the left and right areas of the field of vision. (See Figure 5.)

9.3.2 VISIBILITY CATEGORY II—The visibility is evaluated as Category II, if, when measured in accordance with 6.2.2, the masking conditions in 9.3.1 are met.

9.3.3 VISIBILITY CATEGORY III—The visibility is evaluated as Category III, if, when measured in accordance with 6.2.2, there are more than one of the maskings of 9.3.2 with a chord length of 5 500 mm or less. (See Figure 7.)

9.4 Field of View

9.4.1 VISIBILITY CATEGORY I—The visibility is evaluated as Category I, if, when measured in accordance with 6.2.1, there are no more than two maskings with a masking chord length of 700 mm or less in either the left or the right field of view. (See Figure 5.)

9.4.2 VISIBILITY CATEGORY II—The visibility is evaluated as Category II, if, when measured in accordance with ISO 5006-1:1991, 6.2.3, there are no more than one masking with a masking chord length of 700 mm or less and one masking with a masking chord length of 1 300 mm or less in either the left or right field of view. (See Figure 6.)

9.4.3 VISIBILITY CATEGORY III—The visibility is evaluated as Category III, if, when measured in accordance with 6.2.3, there are no more than one masking with a masking chord length of 700 mm or less and one masking with a masking ure 7.)

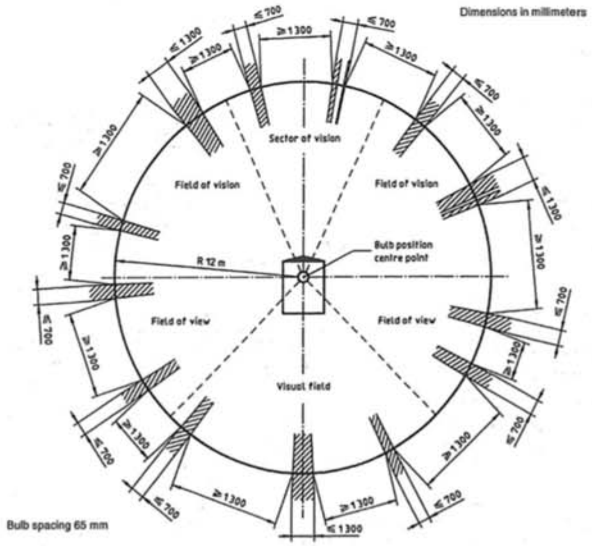


FIGURE 5—CATEGORY I EVALUATION

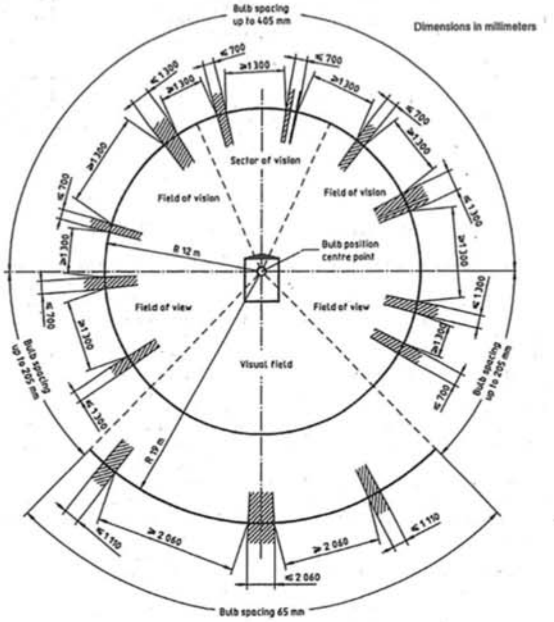


FIGURE 6—CATEGORY II EVALUATION

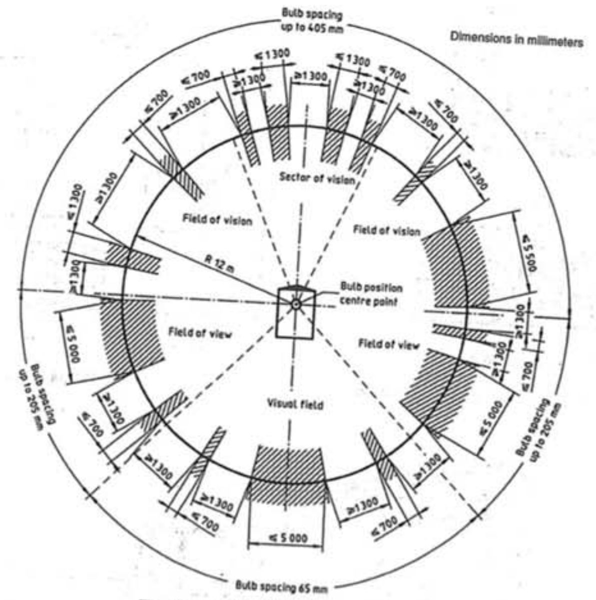


FIGURE 7—CATEGORY III EVALUATION

9.5 Visual Field

9.5.1 VISIBILITY CATEGORY I—The visibility is evaluated as Category I, if, when measured in accordance with 6.2.1, there are no more than two maskings with a masking chord length of 700 mm or less and one masking with a masking chord length of 1300 mm or less in the rear visual field. (See Figure 5.)

9.5.2 VISIBILITY CATEGORY II—The visibility is evaluated as Category II, if, when measured in accordance with 6.2.4, there are no more than two maskings with a masking chord length of 1 110 mm or less and one masking with a masking chord length of 2 060 mm or less. (See Figure 6.)

9.5.3 VISIBILITY CATEGORY III—The visibility is evaluated as Category III, if, when measured in accordance with 6.2.4, there are not more than two maskings with a masking chord length of 700 mm or less and one masking with a masking chord length of 5 000 mm or less. (See Figure 7.)

APPENDIX A
(NORMATIVE) MACHINE SET-UP

Preface—As specified in 5.1, the machine shall be equipped according to the manufacturer's specification.

The machine shall be placed on the test surface described in 4.2 as shown in Sections A.1 to A.9 for each type of earthmoving machine.

A.1 Loader—Bucket in carry position. See Figure A1.

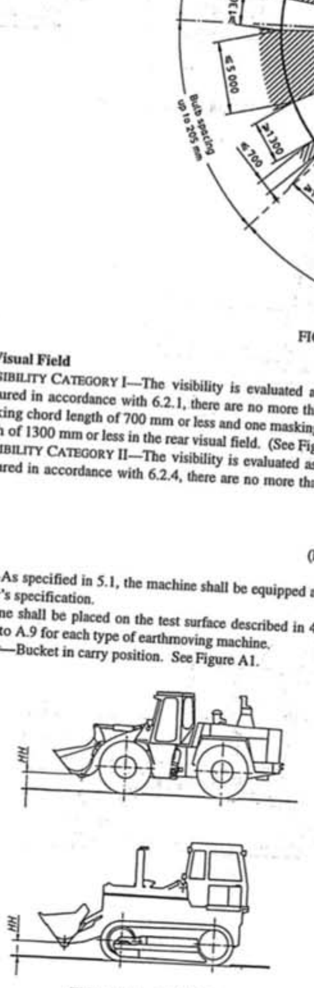


FIGURE A1—LOADER

h. HH = 300 mm ± 50 mm for machines £ 24 000 kg
i. 400 mm ± 50 mm for machines > 24 000 kg

A.2 Backhoe-Loader—See Figure A2.

a. HH = 300 mm ± 50 mm

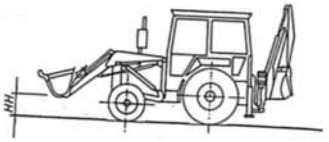


FIGURE A2—BACKHOE-LOADER

A.3 Tractor—ROPS and Cab Fitted. See Figure A3.

a. HH = 150 mm ± 50 mm

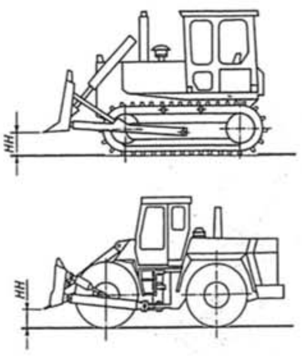


FIGURE A3—TRACTOR

A.4 Excavator—Standard Cab Fitted. See Figures A4a, A4b, and A4c.

a. Dimensions HH and RR shall be recorded and reported in the scaled drawing as required in 8.2.

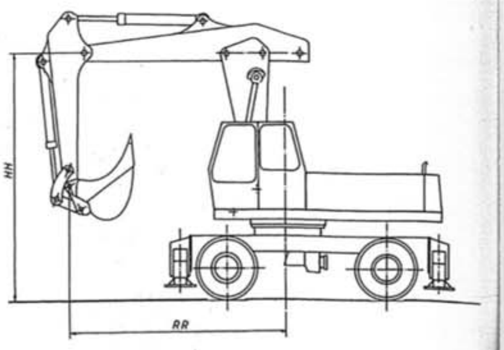


FIGURE A4A—EXCAVATOR

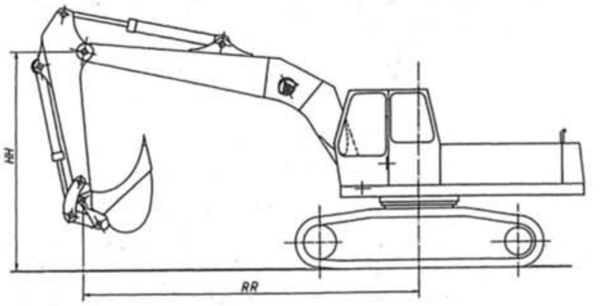


FIGURE A4B—EXCAVATOR

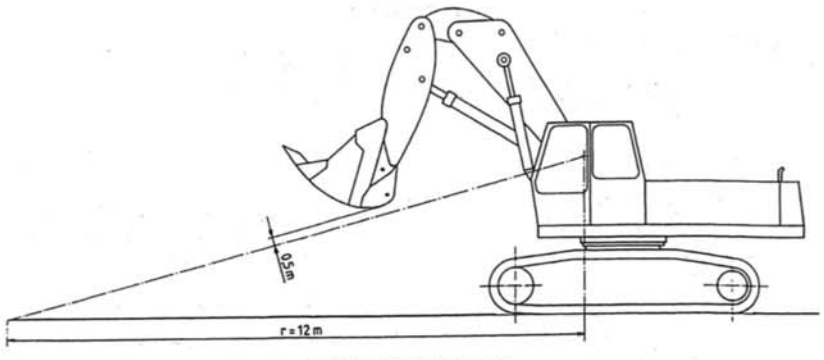


FIGURE A4C—EXCAVATOR

A.5 Tractor-Scraper**—**Cutting edge of the bowl 150 mm ± 50 mm above ground level. See Figure A5.

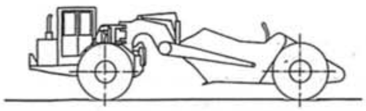


FIGURE A5—TRACTOR-SCRAPER

A.6 Grader**—**All blades 150 mm ± 50 mm above ground level. See Figure A6.

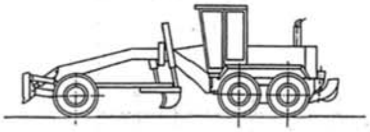


FIGURE A6—GRADER

A.7Dumper

A.7.1 Rear Dump—See Figure A7.

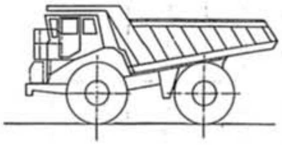


FIGURE A7—REAR DUMP

A.7.2 Bottom Dump—See Figure A8.

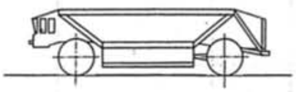


FIGURE A8—BOTTOM DUMP

A.7.3 Side Dump—See Figure A9.

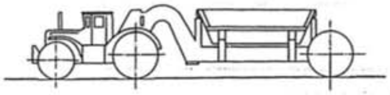


FIGURE A9—SIDE DUMP

A.7.4 Articulated Steer—See Figure A10.

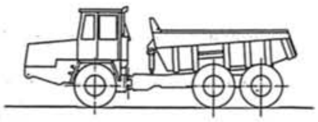


FIGURE A10—ARTICULATED STEER

A.8 Pipelayer**—**See Figure A11.

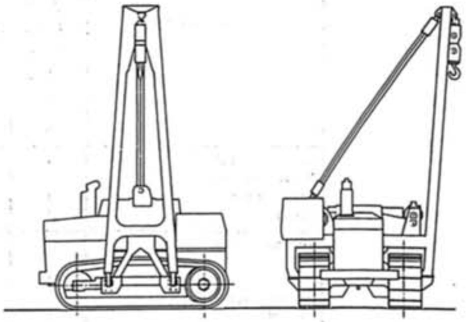


FIGURE A11—PIPELAYER

A.9Roller/Compactor

A.9.1 Roller—See Figure A12.

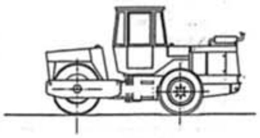


FIGURE A12—ROLLER

A.9.2 Compactor—See Figure A13.

a. HH = 150 mm ± 50 mm

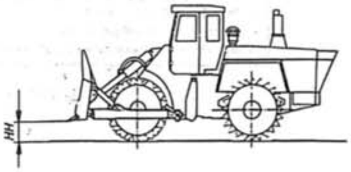
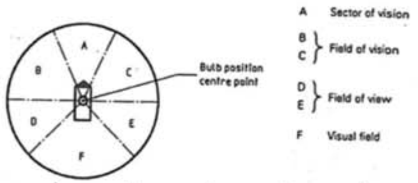


FIGURE A13—COMPACTOR

APPENDIX B
(INFORMATIVE)

B.1 ISO 5006-3:93 Acceptable Visibility Criteria—See Figure B1.



Machine type [2]	Visibility category [1]					
	A	B	C	D	E	F
Dumper - articulated	I	II	III	II	II	[3]
Dumper - rigid frame						
$5\ t < m \leqslant 80\ t$	I	II	III	[3]	[3]	[3]
$m > 80\ t$	I	II	[3]	[3]	[3]	[3]
Excavator - wheel						
$m \leqslant 24\ t$	I	II	III	II	[3]	[3]
$m > 24\ t$	I	II	[3]	II	[3]	[3]
Excavator - track						
$m \leqslant 24\ t$	I	II	III	II	[3]	[3]
$m > 24\ t$	II	II	[3]	II	[3]	[3]
Loader - wheel						
$m \leqslant 24\ t$	I	II	II	II	II	II
$m > 24\ t$	III	II	II	III	III	III
Loader - skid steer						
$m \leqslant 24\ t$	I	II	II	III	III	[3]
Loader - backhoe	II	II	II	II	II	III
Loader - crawler						
$m \leqslant 24\ t$	I	II	II	II	II	I
Rollers and compactors						
$m \leqslant 24\ t$	I	II	II	II	II	II
$m > 24\ t$	III	II	II	III	III	III
Tractor with dozer						
$m \leqslant 24\ t$	II	II	II	II	II	I
$m > 24\ t$	III	II	II	II	II	I
Tractor-scraper	II	II	III	II	[3]	[3]
Grader	II	II	II	II	II	II

[1] See ISO 5006-2:1993, clause 4.

[2] m = machine mass without payload.

[3] Maskings may be greater than those defined for category III.

FIGURE B1—ACCEPTABLE VISIBILITY CRITERIA

OPERATOR'S FIELD OF VIEW—ENGINEERING EVALUATION —SAE J2331 NOV96

SAE Standard

Report of the SAE Human Factors Technical Committee SC3—Visibility approved November 1996. Rationale statement available.

Foreword—This document is a supplement to ISO 5006-1 and SAE J1091. The document provides a procedure for evaluating changes to earthmoving machines to determine and document their effect on the operator's field of view. ISO 5006-1 and SAE J1091 measure only blockages to vision at the test circle. This document provides a procedure to outline the operator's field of view within the test circle. The figure chosen is a large loader and illustrates the use of larger test circles in selected segments (sectors). If documenting the change is not required, a less formal evaluation can be made. This document does not include a criteria section. There is no comparable ISO document.

1. Scope—This SAE Standard specifies a stationary test method for determining and documenting the masking effect caused by parts of the base machine with equipment as specified by the manufacturer within a visibility test circle around the eye position of a seated operator. It applies to earthmoving machinery which has a specific seated operator's position.

2. References

2.1 Applicable Publications—The following standards contain provisions which, through reference in this text, constitute provisions of this document. At the time of publication, the editions indicated were valid. All standards are subject to revision and the user of this document is encouraged to investigate the possibility of applying the most recent editions of the standards indicated in 2.1.1 and 2.1.2.

2.1.1 SAE PUBLICATIONS—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

J1116 JUN 86—Categories of Off-Road Self-Propelled Work Machines
J1163 JUN 91—Determining Seat Index Point
J833 MAY 89—Human Physical Dimensions

2.1.2 ISO PUBLICATIONS—Available from ANSI, 11 West 42nd Street, New York, NY 10036-8002.

ISO 6165:87—Earth-moving machinery—Basic types—Vocabulary
ISO 5353:95—Earth-moving machinery and tractors and machinery for agricultural and forestry—Seat index point
ISO 3411:82—Earth-moving machinery—Human physical dimensions of operators and minimum operator space envelope.
ISO 5006-1:91—Earth-moving machinery—Operator's field of view—Part 1: Test method

3. Definitions

3.1 Filament Position Center-Point—Point located 660 mm above and 20 mm in front of the seat index point as defined by SAE J1163. This is identical to SAE J1091.

3.2 Visibility Test Circle—Circle with a 12 m radius on a horizontal surface with its center at the filament position center. The test circle can be increased in size to extend beyond horizontal blockages created by hoods, buckets, blades, etc.

3.3 Visibility Map—The area within the test circle on which a shadow is created because a part of the base machine and/or its equipment blocks the light rays from both of the filaments. This area is defined by locating the blockage points at the intersection of adjoining surfaces and connecting these points (see Section 6).

3.4 Sector of Vision (Front)—Segment of the visibility test circle to the front of the machine with a cord length of 9.50 m centered to the filament center-point.

3.5 Field of Vision (Front Side)—Segments of the visibility test circle to the front of the machine outside the sector of vision and bounded by the transverse plane through the filament center-point.

3.6 Visual Field (Rear)—Segment of the visibility test circle to the rear 45 degrees to each side of the filament center-point.

3.7 Field of View (Rear Side)—Segments of the visibility test circle to the rear between the visual field and the fields of vision.

3.8 Horizontal Blockage—A blockage that the light source is above and the light can be seen on the ground.

3.9 Vertical Blockage—A blockage that extends above the light source.

4. Test Apparatus

4.1 Light Source—Consisting of two halogen bulbs (or equivalent) mounted with the filaments vertical. The fixture shall be such that the center-point of the filaments is at the location defined in 3.1. Each filament should be 32.5 mm on each side of the filament position center-point, and rotatable. Additional degrees of movement are allowed such as specified in J1091 but must be noted on the test drawing.

4.2 Test Surface—An area of compacted earth or paved surface which has no more than a 3% gradient in any direction.

5. Machine Test Configuration

5.1 The machine shall be equipped according to the manufacturer's specification.

5.2 All machine openings such as doors and windows shall be closed.

5.3 The machine shall be set up according to the specific information given in Appendix A of SAE J1091 for each type of machine.

