Evaluate Ohio Department of Transportation's Ability to Decrease Dump Truck Backing Accidents (Phase 2)



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16. Abstract

As a result of the Phase 1 project, "Improper Backing" and "Inattention while Backing" are identified as two major causes of truck backing accidents. The comprehensive literature indicates that the probability of accidents occurring is about 70% in the rear area of a dump truck and about 20% in the right area. To that end, the overall goal of this research is to decrease ODOT's backing accidents by introducing new technologies to better equip ODOT highway technicians, particularly the drivers, with the ability to perform daily operations in a safer and more efficient manner. To fulfill the goal, the Advanced Vision Safety Enhancement (AdViSE) system for dump trucks has been designed, installed, and tested during the Phase 2 project. The pilot AdViSE system consists of four cameras with night vision (infrared capability) to provide views for areas behind the dump trucks, left (driver) and right (passenger) side of the dump truck, and the dump bed. Two radar sensors are deployed on the rear end of the truck to provide a redundant and supplementary multi-zone object detection for the rear area with audible alerts. The performance of the pilot AdViSE system is evaluated by using the measurable criteria for identifying the zones of camera visibility and radar detection. To facilitate identifying the system detection coverages compared with mirrors, the 360-degree bird's-eye views of camera, radar, and mirror detectable areas with visualized blind spots are generated under low-light and daylight conditions, based on the on-site system testing results. To help promote the applications of the AdViSE system especially under certain financial constraints, multiple optional configurations for the AdViSE system are recommended at different cost estimations to provide a cost-effective choice of the AdViSE application model at different coverage requirements on cameras' visibility and/or radars' detections. While the post-testing survey suggests a positive feedback, it is recommended to keep collecting observations when the AdViSE system is used in the future. More practical data is helpful to identify more insights for improving the AdViSE system and make it more cost-effectively operational in practice.

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Executive Summary

During Phase 1 of the project, a comprehensive literature review along with an online survey was conducted to analyze the current practices nationwide and determine best practices for decreasing backing accidents with dump trucks, and an in-depth evaluation of advanced vision and sensing technologies was performed. As a result of Phase 1 of the project, two major causes of truck backing accidents have been identified, i.e., "Improper Backing" and "Inattention while Backing" occupy 49.13% and 36.86%, respectively, out of all identified reasons. The comprehensive literature review revealed that 70% of backing accidents occurred in the rear area of the dump truck while about 20% occurred in the truck's right area. To that end, advanced camera and radar technologies were recommended as the key components to constitute an integrated technology system as a truck assistant system to achieve satisfactory performance under various construction scenarios.

Based on the recommendation resulting from the Phase 1 of the project, the Advanced Vision Safety Enhancement (AdViSE) system for dump trucks has been designed, installed and tested during Phase 2 of the project. Accordingly, the overall goal of this research is to decrease ODOT's backing accidents by introducing new technologies to better equip ODOT highway technicians, particularly the drivers with the ability to perform daily operations in a safer and more efficient manner. To fulfill the goal, the objectives of the Phase 2 research work are designed as follows.

- By adopting the recommended alternatives presented in the Phase 1 report, an implementation plan is developed to include electrical wiring and mechanical installation of the proposed components into the pilot AdViSE system, including mounting method, schematic diagrams, and procedures for installation and maintenance.
- The field-testing methods are developed to collect the data for measuring and determining quantity-based benchmarking requirements, which can be used to validate various scenarios of the technology alternatives under various conditions to make the functions work for reducing backing accidents.
- The pilot AdViSE system is installed/mounted on one specific ODOT dump truck for a proof-of-concept study with an onsite testing evaluation of the designated functions.
- A post-testing survey is conducted with the ODOT drivers in order to get the maximum feedback of drivers with less time involved.
- Recommendations will be proposed for the use of the AdViSE system, including optional alternatives for configurations of installing the AdViSE system on other trucks, along with cost-benefit estimations, as well as a user manual for the AdViSE system.

The pilot AdViSE system consists of four (4) cameras and two (2) radars. The cameras with night vision (infrared capability) are utilized to provide views for areas behind the dump truck, the left (driver) and right (passenger) sides of the dump truck, and the dump bed. In addition, two radar sensors are deployed on the rear end of the truck to provide a redundant and supplementary multi-zone object detection for the rear area with audible alerts.

The dump truck used for the pilot testing is primarily utilized for asphalting and salt spreading. In order to minimize interference with the regular operations of the truck in compliance with the functional requirements specified by the ODOT technical team, the installation method was designed to provide larger coverage to ensure higher safety.

The performance of the pilot AdViSE system is evaluated by using the measurable criteria for identifying the zones of camera visibility and radar detection. The coverage area of a camera is classified in "zones" based on a visibility score, where Zone 1 represents the "Best" image quality while Zone 4 represents "Unacceptable" quality, Zone 0 represents invisible areas or "blind spots". Similar to the cameras, different zones of radar detection are derived from the audible

alerts and color-coded proximity alert as displayed on the monitor. The radars have five color-coded detection zones and five identified lengths of those detection zones by the AdViSE system for the 7 o'clock and 5 o'clock radars, respectively. Lastly, to facilitate identifying the system detection coverages compared with mirrors, diagrams for the 360-degree bird's-eye views of camera, radar, and mirrors' detectable areas with blind spots are generated under low-light and daylight conditions, respectively. The 360-degree bird's-eye view diagrams indicate that the pilot AdViSE system is capable of covering the rear area and the right areas of the testing dump truck with high visibility and detection quality.

Different optional configurations for the AdViSE system are recommended at different cost estimations to provide a cost-effective choice of an AdViSE application model under certain financial constraints. Those optional system configurations include Full-Equipped (4 Cameras + 2 Radars) at system cost of $7,432, Semi-Equipped (2 Cameras + 2 Radars) at $6,148, and Simple-Equipped (2 Cameras Only) at $3,224 with different coverages of the improved safety functionality. In addition, the post-testing survey indicates that the coverage of the camera visibility and radar detection is found to be more useful for paving operations under both day and night operations as it has been averagely rated 5 by the respondents. The top maintenance operations, as rated by the respondents on the impact of the blind spots, include paving and sweeping, snow clearing, ditching and litter removal operations, as well as pot-hole operations. Respondents gave positive feedback on the pilot AdViSE system for its potential to reduce the impacts of the blind spots while performing various ODOT maintenance/construction activities.

To perform the benefit-cost analysis (BCA), the total cost of accidents to ODOT per truck per year was calculated by dividing the total cost of backup accidents to ODOT/year by the total number of dump trucks used by ODOT. The payback periods were then obtained, which vary depending on the expected percentage of reductions in accidents as determined from the literature. Research (Hurwitz DS, et al., 2010) has shown that even for the average drivers in a variety of accident-prone scenarios, i.e., moving objects including children in the rear area, 88% of those drivers who looked at the rear view system had avoided the backing accident. Furthermore, a research funded by National Department of Transportation (Mazzae EN, et al., 2008) found that the likelihood that a backing crash could be mitigated by use of a rearview video system depends on several conditions, most notably the location and movement (or path) of the obstacle. The literautre indicated a range of accident reduction rate is usually observed at 38 - 52% with a rearview detection system. Therfore, it is assumed that ODOT drivers will use AdViSE while backing, and the backing accidents are expected to be reduced by 50% in the BCA-based evaluation of the AdViSE system. If an accident reduction rate is 50%, the payback periods for a full-equipped, semi-equipped and simple-equipped AdViSE system are 6.43 years, 5.31 years, and 2.79 years respectively assuming only 50% of ODOT trucks will be equipped with AdViSE since they are the trucks that are regularly used and that typically cause the majority of ODOT backing accidents.

The effectiveness of improved safety and reduced backing accidents should be measured by more data as the pilot AdViSE system is applied to more construction/maintenance activities in the future. To help promote the applications of the AdViSE system with certain financial constraints, three configurations with different cost are recommended in this research. It is recommended to keep collecting application experiences and relevant safety/accident data when the AdViSE system is continuously used in the future. With more data to be obtained, more improvement measures on the AdViSE system will be identified or inspired to make the AdViSE more cost-effective in practice.

Chapter 1 Project Background

During Phase 1 of the project, a comprehensive literature review along with an online survey was conducted to analyze the current practices nationwide to determine best practices for decreasing dump truck backing accidents, and an in-depth evaluation of advanced vision and sensing technologies was performed. As a result of the Phase 1 project, two major causes of truck backing accidents have been identified, i.e., "Improper Backing" and "Inattention while Backing" occupy 49.13% and 36.86%, respectively, as illustrated by **Fig. 1** (Wei et al., 2020). Most of backing accidents occurred under clear weather (73.15%) and cloudy weather (19.3%) according to TxDOT's record. Also, "One Vehicle – Backing", "One Backing-One Stopped", "One Straight-One Backing" and "Angle - One Straight-One Backing" are among all major types of collisions, together accounting for 99.12% of collisions. Of 962 fatal occupational injuries at highway construction sites from 2003 to 2010, backing up dump trucks were responsible for 84 reported fatalities. In Washington, 17 workers were killed in work zones between 1999 and 2003. In general, the probability of accidents occurred in the rear area of a dump truck is about 70%, and about 20% in the right area (**Fig. 1**).

To that end, advanced camera and radar technologies were recommended as the key components to constitute an integrated technology system as an assistant system to achieve satisfactory performance under various construction scenarios. The Phase 1 project ultimately proposed two integrated technology system alternatives for ODOT, i.e., <u>Alternative 1</u> (Four Cameras + Two Radars + One Display) and <u>Alternative 2</u> (Two Cameras + Two Radars + One Display). The minimum technology requirements are suggested as a qualitative benchmarking to consider the integrated technology alternatives, including:

- Minimum sufficient blind spot coverage,
- Fast vision alert,
- Minimizing weather impact,
- Sufficient visibility during night conditions,
- Protecting sensors from adverse environmental impacts, and
- User-friendly interface with the detection system.
- Comprehensive considerations on the top of the recommended minimum technology requirements which were proposed in Phase 1,

Based on the recommendation resulting from the Phase 1 project, the Advanced Vision Safety Enhancement (AdViSE) system for dump trucks has been proposed to be designed, installed and tested during the Phase 2 project. The pilot AdViSE eventually adopted <u>Alternative 1</u>, in which four cameras with night vision (infrared capability) are utilized to provide views for areas behind the dump trucks, left and right side of the dump truck, and the dump bed. In addition, two radar sensors are deployed on the rear end of the truck to provide a redundant and supplementary multi-zone object detection for the rear area with audible alerts.

The research team has closely worked with ODOT technical team at ODOT District 6 Garage for the design, installation and testing of the pilot AdViSE system that is equipped with one ODOT dump truck. The matrix of optional configurations of the AdViSE system featured with improved safety functionality and cost-benefit estimations has been recommended for ODOT to increase ODOT's ability to reduce the backing accidents. A user manual for the AdViSE system is also provided alongside the project deliverables.

Accident Causes	Statistics (%)	
	Survey	Literature
Object/Person in Blind Spot	29	-
Improper Guiding	23	-
Inattention when Backing	13	36.86
Insufficient Driver Assistance Technologies	16	-
Improper Backing	-	49.10
Others	19	14.04

Accident Associated with Construction	Survey Response %
Paving	48
Berming	19
Street Sweeping	11
Snow Plowing	22

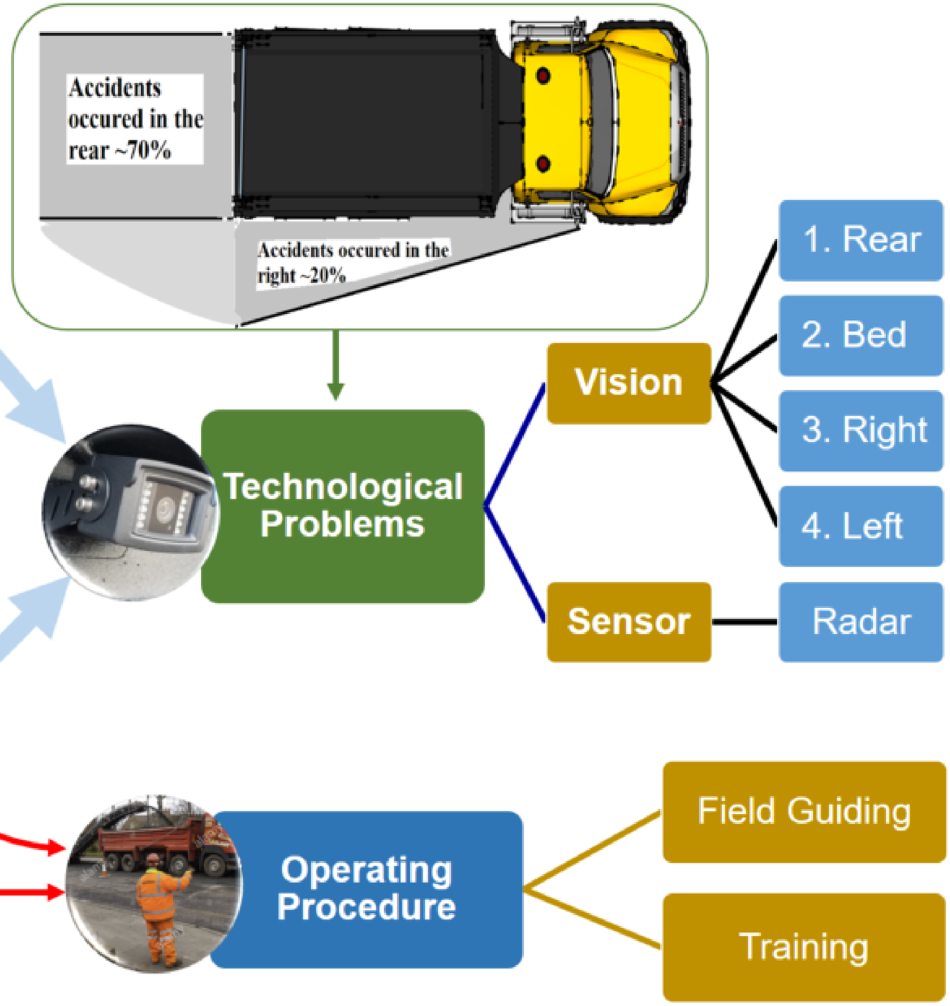


Fig. 1: Illustration of Mapping Potential Solutions with Backing Accident Causes

(Source: Wei et al., 2020)

Chapter 2 Research Context

The overall goal of this research is to decrease ODOT's backing accidents through introducing the new technologies that better equip ODOT highway technicians, particularly the drivers with the ability to perform daily operations in a safer and more efficient manner. To fulfill the goal, the scope of work has been divided into two phases (i.e., Phases 1 and 2). The objectives of the Phase 2 research work for this project are:

- By adopting the recommended alternatives presented in the Phase 1 report, an implementation plan is developed to include electrical wiring and mechanical installation of the proposed components into the pilot AdViSE system, including mounting method, customized installation bracket fabrication if needed, schematic diagrams, and procedures for installation and maintenance.
- The field-testing methods are developed to collect the data for measuring and determining quantity-based benchmarking requirements, which can be used to validate various scenarios of the technology alternatives under various conditions to make the functions work for reducing the backing accidents.
- The pilot AdViSE system will be installed/mounted on one specific ODOT dump truck for a proof-of-concept study with an onsite testing evaluation of the designated functions.
- A post-testing survey will be conducted with the ODOT drivers in order to get the maximum feedback of drivers with less time involved.
- Recommendations will be proposed for the use of the AdViSE system, including optional alternatives for configurations of installing the AdViSE system on other trucks, along with cost-benefit estimations, as well as a user manual for the AdViSE system.

Table 1 summarizes the identified research needs/context and their corresponding methods/solutions to be addressed through the Phase 2 work. The listed methods in response to the identified research context provide a general guidance for development of the research tasks.

Table 1. Identified Research Context and Developed Methods/Solutions

Research Context	Methods/Solutions
System Integration/ Design, Pilot AdViSE System Test, and Evaluation	• To review and determine the detailed methods for system integration, field testing specifications, and the measurements to evaluate system performance in a quality-based way, through pilot AdViSE testing. • Necessary in-person conversation and supplementary field-study survey will be conducted to obtain opinions and thoughts from the view of ODOT drivers regarding their use of the pilot system and expectations of usability, the problems and improvements for system design and tests.
Implementation, Installation, Calibration and Maintenance	• To recommend procurement or purchase procedure of acquiring equipment and supplies for installing the system, and document the steps for installation and guidelines for maintenance.
Operating Procedures	• To identify key findings from the system design and pilot tests, as well as post-testing driver survey to set up the measures for improving the current standard operation procedure under different construction conditions.

The integration/design of the entire integrated technology system follows a six-phase design procedure, which includes: 1) Requirement Analysis, 2) Determination of Specification/Function/Capabilities, 3) System Integration Design, 4) Implementation/installation/ Calibration, 5) Test and Performance Evaluation, and 6) Report and Documentation.

During the Requirement Analysis phase, the research team will conduct a field study to observe the operations of dump trucks to provide quantity-based benchmark for measuring the effect of the system design and analysis involved in different tasks. This work includes performing measurements of trucks and meeting with drivers and crews. Based on the results from Requirement Analysis, the system requirements and capabilities are defined for the AdViSE system. Specific Tasks are designed as follows:

Task 1: Integrated System Design and Procurement of Equipment. In this task, the research team designs the system configuration of the AdViSE system, which includes interfacing and combining different signals from radars and cameras, and specific cameras and radars; an electrical system design including power and signal wiring; a mechanical design including housing unit and installation methods; purchasing required equipment, devices and supplies that are needed for system integration; and developed fault-proof installation procedure for each component installation, schematic diagrams as well as field installation and test plan.