6. Measurement Procedure

6.1 Place the machine on the test surface and mark the test circle on the test surface. If desired, the test can be limited to only a portion of the circle. If this is done, it should include complete segments (sectors). This is identical to SAE J1091.

6.2 With the light bulbs spaced at 32.5 mm either side of the filament position center-point, rotate the light source to be perpendicular to the intersection of two blockage surfaces. Mark this intersection point on the test surface. Using the same technique, continue around the machine marking all the intersection points of the blocking surfaces or a blocking surface and test circle.

6.3 The visibility map is completed by recording the intersection points and connecting lines between these points.

6.4 Testing can include other light spacings as provided in SAE J1091 and these spacings shall be recorded on the test results.

6.5 Total segments (sectors) shall be included in the tests even when the change being evaluated affects only a portion of the segment (sector). This is identical to SAE J1091.

7. Test Report—The test report shall include the information indicated in 7.1 and 7.2.

7.1 Machines Details

a. Manufacturer
b. Model
c. Machine mass or rated payload
d. Product identification number
e. Operator enclosure and/or ROPS description or identification
f. Equipment installed on the machine
g. Any other information which affects the masking measurements

7.2 Drawing—The drawing shall show the maskings on and within the visibility test circle in the segments (sectors) being evaluated. An outline of the machine shall be included for orientation purposes. If light spacings besides that specified in 6.2 are used, they shall be identified on the drawing. A drawing of a large loader is shown in Figure 1.

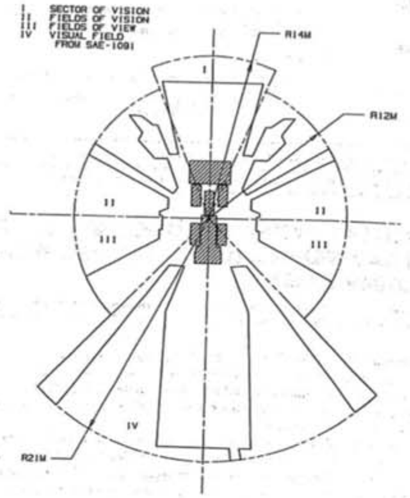
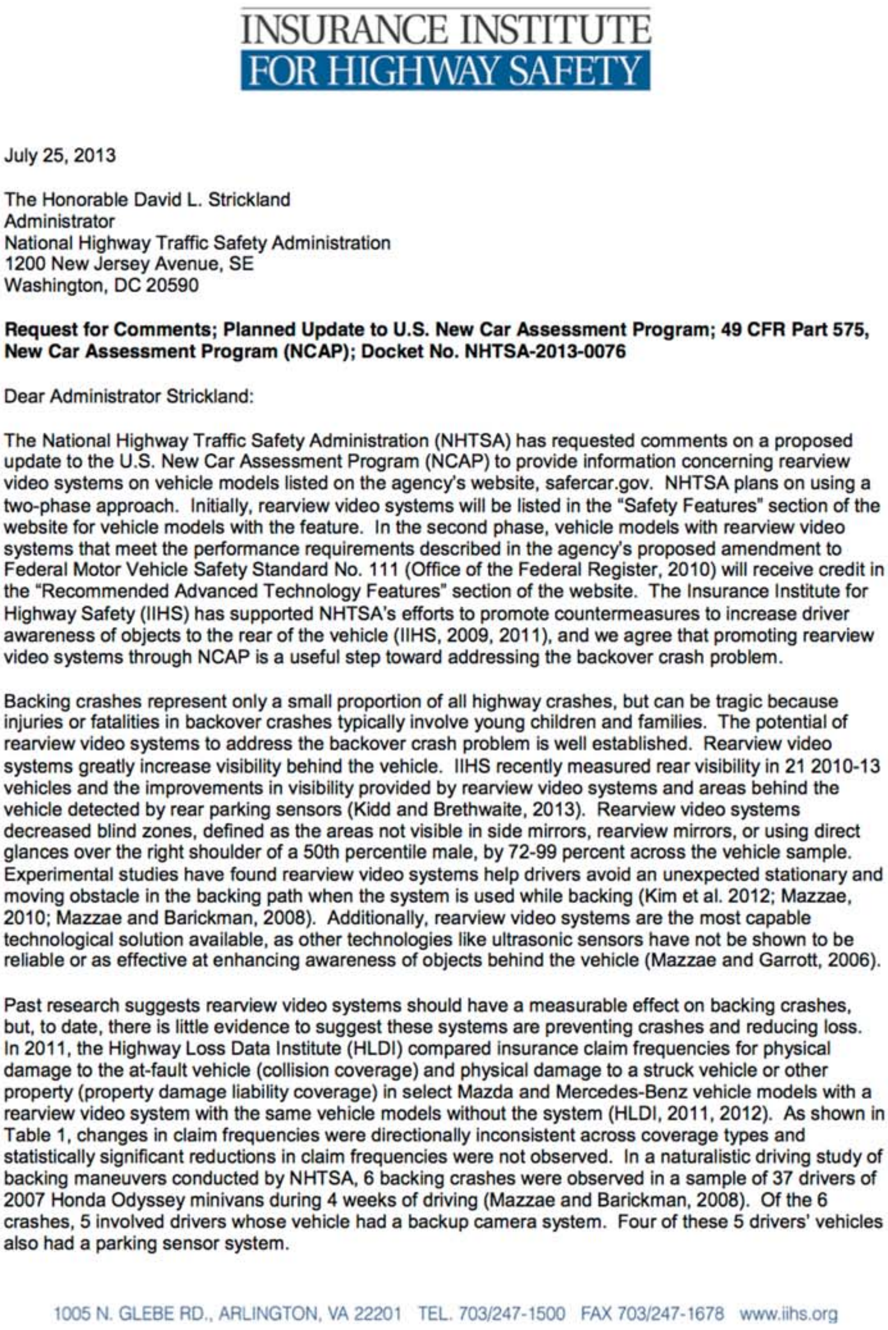


FIGURE 1—LARGE LOADER

Appendix E Insurance Institute for Highway Safety letter to administrator Strickland of NHTSA



INSURANCE INSTITUTE
FOR HIGHWAY SAFETY

July 25, 2013

The Honorable David L. Strickland
Administrator
National Highway Traffic Safety Administration
1200 New Jersey Avenue, SE
Washington, DC 20590

Request for Comments; Planned Update to U.S. New Car Assessment Program; 49 CFR Part 575, New Car Assessment Program (NCAP); Docket No. NHTSA-2013-0076

Dear Administrator Strickland:

The National Highway Traffic Safety Administration (NHTSA) has requested comments on a proposed update to the U.S. New Car Assessment Program (NCAP) to provide information concerning rearview video systems on vehicle models listed on the agency's website, safercar.gov. NHTSA plans on using a two-phase approach. Initially, rearview video systems will be listed in the "Safety Features" section of the website for vehicle models with the feature. In the second phase, vehicle models with rearview video systems that meet the performance requirements described in the agency's proposed amendment to Federal Motor Vehicle Safety Standard No. 111 (Office of the Federal Register, 2010) will receive credit in the "Recommended Advanced Technology Features" section of the website. The Insurance Institute for Highway Safety (IIHS) has supported NHTSA's efforts to promote countermeasures to increase driver awareness of objects to the rear of the vehicle (IIHS, 2009, 2011), and we agree that promoting rearview video systems through NCAP is a useful step toward addressing the backover crash problem.

Backing crashes represent only a small proportion of all highway crashes, but can be tragic because injuries or fatalities in backover crashes typically involve young children and families. The potential of rearview video systems to address the backover crash problem is well established. Rearview video systems greatly increase visibility behind the vehicle. IIHS recently measured rear visibility in 21 2010-13 vehicles and the improvements in visibility provided by rearview video systems and areas behind the vehicle detected by rear parking sensors (Kidd and Brethwaite, 2013). Rearview video systems decreased blind zones, defined as the areas not visible in side mirrors, rearview mirrors, or using direct glances over the right shoulder of a 50th percentile male, by 72-99 percent across the vehicle sample. Experimental studies have found rearview video systems help drivers avoid an unexpected stationary and moving obstacle in the backing path when the system is used while backing (Kim et al. 2012; Mazzae, 2010; Mazzae and Barickman, 2008). Additionally, rearview video systems are the most capable technological solution available, as other technologies like ultrasonic sensors have not be shown to be reliable or as effective at enhancing awareness of objects behind the vehicle (Mazzae and Garrott, 2006).

Past research suggests rearview video systems should have a measurable effect on backing crashes, but, to date, there is little evidence to suggest these systems are preventing crashes and reducing loss. In 2011, the Highway Loss Data Institute (HLDI) compared insurance claim frequencies for physical damage to the at-fault vehicle (collision coverage) and physical damage to a struck vehicle or other property (property damage liability coverage) in select Mazda and Mercedes-Benz vehicle models with a rearview video system with the same vehicle models without the system (HLDI, 2011, 2012). As shown in Table 1, changes in claim frequencies were directionally inconsistent across coverage types and statistically significant reductions in claim frequencies were not observed. In a naturalistic driving study of backing maneuvers conducted by NHTSA, 6 backing crashes were observed in a sample of 37 drivers of 2007 Honda Odyssey minivans during 4 weeks of driving (Mazzae and Barickman, 2008). Of the 6 crashes, 5 involved drivers whose vehicle had a backup camera system. Four of these 5 drivers' vehicles also had a parking sensor system.

1005 N. GLEBE RD., ARLINGTON, VA 22201 TEL. 703/247-1500 FAX 703/247-1678 www.iihs.org

Table 1
Percent change in insurance claim frequency per insured vehicle year for select Mazda and Mercedes-Benz vehicles with rearview video systems compared with those without the systems by coverage type

	Coverage type	
Make	Collision	Property damage liability
Mazda[a]	+3.1[c]	-2.3
Mercedes-Benz[b]	+0.5	-0.5

[a] HLDI (2011), [b] HLDI (2012), [c] $p<0.05$

These preliminary findings suggest the real-world effectiveness of rearview video systems may not be as beneficial as expected, but more extensive evaluations are required. NHTSA's proposed update to the NCAP program may accelerate the penetration of rearview video systems in the U.S. passenger vehicle fleet. Having more passenger vehicles equipped with rearview video systems on the roadways will allow HLDI, NHTSA, and others to better estimate the real-world effectiveness of rearview video systems.

Rearview video systems currently might be the best means of increasing drivers' views of the areas behind their vehicles, but many drivers still rely on mirrors or rearward glances to maintain awareness of their surroundings while backing (Mazzae and Barickman, 2008). In our evaluations of rear visibility, we were surprised to see several instances where smaller passenger cars had larger blind zones than larger trucks or minivans (Kidd and Brethwaite, 2013). As IIHS has expressed in previous comments, we encourage NHTSA to consider implementing direct rear visibility requirements for all vehicles (IIHS, (2009, 2011). Having an available rearview video system on a vehicle model should not justify design choices that restrict direct visibility around the vehicle.

In summary, the tragic nature of backover crashes justifies NHTSA's continuing efforts to promote rearview video systems. IIHS supports the inclusion of rearview video systems in NCAP and will continue to monitor the effects of these systems in the real world. Rearview video systems might only be a partial solution to the backover crash problem, so we encourage NHTSA to consider additional measures to address this issue such as regulating the size and position of directly viewable areas behind vehicles.

Sincerely,

David G. Kidd, Ph.D.
Research Scientist

Attachment

Kidd, D.G. and Brethwaite, A. 2013. Visibility of children behind 2010-13 model year passenger vehicles using glances, mirrors, and backup cameras and parking sensors. Arlington, VA. Insurance Institute for Highway Safety.

References

Highway Loss Data Institute. 2011. Mazda collision avoidance features: initial results. *Bulletin* 28(13). Arlington, VA.

Highway Loss Data Institute. 2012. Mercedes-Benz collision avoidance features: initial results. *Bulletin* 29(7). Arlington, VA.

Insurance Institute for Highway Safety. 2009. Comment to the National Highway Traffic Safety Administration concerning proposed amendments to rearview mirrors standard and no-blind-spot requirement to reduce deaths and injuries associated with backover crashes (Docket no. NHTSA-2009-0041). Arlington, VA.

Insurance Institute for Highway Safety. 2011. Comment to the National Highway Traffic Safety Administration concerning modification of Federal Motor Vehicle Safety Standard 111 Rearview Mirrors to require systems to enhance visibility of the areas directly behind the vehicle (Docket no. NHTSA-2010-0162). Arlington, VA.

Kidd, D.G. and Brethwaite, A. 2013. Visibility of children behind 2010-13 model year passenger vehicles using glances, mirrors, and backup cameras and parking sensors. Arlington, VA. Insurance Institute for Highway Safety.

Kim, R.; Rauschenberger, R.; Heckman, G.; Young, D.; and Lange, R. 2012. Efficacy and usage patterns for three types of rearview camera displays during backing up. *SAE 2012 World Congress & Exhibition* (Paper no. 2012-01-0287). Warrendale, PA: Society of Automotive Engineers.

Mazzae, E.N. 2010. Drivers' use of rearview video and sensor-based backing aid systems in a non-laboratory setting. Docket no. NHTSA-2010-0162. Washington, DC. National Highway Traffic Safety Administration.

Mazzae, E.N. and Barickman, F. 2008. On-road study of drivers' use of rearview video systems (ORSDURVS). Report no. DOT HS-811-024. Washington, DC. National Highway Traffic Safety Administration.

Mazzae, E.N. and Garrott, W.R. 2006. Experimental evaluation of the performance of available backover prevention technologies. Report no. DOT HS-810-634. Washington, DC. National Highway Traffic Safety Administration.

Office of the Federal Register. 2010. *Federal Register*, vol. 75, no. 234, pp. 76186-76250. National Highway Traffic Safety Administration, Docket no. NHTSA-2010-0162, 49 CFR Parts 571 and 585: Federal Motor Vehicle Safety Standard, Rearview Mirrors; Federal Motor Vehicle Safety Standard, Low-Speed Vehicles Phase-in Reporting Requirements. Washington, DC: National Archives and Records Administration.

Appendix F Vehicle rearview image field of view and quality measurement: NHTSA DOT HS 811 512

U.S. Department
of Transportation
**National Highway
Traffic Safety
Administration**

NHTSA
www.nhtsa.gov

DOT HS 811 512 September 2011

Vehicle Rearview Image Field of View and Quality Measurement

DISCLAIMER

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. DOT HS 811 512	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Vehicle Rearview Image Field of View and Quality Measurement		5. Report Date September 2011
		6. Performing Organization Code NHTSA/NVS-312
7. Author(s) Elizabeth N. Mazzae and W. Riley Garrott, National Highway Traffic Safety Administration George H. Scott Baldwin, Adam Andrella, and Larry A. Smith, Transportation Research Center, Inc.		8. Performing Organization Report No.
9. Performing Organization Name and Address National Highway Traffic Safety Administration Vehicle Research and Test Center P.O. Box 37 East Liberty, OH 43319		10. Work Unit No. (TRAIS)
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Highway Traffic Safety Administration 1200 New Jersey Ave., S.E. Washington, D.C. 20590		13. Type of Report and Period Covered Technical Report
		14. Sponsoring Agency Code

15. Supplementary Notes

The authors thank Transportation Research Center Inc. employees Jodi Clark and Tim Van Buskirk for their support of this work.

16. Abstract

The Cameron Gulbransen Kids Transportation Safety Act of 2007 required the National Highway Traffic Safety Administration (NHTSA) to "initiate a rulemaking to revise Federal Motor Vehicle Safety Standard 111 (FMVSS 111) to expand the required field of view to enable the driver of a motor vehicle to detect areas behind the motor vehicle to reduce death and injury resulting from" backover crashes. It stated that this may be accomplished "by the provision of additional mirrors, sensors, cameras, or other technology to expand the driver's field of view."

This report provides additional details regarding the analyses summarized in the December 2010 FMVSS No. 111 NPRM that provided the basis for proposed improved vehicle rear visibility requirements. A more detailed description is presented of the analysis performed to identify what area (i.e., field of view) should be visible to a driver behind a vehicle in order for that driver to have the best opportunity to avoid a backover crash. Likewise, the report contains a detailed description of the basis for determining the proposed criteria for minimum image quality that would need to be present in a rearview image in order for a driver of average vision to have the ability to discern child-sized obstacles located within the field of view.

Test procedures that were developed to assess how well a rearview image meets the proposed field of view and rearview image quality requirements are described in detail. These procedures were developed using available existing systems covering the appropriate field of view (of which all were rearview video systems). The procedures are also considered to be useable for other technologies (such as mirrors or fiber optics) that might be used to provide visual images of the area directly behind a vehicle in the future. The test procedure involves taking a photograph of the rearview image showing several objects of known locations and dimensions from the perspective of a 50th-percentile male driver. The apparent width of an object in a photograph of the display is used to calculate the subtended visual angle of test objects (which can be related to a driver's ability to see each object).

This report demonstrates the measurement procedure by applying it to six 2010-11 model year vehicles equipped with original equipment rearview video systems. One important result obtained in this testing is that a 2.4-inch diagonal sized rearview image is not large enough to provide the degree of minimum image quality proposed in the NPRM.

17. Key Words Backover, rearview video system, blind zone, image quality		18. Distribution Statement Document is available to the public from the National Technical Information Service www.ntis.gov	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 61	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

TABLE OF CONTENTS

LIST OF FIGURES

displayed in the rearview image) was calculated for each test object of known actual size and location using (1) the distance between the rearview image as installed in the vehicle and a camera, mounted so as to represent the view observable by a 50th-percentile height male driver and (2) the test object's scaled linear dimensions as seen in a photograph of the rearview image. Details of the calculation procedure are provided in the main body of the report. The apparent angular size of specified test objects was then evaluated with respect to the asserted criteria to determine whether drivers will be able to adequately see each test object. The criteria were as follows:

1. When the apparent angular size of the three test cylinders that are located 20 feet (6.10 meters) aft of the rearmost point on the vehicle's rear bumper (Cylinders A, B, and C) are measured, the average apparent angular size of the three must not be less than 5 minutes of arc when viewed in the rearview image.
2. When viewed in the rearview image, the apparent angular size of each individual test cylinder must not be less than 3 minutes of arc.

There is no need for size criteria based on the apparent angular size requirements for any of the nearer test objects, because the three furthest test objects will always appear to be the smallest[5], thus representing the worst case for visibility among the seven equally-sized cylinders.

While in recent years rearview video systems a popular vehicle equipment option to aid drivers in performing backing maneuvers, other technologies capable of providing a rearview image are possible. These other technologies may include mirrors or fiber optic-based systems could also be used to provide the driver with an image of the area behind the vehicle. The test procedures developed in this report could also be applied to those technologies.

In order to demonstrate the measurement procedure defined herein, field of view and image quality for six model year 2010-2011 test vehicles equipped with original equipment rearview video systems were measured. All six test vehicles' rearview video systems met the field of view requirements described in the Notice of Proposed Rulemaking for FMVSS No. 111 published in December 2010.[6] The rearview video systems of five of the six test vehicles would meet both of the noted image quality criteria.

---

[5] For reasonably foreseeable camera locations and lens properties.

[6] 75 FR 76186, December 7, 2010

1.0 INTRODUCTION

1.1 Background

The Cameron Gulbransen Kids Transportation Safety Act of 2007[7] required the National Highway Traffic Safety Administration (NHTSA) to "initiate a rulemaking to revise Federal Motor Vehicle Safety Standard No. 111 (FMVSS 111) to expand the required field of view to enable the driver of a motor vehicle to detect areas behind the motor vehicle to reduce death and injury resulting from backing incidents, particularly incidents involving small children and disabled persons." It stated that this may be accomplished "by the provision of additional mirrors, sensors, cameras, or other technology to expand the driver's field of view."

Prior NHTSA research has shown that systems providing the driver with a 3.5-inch[8] (measured diagonally) or larger visual image of the area behind the vehicle are more effective than other types of technologies in aiding the driver to avoid a backing crash. However, for drivers to see and identify objects behind a vehicle equipped with a system providing a rearview image, the system must have an adequate field of view and the visual image must have sufficient quality to permit the average driver to discern critical objects located within the field of view.

1.2 Purpose of This Report

This report provides additional details regarding the analyses summarized in the December 2010 FMVSS No. 111 NPRM[9] that provided the basis for proposed improved vehicle rear visibility requirements. A more detailed description is presented of the analysis performed to identify what area (i.e., field of view) should be visible to a driver behind a vehicle in order for that driver to have the best opportunity to avoid a backover crash[10]. The report contains a detailed description of the basis for determining the proposed[11] criteria for minimum image quality that would need to be present in a rearview image in order for a driver of average vision to have the ability to discern child-sized obstacles located within the field of view. Test procedures that were proposed in the NPRM for assessing a rearview image's compliance with the asserted criteria are described. Finally, the proposed test procedures is demonstrated by applying them to six 2010-2011 model year vehicles equipped with original equipment rearview video system.

---

[7] Cameron Gulbransen Kids Transportation Safety Act of 2007, (Pub. L. 110–189, 122 Stat. 639–642), § 4 (2007).

[8] Rearview images sizes examined included 2.4 inches (measured diagonally), 3.5 inches, and larger sizes. Test results showed that the reduction in crashes with an unexpected rear obstacle for the 3.5-inch image system (48 percent) was nearly twice that seen with a 2.4-inch image (26 percent) system or ultrasonic sensors (25 percent).

[9] 75 FR 76186, December 7, 2010

[10] A different size of field of view behind a vehicle may be necessary to aid a driver in avoiding other types of backing crashes.

[11] 75 FR 76186, December 7, 2010

2.0 DETERMINING IMPROVED VEHICLE REAR VISIBILITY NEEDS

This section provides additional details regarding the analyses summarized in the December 2010 FMVSS No. 111 NPRM[12] that provided the basis for proposed improved vehicle rear visibility requirements.

2.1 Relationship Between Pedestrian Location and Backover Risk

To better understand the importance of rearview image fields of view providing the driver with visibility of specific areas behind the vehicle, Monte Carlo simulation was used to estimate the risk to a pedestrian at a specific location at the start of a backing maneuver.

Important assumptions were made about the behavior of the driver and the pedestrian for this analysis. The vehicle and pedestrian were assumed to begin moving at the same time and were assumed to be unaware of each other. Therefore, the motions of the vehicle and pedestrian were independent of the each other. In this analysis, it was possible for the pedestrian to walk or run into the vehicle. If the impact was with the rear of the vehicle, a backover incident was considered to have resulted. If the impact was with the side or front of the vehicle, the crash was not counted as a backover crash for the purposes of this analysis.

2.1.1 Vehicle Descriptors

Several descriptors were used to define the simulated vehicle in this analysis. The width of the vehicle was assumed to be 6.0 ft for this analysis. The distance that the vehicle backed up during each backing trial was determined by a random draw from a three-parameter Weibull probability distribution[13] for distance backed that was based on data from the *On-Road Study of Drivers' Use of Rear Video Systems* (ORSDURVS) study[14].

The ORSDURVS study observed driver's use of rearview video systems during staged and naturalistic backing maneuvers to determine whether drivers look at the rearview video system's display during backing and whether use of the system affects backing behavior. The 37 test participants aged 25 to 60 years were comprised of 12 drivers of rearview video equipped vehicles, 13 drivers of vehicles equipped with a rearview video system and a rear parking sensor system, and 12 drivers of vehicles having no backing aid.

All ORSDURVS study participants had driven and owned a 2007 Honda Odyssey minivan as their primary vehicle for at least 6 months. Participants visited the sponsor's research lab to have unobtrusive video and other data recording equipment installed in their personal vehicles and take a brief test drive. Participants then drove their vehicles for a period of four weeks in their normal daily activities while backing maneuvers were recorded. At the end of the four weeks, participants returned to the research lab to have the recording equipment removed. Participants

---

[12] 75 FR 76186, December 7, 2010

[13] See Grygier, P. A., Garrott, W. R., and Mazzae, Elizabeth N., *Measured and Calculated Useful Fields of View of Rear-Mounted Convex Mirrors*; NHTSA report, publication pending, National Highway Traffic Safety Administration, in press, for additional information about the Weibull probability distributions used.

[14] Mazzae, E. N., Barickman, F. S., Baldwin, G. H. S., and Ranney, T. A., *On-Road Study of Drivers' Use of Rearview Video Systems (ORSDURVS)*, National Highway Traffic Safety Administration, DOT 811 024, 2008.

took a second test drive, identical to the first, except that when backing out of the garage bay at the end of the drive, an unexpected obstacle appeared behind the vehicle.

During the ORSDURVS study naturalistic backing maneuvers, the 37 participants made 6,145 backing maneuvers. The minimum distance the vehicle backed was 1.38 ft, the average distance 35.2 ft, and the maximum distance 294.3 ft.

To simplify the current analysis, the Monte Carlo simulation assumed that the vehicle backed up at a constant speed based on a random draw from a three-parameter Weibull probability distribution also based on ORSDURVS study[15] data. During the ORSDURVS study, drivers' average backing speed during naturalistic backing maneuvers was 2.26 miles per hour, the minimum backing speed was 0.4 mph, and the maximum speed 7.8 mph.

Because it was assumed that long backing maneuvers more frequently involve turning than do short ones, any backing trial with more than 25.5 ft of backing was assumed to possibly include a turn. To determine whether the vehicle turned to the left, went straight, or turned to the right during each backing trial, a uniformly distributed random number was drawn. There was a 25-percent probability of a left turn, a 25-percent probability of a right turn, and a 50-percent probability of no turn. The turn, if there was one, did not commence until after 25.5 ft of backing. Once turning commenced the rear bumper of the vehicle traveled around a 20-ft radius circle. Because the maximum distance in the turn was 30 ft, the angle through which the vehicle turned ranged from 0 to 86 degrees.

2.1.2 ***Pedestrian Descriptors***

The pedestrian was modeled in the horizontal plane as a circle of radius 0.75 ft. To simplify the analysis, the pedestrian was assumed to move at constant speed and direction. The angle of pedestrian travel was determined by a random draw from a uniform probability distribution extending from -180.0 to +180.0 degrees. The pedestrian was stationary 33 percent of the time. The remaining 67 percent of the time, the pedestrian's walking speed was determined by a random draw from a three-parameter Weibull probability distribution. The pedestrian's minimum speed was 0.6 mph, his average speed 1.2 mph, and his maximum speed 1.8 mph.

To define the position of the pedestrian behind the vehicle, axes were assigned to the grid. An X axis was set up pointing straight back along the longitudinal centerline of the vehicle with its origin at the rear bumper of the vehicle. A Y axis was set up pointing along the (assumed straight) rear edge of the rear bumper with its origin at the center of the rear bumper. Positive Y values were on the driver's side of the vehicle. The pedestrian was always started at the center of one of the one foot grid squares. All possible initial pedestrian positions were simulated. Therefore, initial pedestrian X positions ranged from -19.5 to 89.5 ft in one foot increments. Similarly, the initial pedestrian Y positions ranged from -34.5 to 34.5 ft also in one foot increments.

---

[15] Ibid.

2.1.3 Additional Simulation Information

A total of 200,000 Monte Carlo simulation trials were run with the pedestrian initially in the center of each square. Each trial simulated 60.0 seconds of time unless the pedestrian collided with the vehicle or the vehicle completed its movement first. Actual backing events do not typically last for 60.0 seconds. The longest backing event out of the 6,185 in the ORSDURVS[16] data set was 52.8 seconds long. For the simulation, both the backing distance and average backing speed were determined independently of each other from Weibull probability distributions. This relationship is not so simple in the real world, as statistical analyses of the ORSDURVS data set indicates that for real driving, backing distance increases along with average backing speed. However, for the purposes of this effort to accept the independence of the backing distance and average backing speed so as to simplify the simulation. As a result, 1.1 percent of all simulated backing trials had not been completed after 60.0 seconds of simulation. Also for the purposes of this analysis it was decided that the normalization process would adequately account for not otherwise dealing with the issue of long backing maneuvers.

A count was made of all trials for which the pedestrian collided with the rear bumper of the vehicle. If the pedestrian collided first with either the front or sides of the vehicle, then this was not counted as a backing collision.

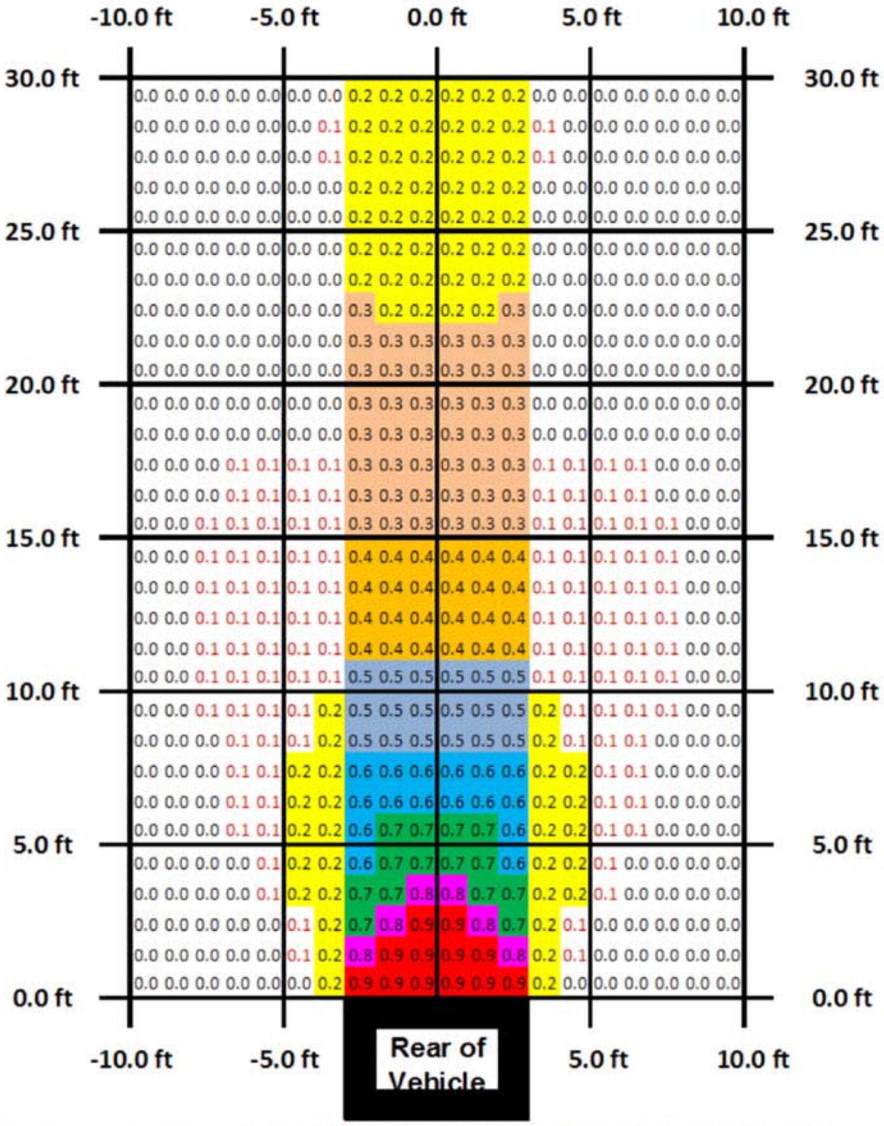
After completion of the simulation for all grid squares, a normalization of the backing crash counts for each grid square was performed. The normalization converted each grid square's crash count into its probability of crash relative to the number of trials for that square. The grid squares for which a crash was most likely to occur were the two directly behind the bumper in the center of the vehicle.

Figure 1 summarizes the simulated relative backover crash risk for each grid square. The risk numbers on the grid are shown to only one significant figure (the remaining decimal places were dropped). For example, a risk of 0.4 represents a risk of at least 0.4 but less than 0.5.

The output of this analysis calculated relative crash risk values for each grid square representing a location behind the vehicle. Analysis results showed that the probability of crash decreases rapidly as the pedestrian's initial location is moved rearward, away from the rear bumper of the vehicle. Areas located behind the vehicle and to the side were also shown to have moderately high risk, giving pedestrians some risk of being hit even though they were not initially directly behind the vehicle. The results suggest that an area 16 ft wide by 39 ft long centered behind the vehicle would address all pedestrian locations having relative crash risks of 0.10 and higher. To address crash risks of 0.20 and higher, an area 10 ft wide and 32 ft long centered behind the vehicle would need to be covered. The analysis showed that an area covering approximately the width of the vehicle out to a range of 15 ft would encompass risk values of 0.40 and higher.

---

[16] Mazzae, E. N., Barickman, F. S., Baldwin, G. H. S., and Ranney, T. A., *On-Road Study of Drivers' Use of Rearview Video Systems (ORSDURVS)*, National Highway Traffic Safety Administration, DOT 811 024, 2008.



0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.2	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.2	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.2	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.2	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.2	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.2	0.2	0.2	0.2	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.3	0.3	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.3	0.3	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.3	0.3	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.3	0.3	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.3	0.3	0.3	0.3	0.3	0.3	0.1	0.1	0.1	0.1	0.0	0.0	0.0
0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.3	0.3	0.3	0.3	0.3	0.3	0.1	0.1	0.1	0.1	0.0	0.0	0.0
0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.3	0.3	0.3	0.3	0.3	0.3	0.1	0.1	0.1	0.1	0.1	0.0	0.0
0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.4	0.4	0.4	0.4	0.4	0.4	0.1	0.1	0.1	0.1	0.1	0.0	0.0
0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.4	0.4	0.4	0.4	0.4	0.4	0.1	0.1	0.1	0.1	0.1	0.0	0.0
0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.4	0.4	0.4	0.4	0.4	0.4	0.1	0.1	0.1	0.1	0.1	0.0	0.0
0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.4	0.4	0.4	0.4	0.4	0.4	0.1	0.1	0.1	0.1	0.1	0.0	0.0
0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.5	0.5	0.5	0.5	0.5	0.5	0.1	0.1	0.1	0.1	0.1	0.0	0.0
0.0	0.0	0.1	0.1	0.1	0.1	0.2	0.5	0.5	0.5	0.5	0.5	0.5	0.2	0.1	0.1	0.1	0.1	0.0	0.0
0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.5	0.5	0.5	0.5	0.5	0.5	0.2	0.1	0.1	0.1	0.0	0.0	0.0
0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.6	0.6	0.6	0.6	0.6	0.6	0.2	0.2	0.1	0.1	0.0	0.0	0.0
0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.6	0.6	0.6	0.6	0.6	0.6	0.2	0.2	0.1	0.1	0.0	0.0	0.0
0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.6	0.7	0.7	0.7	0.7	0.6	0.2	0.2	0.1	0.1	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.6	0.7	0.7	0.7	0.7	0.6	0.2	0.2	0.1	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.7	0.7	0.8	0.8	0.7	0.7	0.2	0.2	0.1	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.7	0.8	0.9	0.9	0.8	0.7	0.2	0.1	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.8	0.9	0.9	0.9	0.9	0.8	0.2	0.1	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.9	0.9	0.9	0.9	0.9	0.9	0.2	0.0	0.0	0.0	0.0	0.0	0.0

Figure 1. Summary of Simulated Relative Backover Crash Risk as a Function of Position

2.2 Determining Rearview Image Field of View Size

To determine a minimum width of a field of view that may be appropriate for preventing backover crashes, NHTSA Special Crash Investigation's (SCI) backover case data and Monte Carlo analysis of backover crash risk as a function of pedestrian initial location were examined. Only the Monte Carlo analysis was used to estimate the lateral threat zone while both SCI backover case data and Monte Carlo analysis were used to establish the longitudinal threat zone.

First, the lateral threat zone from Monte Carlo analysis was estimated. As Figure 1 shows, elevated risk levels greater than 0.1 exist as far as 8.0 feet laterally to the left and right of a rearward extension of a vehicle's longitudinal centerline. However, the higher risk zone (risk levels greater than 0.2) are concentrated within a 10.0 feet wide area that extends symmetrically 5.0 feet laterally to either side of the extended vehicle centerline. Accordingly, the NPRM specified as the desired width of the area of improved rear visibility this area of 10.0 feet (3.05 meters) wide that is centered on the vehicle's centerline.[17]

To determine the appropriate minimum longitudinal range (i.e., length) of the area that should be specified to maximize the feasibility and effectiveness of the proposal in reducing backover crashes, NHTSA considered comments on the Advanced Notice of Proposed Rulemaking that was published in the Federal Register on March 4, 2009[18], SCI backover case data, and the results of our Monte Carlo analysis. Using the 58 SCI backover cases, NHTSA examined the distance the vehicle traveled prior to striking the pedestrian. Figure 2, which was presented in the NPRM[19], shows the percent of cases encompassed by various ranges of longitudinal distance. These data show that in 77 percent of SCI backover cases the vehicle traveled 20.0 feet or less before striking the victim. In comparison, the just described Monte Carlo analysis of backover crash risk as a function of the pedestrian's initial location indicated that the highest risk for pedestrians being struck is within a range that extends 32.0 feet aft of the rear bumper. Given that the SCI data represent actual crashes, the NPRM proposed a 20-foot longitudinal range (extending backward from the rearmost point of the vehicle's rear bumper) for rear visibility.

---

[17] 75 FR 76186, December 7, 2010

[18] U.S. Department of Transportation, National Highway Traffic Safety Administration, 49 CFR Part 571, Docket No. NHTSA-2009-0041, RIN 2127-AK43, Federal Motor Vehicle Safety Standard; Rearview Mirrors, Federal Register /Vol. 74, No. 41/, Pages 9478 – 9520.