Task 2: Installation and Pilot Technology Test on Truck. In this task, the functionalities, specifications of AdViSE system are tested, and the testing data is collected and analyzed. A thorough performance evaluation is conducted to quantify the system's performance using the testing data. Also, it is important to study the drivers' interaction with the technology in detail to ensure that the technology can support the users in an optimal way without causing annoyances, like unnecessary delays caused by the need to check all displays, image distortions, glare caused by a bright display and distractions. We will also interview ODOT drivers and document both their experiences with the technology and their feedback as related to both the advantages and disadvantages of the technology.

Task 3: Quantifying Measurable Requirements/Criteria for Evaluation. The purpose of this task is to set up quantitative variables that can be used to measure the technology requirements for assessing the effectiveness of the integrated system. Such a set of criteria can also be incorporated into the improved operating procedure, as well as driver training materials in the future. In this task, the following work will be completed: 1) field construction observations to study the operations of dump trucks under various conditions; and 2) systematically defining and documenting the required technological specifications and capabilities of the AdViSE system, which can be measured quantitatively in the field. In order to make the system work under different weather conditions and environments, capabilities such as night vision should be considered carefully, as they are factors for electrical system design and wiring.

Task 4: Development of Procedure for Calibration and Maintenance Plan. In this task, regular application and maintenance procedures are developed and demonstrated to ODOT garage mechanics, drivers and crews. In addition, a post-testing survey is conducted based on the AdViSE system's coverage, with improved questions to get the maximum feedback of drivers in less time. With an ultimate goal of passing the regular replacement and maintenance to ODOT mechanics in the future, input from ODOT mechanics are gathered to improve the relevant documents (i.e., user manual and maintenance manual).

Task 5: Drafting and Completing Report. In this task, the final report will be drafted and reviewed by ODOT. The report will summarize all results obtained from each task. Details for each technical part, including methods, pilot test, data collection and analysis, are included in Appendices.

Chapter 3 Research Approach

3.1 System Design of AdViSE and Procurement of Equipment

The flow chart shown in **Fig. 2** illustrates the configuration of the AdViSE system. The pilot AdViSE system consists of four cameras and two radars. The detailed design is illustrated in a system schematic diagram (see **Fig. 3**). An Orlaco Multiview Box II is used to connect all four cameras and multiplex the four camera signals into one signal cable over which the camera signals are output to the Multiview Box II. The SDR interface box integrates the camera signals from the Multiview Box II and radar sensors, and then uses one single cable to output the composite signal to a 12-inch Orlaco Display. A power adapter is used to convert 12 volts voltage source provided by the truck's batteries to 24 volts voltage source to meet the power supply requirement of the 12 inch display.

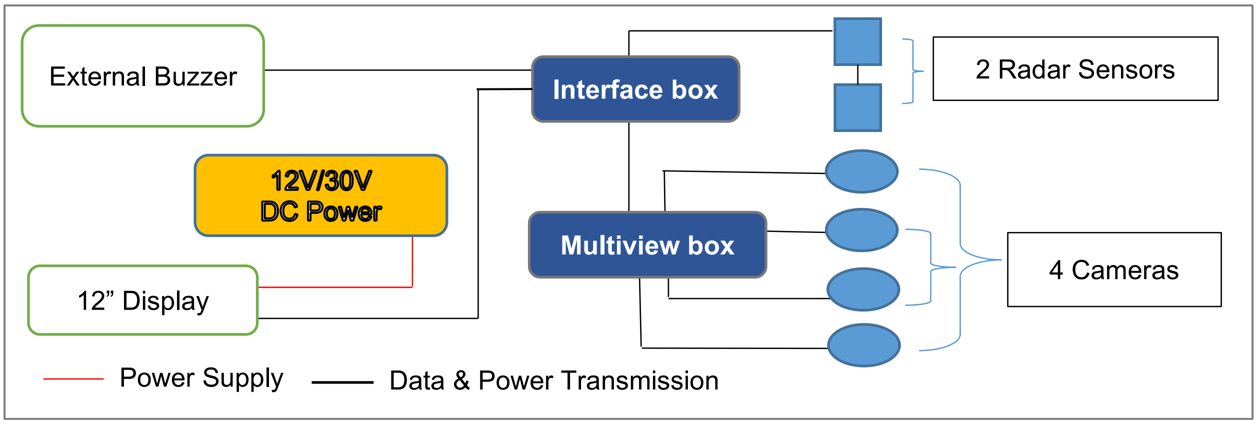


Fig. 2: Conceptual Configuration of the Pilot AdViSE System

3.2 Installation of the Pilot AdViSE System

More details about the installation methods are provided in **Appendices I.2** and **I.3**. The installation method used for the pilot system is briefly summarized as follows.

- The radar sensors (item 5 in **Fig. 3**) were installed at the left and right ends of the truck, away from the yellow-green lid of the truck to avoid obstruction during dumping operations.
- The rear camera (item 1 in **Fig. 3**) was installed on the right side of the truck (passenger side, next to the strobe light (also see **Fig. I-9 B**).
- The side cameras (items 3 and 4 in **Fig. 3**) were installed on the left and right sides of the driver's cab, close to the two large side mirrors (also see **Fig. I-11**).
- The dump bed camera (item 2 in **Fig. 3**) was installed on the right side (passenger side) of the dump bed near the strobe light (also see **Fig. I-8B**).
- The monitor, interface box, and the Multiview box (items 6 through 8 in **Fig. 3**) were located inside the cabin. The display monitor was installed on the dashboard (also see **Fig. I-12**).

3.3 The Pilot AdViSE System Testing and Evaluation

3.3.1 Methodological Flowchart for the Testing Procedure

A procedure for the pilot testing was developed to determine the field-of-view of the cameras and the detection zone of the radar sensors. The approach for on-site tests of the pilot AdViSE system is illustrated in **Fig. 4**, following the methodological framework explained in **Appendix II.1**. More detailed descriptions about tests are provided in **Appendices II** and **III**.

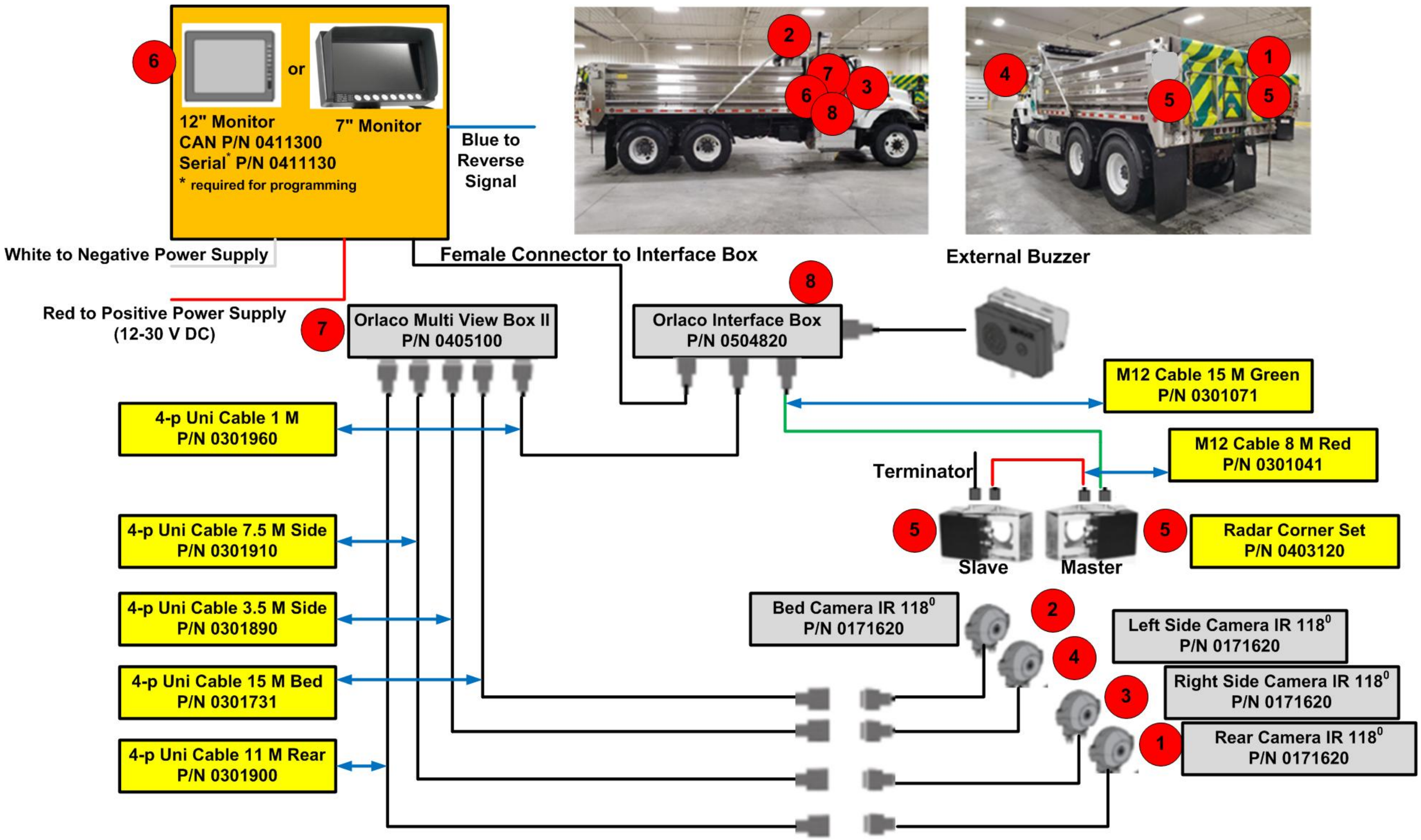


Fig. 3: The Pilot AdViSE System Schematic Diagram

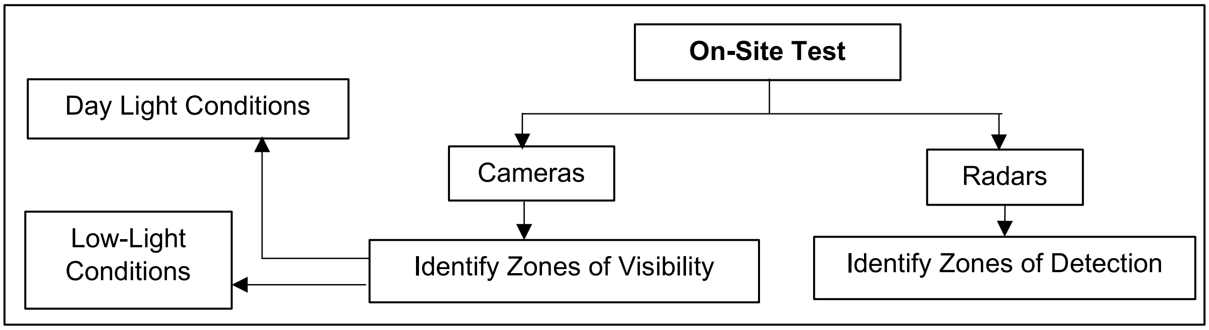


Fig. 4: Illustration of Methodological Procedure for On-Site Tests

3.3.2 Measurable Testing Evaluation Criteria

The measurable criteria include the zones of camera visibility and radar detection. To identify the coverage area of the cameras and determine the blind zones, a 20 ft x 20 ft test ground with 1’x1’ grids was painted on the open ground at the ODOT garage, and parking cones were placed on each grid location (**Fig. II-2** and **Fig. III-1**). The coverage area was classified in “zones” based on a visibility score, where Zone 1 represents the “Best” image quality while Zone 4 represents “Unacceptable” quality, Zone 0 is the area which is not within the FOV (**Table III-1**). The procedures were repeated for both daylight and low-light conditions.

The detection zones of the radars were identified at the same testing ground, based on the operating principles of the radars in relative motion between the truck and the object. During the static test (where the truck remains stationary), a moving object was required. Instead of parking cones, a person moved along the test grid to determine the detection zone (**Fig. II-11**). Using the audible alert and the display, different coverage zones of the radar detection were identified. The radars have five color-coded detection zones (**Table III-2**) and five identified lengths of those detection zones by the AdViSE system for 7 o'clock and 5 o'clock radars (**Table III-7**, **Fig. III-22** and **Fig. III-25** showing the critical detection zones of both radars, respectively).

Based on the on-site testing results of the pilot AdViSE system, all detection outcomes are presented together in a single diagram to illustrate the 360-degree view of camera, radar, and mirror detectable areas with blind spots, as shown by **Fig. 5** (also see **Fig. III-26** and **Fig. III-27, Appendix III.3.1** under low-light conditions and daylight conditions, respectively).

3.3.3 On-Site Testing Results

The on-site testing results show that the cameras of the pilot AdViSE system provide coverage around the truck. The rear section of the truck is covered by by the rear camera (**Appendix III.2.1**), the right side by the passenger side camera (**Appendix III.2.2**), and the left side by the driver side camera (**Appendix III.2.3**). The dump bed camera covers the dump bed, and portions of the right side are of the dump truck (**Appendix III.2.4**). The coverage of individual cameras is divided into zones of visibility, based on the quality of image viewed on the display.

Radars installed in the pilot AdViSE system detect objects behind the truck (**Appendix III.3**). The two radars installed in the AdViSE system are designated as 5 o'clock and 7 o'clock and have a detection capacity beyond 6 meters and five zones of detection.

Using the field measurements, field of views are reproduced in AUTOCAD to develop 360-degree view of zones of visibility and zones of detection. **Fig. 5** shows an example under low-light conditions. The 360-degree view provides the area that is unveiled by the AdViSE system to alert the driver and help reduce accidents.

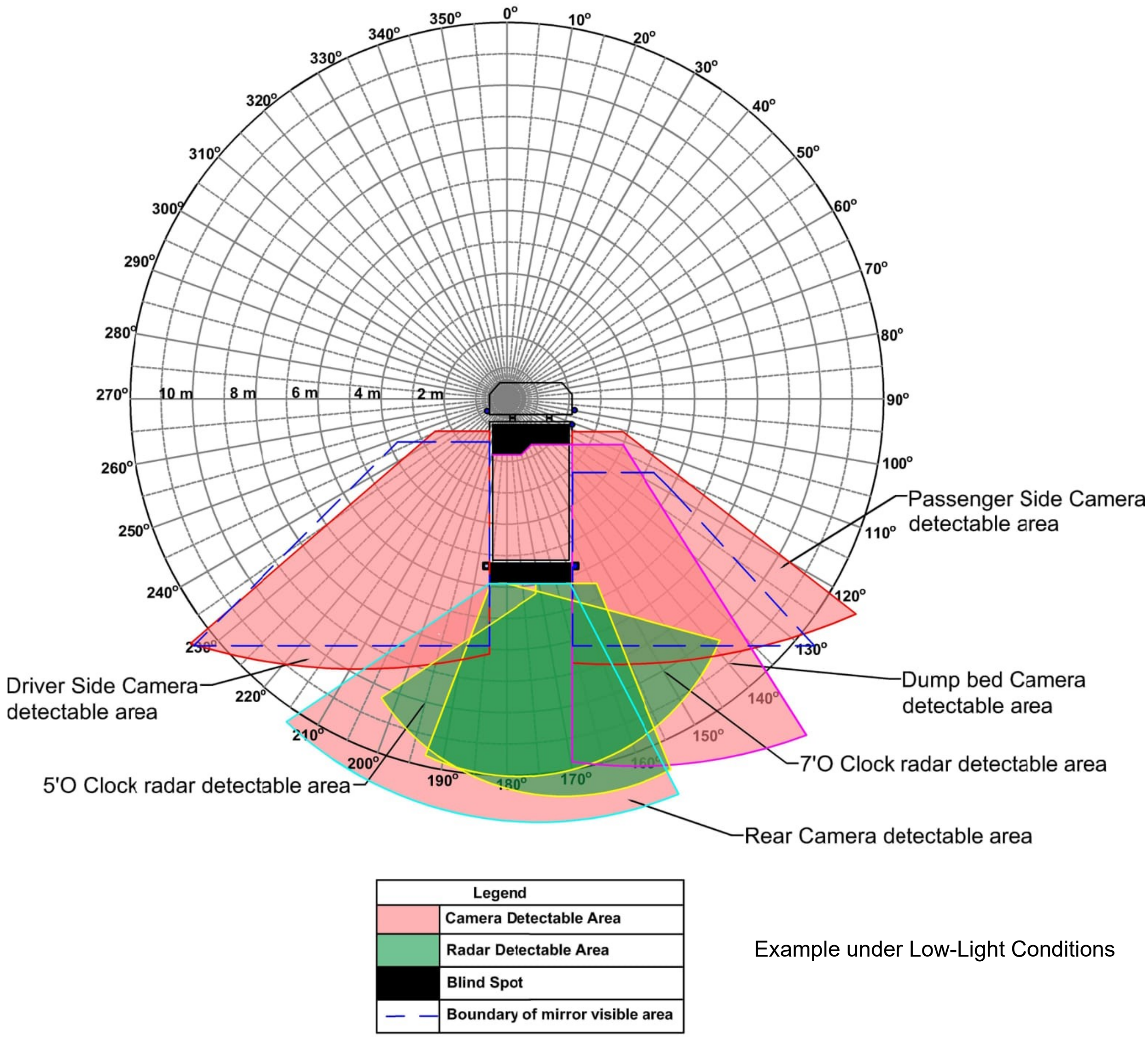


Fig. 5: 360-degree View of the AdViSE's Zones of Camera Visibility and Radar Detection

While this system provides maximum coverage around the truck, it has a blind spot of two feet along the rear part of the truck as mentioned in **Appendix III.5.1**. However, according to discussions with mechanics and several drivers from ODOT, this blind sport should not have any adverse impact during regular use of the truck. The tests performed during low-light conditions were impacted by light posts located on either side of the truck (**Appendix III.5.2**). A light post on the driver side of the truck created a shadow putting the passenger side in complete darkness, so a light tower was added on the passenger side for the low-light tests.

3.4 Post-Testing Survey and Analysis

After installing and testing of the pilot AdViSE system, a post-testing survey was designed and conducted. This survey included the details about the coverage (360-degree views), blind spots and observations during the field tests. As this survey was intended for drivers and mechanics, respondents were asked to identify any limitations they observe in the system.

Out of the given four maintenance operations (**Appendix III.6**), the following are rated by respondents as the top three in respect to the coverage of the AdViSE system. The coverage of the system is found to be more useful for paving operations as it has been averagely rated 5 by the respondents.

- Paving
- Sweeping
- Litter removal

The top three maintenance operations, as rated by the respondents on the impact of the blind spots are as mentioned below. The average rating for the paving and sweeping operations which are found to be highly impacted by the blind spot is 2.33. This shows that the impact is nominal.

- Paving and sweeping
- Snow clearing, ditching and litter removal operations
- Others (pot hole operations)

Respondents gave a positive feedback on the system. They are confident that the AdViSE system is capable of reducing backing accidents.

3.5 Benefit-Cost Analysis of the AdViSE System

A simple payback method is used to perform the benefit-cost analysis (BCA). **Appendix III.7** provides the in-detail description of the analysis. The analysis calculated payback periods for various options of the AdViSE system. Information about the trucks and the backing crashes has been obtained from ODOT and the State wide data about the crashes and the cost of the crashes has been converted to cost to ODOT per truck per year. Using the cost of accidents to ODOT and the cost for different options of the AdViSE system, the payback periods are calculated and they vary vs. different options in accordance with accident reduction rates that were assumed based on the results of the literature review.

The payback period for a particular configuration of the system can be obtained from **Table 2**. For example, if a simple-equipped (2 Cameras Only) of the AdViSE system that will reduce accidents by 50%, the payback period is 2.79 years. It should be noted that the results reported in Table 2 assumes that only 50% of ODOT trucks will be equipped with AdViSE since they are the trucks that are regularly used and that typically cause the majority of ODOT backing accidents.

Table 2. Payback Period (years) for AdViSE System Alternatives

Assumed % accident reduction rate	50%
% of regularly used dump trucks that cause the majority of ODOT backing accidents and that should use AdViSE	50%
AdViSE Alternative 1: Fully-Equipped (4 Cameras + 2 Radars)	6.43 years
AdViSE Alternative 2: Semi-Equipped (2 Cameras + 2 Radars	5.31 years
AdViSE Alternative 3: Simply-Equipped (2 Cameras Only)	2.79 years

Chapter 4 Research Findings and Conclusions

4.1 Functional Benefits from the AdViSE System

Based on the on-site static tests and 360-degree coverage diagrams, as illustrated by **Fig. 4** (also see **Fig. III-26** and **Fig. III-27, Appendix III.4.1**, both of which are produced as a result under low-light and day-light conditions, respectively), we summarize the system benefits as follows:

1. Overall increase of the coverage around and along the body of the truck by means of two side cameras compared to traditional side mirrors; especially on the passenger side.
2. Additional coverage at the rear by means of two cameras which is not otherwise possible with the current measures without the help of a spotter. A rear camera provides coverage directly behind the truck. A dump bed camera provides view of the dump bed, which is useful during work zone operations.
3. Improved visibility provided by the display monitor compared to the mirrors in rain, dirt, snow, etc.
4. Rear view camera and the radar sensors are automatically displayed as soon as the reverse is engaged. In addition, camera views can be manually selected (see section IV.1 AdViSE user manual) according to the need of operation with a user-friendly interface.
5. Increase the attention of the driver while backing by means of the audible alert provided by a buzzer located at the cab. The intensity and frequency of the audible alert increases as an object comes closer to the radar.
6. In addition to the audible alert, the monitor also displays a color-coded indicator which provides an estimation of the distance of a hazardous object from the radar sensors.

As mentioned in Chapter 1, the probability of accidents occurring in the rear area of a dump truck is about 70%, and is about 20% in the right area (see **Fig. 1**). “Improper Backing” and “Inattention while Backing” are two major causes of truck backing accidents out of all identified reasons. The benefits summarized above suggest a great potential to overcome those problems identified in Phase 1.

However, it was identified that two feet immediately behind the dump truck still fall into a blind spot, as shown in **Fig. III-28, Appendix III** (also see **Fig. III-29** and **Fig. III-30**). However, according to discussions with ODOT personnel, this blind spot should not have any adverse impact on regular use of the truck for various operations.

4.2 Potential Cost Benefits

To make the AdViSE application more cost-effective, different optional configurations for the AdViSE system installation are recommended at different cost estimates. In addition to the configuration of the Pilot System, i.e. Full-Equipped (4 Cameras + 2 Radars) at system cost about $7,432, the system configurations for Semi-Equipped (2 Cameras + 2 Radars) at $6,148 and Simple-Equipped (2 Cameras Only) at $3,224 are provided in **Table 2** with different coverages of the improved safety functionality.

The total cost of accidents to ODOT per truck per year (see **Table III-11, Appendix III.7.2**) can be calculated by dividing the total cost to ODOT/year by the total number of dump trucks operated by ODOT. The payback periods obtained (**Table 2**) vary for different options with respect to the percentage of accident reductions. The three options of the AdViSE system show an inverse proportionality with the predicted percentage of accident reduction. This can be understood as the increase in the payback period with a reduced accident reduction rate.

Chapter 5 Recommendations

Phase 2 has provided answers to the following questions raised by the Phase 2 proposal, in compliance with problems identified during the Phase 1 project.

- *What components and configuration of the integrated technology system can be assembled to make the performance effective throughout day and night operations under all types of weather conditions, including severe weather?*

  Answer: Different optional configurations for the AdViSE system are recommended at different cost estimations to provide a cost-effective choice of an AdViSE application model under certain financial constraints. Those optional system configurations include Fully Equipped (4 Cameras + 2 Radars) at system cost of $7,432, Semi-Equipped (2 Cameras + 2 Radars) at $6,148, and Simple-Equipped (2 Cameras Only) at $3,224, as shown in Table 2, which also provides different coverages of the improved safety functionality for each option. In addition, the post-testing survey indicates that the coverage of the camera visibility and radar detection is more useful for paving operations under both day and night operations as it has been averagely rated 5 by the respondents. The top maintenance operations, as rated by the respondents on the impact of the blind spots, include paving and sweeping, snow clearing, ditching and litter removal operations, as well as pot-hole patching operations. Respondents gave positive feedback on the pilot AdViSE system and they are confident that the AdViSE system is capable of reducing the impacts of the blind spots for the construction activities as concerned by ODOT.

- *How to measure the effect of the integrated technology system in a quantity-based test method to ensure the system satisfies the minimum technology requirement?*

  Answer: The performance of the pilot AdViSE system is evaluated by using the measurable criteria for identifying the zones of camera visibility and radar detection. Visibility of the construction cones assumed as field objects was recorded during the tests. The coverage area of a camera was classified into "zones" based on a visibility score, where Zone 1 represents the "Best" image quality while Zone 4 represents "Unacceptable" quality, Zone 0 is the area which is not within the FOV (see Table III-1). Similar to the cameras, different zones of detection were derived from the audible alerts and color-coded proximity alert (see Fig. III-2) as displayed on the monitor. The radars have five color-coded detection zones (see details in Table III-2) and five identified lengths of those detection zones by the AdViSE system for 7 o'clock and 5 o'clock radars (see details in Table III-7, and Fig. III-22 and Fig. III-25 showing the critical detection zones of both radars, respectively). Lastly, to facilitate identifying the system detection coverages compared with mirrors, diagrams for the 360-degree views of camera, radar, and mirror detectable areas with blind spots are generated under low-light and daylight conditions, respectively (see Fig. III-26 and Fig. III-27).

- *How to incorporate the technology system into the current Operating Procedure in Practice to reduce or avoid "improper backing" and "inattention while backing" occurrences?*

  Answer: To facilitate incorporating the technology system into the current Operating Procedure in practice, a user-friendly designed *AdViSE User Manual* and *AdViSE Maintenance Manual* are generated and recommended for ODOT. They can also be used as fundamental materials in the future for training drivers who are new to the AdViSE system.

As mentioned earlier, different optional configurations for the AdViSE system can be considered when it is mounted on other trucks, depending on the requirements on its application to construction duties and budget constraints. As a result of the decision-making process, a cost-effective choice of an AdViSE application model may be determined.

The effectiveness of improved safety and reduced backing accidents is hoped to be continuously measured by more data as the pilot AdViSE system is applied for more construction activities in the future. It is hence recommended to keep collecting application experiences and relevant safety/accident data when the AdViSE system is continuously used in the future. With more data to be obtained, more improvement measures on the AdViSE system will be identified while the contents of **Table 2** will be updated with more effective guides.

Bibliography

Cooper, D. L., Duffy, S., Orrick, P., & Ragland, D. R. (2010). Develop Methods to Reduce or Prevent Backing Crashes. California PATH Program, Institute of Transportation Studies, University of California at Berkeley.

Fan et al., (2019). *Prevention of Backing Fatalities in Construction Work Zones*. Report No. FHWA/TX-13/0-6703-1.

Ferreira-Diaz, C. A., Torres-Zapata, A., Nanovic, C. A. and Abraham, D. M. (2009). *Worker Injury Prevention Strategies*. Technical report <https://docs.lib.purdue.edu/jtrp/1149/>

FHWA Safety Program (2018). *Highway Safety Benefit–Cost Analysis Guide*. <https://safety.fhwa.dot.gov/hsip/docs/fhwasa18001.pdf> (December 2, 2020).

Fornell Fagerström, K. and Gårdlund, A. (2012). *Mirror Replacement in Trucks*. M. S Thesis. Charlmers University of Technology, Göteborg, Sweden, June 2012. <https://odr.chalmers.se/bitstream/20.500.12380/163169/1/163169.pdf>

Hall, A. D. and Roberts, G. E. (2011). *Investigation of the Performance of backing Cameras on NHDOT Maintenance Vehicles*. Report No. FHWA-NH-RD-15680A. New Hampshire. Department of Transportation.

Hurwitz, DS, et al., (2010). Backing collisions: a study of drivers' eye and backing behaviour using combined rear-view camera and sensor systems. *Injury Prevention*, 16(2):79-84. doi: 10.1136/ip.2009.021535. PMID: 20363812; PMCID: PMC3472446.

International Organization for Standardization (2008). "ISO 9241-302: Ergonomics of human system interaction." Geneva: International Organization for Standardization

Kourtellis, A., Lee, C., Lin, P. P. S., and Lu, J. (2009). Evaluation of the Effectiveness of Rear-View Camera Systems as a Countermeasure for Truck Backing Crashes: Lessons Learned from Actual Field Deployment (No. 09-1569).

Mazzae, E.N., Barickman, F., Baldwin, G. H., & Ranney, T. (2008). *On-Road Study of Drivers' Use of Rearview Video Systems (ORSDURVS)*, Technical Research Report (No. DOT HS 811 024). <https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/811024.pdf>.

Mazzae, E. N. and Garrott, R. W. (2007). *Experimental Evaluation of the Performance of Available Backover Prevention Technologies for Medium Straight Trucks*. Final Report (DOT HS, 810, 865).

Megalingam, R. K., Shriram, V., Likhith, B., Rajesh, G., & Ghanta, S. (2016). "Monocular distance estimation using pinhole camera approximation to avoid vehicle crash and back-over accidents." In 2016 10th International Conference on Intelligent Systems and Control (ISCO) (pp. 1-5). IEEE.

Perez, et al., (2011). *Advanced Crash Avoidance Technologies (ACAT) Program-Final report of the GM-VTTI Backing Crash Countermeasures*. Project report (No. DOT HS 811 452). National Highway Traffic Safety Administration, United States.

Ruff, T. M. (2003). *Evaluation of Systems to Monitor Blind Areas behind Trucks used in Road Construction and Maintenance: Phase 1*. Final report.

Schmidt, E. A., Hoffmann, R., Bierbach, M., Gail, J. and Lots-Keens, C. (2015*). Camera-Monitor Systems as a Replacement for Exterior Mirrors in Cars and Trucks*. Final Report for Federal Highway Research Institute.

Skolnik, M. I. (1990). *Radar Handbook* (second edition). McGrawHill.

Terzis, A. (Ed.). (2016). *Handbook of Camera Monitor Systems: The automotive Mirror-Replacement Technology Based on ISO 16505* (Vol. 5). Springer.

Victoria Transport Policy Institute (2016). *Transportation Cost and Benefit Analysis II - Safety and Health Costs*. Book chapter <https://www.vtpi.org/tca/tca0503.pdf> (April 2018).

Wei, H., Zhou, X. and Elzarka, H. (2020). *Evaluate Ohio Department of Transportation's (ODOT) Ability to Decrease Dump Truck Backing Accidents (Phase 1)*. Final draft report for FHWA/ODOT (SJN 135975). February 2020.

Zockaie, A., Saedi, R., Gates, T. J., Savolainen, P. T., Schneider, B., Ghamami, M., ... and Zhou, C. (2018). *Evaluation of a Collision Avoidance and Mitigation System (CAMS) on Winter Maintenance Trucks*. Report No. OR 17-103. Michigan. Department of Transportation. Research Administration.

Appendix I: Technical View of the Pilot AdViSE System

I.1 Takeaways from Phase 1 Project

The Phase I project has identified two major causes of truck backing accidents, i.e., “Improper Backing” and “Inattention while Backing” occupy 49.13% and 36.86% respectively of all identified reasons, as shown in Fig. I-1 (Wei et al., 2002). Most backing accidents occurred under clear weather (73.15%) and cloudy weather (19.3%) according to TxDOT’s record. Also, “One Vehicle – Backing”, “One Backing-One Stopped”, “One Straight-One Backing” and “Angle - One Straight-One Backing” are among all major types of collisions, together accounting for 99.12%. Of 962 fatal occupational injuries at highway construction sites from 2003 to 2010, backing up dump trucks were responsible for 84 reported fatalities. In Washington, 17 workers were killed in work zones between 1999 and 2003. In general, the probability of accidents occurring in the rear area of a dump truck is about 70%, and about 20% in the right area, as shown Fig. I-1.

Minimum technology requirements are suggested as a qualitative benchmarks to consider the integrated technology alternatives, including:

- Minimum sufficient blind spot coverage,
- Fast vision alert,
- Minimizing weather impact,
- Sufficient visibility during night conditions,
- Protecting sensors from adverse environment impacts, and
- User-friendly interface with the detection system.

Based on the recommendation resulting from the Phase I study, the Advanced Vision Safety Enhancement (AdViSE) system for dump trucks has been designed, installed and tested during the Phase 2 work. The AdViSE system utilizes four cameras with night vision (infra-red capability) to provide views for areas behind the dump trucks, left and right side of the dump truck, and dump bed. In addition, two radar sensors are deployed at the rear of the truck to provide a redundant and supplementary multi-zone object detection for the rear area with audible alerts. More details about the AdViSE system are described in the sections below.

I.2 System Components and Integration of the AdViSE System

I.2.1 General Requirements for Installation

The dump truck (License Plate T6920) is used to prototype the AdViSE, as shown by **Fig. I-2**. The key measurements obtained from the UC team’s visit at the ODOT garage on March 12 are shown in **Fig. I-3**. It can be configured for two tasks including paving and salt spreading. The configurations for both tasks are illustrated in **Fig. I-3** and **Fig. I-4**, respectively. The following factors and preferences need to be considered for the installation and proper operation of AdViSE:

- As a required operational behavior, the dump bed is frequently lifted up during the dumping process. It is required to ensure that wiring cables work properly during dumping operations.
- During the dumping process, the asphalt is dumped through the rear gate (yellow-green truck lid is shown in **Fig. I-2**). Therefore, the rear-view camera cannot be installed in the center of the rear bumper, or dump bed. In addition, to protect the radar units against damage caused by asphalt being dumped, the radars need to be placed at optimal location and height.