[19] 75 FR 76186, December 7, 2010

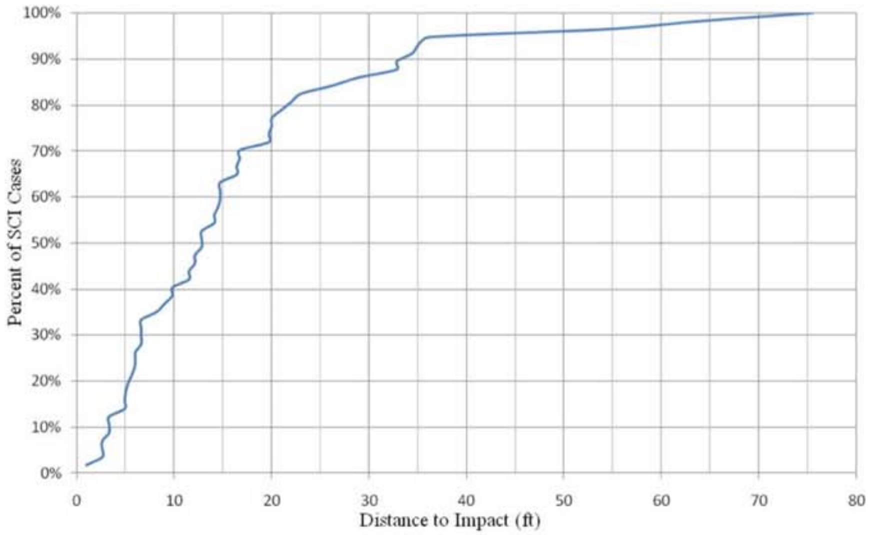


Figure 2. **Percent of SCI Backover Cases as a Function of Distance to Impact**

In summary, if a driver can see a good-quality image of the 10.0 feet (3.05 meters) wide by 20.0 feet (6.10 meters) long area in which a majority of backover crash victims have been located, the majority of backover crashes could be preventable. Therefore, this field of view was selected for use in evaluating rearview images in this research.

Given the size and geometry of this area, a view of the entire area should be obtainable through the installation of a single video camera that is located at or near the centerline of the vehicle.

To ensure adequate visibility of this area, the procedure used in this work involved outlining the field of view using seven test objects (cylinders) as shown in Figure 3. The testing described here assumed that if these cylinders could be seen in the rearview image, then the entire enclosed area could also be seen in the image.

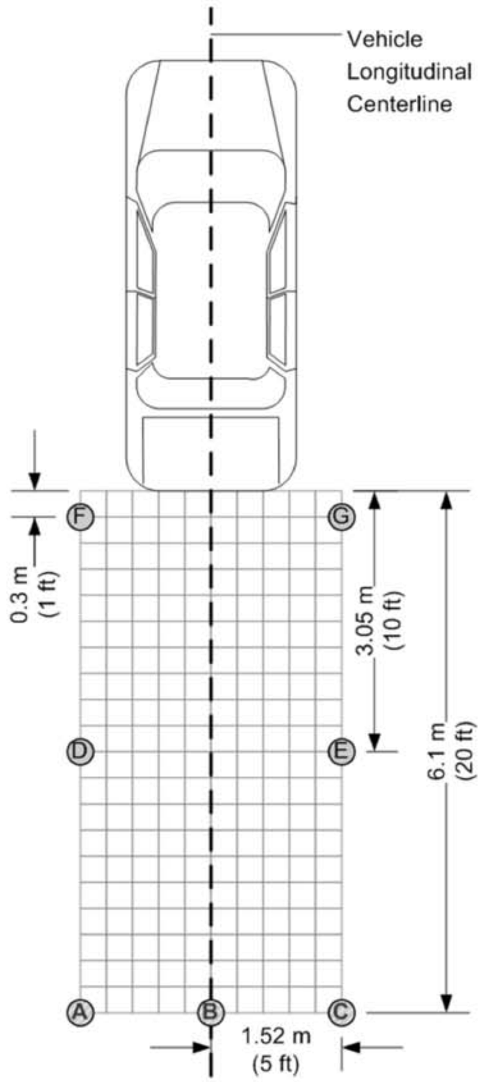


Figure 3. **Cylinder Test Object Locations**

For school bus cross-view mirrors, FMVSS No. 111 requires that the entire top surface of each cylinder must be visible. However, due to the potential for rearview video cameras to be mounted at heights of less than 32 inches on some compact cars and sporty vehicles, NHTSA proposed in a December 2010 Notice of Proposed Rulemaking an alternative detection criterion for this test. For test objects located 10 or more feet aft of the vehicle's rear bumper, the entire height and width of each test object must be visible. This criterion equates to the driver being able to see the entirety of an average sized 18-month-old child and serves to ensure that detection of such a child, if present, between 10 and 15 feet behind the vehicle is possible.

Due to the approximately conical shape of the volume captured by the video camera's curved lens, only a portion of a child or child-sized object in close proximity to the rear bumper may be visible, particularly at the edges of the camera's viewing angle. To ensure that at least a portion of test objects 'F' and 'G' (in Figure 6) may be visible in a rearview image, the test procedure outlined here positions them 1 foot aft of the rear bumper face. To ensure that the driver has enough information to be able to discern whether an "object," such as a child, is present, it is important to indicate how much of the test objects must be visible. Seeing a child's face or another body area of similar size would likely result in successful visual recognition of the child by the driver. The average breadth of an 18-month-old child's head is stated to be 5.9 inches (150 mm).[20] Based on this, it was asserted that in order to give the driver the best opportunity to identify an object or child in close proximity to the rear of the vehicle, a 5.9-inch (150 mm) wide portion of the test object should be visible at some point along the height of both F and G.

2.3 Establishing Rearview Image Quality Criteria

Image quality measurements assess whether a rearview image provided to a driver will enable the driver to discern objects within the displayed field of view. Image quality in this context was based on the apparent angular size (i.e., visual angle subtended) of a test object having a known actual size and location. The visual angles subtended by test objects as part of this test procedure were calculated using (1) the distance between the rearview image and a camera, mounted so as to represent the view observable by a 50th-percentile height male driver and (2) the test object's linear dimensions as seen in a photograph of the rearview image. Details of the calculation procedure are provided in Section 3.4. The following criteria for adequate image quality based on the apparent angular size of each test object were asserted in the NPRM:

1. When the apparent angular size of the three test cylinders that were located 20.0 feet aft of the rearmost point on the vehicle's rear bumper (Cylinders A, B, and C in Figure 3) are measured, the average apparent angular size of the three must not be less than 5 minutes of arc when viewed in the rearview image.
2. When viewed in the rearview image, the apparent angular size of each individual test cylinder must not be less than 3 minutes of arc.

There is no need for image quality criteria based on the apparent angular size for any of the nearer test objects, since the geometry of the test object arrangement ensures that the three furthest test objects will always appear to be the smallest, thus representing the worst case for

---

[20] The 5.9 in (150 mm) dimension is the average breadth of an 18-month-old child's head per Center for Disease Control's "Clinical Growth Charts, Birth to 36 months: Boys; Length-for-age and Weight-for-age percentiles" and "Clinical Growth Charts, Birth to 36 months: Girls; Length-for-age and Weight-for-age percentiles," published May 30, 2000 (modified 4/20/2001).

visibility among the seven cylinders.[21] The reasons for the above listed criteria are discussed in the remainder of this section.

One measure of *visual acuity* is the ability of the human eye to distinguish a pattern of alternating black and white stripes of equal width as stripes instead of a solid gray block. The maximum number of distinguishable black/white pairs may be expressed in *cycles per degree.* "*For a human eye with excellent acuity, the maximum theoretical resolution is 50 CPD*[22]." This is equivalent to stating that the minimum detectable angle is

60 minutes/degree ÷ 50 cycles/degree = *1.2 minutes of arc*

However, many drivers do not have excellent visual acuity. A survey of driver's licensing requirements by state shows that visual acuity of drivers without corrective lenses of 20/40 to as low as 20/60 in some states is sufficient to obtain an unrestricted driver's license. Furthermore, when driving a vehicle, drivers have to do more than distinguish a pattern of alternating black and white stripes of equal width as stripes instead of a solid gray block – they have to be able to make judgments about the nature of the object in sight. In 1983, Satoh, Yamanaka, Kondoh, Yamashita, Matsuzaki, and Akisuzuki[23] examined the relationship between an object's subtended visual angle[24] at a person's eyes and a person's subjective ability to see the object and to make judgments about what he or she is seeing. This research by Satoh et al. indicated that 5 minutes of subtended arc was the minimum size for an average person to be able to make judgments about an object and 3 minutes of subtended arc was the limit below which the average person could not see an object.

In the past, NHTSA has based its requirements for minimum image size (the minimum subtended visual angle at the driver's eyes) on the 3 minutes of subtended arc limit in the Satoh et al. research.[25] For example, the school bus cross-view mirror requirements in FMVSS No. 111 for minimum apparent angular size are based on the Satoh research. Section S9.4 of FMVSS No. 111[26] requires, for the worse case test object, Cylinder "P", that a school bus cross-view mirror show the driver a specified child surrogate test object located at a specified location with a subtended visual angle of at least 3 minutes of arc.

The December 2010 NPRM[27] illustrated the rationale for requiring a minimum subtended visual angle at the driver's eyes of at least 5 minutes of arc (on the average) in the current case instead of the 3 minutes of arc used in the school bus mirror requirements for the following reasons:

---

[21] For the optical characteristics of the types of technologies anticipated for use in this application.

[22] Russ, J.C., *The Image Processing Handbook*, CRC Press, 2006.

[23] Satoh, H., Yamanaka, A., Kondoh, T., Yamashita, M., Matsuzaki, M., and Akisuzuki, K., "Development of a Periscope Mirror System," JSAE Review, 1983.

[24] The angle which an object or detail subtends at the point of observation; usually measured in minutes of arc. If the point of observation is the pupil of a person's eye, the angle is formed by two rays, one passing through the center of the pupil and touching one edge of the observed object and the other passing though the center of the pupil and touching the opposite edge of the object.

[25] Garrott, W. R., Rockwell, T. H., and Kiger, S. W., *Ergonomic Research on School Bus Cross View Mirror Systems*, National Highway Traffic Safety Administration, DOT 807 676, 1990.

[26] 49 CFR 571.111, Standard No. 111, Rearview mirrors.

[27] 75 FR 76186, December 7, 2010

> "First, school bus drivers must be specially licensed before they can drive a school bus carrying children. They are required to obtain a Commercial Drivers License with a School Bus Endorsement. The training required to obtain this special license and the necessity of being vigilant in all types of crashes in order to retain their license and employment is expected to increase school bus drivers' awareness of the possibility of pedestrians suddenly entering danger areas around their bus. The combined effect of this training and the necessity for attentiveness is expected to encourage drivers to pay more attention to small images that are visible in a bus's convex mirrors.
>
> Second, school bus drivers are specifically trained in the use of their bus's convex cross-view mirrors. In the late 1980's, when the school bus cross-view mirror requirements of FMVSS No. 111 were being developed, 49 states plus Washington, DC[28] required annual training for all school bus drivers in the use of their bus's cross-view mirrors. This training is expected to allow drivers to make better use of very small images that they see in the convex mirrors.
>
> Third, school bus cross-view mirrors are intended to be used before the bus begins to move, while the bus is stationary. As a result, drivers can take as much time as they need to determine what they see in their bus's cross-view mirrors. In contrast, in the passenger vehicle environment, drivers may use the display while the vehicle is stationary and while the vehicle is in motion backing up (albeit at fairly low speeds). As a result, drivers may have limits on the amount of time that they may use to determine what they are seeing in a rearview video display. Again, this argues for a larger minimum image size requirement."

In summary, as stated in the December 2010 NPRM[29], a stronger requirement may be more appropriate for passenger vehicles since their drivers do not have the same vehicle and system (e.g., mirror use) training as school bus drivers do, nor do passenger vehicles typically use the systems in a stationary scenario. Based on this, the Satoh-recommended 5 minutes-of-arc subtended visual angle requirement was proposed in the NPRM.

Testing (performed in parallel with the current study and not described in this report) was performed with a 2007 Honda Odyssey minivan fitted both with an original equipment (from a 2008 Honda Odyssey) 2.4-inch diagonal rearview video display and an original equipment 3.5-inch diagonal rearview video display (from a vehicle of a different manufacturer). Testing results are described in the short NHTSA docket report "Drivers' Use of Rearview Video and

---

[28] California had no such requirement.
[29] 75 FR 76186, December 7, 2010

Sensor-Based Backing Aid Systems in a Non-Laboratory Setting."[30] Driver performance detecting a child surrogate while backing was substantially worse when the Odyssey was equipped with a 2.4-inch diagonal rearview video display than when it was equipped with a 3.5-inch diagonal rearview video display. This result demonstrates that drivers performed better when the displayed test object subtended 5 minutes of arc instead of 3 minutes of arc since for both displays the child surrogate subtended more than 3 minutes of arc but only for the 3.5-inch diagonal display did the child surrogate subtend 5 minutes of arc. For this vehicle, a 2.8-inch or larger (measured diagonally) rearview image presented in the interior rearview mirror is necessary to meet the 5 minutes of arc requirement.

Performance of subtended visual angle measurement in related work[31] demonstrated that up to approximately ±2 minutes of arc of experimental noise may be seen in individual test object measurements. Such noise can stem from inaccuracies in cylinder width measurements stemming from low image resolution (resulting from video camera and/or LCD resolution) as well as less than perfect measurement reliability (humans measure the photos so there is some subjectivity involved, especially if cylinders appear blurry in the photo). To compensate for this experimental noise, the measurements of the three test cylinders are averaged. By averaging these values, the expected measurement error is reduced to less than 1.2 minutes of arc. The 5 minutes of arc minimum size requirement was applied to only the average value of the three of the rearmost test cylinders. For each individual cylinder, a 3 minutes of arc limit is applied (desired limit of 5 minutes of arc minus up to 2 minutes of arc due to experimental noise gives an actual limit of 3 minutes of arc).

---

[30] Mazzae, E. N., *Drivers' Use of Rearview Video and Sensor-Based Backing Aid Systems in a Non-Laboratory Setting*, Document ID: NHTSA-2010-0162-0001, Docket ID: NHTSA-2010-0162, 2010.

[31] Grygier, P. A., Garrott, W. R., and Mazzae, Elizabeth N., *Measured and Calculated Useful Fields of View of Rear-Mounted Convex Mirrors*; NHTSA report, publication pending.

3.0 TEST METHOD

This section describes how the developed measurement procedures are carried out for the assessment of rearview image field of view and image quality.

3.1 Preparations for Rearview Image Measurements

Vehicles to be measured were prepared according to these conditions to ensure consistency of test conditions and vehicle pitch.

- Test vehicle fuel tanks were filled to capacity in order to provide a consistent fuel level across vehicles.
- Vehicle tires were verified to be of the original equipment size and were inflated to the manufacturer's recommended inflation pressure values.
- Vehicle windows were cleaned, cleared of any obstructions such as window stickers, and were fully closed during testing.
- Each vehicle was loaded to simulate the weight of the driver and four passengers (or the designated occupant capacity, if less), at an average weight of 68 kg per occupant (including the driver).

Each test vehicle was positioned on a flat, level, indoor test grid marked with 1-foot squares and a reference coordinate system. The vehicle was driven onto the grid and positioned with the rear bumper flush with the 0.0-foot line and the vehicle centerline directly above the longitudinal axis of the test grid. The vehicle's position on the test grid was confirmed using a plumb bob hung from the trunk or rear hatch latching mechanism at the vehicle's centerline as a reference point. Wheeled jacks may be used to maneuver the vehicle and adjust its position on the grid by lifting the vehicle off the floor surface so the vehicle could be pushed into position. Once positioned accurately on the grid, the vehicle is lowered into place and the jacks removed.

Before photographs were taken, a ruler was affixed to the base of the rearview image screen such that it was level with the ground. The ruler was included in the photo frame to be used for a scaling factor (s) when objects in the photo are measured. The ruler should have a matte finish so as not to cause reflections when taking the data photograph.

3.2 Reference Eyepoint Determination

The reference eyepoint is intended to simulate the location of a 50th percentile male driver's eyes (rather than the 95th-percentile male used in existing FMVSS No. 111 rearview mirror requirements) when looking at the rearview image. The eyepoint of a 50th-percentile male driver was chosen for use in this work to represent a midpoint of driver size.

Based on observations of drivers using rearview video systems in NHTSA testing[32], for visual displays located in the vicinity of the center console or interior rearview mirror, the driver will typically turn his or her head to look at the display with little or no lateral eye shift. Therefore, to estimate the location of the driver's eyes when looking at a rearview image, the forward-looking eyepoint of the driver was simulated to rotate toward the centerline of the vehicle as though the driver is turning his or her head toward the image. Anthropometric data from a NHTSA-

---

[32] Mazzae, E. N., Barickman, F. S., Baldwin, G. H. S., and Ranney, T. A., *On-Road Study of Drivers' Use of Rearview Video Systems (ORSDURVS)*, National Highway Traffic Safety Administration, DOT 811 024, 2008.

sponsored study of the dimensions of 50th percentile male drivers seated with a 25-degree seat back angle ("Anthropometry of Motor Vehicle Occupants"[33]) give the longitudinal and vertical location, with respect to the H point, of the left and right infraorbitale (a point just below each eye) and the head/neck joint center (J) at which the head rotates about the spine. Given an average vertical eye diameter of approximately 0.96 inch (24 mm), the center of the eye is located 0.48 inches (12 mm) above the infraorbitale. By determining the midpoint of the lateral locations of the driver's eyes, a point is obtained which resides in the mid-sagittal plane (the vertical/longitudinal plane of symmetry of the human body) of the driver's body. This point is referred to in this work as the eye midpoint and is denoted by 'M_f'. Using the point at which the head rotates (J), M_f can be rotated toward the rearview image to obtain a new eyepoint, M_r, which serves as the test reference point representing the location of the midpoint of a 50th percentile male driver's eyes when the head is turned to look at a rearview image. These points are illustrated in Figure 4.

---

[33] Schneider, L. W., Robbins, D. H., Pflüg, M. A. and Snyder, R. G., *Anthropometry of Motor Vehicle Occupants; Volume 1 – Procedures, Summary Findings and Appendices*, National Highway Traffic Safety Administration, DOT 806 715, 1985.

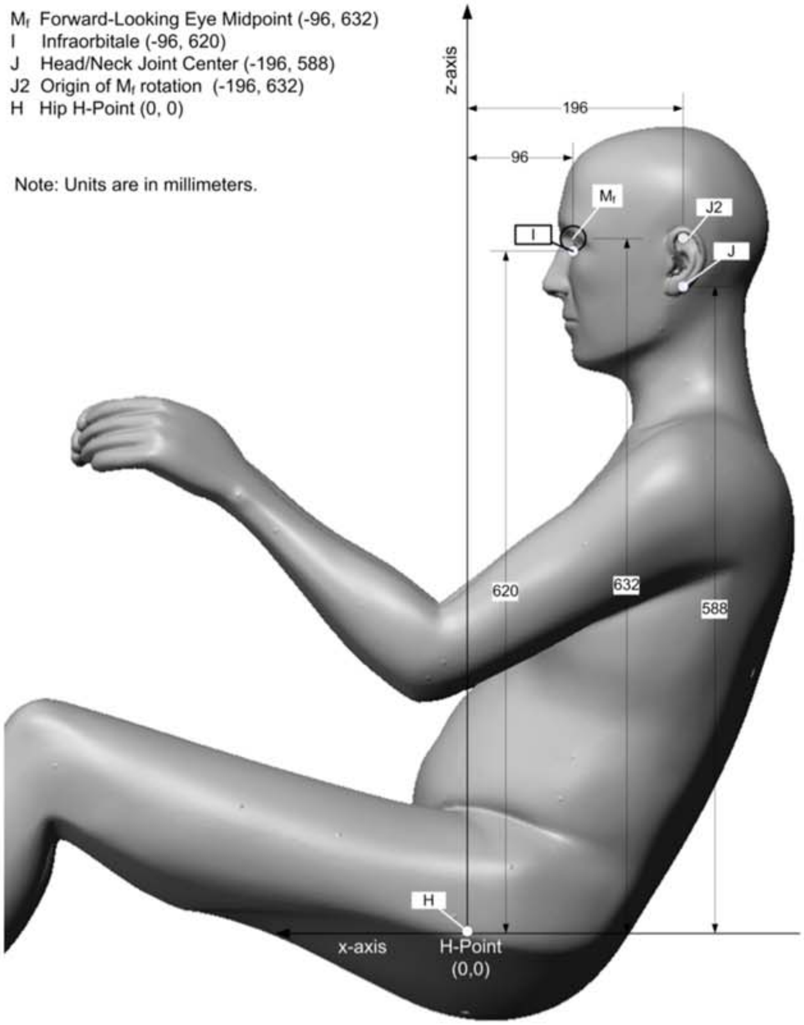


Figure 4. Coordinates of the Forward-Looking Eye Midpoint (Mf) and Joint Center (J) of Head/Neck Rotation of a 50th Percentile Male Driver with respect to the H-Point (H) in the Sagittal Body Plane.

For measurements performed in this work, each vehicle's driver's seat was adjusted to the midpoint of its longitudinal adjustment range and to the lowest point of the vertical adjustment range. An H-Point machine was installed in the vehicle driver's seat per the installation procedure outlined in SAE J826[34]. An image quality measurement fixture, described in detail in Appendix 1, and a camera attached to the H-Point machine as shown in Figure 5. The driver's seat seatback angle was adjusted to 25 degrees[35] at the vertical portion of the H-Point machine's torso weight hanger. If a seatback angle of 25 degrees was not selectable due to the location of seatback angle detents for a particular test vehicle, the seatback angle position corresponding most closely to 25 degrees was used. Once the seat was properly adjusted, the camera and fixture were adjusted to simulate the geometry of a driver's head turning to look at a rearview image. Specifically, the point M_f was rotated about the head/neck rotation point (J2) until the camera lens was pointed at an angle corresponding to the lateral position of the rearview image. This new, rotated location of M_f was referred to as M_r. Lastly, the camera was rotated about a horizontal axis containing M_r to create pitch that served to simulate the driver's eyes looking upward or downward as needed to cause the line of sight to intersect with the center of the rearview image (which might be mounted higher or lower than M_r. No head pitch was simulated as it was assumed to be unlikely or negligible.

Figure 5. Rearview Image Measurement Fixture

---

[34] SAE J826, *Devices for Use in Defining and Measuring Vehicle Seating Accommodation,* Rev. JUL95, Society of Automotive Engineers, 1995.

[35] SAE J826, *Devices for Use in Defining and Measuring Vehicle Seating Accommodation,* Rev. JUL95, Society of Automotive Engineers, 1995.

To facilitate calculation of image quality, the distance (*d*) from the rotated eyepoint (M_r) to the center of the rearview image screen was determined. This viewing distance is a factor in the formula for calculating the subtended visual angle of the test objects in this procedure.

To determine the viewing distance as accurately as possible, a measurement is made from the center of the rearview image to a point inside the camera lens which is the center of the camera's CCD chip (the "image plane"). Measurements were taken from the center of the rearview image display to an external point on the side of the camera that lies on a plane containing that focal point, with the plane being parallel to the rearview image screen. This provided an approximate distance measurement. Using the Pythagorean Theorem and the distance from the external point on the side of the camera to the focal point inside the camera, the approximate distance measurement was corrected to yield an accurate value for *d*.

Figure 26 shows the geometry of the situation and defines the symbols used.

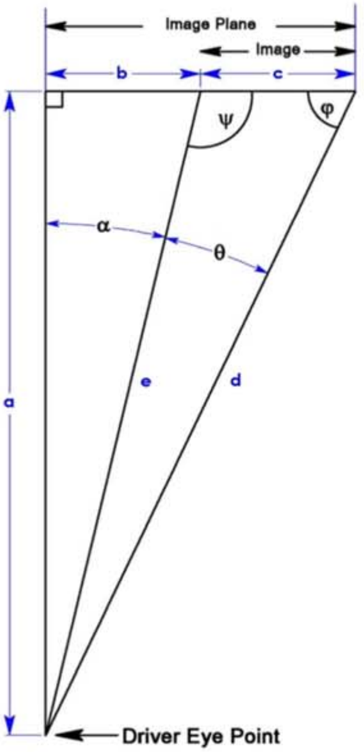


Figure 6. **Geometry Used to Derived Subtended Visual Angle Equation**

3.3 Rearview Image Field of View Test Procedure

A test procedure was developed to ensure that a rearview image provided to the driver covers a sufficiently large area behind the vehicle (described in this section).

The test procedure used in this research to measure the rearview image field of view is similar to that currently used for school bus mirrors[36]. Like the school bus mirror test, the current test procedure used a large format camera placed with the imaging sensor located at the "reference eyepoint" (see Section 3.2). A matte finish ruler affixed beneath the visual display and aligned laterally along the bottom edge of the visual display provided a reference for scaling purposes in the image quality portion of the test procedure (see Section 3.4).

To demonstrate that a rearview image provides a field of view large enough to permit a driver to view obstacles and pedestrians over an area known to be related to backover crashes, the perimeter of a minimum visible area was outlined. Seven test objects (cylinders), represented by black circles in Figure 3 were used to outline the visible area of interest. Each test object was a cylinder 12.0 inches (305 mm) in diameter and 32.00 inches (813 mm) tall. The three rearmost test objects (Cylinders A, B, and C in Figure 6) had a horizontal band encircling the top 5.9 inches (150 mm). The color of the band was chosen to have high contrast with respect to the coloring of the rest of the cylinder. The centerlines of Cylinders A and C were located 5.0 feet (1.52 meters) laterally and 20.0 feet (6.10 meters) longitudinally from the center of the vehicle's rear bumper, with Cylinder B located between them along the centerline of the vehicle. The two test objects closest to the vehicle (Cylinders G and F) had a 5.9-inch (150 mm) wide vertical stripe spanning the full height of the cylinder. The coloring vertical stripe also was selected to have high contrast with respect to the coloring of the rest of the cylinder. The cylinders and their markings are pictured in Figure 7.

---

[36] 49 CFR 571.111, Standard No. 111, Rearview mirrors, Section 13: School bus mirror test procedures.

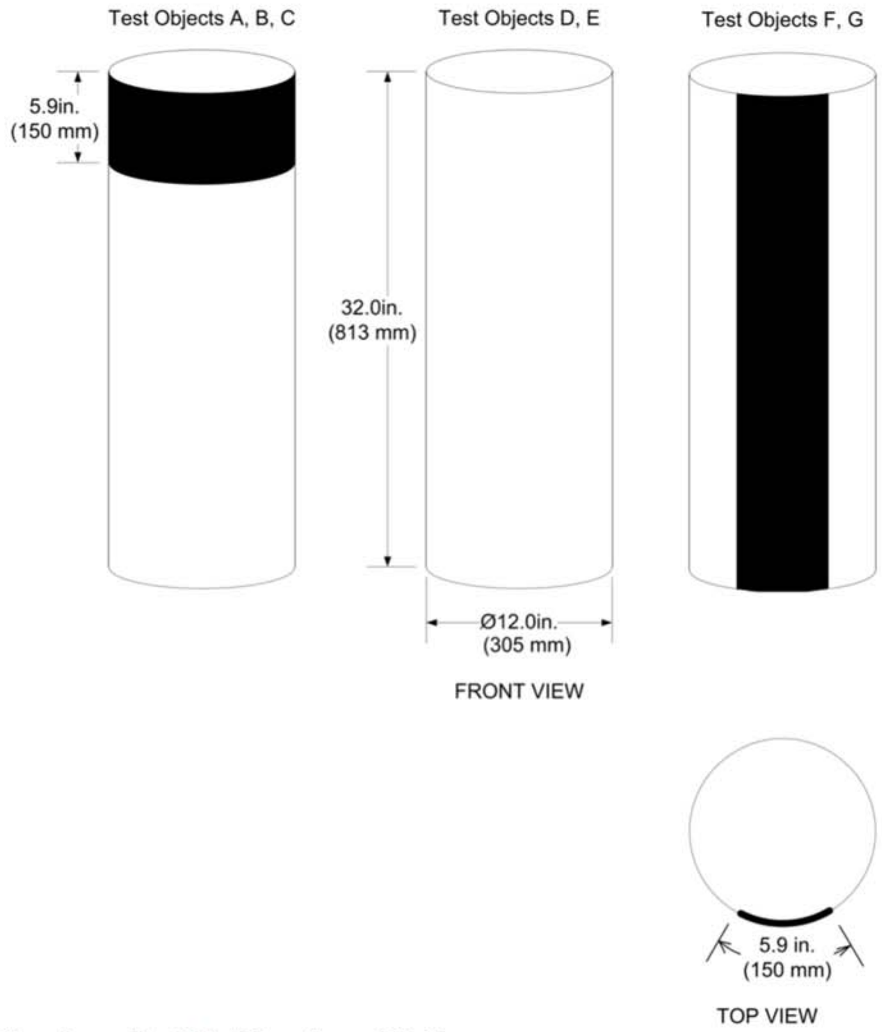


Figure 7. **Test Object Dimensions and Markings**

The cylinders are pictured in their test positions as displayed in a rearview image in Figure 8. The centerlines of Cylinders F and G were located 5.0 feet (1.52 meters) laterally from the center of the vehicle's rear bumper and 12.0 inches (305 mm) longitudinally aft of the rearmost point of the bumper face with the contrasting stripe oriented toward the vehicle's video camera. Between these sets of cylinders, the centerlines of Cylinders D and E were located 5.0 feet (1.52 meters) laterally and 10.0 feet (3.05 meters) longitudinally from the center of the vehicle's rear bumper.

Figure 8. **Test Object Arrangement as Displayed in Rearview Image**

For school bus cross-view mirrors, FMVSS No. 111 requires that the entire top surface of each cylinder must be visible. However, given that rearview video cameras (or other image sensing equipment) installed on some compact cars and sporty vehicles may be mounted at heights of less than 32.00 inches (813 mm), the tops of the test cylinders may not be visible in the rearview images of these vehicles. For test objects located 10.0 feet (3.05 meters) or more aft of the vehicle's rear bumper, the criterion used in this research was that the entire height and width of each test object should be visible. This criterion equates to the driver being able to see the entirety of an average sized 18-month-old child and serves to ensure that detection of such a child, if present, between 10 and 15 feet behind the vehicle is possible.

Due to the approximately conical shape of the volume captured by the video camera's curved lens, only a portion of a child or child-sized object in close proximity to the rear bumper may be visible, particularly at the edges of the camera's viewing angle. To ensure that at least a portion of Cylinders F and G (in Figure 3) are visible, the test procedure positioned these cylinders 12.0 inches (305 mm) aft of the rear bumper face. To give the driver enough information to be able to discern if an "object," such as a child, is present and to provide a quantitative basis for assessing that the desired field of view can be seen, it is important to indicate how much of each test object must be visible. Seeing a child's face or another body area of similar size would likely result in successful visual recognition of the child by the driver. The average breadth of an 18-month-old child's head is stated to be 5.9 inches (150 mm).[37] Based on this, the criterion was developed that the full width of the 5.9-inch (150 mm) vertical stripe should be visible at some point along the height of both F and G. It was assumed that this criterion would result in an approximately 5.9-inch (150 mm) square portion of an object or child being visible. Therefore no vertical extent of the visible portion of the stripe was assessed.

In summary, for a rearview image to meet the current test procedure's criteria, two conditions must be met: First, the front surfaces of Cylinders A, B, C, D and E have to be fully visible in the display (the entire height and width of each cylinder). In addition, the full width of the 5.9 inch-wide (150 mm) vertical stripe on Cylinders F and G must be visible at some point along the height of the cylinder. If both conditions are met, then the system meets the field of view criteria established here. Figure 7 shows an image of a rearview image that meets these criteria, where Cylinders A through E are the ones furthest away in the image and Cylinders F and G have a substantial portion of their vertical stripes showing in the front corners.

To determine whether a rearview image's field of view meets the specified criteria, the displayed image was photographed to document the test results of this field of view test, as well as to provide data for use in completing the rearview image quality test, as is described in the next section.

3.4 Rearview Image Quality Test Procedure

Standardized industry standards for the assessment of the quality of a visual image of the area behind a vehicle do not currently exist. Therefore, to develop a method for assessing image quality, as previously mentioned, prior work relating to school bus cross-view mirrors was examined. The test procedure described below follows the same basic concept as the existing school bus mirror test procedure in FMVSS No. 111. This test procedure serves to ensure that a minimum image quality is maintained throughout the specified field of view of the rearview image. Essentially, meeting the image quality criteria requires that the apparent sizes of the images of the individual test objects are large enough for an average driver to quickly determine their presence and nature.

---

[37] The 5.9 in (150 mm) dimension is the average breadth of an 18-month-old child's head per Center for Disease Control's "Clinical Growth Charts, Birth to 36 months: Boys; Length-for-age and Weight-for-age percentiles" and "Clinical Growth Charts, Birth to 36 months: Girls; Length-for-age and Weight-for-age percentiles," published May 30, 2000 (modified 4/20/2001).

The test procedure for use in assessing countermeasure visual display image quality required one additional step beyond the rearview image viewable area test described above. Using the printed photograph of the rearview image taken to document the viewable area covered by the system, the sizes of each of the three test objects positioned 20.0 feet aft of the rear bumper (Cylinders A, B, and C in Figure 3) were measured. The horizontal width of each of the three test objects was measured within the colored band surrounding the upper portion of the cylindrical test object by selecting a point at both the left and right edges of the object's displayed image. Similarly, two points on the ruler shown in the photograph were selected to acquire a measurement for use as a lateral scaling factor. Using the two measured widths and the distance between the driver's eyepoint (i.e., midpoint between an average 50th percentile male's eyes) and the center of the rearview image, the visual angle subtended by each test object was calculated. To reduce the effects of measurement errors, the measured visual angle subtended from each of the three test objects (Cylinders A, B, and C) were averaged together. Acceptable image quality was defined as the average measured visual angle subtended by the test object's width from these three locations exceeding 5 minutes of arc. The average value was used to minimize the effect of individual measurement error. The subtended visual angle for each of the three individual cylinders must exceed 3 minutes of arc.

In order to evaluate the quality of the rearview image, the photo taken from the perspective of a 50th percentile adult male was analyzed to determine the size of the displayed visible area and the visual angle subtended by the object.

3.4.1 ***Photographic Data Extraction***

In addition to the field of view test, the apparent widths of Cylinders A, B, and C were measured for calculating their subtended visual angle in the photograph. A 2.0 inch delineated section of the ruler affixed to the base of the rearview image was also measured, to provide a scale factor (*s*) for converting measurements from pixels on a computer monitor to inches. In addition to the photographic image measurements, the viewing distance (*d*) from the camera lens to the center of the rearview image was previously determined (see Section 3.2) to provide the third component needed for calculating the subtended visual angle of a test object in the displayed image.

Any photo editing software which provides zoom and pan functions, rotations, and a high resolution XY coordinate system may be used to measure the apparent size of the cylinders. For the tests described in this report, Corel Paint Shop Pro Photo X2 was used.

The photographic data extraction process is as follows:

- In-vehicle rearview video system display screens are commonly located so they do not directly face the driver but are offset from the driver's direct forward line of sight. The human eye can compensate for this and interpret the image as "normal", whereas a camera lens tends to make images appear a bit skewed and not quite horizontal when the image is offset, as shown in Figure 9. For this reason a working copy of each digital photo was first rotated to make it appear approximately horizontal. It is important to ensure that any modifications to the digital photos (including rotations) do not distort the relative distances between points in the image.

Figure 9. **Example of Photographic Image, Before and After Image Rotation.**

- The next step in the measurement process was to identify the points to be measured on each of the three cylinders A, B, and C and also on a 2-inch section of the ruler. For reference and to permit data quality checking, arrows were inserted in the copied photo to mark the points to be measured, as illustrated in the close-up view in Figure 10. In this testing, measurements of cylinder width were made at the lower edge of the horizontal band (highlighted in Figure 10 using arrows to ensure a horizontal measurement of width was obtained.

- After the desired reference points were marked in the image by arrows, the software "zoom" function was used to determine the coordinates of each arrow tip. The XY coordinates in pixels of each arrow tip were determined from the graphics software and entered into a spreadsheet. The 2- inch section of the ruler was measured from the tip of one inch line to the tip of another inch line 2.0 inches away to obtain a consistent method for obtaining a scaling factor.

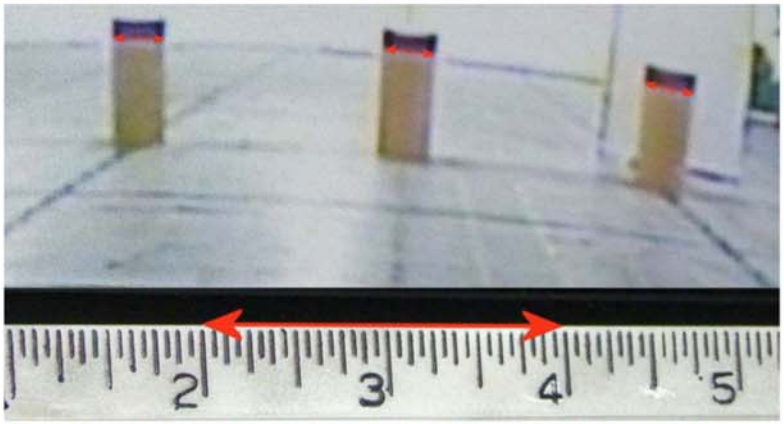


Figure 10. **Close-Up View Portions of Display with Measurement Points Indicated.**

3.4.2 Calculations for the Determination of Test Cylinder Subtended Visual Angle

Appendix 2 contains a derivation of the equation used to calculate the subtended visual angle of each test object. A spreadsheet was set up with formulas attached to the appropriate cells to calculate the width and visual angle of each object as the pixel coordinates were entered. This allowed for instant data quality checks.

Using the pixel coordinates obtained for each edge of each cylinder and the 2.0 inch section of the ruler, along with the previously determined viewing distance (*d*), the scale factor (*s*), apparent width in pixels (c_i), and the subtended visual angle (Θ_i) of each cylinder were calculated.

The scale factor (*s*) for the ruler in pixels per inch was found by dividing the distance between two points on the ruler in pixels by the actual distance in inches between the same two points:

$$\mathbf{s} = \mathrm{SQRT}((X_2 - X_1)^2 + (Y_2 - Y_1)^2) / 2$$

where **(X1, Y1)** and **(X2, Y2)** are the coordinates in pixels of the endpoints of the 2.0 inch segment of the ruler used to establish the scale.