Accident Causes	Statistics (%)	
	Survey	Literature
Object/Person in Blind Spot	29	-
Improper Guiding	23	-
Inattention when Backing	13	36.86
Insufficient Driver Assistance Technologies	16	-
Improper Backing	-	49.10
Others	19	14.04

Accident Associated with Construction	Survey Response %
Paving	48
Berming	19
Street Sweeping	11
Snow Plowing	22

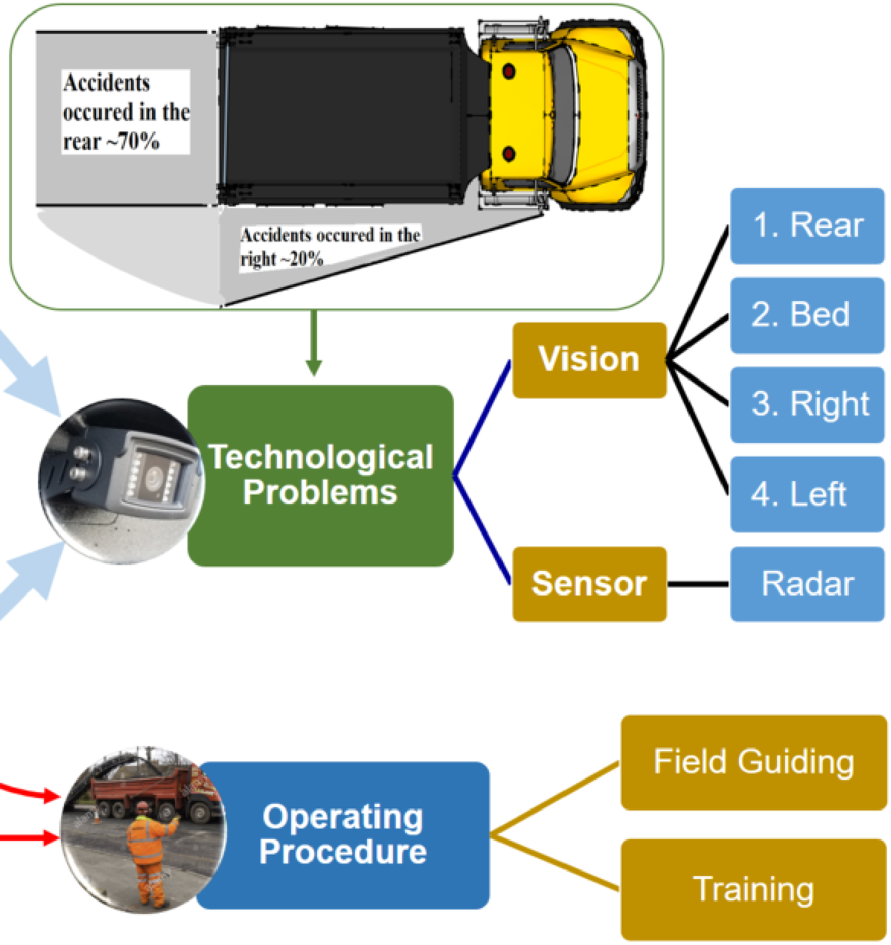


Fig. I-1: Illustration of Mapping Potential Solution with Backing Accident Causes Resulting from Phase I

- The dump truck uses two 12V batteries (in parallel). Therefore, a DC-DC converter is recommended to increase the voltage to 18V~24 DC to meet the power requirement of the advanced driver assistance system.
- While spreading salt, the spreading attachment is extended lengthwise over 40 inches (see **Fig. I-4**), the attachment may trigger a radar alert. The driver can turn off the radar units while driving forward (during normal operation).
- With regarding the coverage provided by two side cameras, the ODOT technical team prefers that the two cameras can provide as much coverage as possible along the entire dump truck.
- Night vision capability is needed for all the cameras.
- The AdViSE system should work in harsh environments and all weather conditions, so the protection measures of cameras, sensors, and connectors need to be considered. An appropriate ingress protection (IP rating) is needed for all AdViSE components including cable and wiring.

Fig. I-2: Dump Truck for Paving (Asphalt)

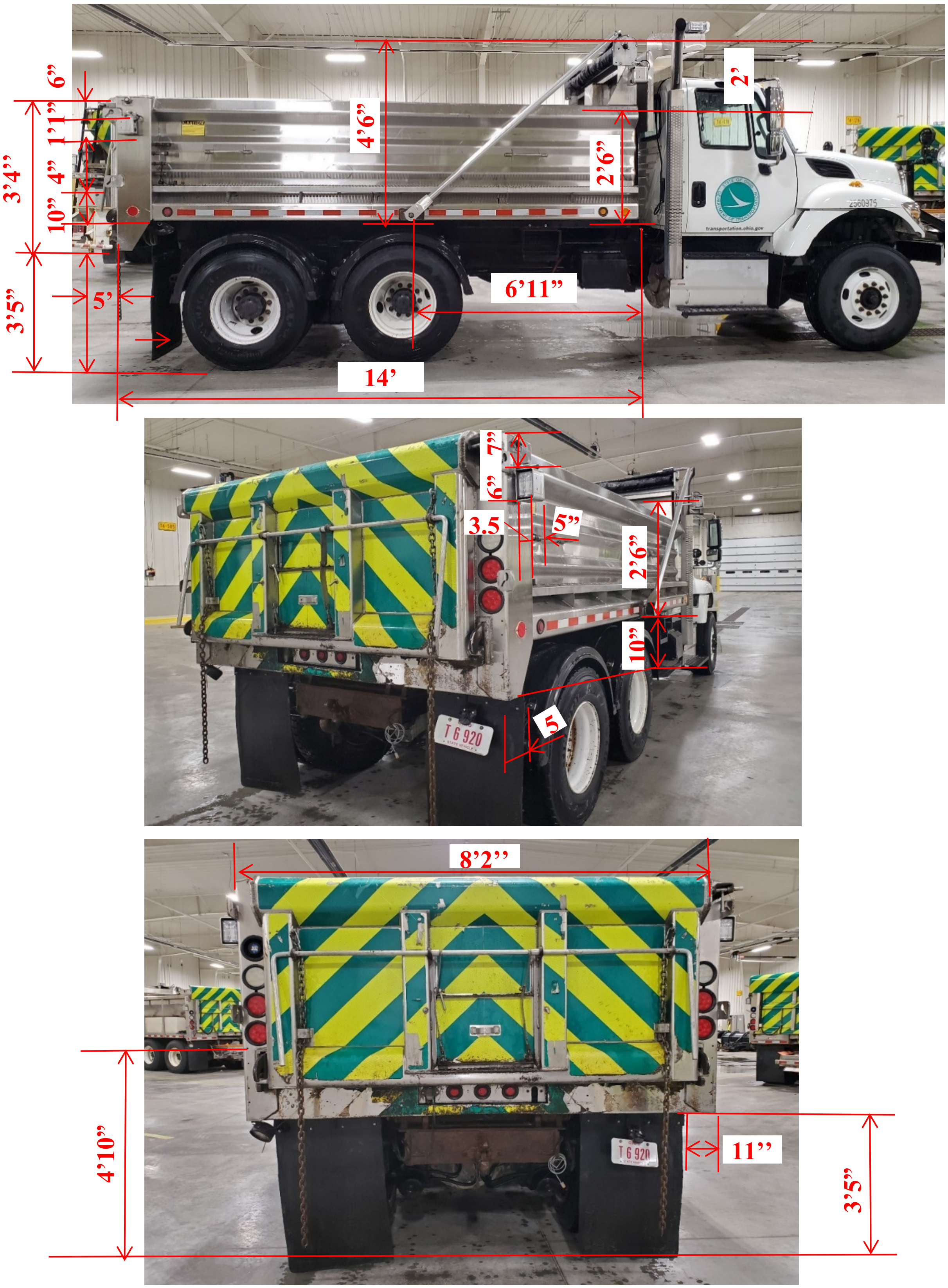


Fig. I-3: Dump Truck for AdViSE Prototyping

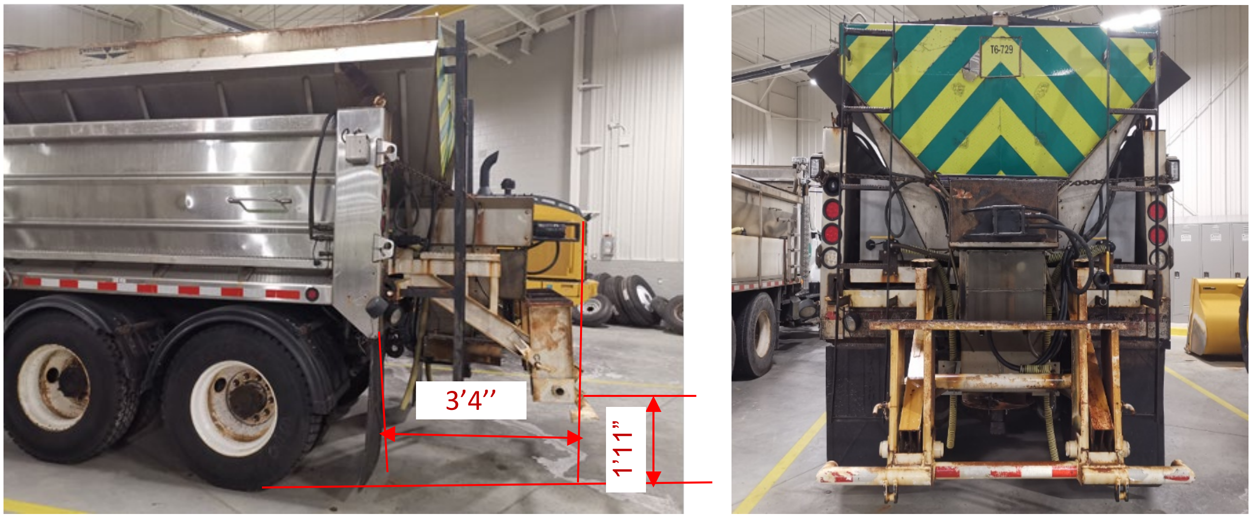


Fig. 1-4: Dump Truck for Snow Spreading

I.2.2 The Pilot AdViSE Configuration

The flow chart shown in **Fig. I-5** illustrates the configuration of the pilot AdViSE system. The pilot AdViSE system consists of four (4) cameras and two (2) radars. An Orlaco Multiview Box II is used to connect all four cameras and multiplex the four camera signals into one signal cable over which the camera signals are output to an Orlaco SRD Interface Box. The SDR interface box integrates the camera signals from Orlaco Multiview Box II and radar sensors, and then uses one single cable to output the composite signal to a 12-inch Orlaco Display. Since the 12 inch display is to be powered by a 18~30 V DC source, a DC–DC power adapter is used to convert 12V DC to 30V V DC. The power supply is provided by the 12V batteries of dump truck.

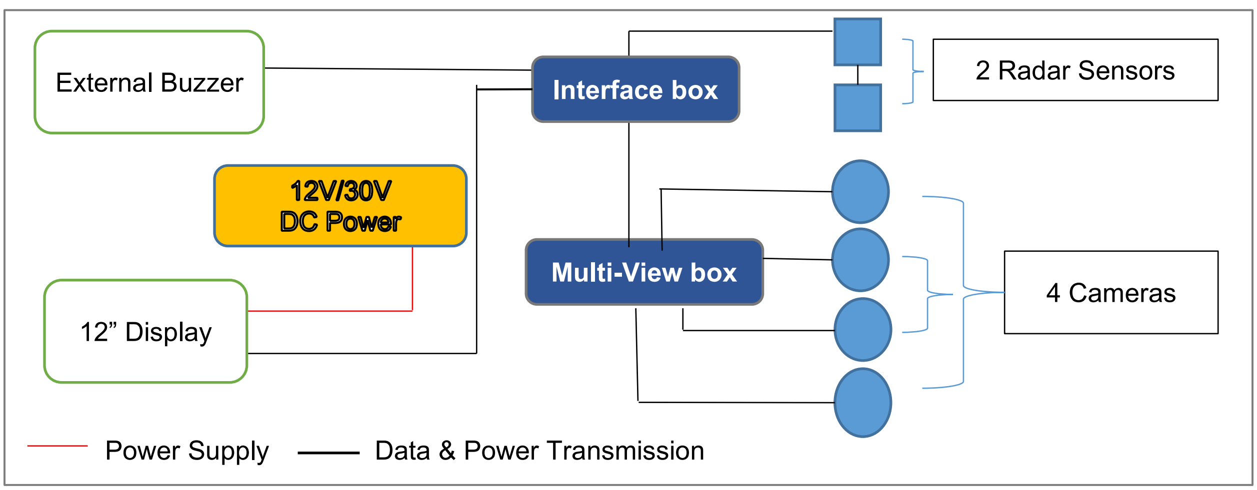


Fig. I-5: Conceptual Configuration of the Pilot AdViSE System

I.2.3 System Installation Methods

The most challenging portion of installation lies in the moving truck bed and asphalt dumping. All cameras, radar sensors and cables should be well positioned to have maximum protection due to asphalt dumping and the lifting-up of the dump bed. Without compromising the design and coverage, two installation/implementation alternatives were initially considered to address those challenging issues. An easy-to-wire spiral cable method was rejected in favor of wiring through the existing strobe light cable channel due to its reliability and durability. The pros and cons of the chosen installation method are listed in Table I-1. Table I-1 also shows a list of the major parts for the system tested. A complete list of parts and their estimated cost is listed in Table I-7. The subsequent schematic diagram design of the AdViSE system is shown in **Fig. I-6**.

Table I-1. Features of the Installation Method through Strobe Light Cable Channel

Wiring Method	Pros	Cons	Note
Strobe Light Cable Channel	Side cameras cover areas behind the side mirrors; More reliable; Good protection for interfacing box.	Long installation time; hard to wire; long cables	Parts and their corresponding costs are listed below (based on quote of Orlaco's distributor Berendsen Fluid Power, Inc.)

ITEM	QTY.	DESCRIPTION	
1	1	0411130	SET MONITOR 12" RLED SERIAL R6
2	4	0171620	CAMERA FAMOS 118∅ NTSC IR
3	1	0504820	SRD INTERFACE BOX WITH EXTERNAL BUZZER
4	1	0405100	MULTIVIEW BOX 2
5	1	0301071	CABLE 15M M12 GREEN
6	1	0301041	CABLE 8M M12 MASTER-SLAVE RED
7	1	0403120	SRD CORNER REAR
8	4	0402320	RAIN COVER FOR COMPACT CAMERA
9	1	0301890	CABLE 3.5M UNI 4P
10	1	0301910	CABLE 7.5M UNI 4P
11	1	0301731	CABLE 15M UNI 4P MOLDED
12	1	0301900	CABLE 11M UNI
13	1	0301960	CABLE 1M UNI 4P
14	1	1001796	MASCOT 8862, 12/24V DC-DC

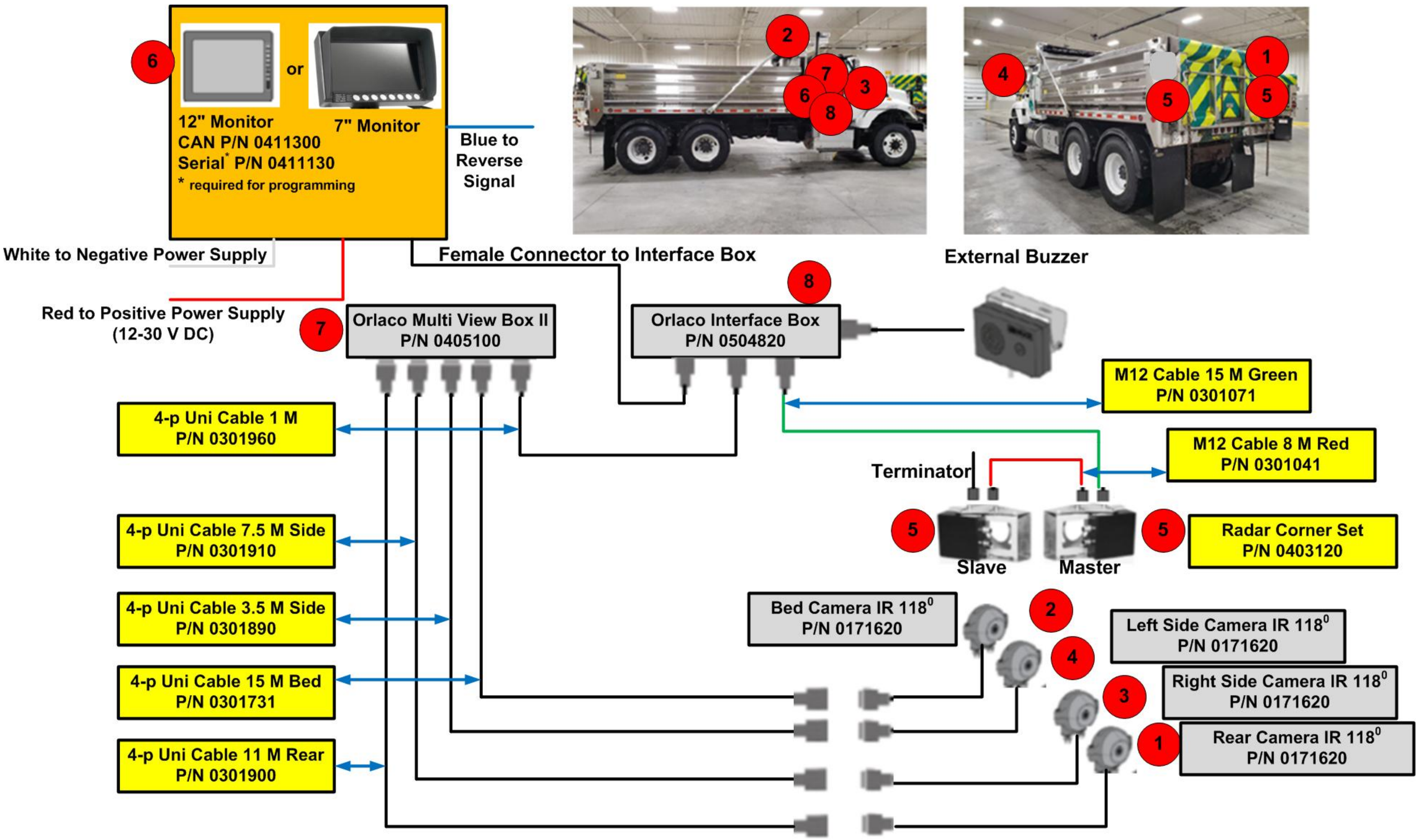


Fig. I-6: AdViSE System Schematic Diagram

1.2.2.1 Installation Method

As shown by **Fig, I-7**, the monitor, radar interface box and Multiview box II (items 6 through 8) in **Fig. I-6**) are all located inside the cabin. **Table I-1** lists the inventory of the parts for the installation method.