Then, if the endpoints of the arrow spanning the width of Cylinder ***i*** are (X_{i1}, Y_{i1}) and (X_{i2}, Y_{i2}), the apparent width of each cylinder in pixels is given by

$$c_i = \mathrm{SQRT}((X_{i2} - X_{i1})^2 + (Y_{i2} - Y_{i1})^2)$$

Once the width of a cylinder had been calculated in pixels, the subtended visual angle was calculated using the following formula:

$$\Theta_i = \sin^{-1}(c_i / (d * s))$$

The angular widths of the cylinders were reported in minutes of arc for each vehicle's rearview image. Visual angle results were interpreted using the previously discussed human visual performance criteria to determine whether or not an object in the view of a rearview image subtends a large enough visual angle to be detectable by a driver seated at the 50th-percentile adult male location.

4.0 APPLICATION OF THE TEST PROCEDURE AND RELATED RESULTS

The test procedures described in this report were applied to several late model vehicles to demonstrate how to carry out the measurements and how some current vehicles fare with respect to the criteria asserted in this report.

4.1 Test Vehicles Measured

Six model year 2010-2011 test vehicles were acquired for measurement. The vehicles measured were ones that happened to be on site for other research programs and were equipped with an original equipment rearview video system. Table 1 lists the model information for these vehicles.

Table 1. Vehicles Tested for the Current Study

Year	Make	Model	Vehicle Identification Number
2010	Dodge	Grand Caravan SE	2D4-RN4DE9AR-11****
2010	Ford	F-150 (super crew)	1FTFW1EU1AFB2****
2010	Nissan	Maxima	1N4AA5AP6AC82****
2010	Nissan	Murano	JN8AZ1MW7AW118****
2011	Toyota	Camry	4T4BF3EK2BR09****
2011	Toyota	Sienna	5TDYK3DC8BS01****

Table 2 shows the information recorded during the measurement fixture configuration process for each vehicle. Head/neck rotation angle is the amount of rotation from a directly forward line of sight the fixture was rotated to allow the camera's line of sight to align with the lateral location of the rearview image. 'Pitch Angle' in Table 2 refers to the amount of pitch about a horizontal axis containing M_r the camera was rotated in order for the camera's line of sight to intersect with the center of the rearview image. The viewing distance (*d*) from the rotated eye point (M_r) to the center of the rearview image was measured for use in calculating subtended visual angle of the test cylinders. Number of occupied seats refers to the number of occupant locations in which weights were location to simulate the weight of vehicle passengers.

Table 2. Image Quality Measurement Data and Fixture Positioning Information by Vehicle

Vehicle Year/Make	**Vehicle Model**	**Rearview Image Diagonal Length** (in)	**Rearview Image Location**	**Head/Neck Rotation Angle**	**Pitch Angle** (Camera rotated about a horizontal line containing M_r)	**Number of 'Occupied' Seats** (other than driver's)	***d*** (in)
2010 Dodge	Caravan	7.25	Center Stack	35°	-17.9	3	29.34
2010 Ford	F-150	2.40	Interior Mirror	35°	--	0	27.20
2010 Nissan	Maxima	7.25	Center Stack	25°	-13.2	4	32.48
2010 Nissan	Murano	7.80	Center Stack	30°	-15.8	4	33.98
2011 Toyota	Camry	7.25	Center Stack	27°	-24.0	4	30.34
2011 Toyota	Sienna	7.25	Center Stack	33°	-18.0	4	32.60

* Pitch Angle was unavailable for the 2010 Ford F-150.

4.2 Rearview Image Field of View Assessment

Figures 11 through 16 show photographs of each test vehicle's rearview video system display. These photographs were used to determine whether each rearview image met the field of view specified in Section 2.2 and Section 3.3 as well as the image quality requirements described in

Section 3.4. As can be determined from an examination of these figures, all six test vehicles rearview video systems met the field of view requirements described in Section 2.2.

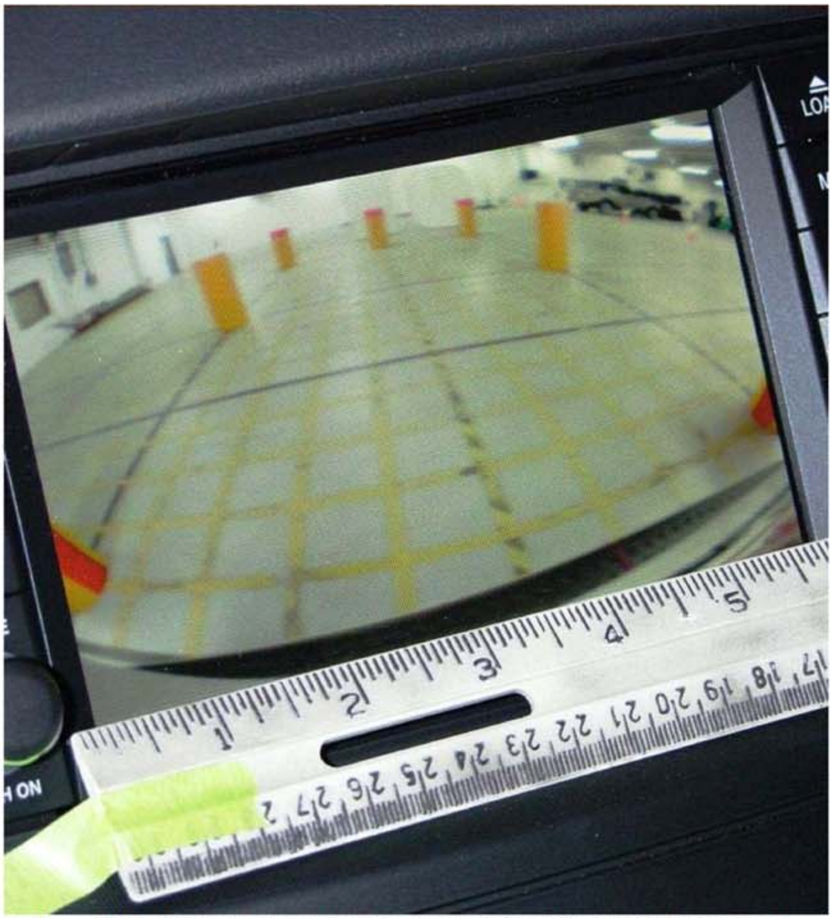


Figure 11. Field of View and Image Quality Assessment Photo for the 2010 Dodge Grand Caravan

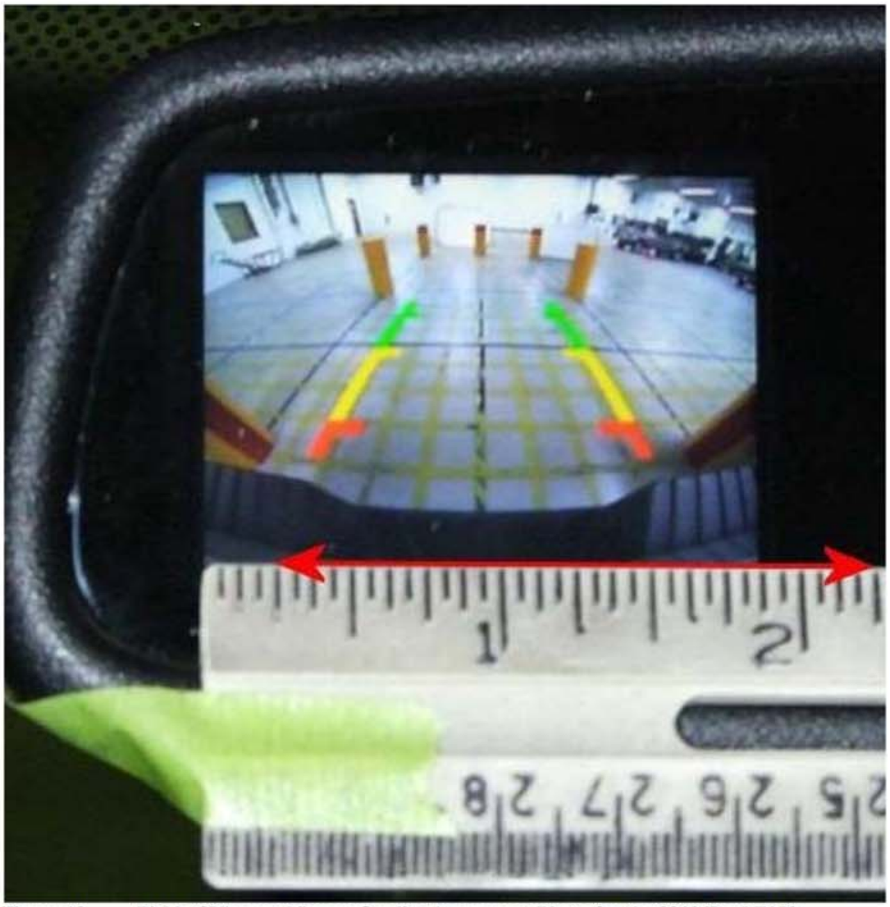


Figure 12. Field of View and Image Quality Assessment Photo for the 2010 Ford F150

Figure 13. Field of View and Image Quality Assessment Photo for the 2010 Nissan Maxima

Figure 14. **Field of View and Image Quality Assessment Photo for the 2010 Nissan Murano**

Figure 15. Field of View and Image Quality Assessment Photo for the 2011 Toyota Camry

Figure 16. **Field of View and Image Quality Assessment Photo for the 2011 Toyota Sienna**

4.3 Rearview Image Quality Assessment

Measured image quality data for the six vehicles determined Figures 10 through 15 and is summarized in Table 3. This table shows the image scale calculations, the x and y pixel coordinates of Cylinders A, B, and C, and the apparent width and visual angle calculations for each of these cylinders.

The 2010 Ford F-150 had the smallest subtended visual angles for Cylinders A, B, and C (an average of 4.12 minutes for the three) and the 2010 Dodge Grand Caravan had the largest subtended visual angle (an average of 14.84 minutes for the three). The 2010 Ford F-150 subtended visual angles were small, compared to the other five test vehicles, because it was the only one of the six vehicle to have a 2.4-inch diagonal video display in its interior rearview mirror. The other five test vehicles, all of which had 7- to 8-inch diagonal video displays in their center consoles, all had approximately equal subtended visual angles.

Section 2.3 lists the two image quality criteria used in this research. They were:

1. When the apparent angular size of the three test cylinders that are located 20.0 feet aft of the rearmost point on the vehicle's rear bumper (Cylinders A, B, and C in Figure 6) are measured, the average apparent angular size of the three must not be less than 5 minutes of arc when viewed in the rearview image.
2. When viewed in the rearview image, the apparent angular size of each individual test cylinder must not be less than 3 minutes of arc.

As can be seen by inspection of Table 3, the 2010 Ford F-150 does not meet the first of these requirements. As discussed above, this is due to the size of its video display. If this vehicle were equipped with a 3.0 inch or larger diagonal display, it would have met the first criterion. This vehicle did meet the second criterion with its current display.

Even though the 2010 Ford F-150 the rearview video system display installed in this vehicle is not large enough to meet the image quality requirements contained in this report, this display should certainly improve safety relative to not having a display.

The rearview video systems of the other five test vehicles would meet both of the above listed image quality criteria.

Table 3. Image Quality Measurements: Apparent Linear Width and Visual Angle Calculations for Cylinders A, B, and C Positioned 20.0 Feet Behind the Vehicle's Rear Bumper

Vehicle	d (in)	Ruler Measurements (2 inches)				s	Cylinder A Measurements				c_a Width		Θ_a Visual Angle
		x1	y1	x2	y2	Pixels/ Inch	x1	y1	x2	y2	Pixels	In.	Min.
2010 Dodge Grand Caravan	29.34	351	2278	1305	2298	477.1	1400	865	1455	874	55.7	0.117	13.7
2010 Ford F-150	27.20	926	2378	2298	2390	686.0	1513	1613	1535	1614	22.0	0.032	4.1
2010 Nissan Murano	33.98	1250	2786	2174	2802	462.1	2035	1432	2094	1438	59.3	0.128	13.0
2010 Nissan Maxima	32.48	1363	2703	2270	2716	453.5	1968	1469	2029	1471	61.0	0.135	14.2
2011 Toyota Camry	30.34	1982	3022	2822	3022	420.0	2198	1687	2252	1688	54.0	0.129	14.6
2011 Toyota Sienna	32.60	1449	3059	2307	3069	429.0	2052	1564	2111	1566	59.0	0.138	14.5
Vehicle	d (in)	Ruler Measurements (2 inches)				s	Cylinder B Measurements				c_b Width		Θ_b Visual Angle
		x1	y1	x2	y2	Pixels/ Inch	x1	y1	x2	y2	Pixels	In.	Min.
2010 Dodge Grand Caravan	29.34	351	2278	1305	2298	477.1	1078	812	1141	819	63.4	0.133	15.6
2010 Ford F-150	27.20	926	2378	2298	2390	686.0	1385	1606	1408	1606	23.0	0.034	4.2
2010 Nissan Murano	33.98	1250	2786	2174	2802	462.1	1705	1397	1769	1401	64.1	0.139	14.0
2010 Nissan Maxima	32.48	1363	2703	2270	2716	453.5	1653	1445	1715	1447	62.0	0.137	14.5
2011 Toyota Camry	30.34	1982	3022	2822	3022	420.0	1948	1660	1997	1662	49.0	0.117	13.2
2011 Toyota Sienna	32.60	1449	3059	2307	3069	429.0	1769	1526	1827	1527	58.0	0.135	14.3
Vehicle	d (in)	Ruler Measurements (2 inches)				s	Cylinder C Measurements				c_c Width		Θ_c Visual Angle
		x1	y1	x2	y2	Pixels/ Inch	x1	y1	x2	y2	Pixels	In.	Min.
2010 Dodge Grand Caravan	29.34	351	2278	1305	2298	477.1	743	795	805	799	62.1	0.130	15.3
2010 Ford F-150	27.20	926	2378	2298	2390	686.0	1253	1608	1275	1608	22.0	0.032	4.1
2010 Nissan Murano	33.98	1250	2786	2174	2802	462.1	1373	1395	1431	1395	58.0	0.126	12.7
2010 Nissan Maxima	32.48	1363	2703	2270	2716	453.5	1334	1448	1393	1449	59.0	0.130	13.8
2011 Toyota Camry	30.34	1982	3022	2822	3022	420.0	1682	1642	1732	1642	50.0	0.119	13.5
2011 Toyota Sienna	32.60	1449	3059	2307	3069	429.0	1467	1518	1527	1518	60.0	0.140	14.7

5.0 SUMMARY

In support of the mandate to improve vehicle rear visibility outlined in the Kids Transportation Safety Act of 2007, NHTSA investigated the nature of backover crashes and looked into what information may be effective in aiding drivers to avoid backover crashes. Crash data were examined to better understand the backover problem and the locations in which victims tend to be located with respect to the backing vehicle in documented incidents. NHTSA also examined technologies that may aid the driver in detecting rear obstacles and pedestrians. This report describes the process used to determine what field of view behind a vehicle (i.e., their field of view) affords a driver the best chance of preventing a backover crash. The degree of the image quality needed for a driver to effectively discern relevant obstacles within this field of view was also determined. The development of test procedures for measuring both the field of view and image quality of rearview images was described. Finally, the use of the developed test procedures was demonstrated through the measurement of the field of view and image quality of rearview images associated with six 2010-2011 model year vehicles equipped with original equipment rearview video systems.

NHTSA's research to date has shown that systems providing the driver with an image of the area behind the vehicle are more effective in aiding a driver to avoid a backing crash with a rear obstacle than other types of technologies. However, for drivers to see and identify objects displayed within a rearview image, the image must have an adequate field of view and sufficient image quality to permit the average driver to see what is in the field of view.

A procedure was developed for use in assessing a rearview image's ability to meet the specified field of view. The field of view specified consisted of a 10.0 feet wide by 20.0 feet long area and was delineated using seven test objects. Each test object was a cylinder of 12.0 inches (305 mm) in diameter and 32.00 inches (813 mm) in height. For the purposes of this work, criteria for visibility of the test objects were asserted to ensure that the field of view would be useful to drivers in discerning child-sized objects behind a vehicle. For test objects located 10.0 feet (3.05 meters) or more aft of the vehicle's rear bumper, the entire height and width of each test object should be visible. This criterion equates to the driver being able to see the entire body of an 18-month-old child, if present, between 10.0 feet (3.05 meters) and 15.0 feet (4.57 meters) behind the vehicle. Due to camera angle, only a portion of a child or child-sized object in close proximity to the rear bumper may be visible, particularly at the edges of the camera's viewing angle. To ensure that at least a portion of Cylinders F and G were visible; the test procedure used here positioned these cylinders 12.0 inches (305 mm) aft of the rear bumper face. To give the driver enough information to be able to discern if an "object," such as a child, is present and to provide a quantitative basis for assessing that the desired field of view can be seen, it is important to indicate how much of each test object must be visible. Seeing a child's face or another body area of similar size would likely result in successful visual recognition of the child by the driver. The average breadth of an 18-month-old child's head is stated to be 5.9 inches (150 mm).[38] Based on this, the measurement procedure used here assessed whether the full 5.9-

---

[38] The 5.9 in (150 mm) dimension is the average breadth of an 18-month-old child's head per Center for Disease Control's "Clinical Growth Charts, Birth to 36 months: Boys; Length-for-age and Weight-for-age percentiles" and "Clinical Growth Charts, Birth to 36 months: Girls; Length-for-age and Weight-for-age percentiles," published May 30, 2000 (modified 4/20/2001).

inch (150 mm) width of the vertical stripe was visible at some point along the height of both F and G.

In summary, for a rearview image to meet this effort's test procedure requirements, two conditions needed to be met: First, the front surfaces of Cylinders A, B, C, D and E have to be fully visible in the system's display (the entire height and width of each cylinder). In addition, the full width of the 5.9- inch (150 mm) wide vertical stripe on Cylinders F and G must be visible at some point along the height of the cylinder. If both conditions were met, then the system is considered to have met the field of view criteria outlined here.

Image quality measurements assess whether a rearview image will enable the driver to see and identify objects behind the vehicle's rear bumper. For this effort, the apparent angular size of a test object having known actual size and location was calculated using (1) the distance between the display screen and a camera, mounted so as to represent the view observable by a 50th-percentile height male driver and (2) the test object's linear dimensions as seen in a photograph of the rearview image. Details of the calculation procedure were provided in the main body of the report. Image quality criteria based on the apparent test object angular size were then applied to determine whether drivers will be able to see each test object. (Image quality also includes image distortion; however, distortion was not measured here because it is not an issue for the technologies assessed in this effort; i.e., rearview video systems.) The following criteria were used in this evaluation:

1. When the apparent angular size of the three test cylinders that are located 20.0 feet aft of the rearmost point on the vehicle's rear bumper (Cylinders A, B, and C) are measured, the average apparent angular size of the three must not be less than 5 minutes of arc when viewed in the rearview image.
2. When viewed in the rearview image, the apparent angular size of each individual test cylinder must not be less than 3 minutes of arc.

There is no need for criteria based on the apparent angular size requirements for any of the nearer test objects, since with the types of technologies anticipated for this application, the three furthest test objects will always appear to be the smallest, thus representing the worst case for visibility among the seven cylinders.