Fig. I-7: Installation Option using Strobe Light Cable Channels

The two radar sensors are installed at the left and right rear end of the truck, away from the moving yellow-green truck lid during the dumping process. The rear camera is installed next to the radar unit brackets on the passenger side of the truck. The two side cameras are installed on the left and right sides of driver's cab, close to the two large side mirrors. One single cable from each camera, and the radar set to the driver's cab need to be wired appropriately to avoid damage and address the dump bed movement issue. Since the dump truck has a few cable channels for the strobe light, the dump bed camera, rear camera and two radar sensors can all use the existing cable channels to route the wiring cables to the driver's cab and address the dump bed movement problem. Certainly, this method needs much more work than using spiral cables, but can offer better protection, coverage and reliability.

I.2.2.2 Installation Spots and Wiring Dump Bed Camera

The most challenging portion is how to wire the dump bed camera so that the cable will not be damaged during the dumping process. The wiring for the bed camera (i.e, covering the dump bed) will be routed down along the existing cable channel for strobe light to the rear end of the dump truck, and then wired along another cable channel to the driver's cab. **Fig. I-8(A)** illustrates the area close to the strobe light, and **Fig. I-8(B**) illustrates the wiring route for the bed camera, wherein the red, blue and green routes are the wiring paths for bed camera, rear camera and radar sensor, respectively.

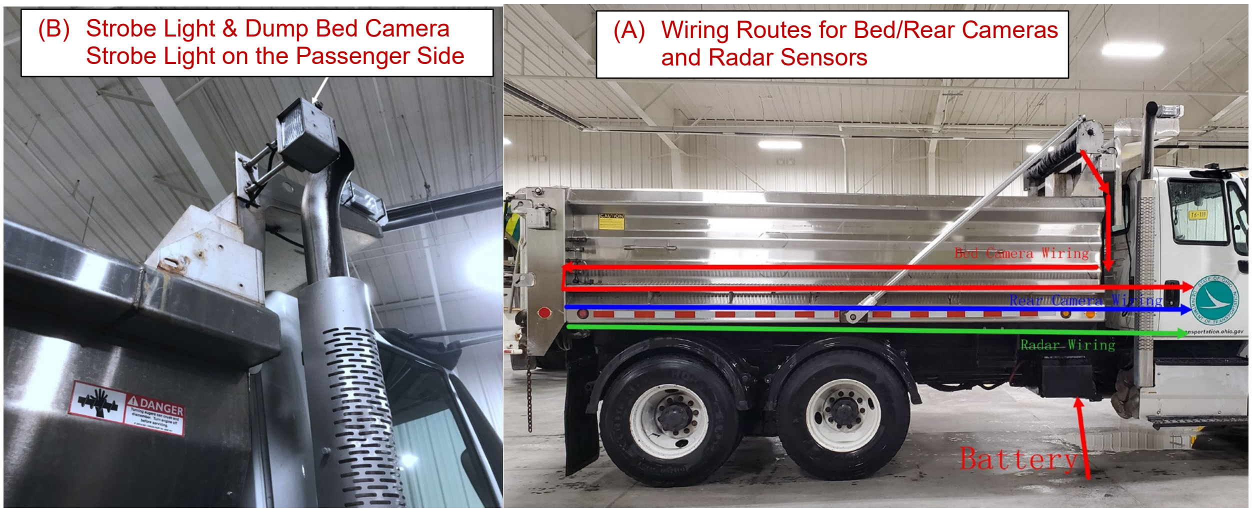


Fig. I-8: Illustration of Wiring Dump Bed Cameras and Radar Sensors

I.2.2.2 Protecting Radars and Rear Camera

When dumping asphalt, the radars and rear camera need to be protected against potential damage. Thus, the radar installation points are to be on left side and right side, at least 55 inches above the ground. A height below 55 inch may be subject to the dumping asphalt damage. The rear camera can be placed next to the strobe light (**Fig. I-9** (B)), either on the left or right side. We recommend the rear camera to be installed on the passenger side. **Fig. I-9** A) illustrates the installation area for radar sensors.

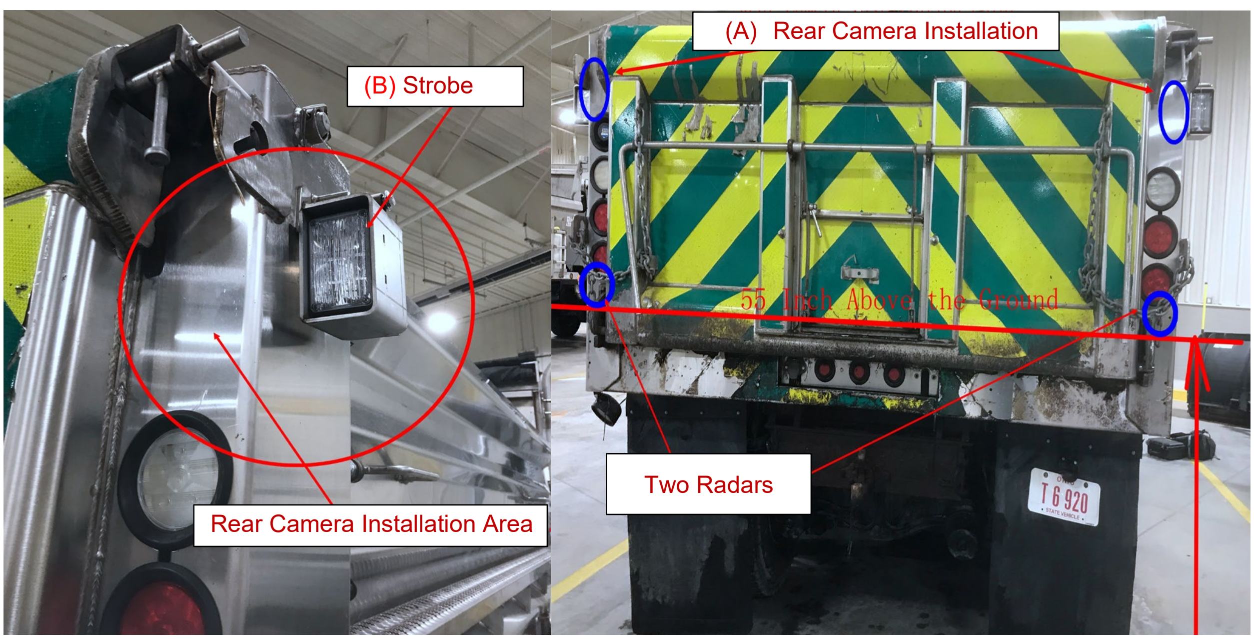


Fig. I-9: Rear Camera and Radar Installation Area

I.2.2.4 Batteries

The dump truck uses two 12V batteries in parallel. Thus, a DC step-up module is needed to convert 12V DC to 18~24 V DC to meet the power requirement of the AdViSE system (input voltage is 18~24v). **Fig. I-10(A)** and **Fig. 1-10(B)** show the battery location and view of the batteries inside, respectively.

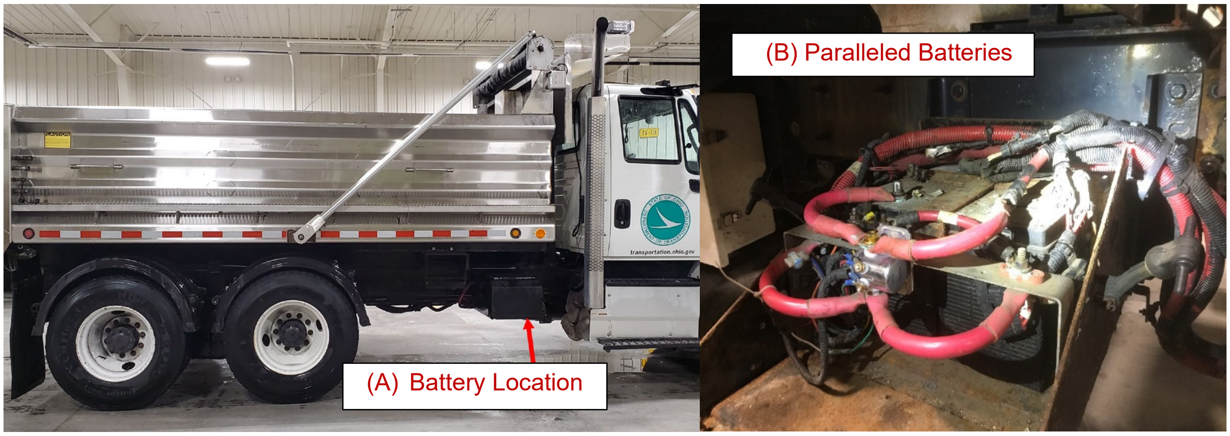


Fig. I-10: Battery for Dump Truck - Two 12-V Paralleled Batteries

I.2.2.5 Two Side-Cameras

The ideal views provided by the two side cameras may require the cameras to be installed on the left and right sides of the driver's cab, for example, close to the two large side mirrors. **Fig. I-11** shows the passenger side of the driver's cab.

Fig. I-11: Side View of the Driver's Cab

I.2.2.6 Installation of Display

The current dashboard has one existing opening (**Fig. I-12**) which can be used to install the display.

Fig. I-12: Dashboard Installation for Display

I.3 Key Programming of the AdViSE System

I.3.1 Monitor Programming

The monitor programming information below refers to multiple Orlaco manuals and provides directions to users of the AdViSE system.

I.3.1.1 Abbreviations

ABC = Auto Backlight Control
AFZ = Auto Focus Zoom
AGC = Automatic Gain Control
BHO = Black Hot
CCC = Compact Color Camera
LUT = Look Up Table
DDE = Digital Detail Enhancement
FFC = Flat Field Correction
FUS = Fusion
I&F = Ice and Fire
NTS = NTSC
OSD = On Screen Display
PIP = Picture in Picture
PTZ = Pan & Tilt Zoom
RB = Rainbow
Stndrd = Std = Standard
TCH = Tachometer
TIC = Thermal Image Camera
WHO = White Hot
ZOO = Zoom

I.3.1.2 Monitor Control Buttons

There are 8 buttons on the 12 inch monitor screen as shown by **Fig. I-13** and **Fig. I-14**.

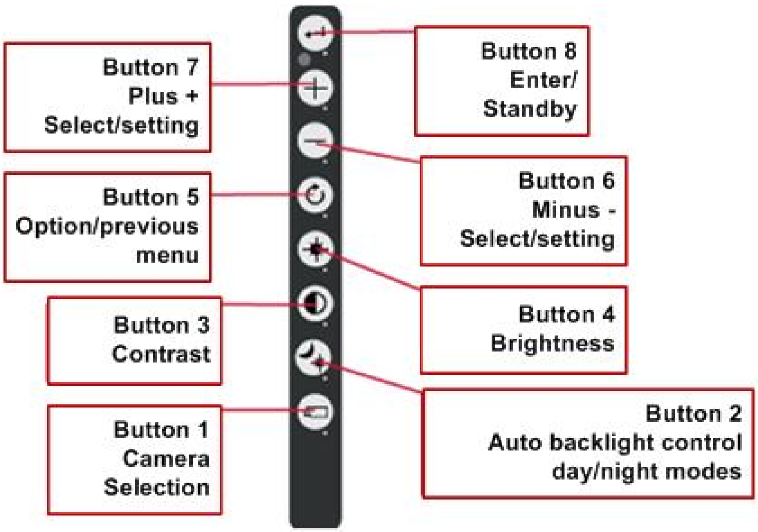
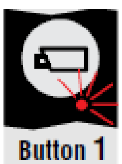
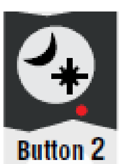


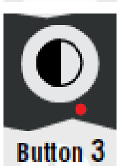
Fig. I-13: Buttons Shown on the Right Side of 12 Inch Monitor



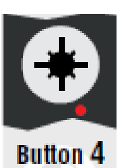
Button 1, camera selection
Press the camera selection button once. The camera LED flashes to indicate that manual camera selection is enabled. Use the minus and plus buttons to select the camera. Press the button again to disable manual camera selection.



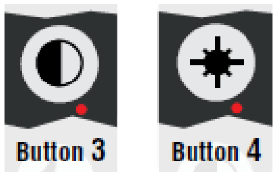
Button 2, auto backlight control day/night settings
Press this button to switch between the auto backlight day and night settings.



Button 3, setting the contrast
Press the button once in order to enable the setting mode. Use the minus and plus buttons to set the required contrast. Press the button again to disable the setting mode.



Button 4, setting the brightness
Press the brightness button once in order to enable the setting mode. Set the required brightness using the minus and plus buttons. Press the button again to disable the setting mode.

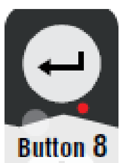


Buttons 3 and 4, setting color saturation
Press the contrast (3) and brightness (4) buttons simultaneously to enable the setting mode. Set the required color saturation using the minus and plus buttons. This setting must be set separately for each camera.

Button 5, option/previous menu
Return to the previous menu.

Button 6, minus
Go to the next menu option or move left.

Button 7, plus
Go to the previous menu option or move right.



Button 8, enter
Switch to Standby or in the menus, select or activate the chosen option.

Fig. I-14: Function Descriptions of Buttons on the 12 Inch Monitor

I.3.1.3 Power ON

When switched on for the first time the monitor will display a disclaimer message in shown in **Fig. I-15**.

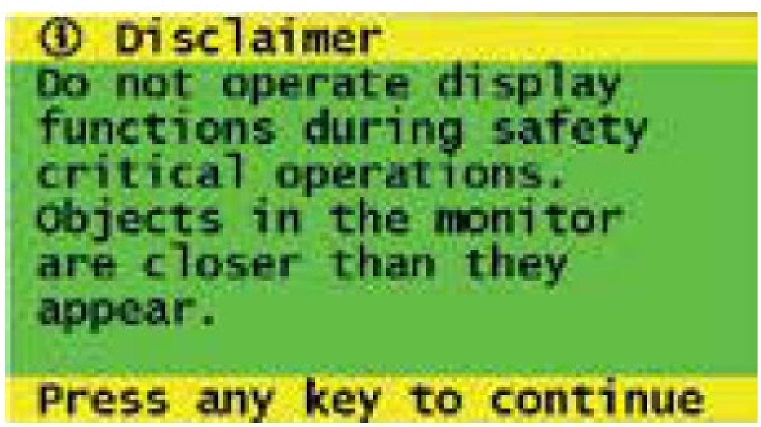


Fig. I-15: Disclaimer Message on Power ON

I.3.1.4 Keyboard Menu

When switched on for the first time the monitor will display a disclaimer message in shown in **Fig. I-16**.

Button 1: camera selection

Press the camera selection button (1) once (see **Fig. I-16A**). The camera LED flashes to indicate that manual camera selection is enabled (**Fig. I-16B**). Press the button again to disable manual camera selection. Use the minus (button 6) and plus (button 7) buttons to select the desired camera.

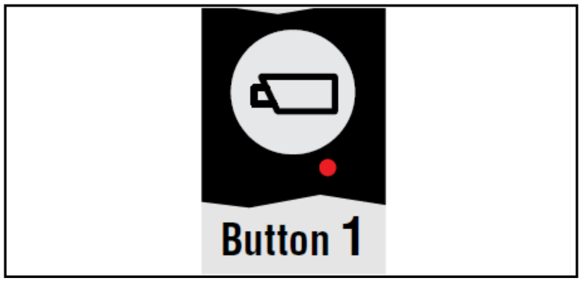


Fig. I-16A: Button 1 for Manual Camera Selection

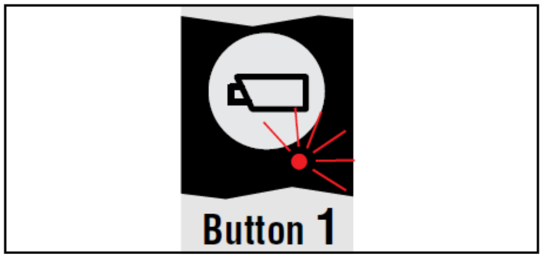


Fig. I-16B: Manual Camera Selection Indicated by Flashing LED

Button 2: ABC and LCD day/night setting

Press this button (**Fig. I-17**) to switch between the ABC mode, the LCD backlight day setting, or the LCD backlight night setting. In the day and night mode (STND_RED_BLUE) the brightness of the backlight can be manually set using the minus and plus buttons (the settings are saved). These settings are not camera dependent and therefore apply for all cameras.

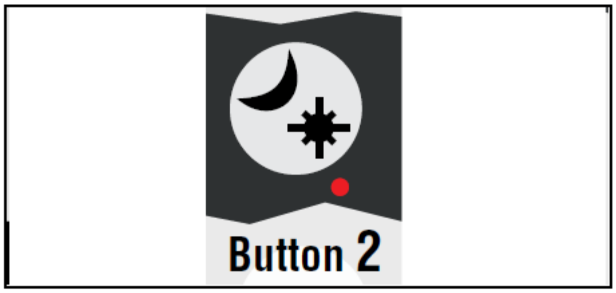


Fig. I-17: Button 2 for Selection of ABC and Day/night Settings

Button 3: setting contrast

Press the contrast button (3) once to enable the setting mode (**Fig. I-18**). Use the minus and plus buttons to set the required contrast. This setting must be set separately for each camera (see Button 1: camera selection).

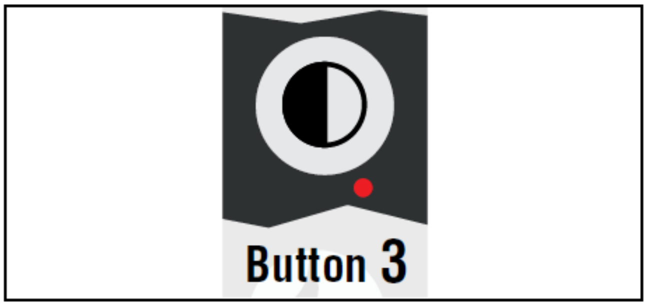


Fig. I-18: Button 3 for Contrast Setting

Button 4: setting brightness

Press the brightness button (4) once to enable the setting mode (**Fig. I-19**). Set the required brightness using the minus and plus buttons. This setting must be set separately for each camera (see Button 1: camera selection).

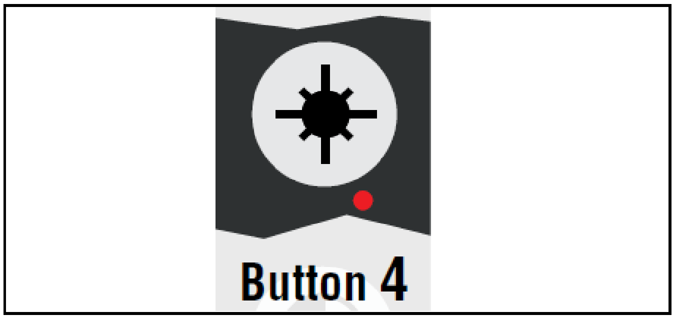


Fig. I-19: Button 4 for Brightness Setting

Buttons 3 & 4: setting color saturation

Press the contrast (3) and brightness (4) buttons simultaneously to enable the setting mode. Set the required color saturation using the minus and plus buttons. This setting must be set separately for each camera.

I.3.1.4 Service Menu

To open the service menu, simultaneously press the camera selection button (1), the minus button (6) and the plus button (7) (**Fig. I-20A**). The display (see Fig. **Fig. I-20B**) will appear. The following buttons are used to navigate through the menus (**Table I-2**):

Table I-2. Navigation Buttons

Button	**Function**
5 - Option/previous menu	Return to the previous menu
6 - Minus	Go to the next menu option
7 - Plus	Go to the previous menu option
8 - Enter	Select or enable the chosen option

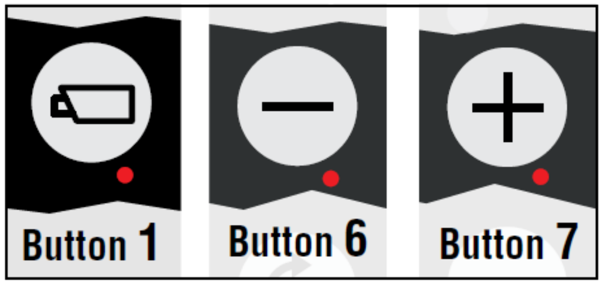


Fig. I-20A: Combination of Buttons to Activate the Service Menu

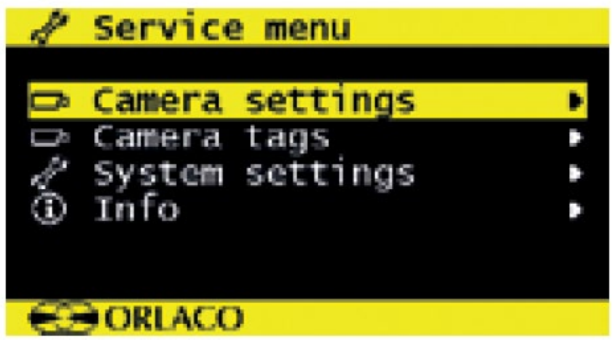


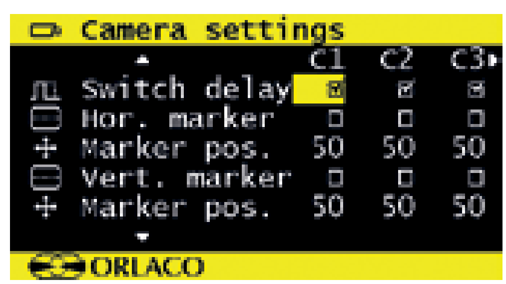
Fig. I-20B: Screen Shot of the Service Menu on Display

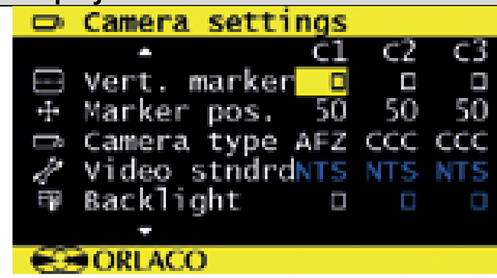
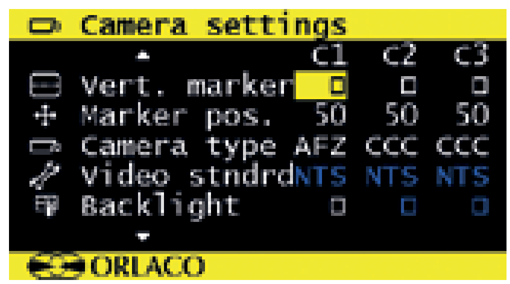
<u>I.3.1.5 Camera Settings</u>

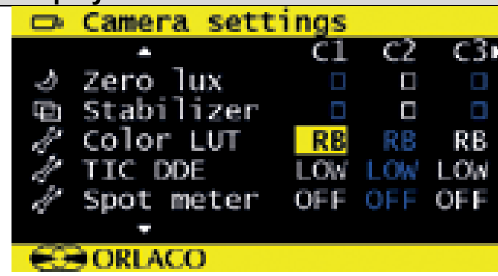
Select camera settings. Press enter to open the 'Camera settings' menu. Use the minus (6) and plus (7) buttons to select which camera to configure. Then confirm this selection by pressing the enter button (8). The yellow cursor is now activated in the list of items. Use the minus (6) and plus (7) buttons to select the item to adjust and then confirm this selection by pressing the enter button. If the selection is an on/off switch, you can choose between on and off. If the selection is a number, you can change the value using the minus (6) and plus (7) buttons. Save the new settings by pressing the enter button (8).

The following camera setting options are available to select (**Table I-3**):

Table I-3. Camera Settings Menu

Option	Description	Display
Mirror	Enable this option to reverse the image (left/right).	
Upside down	This option flips the image (upside down).	
Brightness	The setting for the brightness of the monitor. For direct button operation: Button 4.	
Contrast	The setting for contrast on the monitor. For direct button operation: Button 3.	
Saturation	The color saturation setting for the camera image. For direct button operation: Buttons 3+4.	
Switch delay	Enable this option if the switch-wire is controlled by an intermittent signal (e.g. from an indicator light).	
Horizontal line mark	Enable this option to show a reference line. The reference line is displayed as a	

Option	Description	Display
	horizontal green line. See Figure 40 on page 18.	
Marker position	Adjusts the vertical height of the reference line. 0 corresponds to the top edge of the monitor and 100 to the bottom edge.	
Vertical line mark	Enable this option to show a reference line. The reference line is displayed as a vertical green line.	
Marker position	Adjusts the vertical position of the reference line. This can be set between 38 and 63. The left and right sides swap position depending on the settings of the camera mirror-image function.	
Camera type	Select the camera type that is connected. The special features of that camera type will then become available. The camera types that can be selected are: **AFZ**: Enable this option if an AFI/AF zoom camera is connected. If AFZ is selected, the backlight, zero lux and stabilizer options are enabled. Operation of the zoom function: **Button 5 -** Enable the zoom function. The zoom function is disabled if the button is pressed again. **Button 6 -** Zoom out. **Button 7** - Zoom in. **TIC**: Enable this option if a Thermal Image Camera (TIC) is connected. If TIC is selected, then the video standard, color LUT, TIC DDE and spot meter options are enabled. **CCC**: Enable this option if a Compact Color Camera (CCC) is connected.	
Video standard	Video standard: The camera type must be set to TIC. Select the standard video output for the camera: PAL or NTSC (NTS).	
Backlight	This option corrects the background light in order to improve the screen display of dark objects in bright/lit surroundings. This option is only available if an AFZ camera is connected to a serial 12" monitor. For direct button operation: Button 2.	
Zero lux	Enable this option to improve the light sensitivity of the camera in dark surroundings. This option is only available if an AFZ camera is connected to the monitor 12" serial.	
Stabilizer	This option enables the stabilizer function, if the camera has one. This	

Option	Description	Display
	option is only available if an AFZ camera is connected to a serial 12” monitor.	
Color LUT (look up table)	The camera type must be set to TIC. Select the color palette to be used to give the correct color temperature. Select from WHO (white hot), BHO (black hot), FUS (mixed), RB (rainbow) and I&F (ice and fire). The AGC (automatic gain control) is automatically set for the WHO, BHO, FUS and RB settings.	
TIC DDE (TIC digital detail enhancement)	Possible settings are: OFF, LOW, MED and HI. Select the desired degree of image enhancement.	
Spot meter	Only works if TIC is selected as the camera type (see Video standard above): **OFF** (spot meter off) **B C** (bar in Celsius) **B F** (bar in Fahrenheit) **N C** (number in Celsius) **N F** (number in Fahrenheit) **BNC** (bar + number in Celsius) **BNF** (bar + number in Fahrenheit)	
Pan/tilt	Enabling the pan/tilt function makes standard pan and tilt operation possible (option button = button 5). It is possible to use digital pan/tilt when the TIC image is zoomed 2x or 4x.	
PIP/Split Screen	Set this option to ON to enable Picture In Picture or Split Screen. Visible only when the camera switch is set to 2C or 4C **PIP Mirror** Select this option to see the monitor in mirror mode. **Camera No.** Select which camera should be shown in the PIP or Split Screen Window. **Width, Height, Horizontal position, Vertical position** of the PIP or Split Screen window can be adapted.	

I.3.1.6 Camera Tags

In this menu, names can be given to the camera inputs (**Fig. I-21**). The number of inputs depends on the video switch type that is set.

Fig. I-21: Screen Shot of Camera Tags Menu

I.3.1.7 System Settings

The following options are available in System settings sub-menu (**Fig. I-22**):

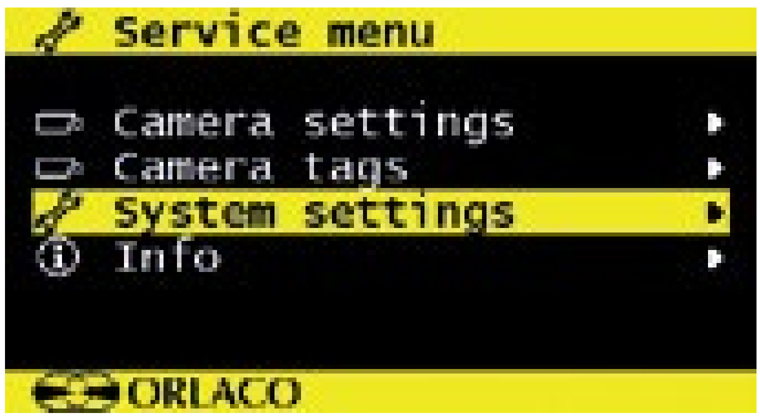
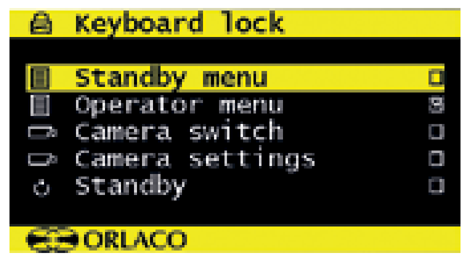
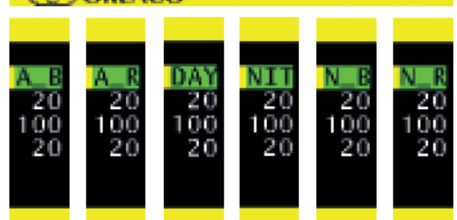


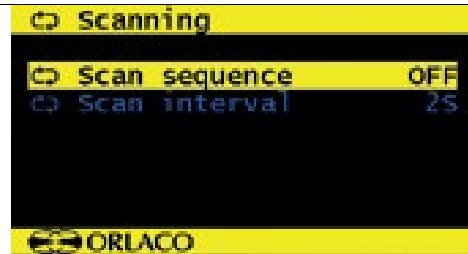
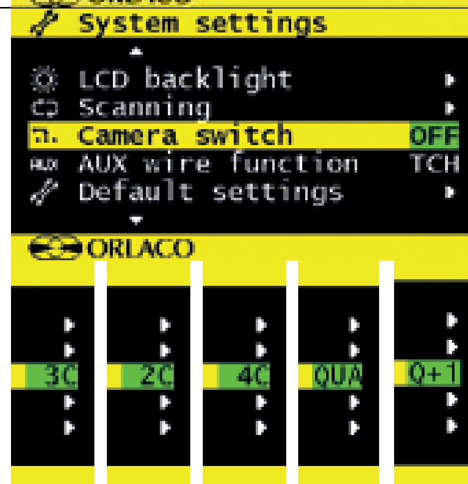
Fig. I-22: Screen Shot of System Settings Sub-menu

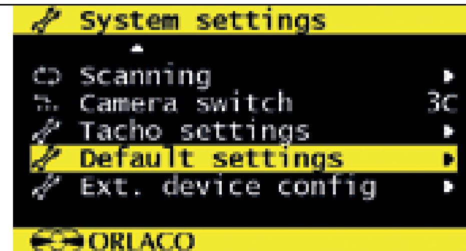
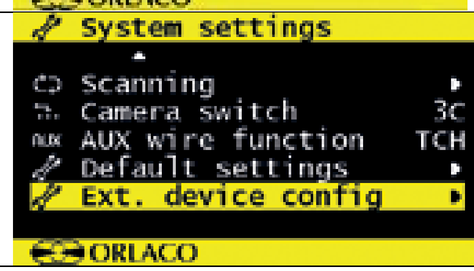
Table I-4. System Settings Menu

Option	Description	Display
Language	This option opens the language selection menu. The selected language will be used for all OSD menus. The OSD menu is available in English, Dutch, German, French, Italian, Polish, Portuguese, Spanish, Swedish, Finnish, Danish and Norwegian. For the Monitor 12“ CAN SRD Art. No. 0207930, the OSD menu is only available in English and Dutch.	

Option	Description	Display
On Screen Display (OSD)	This option opens the OSD settings menu. See the figure on the right. The following can be set in this menu: **OSD time-out** Sets the time (in seconds) that the OSD (camera number/name, top left) appears on the monitor. Select 'Off' to disable this and 'On' to have this permanently enabled. **OSD menu help** This function enables or disables the automatic text messages of the OSD help menus. If enabled, help messages automatically appear in all menus after 10 seconds of inactivity.	
Keyboard	This option opens the keyboard menu. This menu has the following 3 options: **Keyboard lock** This option opens the settings menu for the keyboard lock. It is possible to lock various functions in order to prevent any unwanted changes as shown by the figure on the right. • *Standby menu:* When **ON**, the monitor cannot be set in standby mode. • *Operator menu:* When **ON**, operator menu is not available, see section 1.3.1.9 Operator menu of the manual. • *Camera switch:* When **ON** the manual camera switch is not operational • *Camera settings:* When **ON**, the camera settings cannot be changed via the keyboard. • *Standby:* When **ON**, the monitor can be set in standby mode once and the mode stays active. This can only be deactivated to enter the service menu again.	 
Power settings	This menu has the following 2 options: **Standby mode** There are three available choices — use the minus and plus buttons to select the various functions. **MNU** = With this setting you access the operator menu via the enter button (8). Select the required setting. **IMM** = Immediate standby **2S** = Standby after a delay of 2 seconds **Standby, camera off** If this option is enabled, the camera power is off during standby.	