Field of view and image quality measurements outlined in this report were evaluated for six model year 2010-2011 test vehicles equipped with original equipment rearview video systems. These rearview video systems use a video camera and visual display to provide the driver with an image of the area behind the vehicle. While other rearview imaging technologies, such as mirrors or fiber optics, could also be used to provide the driver with an image of the area behind the vehicle, no original equipment of this type was known to be available in any current production vehicle. However, should other imaging technologies come to be used, the test procedures described in this report could also be applied to these technologies.

All six test vehicles rearview video systems met the field of view requirements outlined in this report. Based on the performance of original equipment systems examined by NHTSA, the field of view proposed in the NPRM should be obtainable through the installation of a single video camera with a minimum horizontal viewing angle of 130 degrees located at or near the centerline of the vehicle.

With regard to image quality measurements performed, the 2010 Ford F-150 had the smallest subtended visual angles for Cylinders A, B, and C (an average of 4.12 minutes for the three) and the 2010 Dodge Grand Caravan had the largest subtended visual angle (average of 14.84 minutes for the three). The 2010 Ford F-150 subtended visual angles were small, compared to the other five test vehicles, because it was the only one of the six vehicle to have a 2.4-inch diagonal video display in its center rearview mirror. The other five test vehicles, all of which had 7- to 8-inch diagonal video displays in their center consoles, all had approximately equal subtended visual angles.

The 2010 Ford F-150 did not meet the first of the two image quality requirements listed above due to the small size of its video display. If this vehicle were equipped with a 3.0-inch or larger diagonal display, it would have likely met the first criterion. This vehicle did meet the second criterion with its current display. Even though the 2010 Ford F-150 the rearview video system display installed in this vehicle was not large enough to meet the image quality requirements proposed in the NPRM.

The rearview video systems of the other five test vehicles would meet both of the above image quality criteria.

APPENDIX 1. DEVELOPMENT OF A REARVIEW IMAGE QUALITY MEASUREMENT FIXTURE

Objective

To perform consistent and repeatable image quality measurements of objects visible in vehicle rearview video displays, a fixture was developed to hold a camera at a test reference point representing a location between the eyes of a 50th-percentile adult male driver looking at a rearview video display inside the vehicle. With a camera in this position, photographs can be taken that represent the view observable by a fiftieth percentile adult male driver. By extracting measurements from such photographs, the quality of an image provided by a rearview video system can be assessed.

Fixture Design

To facilitate a repeatable test procedure, an H-Point machine representing the 50th- percentile adult male was used as the base for the fixture. The H-Point machine was selected as the base to provide a standardized representation of the seated posture of an adult male driver. The H-point machine's standard configuration was modified to incorporate a fixture mounted in place of the device's neck, as seen in Figure 17. The fixture has multiple points of adjustment such that it can be adjusted to hold the camera in a specific position that corresponds to the selected eye midpoint of a 50th-percentile adult male driver.

Figure 17. Camera & Mounting Fixture on Neck of H-Point Machine

The location of the forward-looking eye midpoint (M_f) was calculated using the measurements described in the NHTSA Technical Report "*Direct Rear Visibility of Passenger Cars: Laser-Based Measurement Development and Findings for Late Model Vehicles* "[39]. Calculations based on the previous findings determined that the M_f point would need to be located 24.88 inches (632mm) vertically and -3.80 inches (-96mm) longitudinally (i.e., rearward) with respect to the H-Point machine, as shown in Figure 4 (Note: the coordinates shown in Figure 4 are also presented in Figure 23 on the actual camera mount fixture drawings.)

In addition to the forward-looking eye midpoint (M_f), the fixture also needed to have points of head and neck rotation similar to a 50th percentile adult male. The fixture was designed to rotate about the head/neck joint center (J) in a horizontal plane. To accomplish this rotational capability, a panoramic head (a camera mount typically used for taking panoramic photos) was mounted to the centerline of the neck. This provided the rotation with the ability to lock the fixture into a desired location. The panoramic head included graduated markings to provide a record of the rotation angle used, as shown in Figure 18.

Figure 18. **Neck of Fixture, a Panoramic Head**

To allow for fine adjustment and future versatility, two quick release adapters with sliding plates and a rotation index guide (from a Manfrotto Virtual Reality SPH/Cubic Head) were used in conjunction with a mounting plate made of a section of angled aluminum. While in the forward-looking position, the first quick release adapter, sliding plate and section of aluminum allowed for making fine longitudinal adjustments. The horizontal portion of the section of aluminum provided a 2.91 inch lateral offset to center the camera lens with the center of the body line. The vertical portion of the section of aluminum produces the majority of the longitudinal offset to position the CCD of the specific camera used at the approximate M_f point. The vertical portion of the section of aluminum also has a rotation index guide mounted to the second quick release adapter and sliding plate combination. These parts mount the camera to the section of aluminum and allow the CCD to pitch about a horizontal axis containing the point M_r (rotated M_f) to

---

[39] Mazzae, E. N. and Barickman, F., *Direct Rear Visibility of Passenger Cars: Laser-Based Measurement Development and Findings for Late Model Vehicles*, U.S. Department of Transportation, National Highway Traffic Safety Administration, DOT HS 811 174, March 2009.

simulate the eye looking up or down, as needed, to shift the line of sight to intersect with the center of the rearview image. No head pitch was simulated as it was assumed to be unlikely or negligible.

A close-up image of the camera mounting system (adapters, sliding plates, rotation index guide, section of aluminum and panoramic head) is presented in Figure 19. Engineering drawings of the fixture design can be found in Figures 20 through 25.

Figure 19. Camera Mounting System.

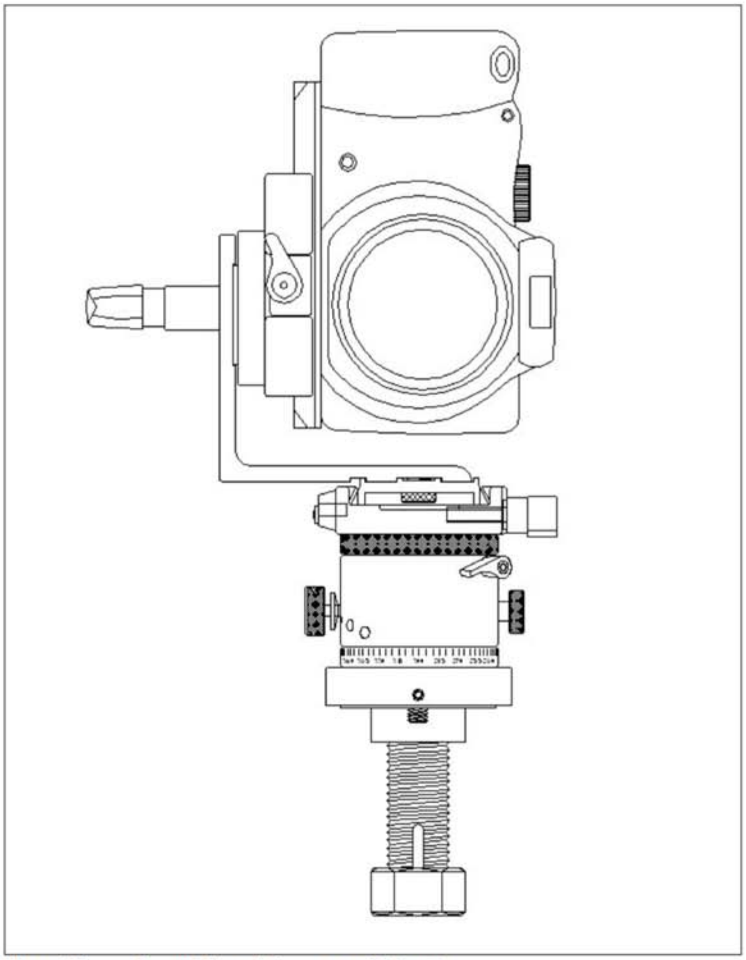


Figure 20. **Front View of Camera and Mount**

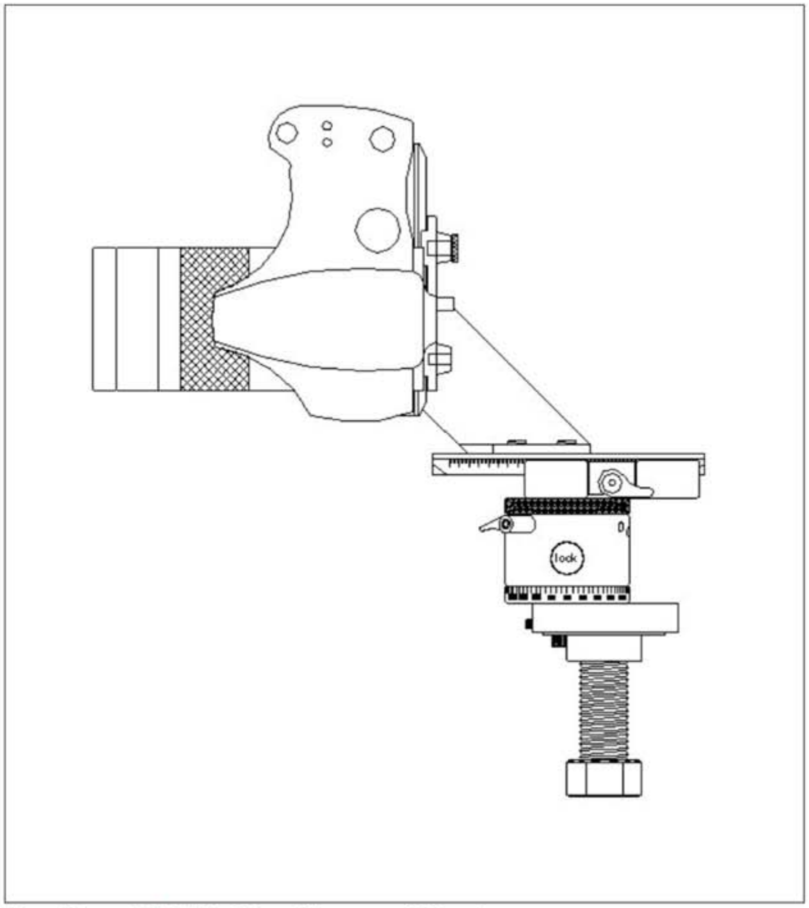


Figure 21. **Right Side View of Camera and Mount**

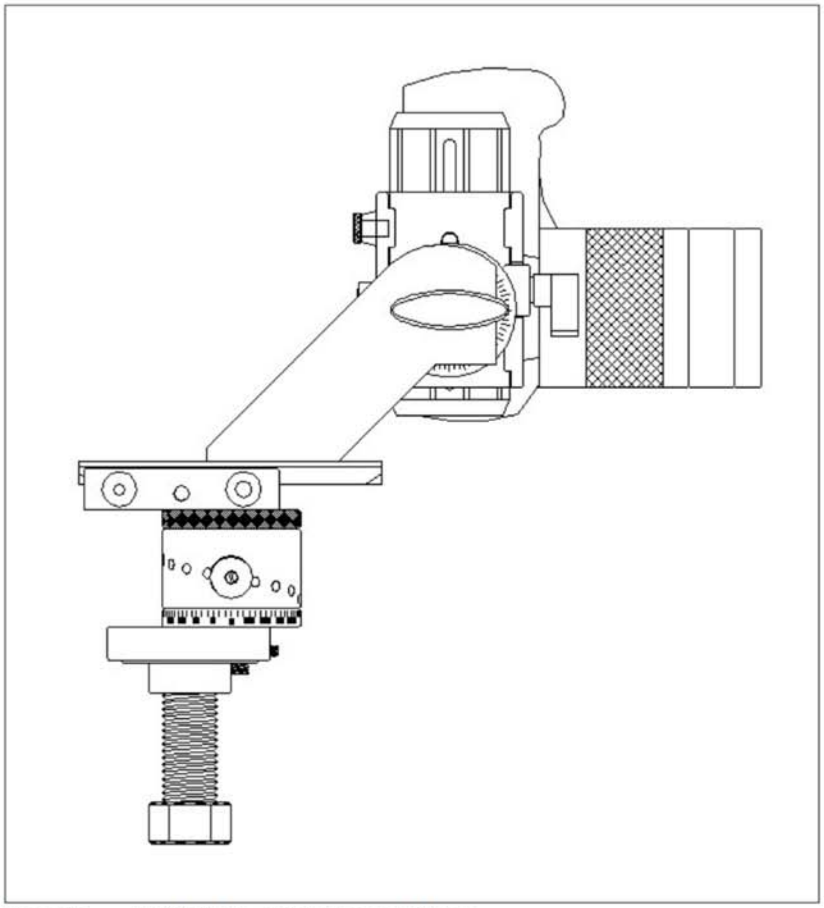


Figure 22. Left Side View of Camera and Mount

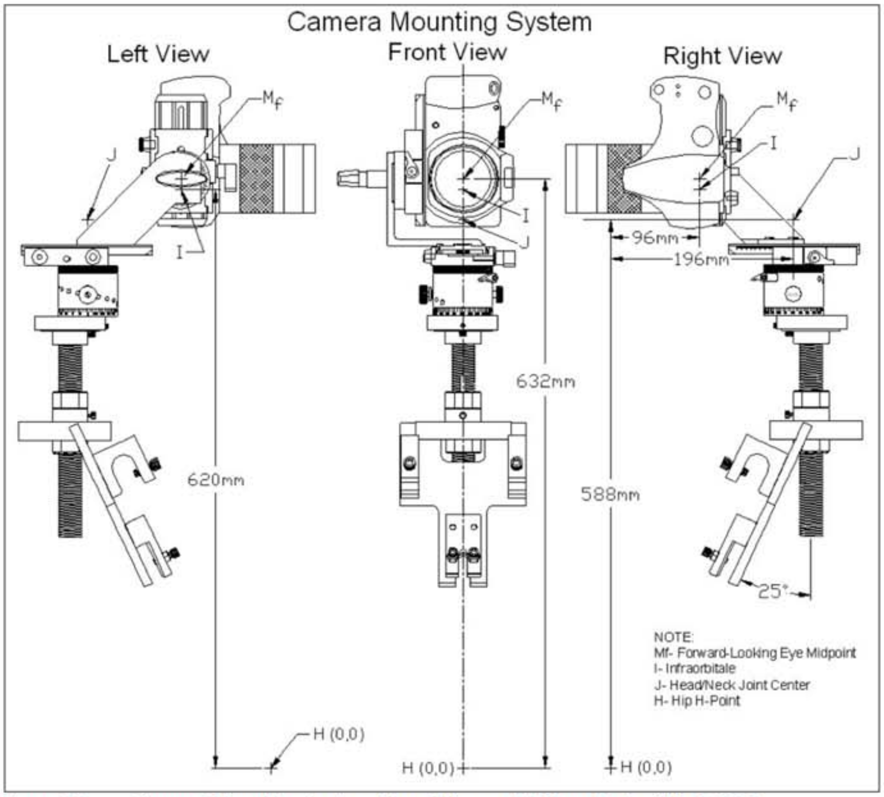


Figure 23. Camera Mounting System, Three Views, with Coordinates (M_f, I, J, H)

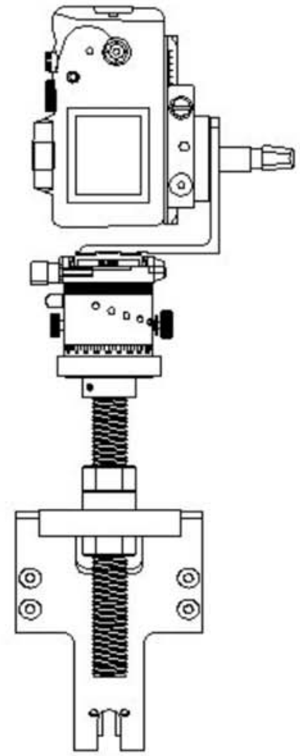


Figure 24. **Back View of Camera and Mount**

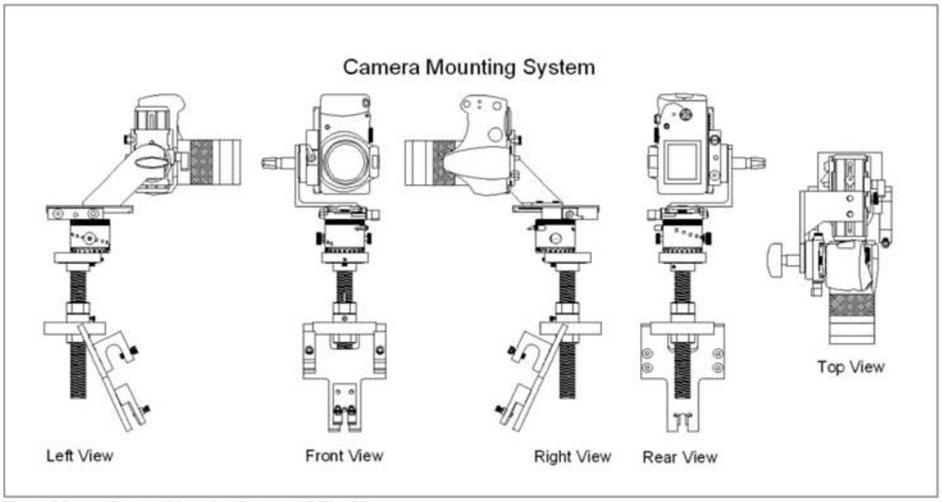


Figure 25. **Camera Mounting System, All Five Views**

Below are views of the image quality camera fixture as installed in two of the test vehicles.

Figure 26. Photos of the Image Quality Assessment Camera Fixture Installed in Test Vehicles

Top: 2010 Ford F-150, Side View
Bottom: 2010 Nissan Maxima, Side View (Left), Front View (Right)

APPENDIX 2. A DERIVATION OF THE EQUATION USED TO CALCULATE THE SUBTENDED VISUAL ANGLE OF EACH TEST OBJECT

Assumption 1: The plane upon which the image is displayed (may be a mirror, a video display, or some other surface) is, at least locally, flat. (This works, even for convex mirrors, because the image being analyzed is small compared to the radius of curvature of the mirror, video display, or other surface.)

Assumption 2: The plane upon which the image is displayed (may be a mirror, a video display, or some other surface) is perpendicular to the driver's line of sight at some point. While this is not in general exactly true, the difference from perpendicularity has been typically small in systems that NHTSA has tested to date.

Figure 27 shows the geometry of the situation and defines the symbols used.

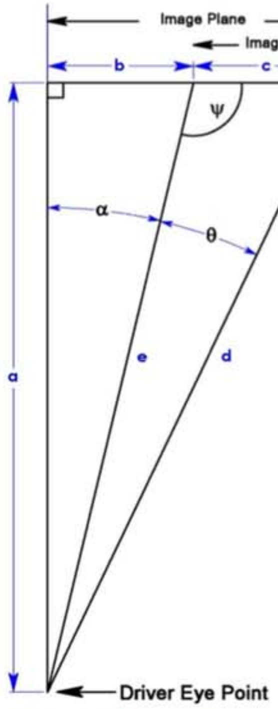


Figure 27. **Geometry Used to Derived Subtended Visual Angle Equation**

Definitions:
In the figure, c is the width of the actual image in the Image Plane, a is the perpendicular distance from the Driver's Eyepoint to the Image Plane, and Greek letters denote angles. The subtended visual angle that is to be determined is denoted by θ.