Option	Description	Display
CAN bus	This option opens the CAN bus menu. This menu has the following 4 options: **CAN protocol** This option selects the signal, or CAN protocol, that the monitor uses. By default, this is Orlaco CAN protocol 1. For the Orlaco Radar system, Orlaco CAN protocol 6 must be set. Other protocols are customer-specific. The CAN speed is automatically adjusted, but it can also be set manually once the protocol has been selected. **Set CAN-ID** The Orlaco CAN protocol has an ID (default 0) to control multiple monitors via one CAN bus. The ID is inactive when the text is blue and becomes active when the protocol is set to 1. The CANID can be set from 0-15 where 0 is the default value. **CAN speed** This option selects the bit rate of the CAN bus. Available options are: 100, 125, 200, 250, 500 and 1000 kbit. **Main terminator** Enable/disable the 120 Ω terminator (CAN or RS485) between Rx and Tx. **AUX terminator** Enable/disable the 120 Ω terminator (CAN or RS485) between AUX1 and AUX2.	
LCD backlight	This option opens the backlight submenu for the monitor 12”. This menu has the following 4 options: **LCD backlight mode** This option enables automatic backlight control (ABC). The monitor automatically adapts its brightness to the ambient light. Metering sensor on the keyboard. If required, a specific day or night brightness can be manually set. Alternatively, the user can choose to manually adjust the day or night brightness setting or select a red or blue night mode. **ABC** = Standard Automatic Brightness Control, **A_B** = ABC blue mode, **A_R** = ABC red mode, **DAY** = Day mode (can be adjusted between 50–100%), **NIT** = Night mode (can be adjusted between 0–50%), **N_B** = Night blue mode (can be adjusted between 0–50%), **N_R** = Night red mode (can be adjusted between 0–50%) **ABC minimum level** This setting determines the minimum brightness the ABC can use when there is low ambient light.	

Option	Description	Display
	LCD backlight day This option allows the day brightness setting to be manually adjusted (50–100%). **LCD backlight night** This option allows the night brightness setting to be manually adjusted (0–50%).	
Scanning	This option opens the camera scanning submenu. This menu has the following options: **Scan sequence** This option selects the cameras from which images are to be shown in sequence. **Scan interval** This option selects how long a camera image is displayed.	
Camera switch	This option configures the type of video switch that is used. **'OFF'** if no camera switch is used →□1 camera system. **'3C'** for an external camera switch →□3 camera system. **'2C'** if a *2–4 camera cable* is used →□2 camera system. **'4C'** if a combination of internal and external switches and a *2–4 camera cable* are used →□4 camera system. **'QUA'** for a quad system, only in combination with the quad switch. **'Q+1'** Combination of Quad system with 2–4 camera cables; 1–5 Multiview channels + extra camera. With the settings **2C** and **4C** the PIP or Split Screen function can be used, see also chapter 4.1.20.	
Tacho settings	Settings related to switching a camera based on tacho speed: **AUX wire function:** Select the function of the AUX1 and AUX2 wires. Set to **TCH** for the tachometer or **KEY** for + and - key functions on AUX1/2. Select **C+-** to select the *next* and *previous* camera with the AUX switch wires. **ZOO** for the camera zoom function (only available in combination with an auto focus camera). Use in this case the AUX1 and AUX2 switching wires to zoom in and out. Switch AUX to **OFF** to use the gray wire as trigger wire for the **4C** system **Pulses per meter** Set this value to the amount of pulses the tachometer generates per meter. (0 - 250). **Cam to activate** Select which camera should be activated when tacho speed is within selected range. (C1 - C6)	

Option	Description	Display
	Cam on if speed >= (0 - 130) Tacho low limit, Camera not activated when tacho < low limit. **... and speed <** (0 - 130) Tacho high limit, Camera not activated when tacho > high limit Both menus Cam if speed >= and speed < are connected; Camera activated when tacho >= low limit and tacho < high limit. The 2 conditions together must be active to switch the camera.	
Default settings	This option opens the menu to restore the factory default settings. Select the number of the factory settings that you require (1 = default Orlaco settings). You can choose between 30 sets of default settings. Contact ORLACO for further information. Select the option 'Restore defaults' to restore the factory settings. **Warning:** All user settings are lost when the factory defaults are restored!	
External device configuration	This option opens the configuration menu for an external device. Only use this option if a device is connected that has its own OSD (Multiview, Spectrum Scanner, etc.). Exit the menu by pressing the option button (5) for 3 seconds.	

I.3.1.8 Info

This user manual describes the functions of the software version indicated on this display (**Fig. I-23**).

I.3.1.9 Operator Menu

The operator menu is not available by default due to the keyboard lock. To disable the lock, please refer to Keyboard in system settings (i.e. section I.3.1.7 System settings). Press the minus and plus buttons simultaneously to open the operator menu. See **Table I-2** for list of buttons used for navigation. The following options (**Table I-5**) are available in the operator menu (see **Fig. I-24**).

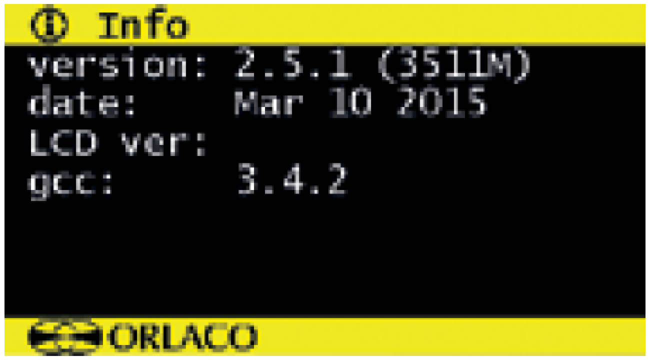


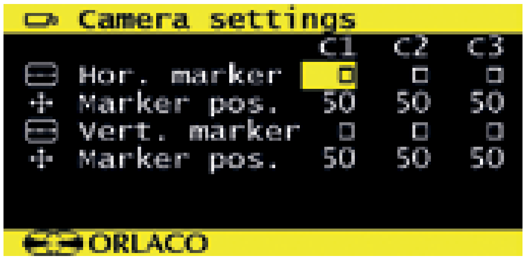
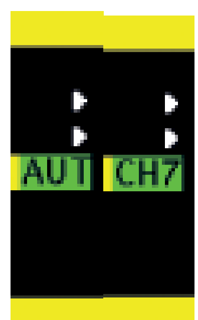
Fig. I-23: Screen Shot of the Info Sub-menu on Display

Fig. I-24: Screen Shot of the Operator menu

Table I-5. Operator Settings Menu

<table>
<tr><th>Option</th><th>Description and Display</th></tr>
<tr><td>Language</td><td>This option opens the language selection menu (see figure on the right). The selected language will be used for all OSD (On Screen Display) menus. The OSD menu is available in English, Dutch, German, French, Italian, Polish, Portuguese, Spanish, Swedish, Finnish, Danish and Norwegian. For the Monitor 12“ CAN SRD Art. No. 0207930, the OSD menu is only available in English and Dutch.

</td></tr>
<tr><td>Camera settings</td><td>Horizontal line mark
Enable this option to show a reference line. The reference line is displayed as a horizontal green line.
Line position
Adjusts the vertical height of the reference line. 0 corresponds to the top edge of the monitor and 100 to the bottom edge.
Vertical line mark
Enable this option to show a reference line. The reference line is displayed as a vertical green line. This option is not available on all
12” models.</td></tr>
</table>

	Line position Adjusts the vertical position of the reference line. This can be set between 38 and 63. The left and right sides swap position depending on the settings of the camera mirror-image function.  Camera setting  Horizontal (green line)  Vertical (green line)  Horizontal and vertical (green line)
Video channel settings	This option sets the video channel for the Orlaco Spectrum Scanner. The following options are available: • CH0 = channel 0 to CH7 = channel 7 • AUT = automatic • See the Spectrum Scanner IM0973610 installation manual for descriptions of these channels.  

I.3.1.10 Overview of Menus

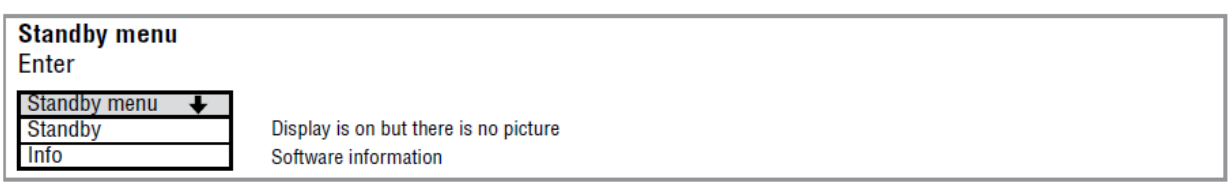


Fig. I-25: Standby Menu

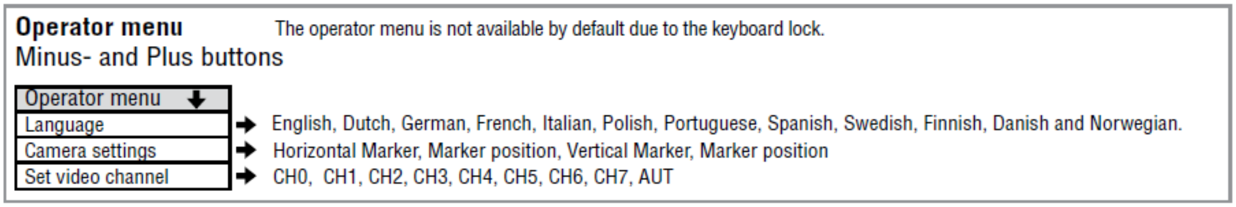


Fig. I-26: Operator Menu

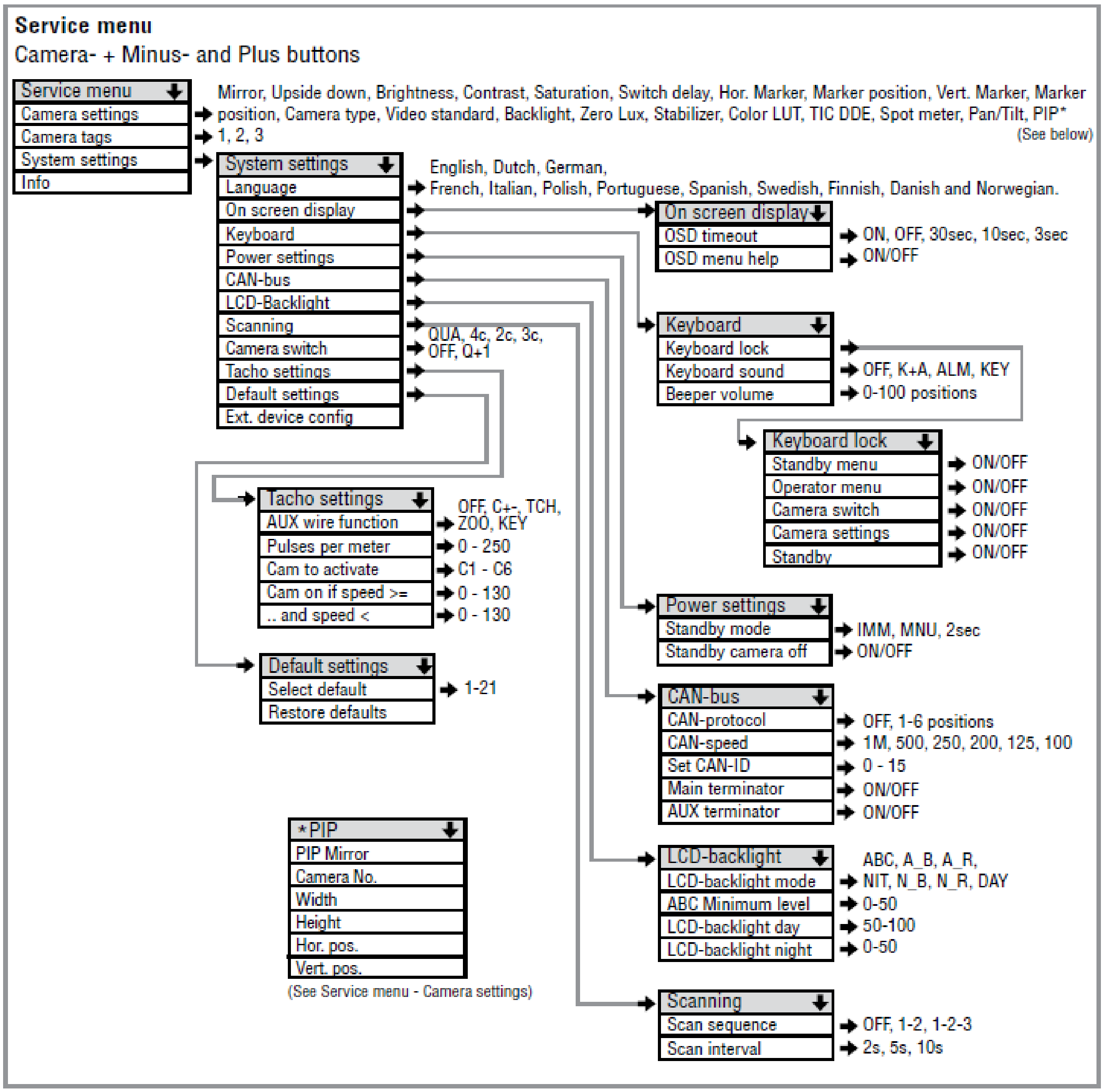


Fig. I-27: Service Menu

I.3.2 Multiview Box Programming

I.3.2.1 Multiview Box Programming

Please note the 12-inch serial monitor (P/N 0411130) is required to program the multiview box. The 12-inch CAN monitor (P/N 0411300) or the 7-inch monitors (e.g. P/N 0208632) can be used for regular operation after all programming is done.

First go to the 12-inch monitor System Settings menu and select "Ext. Device Config." Refer to the monitor user manual Table I-6, item "External device configuration" and **Fig. I-28A** for more details.

Fig. I-28A: System Settings Menu on the 12-inch Display

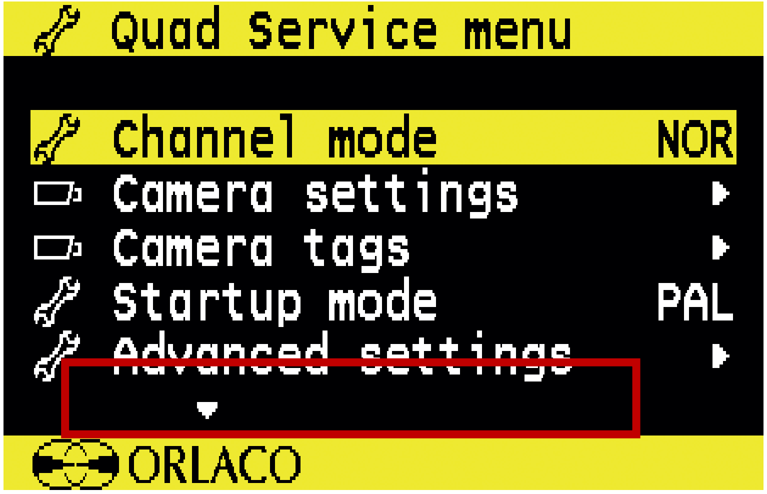


Fig. I-28B: Quad Service Menu for the Multiview Box

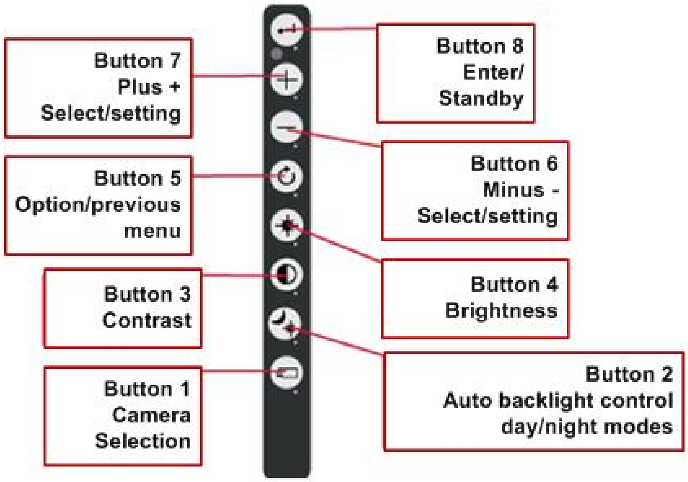
When the Ext. device config is selected you will see the Quad Service menu, see **Fig. I-28B**. The 'Quad Service' menu offers the following options:

- Channel mode,
- Camera settings
- Camera tags
- Startup mode
- Advanced settings

- Info

Please note, to program the cameras (Multiview box) you must go to System settings -> Ext. Device Settings -> Advanced settings -> Channel settings. Please do not use the Camera settings menu under Quad service menu.

To exit the Quad Service menu, press the option button (button 5 on the 12-inch display, **Fig. I-13 on section I.3.1.2**) for 3 seconds. To facilitate reading here, **Fig. I-13** is copied below.



Copy of Fig. I-13 (see Section I.3.1.2)

I.3.2.2 Advanced Settings

A screen shot of this menu is shown in **Fig. I-29**. To program the camera windows and to assign cameras to each window please go to the Channel Settings menu as shown in **Fig. I-29**. In order to scroll through the menu or choose options please use the +/- buttons (see **Fig. I-14**).