Case 1: One Edge of Image at Perpendicular Point

This is a special case in which one edge the image is at the point in the Image Plane that is intersected by the perpendicular line emanating from the Driver's Eyepoint. In the figure, this corresponds to the angle, α, and the distance, b, being zero. For this case, using the standard trigonometric definition of tangent,

$$\tan\theta = \frac{c}{a} \qquad (1)$$

Equation (1) can be rearranged to:

$$\theta = \tan^{-1}\frac{c}{a} \qquad (2)$$

Case 2: One Edge of Image Not at Perpendicular Point

This is a more general case in which an edge the image is no longer assumed to be at the point in the Image Plane that is intersected by the perpendicular line emanating from the Driver's Eyepoint. Then, from the Law of Sines, the following equation is true:

$$\frac{\sin\theta}{c} = \frac{\sin\Psi}{d} = \frac{\sin\varphi}{e} \qquad (3)$$

Where

$$e = \sqrt{b^2 + a^2} \qquad (4)$$

$$d = \sqrt{(c + b)^2 + a^2} \qquad (5)$$

$$\Psi = 90° + \alpha \qquad (6)$$

$$\alpha = \tan^{-1}\frac{b}{a} \qquad (7)$$

$$\varphi = 90° - \alpha - \theta \qquad (8)$$

Using Equations (6) and (8), Equation (3) can be reduced to:

$$\frac{\sin\theta}{c} = \frac{\cos\alpha}{d} = \frac{\cos(\alpha + \theta)}{e} \qquad (9)$$

It is difficult to determine the exact point on the Image Plane that is precisely perpendicular to the line emanating from the Driver's Eyepoint. Therefore, it is practically impossible to accurately measure the distance e. To allow for an approximate solution of Equation (9), to additional assumptions will be made:

Assumption 3: The distance c is much smaller than the distance a. Therefore, the angle θ will be small (less than 1 degree for the situations being considered).

Assumption 4: The distance b is much smaller than the distance a. Therefore, the angle α will be small (less than 1 degree for the situations being considered).

Using Assumptions 3 and 4, the quantity $(b+c)$ is also much smaller than the distance d.

Assumptions 3 and 4 were used to simplify the $\cos\alpha/_{d}$ term in Equation (9). Each part of this term was expanded in a MacLaurin series in powers of $^{c}/_{a}$ and $^{b}/_{a}$ and second order, or higher, terms deleted as too small to matter.

Start with simplifying Equation (5):

$$d = a\sqrt{1+f^2} \qquad (10)$$

where

$$f = \frac{b+c}{a} \qquad (11)$$

As stated above,

$$f \ll 1 \qquad (12)$$

To expand c in a MacLaurin series, the first two derivatives of c with respect to f need to be calculated and evaluated at $f = 0$

$$\frac{dd}{df} = \frac{fa}{\sqrt{1+f^2}} \qquad (13)$$

$$\left.\frac{dd}{df}\right|_{f=0} = 0 \qquad (14)$$

$$\frac{d^2d}{df^2} = \frac{a}{\sqrt{1+f^2}} - \frac{f^2a}{\sqrt{(1+f^2)^3}} \qquad (15)$$

$$\left.\frac{d^2d}{df^2}\right|_{f=0} = a \qquad (16)$$

$$d = a + \frac{a}{2}f^2 + Higher\ Order\ Terms \qquad (17)$$

Neglecting all terms of order f^2 or higher, compared to a, yields

$$d \cong a \qquad (18)$$

Next, simplify Equation (7) using the standard MacLaurin series expansion for arctangent:

$$\alpha = \tan^{-1}\frac{b}{a} = \frac{b}{a} - \frac{1}{3}\left(\frac{e}{a}\right)^3 + Higher\ Order\ Terms \qquad (19)$$

Neglecting all terms of order $\left(^{b}/_{a}\right)^2$ or higher yields

$$\alpha \cong \frac{b}{a} \qquad (20)$$

Using the standard MacLaurin series expansion for cosine:

$$\cos\alpha = 1 - \frac{1}{2}\left(\frac{b}{a}\right)^2 + Higher\ Order\ Terms \qquad (21)$$

Neglecting all terms of order $\left({}^{b}/_{a}\right)^2$ or higher yields

$$\cos\alpha \cong 1 \qquad (22)$$

The ${}^{\cos\alpha}/_{d}$ term in Equation (9) therefore can be simplified, based to the assumptions made, to ${}^{1}/_{a}$. The first two terms in Equation (9) have, therefore, been reduced to:

$$\frac{\sin\theta}{c} = \frac{1}{a} \qquad (23)$$

or

$$\theta = \sin^{-1}\frac{c}{a} \qquad (24)$$

Two equations, Equations (2) and (24), have now been developed for the subtended visual angle θ. Equation (2) is exact but only applies to the special case in which one edge the image is at the point in the Image Plane that is intersected by the perpendicular line emanating from the Driver's Eyepoint. Equation (24) applies to the more general case in which one edge the image is **not** at the point in the Image Plane that is intersected by the perpendicular line emanating from the Driver's Eyepoint, however, it relies on small angle approximations. Note that for small angles, both Equations (2) and (24) are identical since

$$\sin^{-1}\theta \cong \tan^{-1}\theta \cong \theta \qquad (25)$$

Therefore, both Equations (2) and (24) reduce, for small angles to:

$$\theta = \frac{10800}{\pi} \times \frac{c}{a} \qquad (26)$$

Where $10800\,/\,\pi$ is the correct constant to convert ${}^{c}/_{a}$ into minutes of arc. Equation (26) provides a third equation for determining the subtended visual angle.

Each of Equations (2), (24), and (26) was used to calculate a subtended visual angle for a given ${}^{c}/_{a}$ value. The ${}^{c}/_{a}$ value used was 0.00145444053054153000. The resulting values of θ were 4.999994711511520 minutes of arc from Equation (2), 5.000000000000000 minutes of arc from Equation (24), and 4.999998237167900 minutes of arc from Equation (26).

The above calculations demonstrate two things:

1. For the angles of interest, there is a minimal difference in the subtended visual angle that was calculated with a maximum difference of 0.000005288488482 minutes of arc. This sixth decimal place difference is well beyond the accuracy of the procedures used to

measure a and d. Therefore, from an accuracy point of view, it does not matter which of these equations is used.

2. Equation (24), which utilized the arcsine function, calculated the largest value of θ. Therefore, this is the equation that helps the most when trying to fare well in an image quality assessment based on a minimum subtended visual angle.

Based on the above discussion, the preferred equation for calculating the subtended visual angle is:

$$\theta = \sin^{-1}\frac{c}{a} \qquad (24)$$

In the case where Assumption 2 is not true (the plane upon which the image is displayed is not perpendicular to the driver's line of sight, the subtended angle will be calculated based on the apparent size of the object in the plane in which the image is displayed. As the ultimate goal of measuring subtended angles is to determine how much area the reflected object occupies in the driver's field of view, the apparent size is the correct measurement. Define e as zero and the projection of α onto a plane perpendicular to the line of sight will be designated as α' (see Figure 28). In this case Equation 2 can be used:

$$\theta = \tan^{-1}\frac{c'}{a} \qquad (27)$$

Using the small angle approximation, Equation 27 becomes:

$$\theta = \sin^{-1}\frac{c'}{a} \qquad (28)$$

Which is the same as Equation 24 with α' substituting for α.

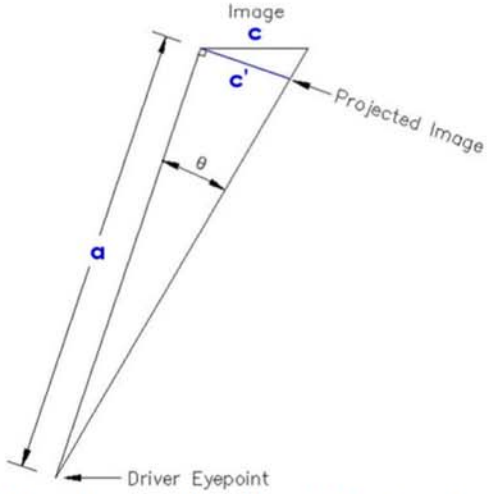


Figure 28. **Calculation of Subtended Visual Angle for Case Where Plane in Which Image is Displayed is Not Perpendicular to Driver's Line of Sight**

VITA

VITA

SHAWN G. EHLERS

EDUCATION

2014-Present Purdue University West Lafayette, Indiana
Ph.D. Candidate: Agricultural and Biological Engineering, Agricultural Systems Management
Dissertation: Rearward Visibility Issues Related to Agricultural Machinery: Contributing Factors, Potential Solutions

2010 - 2013 Purdue University West Lafayette, Indiana
Master of Science: Agricultural and Biological Engineering, Agricultural Systems Management
Thesis: Design and Use of an Adjustable Clearance Flailing Knife Biomass Shredder to Mechanically Increase Particle Surface Area

2005 - 2009 Purdue University West Lafayette, Indiana
Bachelor of Science: Agricultural Systems Management
Associate of Agriculture: Agricultural Economics
Minor: Food and Agribusiness Management

RESEARCH EXPERIENCE

2014-Present Purdue University West Lafayette, Indiana

Graduate Research: A system for measuring rearward visibility of agricultural machinery was developed. Incident case studies were analyzed for contributing factors with historical and emerging technology applicability for reducing future occurrences.

2010 - 2013 Purdue University West Lafayette, Indiana

Graduate Research: A flailing knife shredder was designed and tested as an alternative to a hammermill for processing biomass. Energy usage, output characteristics and device capacities were compared with corn stover processed at varied moisture contents.

TEACHING EXPERIENCE

2014-Present Purdue University West Lafayette, Indiana
Course Instructor

ASM 201: Fundamental principles in the selection and use of tools for the construction and maintenance of agricultural, and related facilities, structures, equipment and machines.

Fall 2013 Purdue University West Lafayette, Indiana
Teaching Assistant & Grader

ASM 222 Crop Production Equipment: Principles of machine performance, capacity, machinery components, and operation.

Fall '12 & '13 Purdue University West Lafayette, Indiana
Teaching Assistant & Grader

ASM 345 Power Units and Power Trains: An introduction to power generation and transfer in mechanical and fluid power systems.
ABE 545 Design of Off-Highway Vehicles: Problems associated with the design of off-highway vehicles, with special emphasis on farm and industrial tractors and self-propelled machines, engines, power trains, traction, vehicle control systems, human factors, testing and evaluation of performance.

Spring 2013 Ivy Tech Community College Lafayette, Indiana
Course Instructor

AGRI 114 Introduction to Agricultural Systems Management: Basic mathematical problem solving techniques; power generation, transfer and utilization; principles of agricultural operations management; soil and water management; crop handling and conditioning; and heat transfer.

Spring 2009, 2012, 2013 Purdue University West Lafayette, Indiana
Teaching Assistant & Grader

ASM 105 Agricultural Systems Computations and Communication: Use of computers to solve problems related to agricultural technology and businesses. Emphasis on logical problem solving and data processing/presentation with Microsoft Office suite.

SKILLS

Strong Agricultural Background
6th generation partial owner and operator of an Indiana grain farm. Involved with the selection and purchasing of all inputs, and machinery. Digitized geographic specific farm records. Upgraded dated electrical & plumbing services and structural rigidity of various farm structures.

Extensive Tool and Machinery Experience
Knowledgeable and skilled in woodworking, metal fabrication, machining, welding, electrical, hydraulic, internal combustion engines and plumbing. Row-crop agricultural machinery operation, maintenance; Industrial equipment operation, maintenance; full restoration of multiple antique tractors, and multiple vehicles; structure maintenance with electrical and plumbing experience. Designed agricultural structures and a greenhouse with fully automated temperature control and watering systems.

Computer Skills
Skilled in Microsoft Office (Word, PowerPoint & Excel); Multi-platform adept (Windows & Mac); proficient with multiple CAD software suites; possess' ability of programming electronic hydraulic controls (IQAN software) and Programmable Logic Controllers (PLC); Geographical Information Systems (GIS)

Ergonomic Training
Understands ergonomic principals and applicability to biomechanical and physiological bases of musculoskeletal disorders. Possesses ability to develop ergonomic processes for maximum benefit to assembly lines, lean manufacturing processes, tool and equipment safety and efficiency.

Workplace Compliance
OSHA General Industry certified. Able to identify hazards of general industry, ascertain appropriate OSHA standards, policies and procedures while utilizing OSHA standards to supplement an ongoing safety and health program.

WORK EXPERIENCE

2009 – Present Purdue University West Lafayette, Indiana
-Researcher, course instructor, grader, teaching assistant, AgrAbility team member

2014 – Present Agricultural Consultant Lafayette, Indiana
-Compiled data for risk assessment of agricultural loans for a multi-location bank.
-Accessed needs and implemented vision aiding technology on agricultural machinery for a farmer/rancher.
-Advised on greenhouse startup and drip irrigation implementation for small vegetable production operation.
-Counseled landowner on appropriate machinery selection with constraint to task performance, budget, and value.

Summer 2008 **Cummins Inc.** (Internship) **Columbus, Indiana**

Mid-range Engineering, Mechanical Development: Performed data analysis of engine tests, assisted with design and implementation of test cell data recovery tool, developed cost analysis tool for offsite facilities, and designed warehouse inventory management tool.

Summer 2007 **Land Surveyor** (Internship) **Versailles, Indiana**

French and Associates Surveying: Performed boundary surveys, precision placement of property markers, and assisted with subdivision development construction layout.

PUBLICATIONS AND PRESENTATIONS

Publication: Journal of Agricultural Safety and Health, 2016

Rearward Visibility Issues Related to Agricultural Tractors and Self-Propelled Machinery: Contributing Factors, Potential Solutions (Manuscript # JASH 11127)

Publication Submitted to Journal of Agricultural Safety and Health, 2016

Methods of Collecting and Analyzing Rearward Visibility Data: Hazard and/or Object Detectability

American Society of Agricultural and Biological Engineers (ASABE)

International Annual Meeting, Orlando, FL, July 2016; Abstract Title: Examination of Factors Impairing Operator Visibility for Large Self-propelled Machinery with Known Blind Spots

Indiana Prairie Farmer, October 2015

See behind you and avoid trouble this fall, October 2015; Pg. 67.

American Society of Agricultural and Biological Engineers (ASABE)

International Annual Meeting, New Orleans, LA, July 2015; Presentation Title: Methods of Collecting and Analyzing Rearward Visibility Data: Hazard and/or Object Detectability

Indiana Small Farms Conference, & AgrAbility Webinar Series 2015

Presentation Title: Small Farm Guide to Selecting and Purchasing Equipment

International Society for Agricultural Safety and Health Conference 2015 *(ISASH)*

Paper and Presentation: Examination of Rearward Movement Incidents Involving Agricultural Machinery

AgrAbility National Training Workshop (NTW)

NTW Lexington, Kentucky, March 2014; Presentation Title: Assistive Viewing Technology to Improve Agricultural Safety

American Society of Agricultural and Biological Engineers (ASABE)
International Annual Meeting, Montreal, QC, Canada, July 2014; Presentation Title: Assistive Viewing Technology to Improve Agricultural Safety

AgrAbility Webinar Series
Presentation Title: Increasing Visual Accessibility on Agricultural Machinery, August 2014

American Society of Agricultural and Biological Engineers
International Annual Meeting, Kansas City, Kansas, July 2013; Presentation: Design and Use of a Flailing Knife Biomass Shredder to Mechanically Increase Particle Surface Area

MEMBERSHIPS

2015 - Current ISASH (International Society for Agricultural Safety and Health)

2014 - Current SAE (Society of Automotive Engineers) Academic Contributor:
Visual Standards Committee

2009 - Current **ASABE** (American Society of Agricultural and Biological Engineers)

2007 - Current **Alpha Mu Honors Fraternity** Purdue University, Vice President of Initiation (2016)

2006 - Current Purdue Trap and Skeet Purdue University

2012 - 2013 **ABEGSA Social Chair** (Agricultural and Biological Engineering Graduate Student Association), Purdue University

CERTIFICATIONS & AWARDS

2016 **Estus H. and Vashti L. Magoon Teaching Award for the College of Engineering**
Department of Agricultural and Biological Engineering

2015 **Teaching Academy Graduate Teaching Excellence Award**
Department of Agricultural and Biological Engineering

2014 **Occupational Safety and Health Administration (OSHA)**
General Industry Safety and Health (30-hour training)

2013 **FERPA** (Purdue University)
Family Educational Rights and Privacy Act

2013 **Protecting Social Security Numbers** (Purdue University)

2013 **HIPAA** (Purdue University)
Federal Health Insurance Portability and Accountability Act

2011 **FEMA Emergency Management Institute**
S-00200.b; ICS for Single Resources and Initial Action Incident, ICS-200

2011 **FEMA Emergency Management Institute**
IS-0100.b; Introduction to Incident Command System ICS-100

2011 **FEMA Emergency Management Institute**
IS-00111; Livestock Disaster

2010 **FEMA Emergency Management Institute**
IS-0700.a; National Incident Management System (NIMS) Introduction

2010 **FEMA Emergency Management Institute**
IS-0800.b; National Response Framework, Introduction

2009 **Indiana Soybean Alliance** **Indianapolis, Indiana**
Soy Innovation Competition: Development of the Enviropot, an environmentally friendly gardening container. Completely comprised of corn and soybean by products, this gardening container would decompose after transplanting reducing risk of damage to plant while introducing soluble nutrient

PUBLICATIONS

PUBLICATIONS

Publication: Journal of Agricultural Safety and Health, 2016

Rearward Visibility Issues Related to Agricultural Tractors and Self-Propelled Machinery: Contributing Factors, Potential Solutions (Manuscript # JASH 11127)

Publication Submitted to Journal of Agricultural Safety and Health, 2016

Methods of Collecting and Analyzing Rearward Visibility Data: Hazard and/or Object Detectability

American Society of Agricultural and Biological Engineers (ASABE)

International Annual Meeting, Orlando, FL, July 2016; Technical paper:

Examination of Factors Impairing Operator Visibility for Large Self-propelled Machinery with Known Blind Spots

Indiana Prairie Farmer, October 2015

‘*See behind you and avoid trouble this fall’, October 2015; Pg. 67.*

American Society of Agricultural and Biological Engineers (ASABE)

International Annual Meeting, New Orleans, LA, July 2015; Technical paper: Methods of Collecting and Analyzing Rearward Visibility Data: Hazard and/or Object Detectability

International Society for Agricultural Safety and Health Conference 2015 *(ISASH)*

Technical paper: Examination of Rearward Movement Incidents Involving Agricultural Machinery

American Society of Agricultural and Biological Engineers (ASABE)

International Annual Meeting, Montreal, QC, Canada, July 2014; Technical paper: Assistive Viewing Technology to Improve Agricultural Safety

American Society of Agricultural and Biological Engineers

International Annual Meeting, Kansas City, Kansas, July 2013; Technical paper: Design and Use of a Flailing Knife Biomass Shredder to Mechanically Increase Particle Surface Area