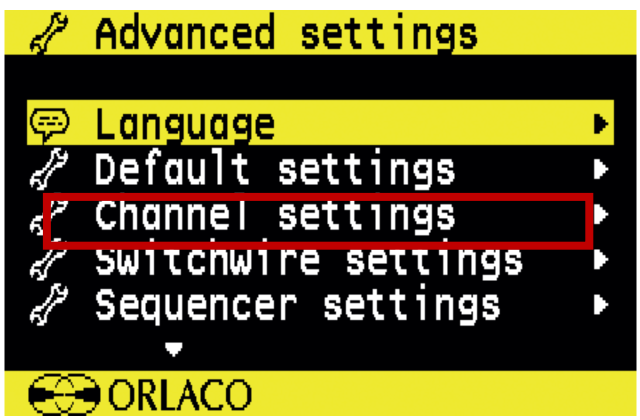


Fig. I-29: Advanced Settings Menu

- **Step 1.** First go to the Channel settings to customize the monitor view (**Fig. I-30**): up to 4 windows (W1 to W4) can be shown on a particular channel with nine possible orientations (note: please refer to **Fig. I-34** for the more detailed available configurations in the following section I.3.2.3). The cameras are denoted from C1 to C4.

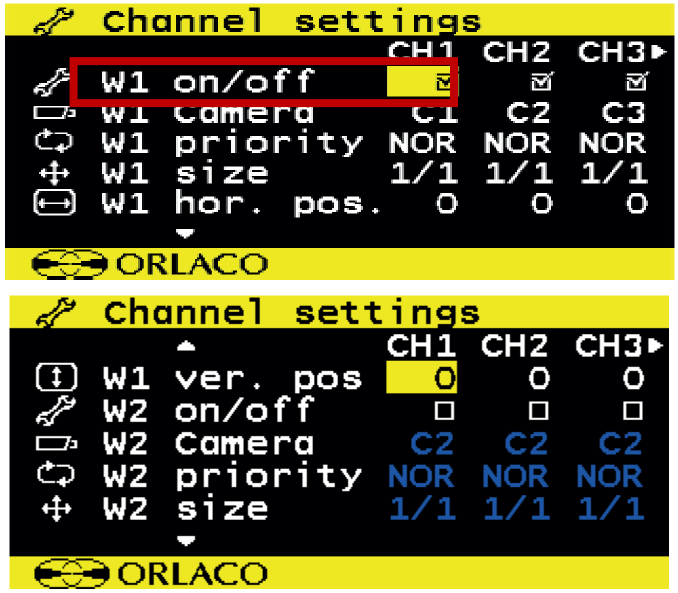


Fig. I-30: Settings that Can Be Programmed in Channel Settings

- **Step 2.** For each channel set which windows (one of W1 to W4) will appear. For example, for W1 to appear on CH1 check the "W1 on/off" option.
- **Step 3.** Next assign a camera to the window. For example, to assign camera tagged as C1 (suppose it is the rear camera), select C1 for "W1 camera" option.
- **Step 4.** Set location of each window on the screen (**Fig. I-31**). For example, to set the location of the W1 (for CH 1) on the top-left of the monitor window set "W1 hor. Pos." to 0 and set "W1 ver. Pos." to 0. Similarly, to select W4 to the bottom-right set "W4 hor. Pos." to 50 and set "W4 ver. Pos." to 50.
- **Step 5.** Set size of each window on the screen. The "W1 size" determines the size of W1 window with respect to the entire monitor area.

Adjustable options are: 1/1, 3/4, 2/3, 1/2, 1/3, 1/4, 1/5, 1/6, 3/4, 2/3, 1/2. Please see **Fig. I-32** for interpretation of the options.

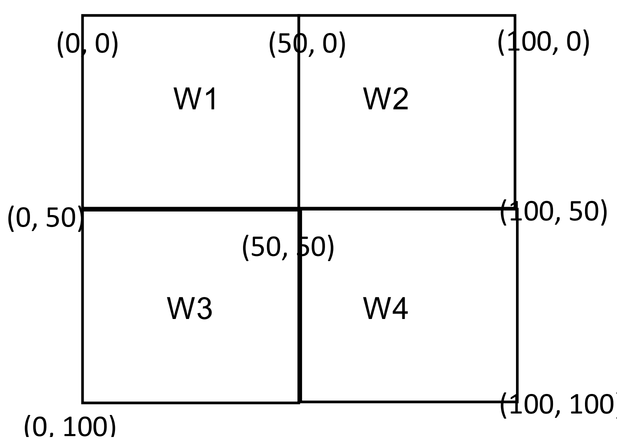


Fig. I-31: Coordinate System for the Window Settings for a Quad-view Mode

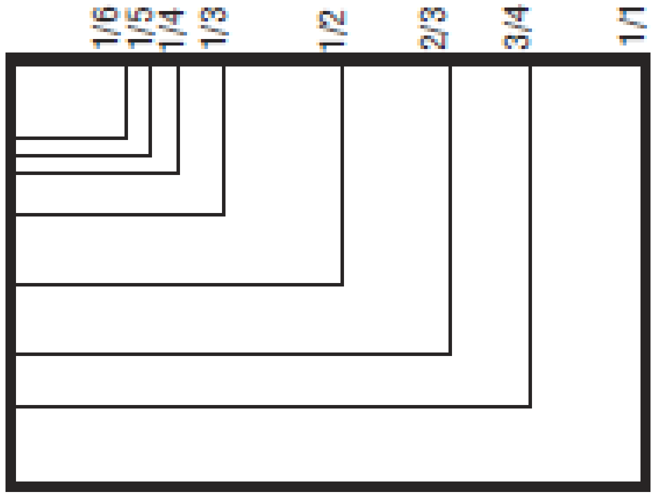


Fig. I-32: Window Size Settings for the Monitor

- **Step 6.** Set window priority, meaning which window to get preference in case of overlap. For each window 3 priorities are possible – LOW, NOR, and HI. See the screen shot of **Fig. I-33**.

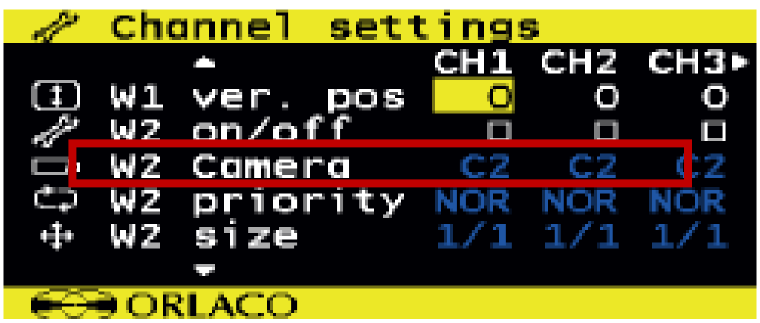


Fig. I-33: Priority Setting for W2

In the current AdViSE setup, CH1 is set for the quad view with dump bed, rear, driver and passenger side cameras. CH1 is the default setting and activates when the system is turned ON. The CH2 is set for rear camera only and activates only when the vehicle is on reverse gear.

Ch3 is a dual view with dump bed and rear camera and can be manually activated. To manually select a particular channel view press camera selection on the monitor (Button 1, see **Fig. I-13**) and then use the +/- buttons to navigate.

<u>I.3.2.3 Channel Modes</u>

The Orlaco Quad has five camera channels. For the first four channels you can select a default image layout or a customer image layout. Channel five is always the quad layout (**Fig. I-34**). You can press the camera button (button 1, referring to **Fig. I-13**) on the 12-inch display to switch between channels.

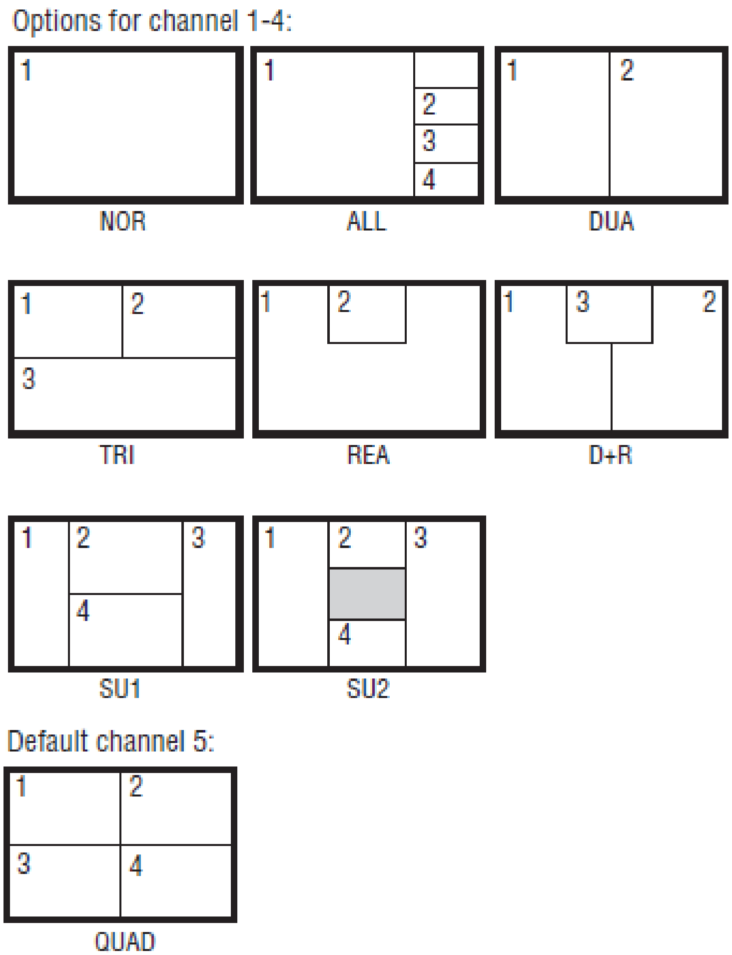


Fig. I-34: Various Channel Modes on the Display

The abbreviations of different channel modes in **Fig. I-35** are listed in **Fig. I-36**. Channel 1-4 can be customized for one of these modes. Channel 5 is fixed to the quad display.

NOR	NOR-mode:	full view
ALL	ALL-mode:	all view
DUA	DUA-mode:	dual view
TRI	TRI-mode:	1-2 top view
REA	REA-mode:	3-1 bottom view
D+R	D+R-mode:	dual inset top view
SU1	SU 1 mode:	surround view 1
SU2	SU 2 mode:	surround view 2

Fig. I-35: Abbreviations of Different Channel Modes

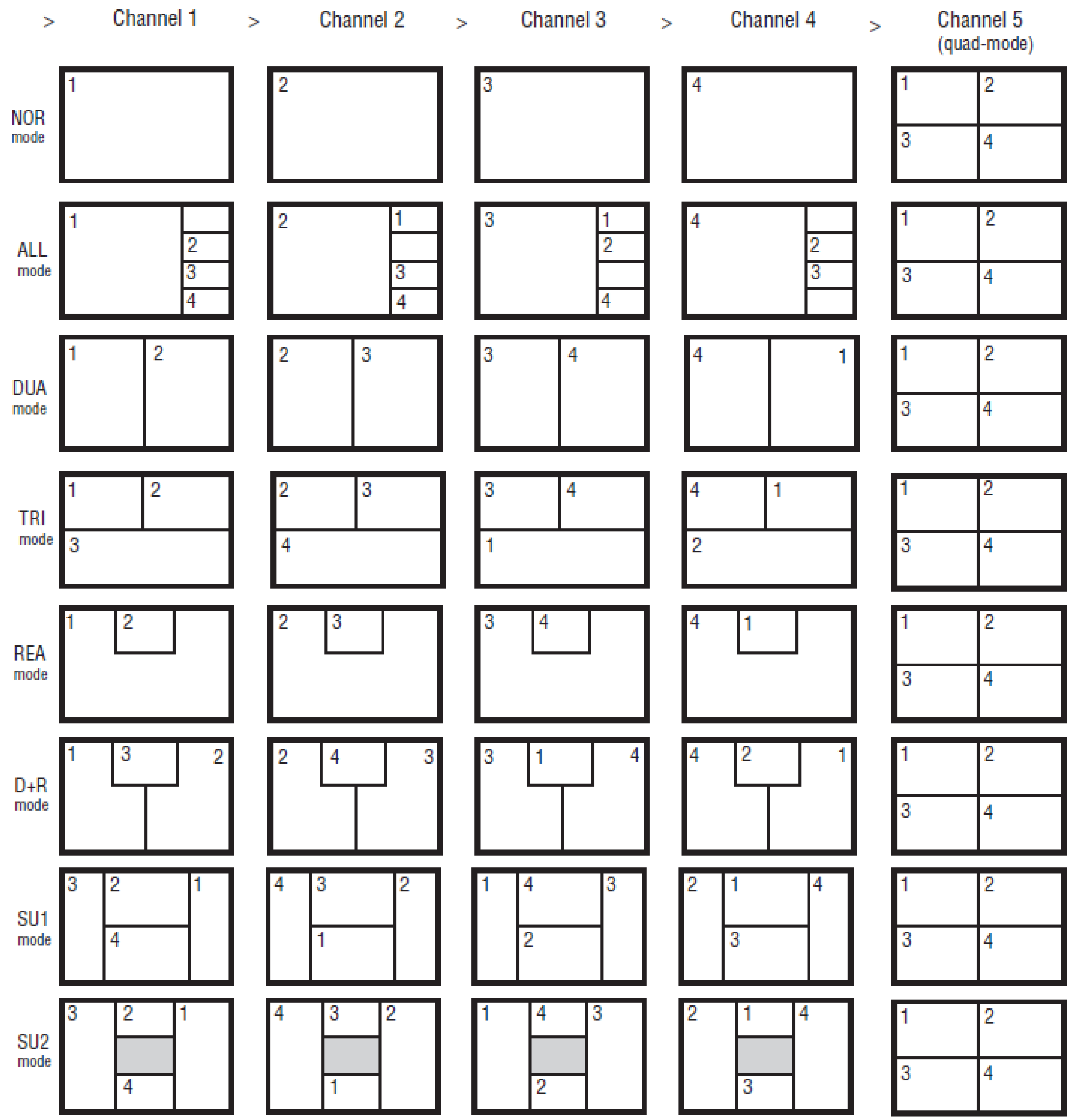


Fig. I-36: Overview of Different Mode Available for Channels 1-4

I.3.3 Radar Programming

I.3.3.1 Connection

While programming the radar sensors, it is important to only have one of them connected at a time to the 12-inch monitor via the SRD interface when entering the sensor settings menu and making changes. The system will only recognize the sensor with the lowest ID. The sensor ID refers to the direction at which the sensor operates, as explained in **Figure I-37**.

For the purpose of programming, the radar sensors are designated an ID which denotes the direction (front, rear, corner, etc.) at which the sensor operates. Figure I-37 shows the valid radar IDs that can be entered during programming. For the AdViSE system the radar sensors are mounted at either corners of the rear of the truck, hence the driver-side sensor is designated ID = 7 and the passenger-side sensor is designated ID = 5.

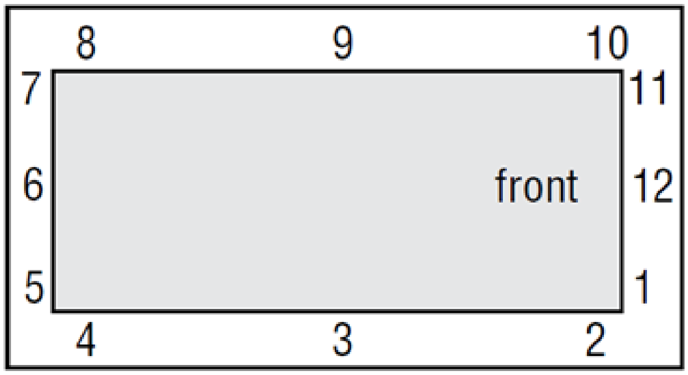


Fig. I-37: Possible Direction Assignment for the Radar Sensors

For the wiring portion of the display:

- Red lead is the positive/hot.
- White lead is the negative/ground.
- If trigger wire is requested to be used contact Orlaco for the best set up option. For the rear radar setup, they can be switched or activated connecting the blue switch wire.

I.3.3.2 Programming

The radar sensors can be programmed using the 12-inch monitor. The keyboard buttons on the monitor are used to enter and navigate through the settings menu. Please refer to Figure I-13 for an explanation of the functionality of different buttons on the keyboard. The steps to program the sensors are as follows:

Step1. Enter the service menu of the display. To open the service menu, simultaneously press the camera selection button (1), the minus button (6) and the plus button (7). The display in **Fig. I-38** will appear.

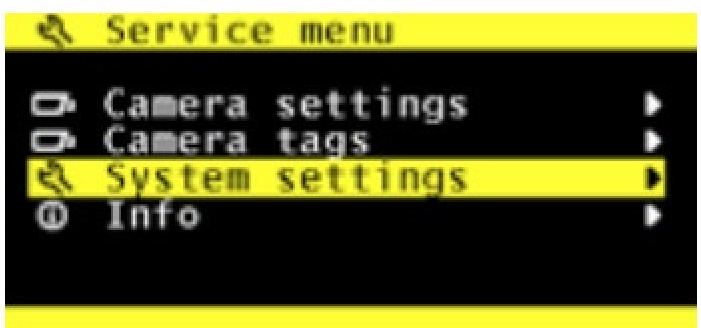


Fig. I-38: Screen Shot of Service Menu on Display

Step 2. Navigate to system settings (highlighted by yellow in **Fig. I-38**) using the **+/-** buttons and select (button 8: enter).

Step 3. Select radar setup as shown in Fig. I-39.

Fig. I:39: Screen Shot of System Settings Menu with Radar Setup Highlighted

Step 4. Select sensor settings as shown in Figure I-40A. A warning message will show up as shown in **Fig. I-40B**. Select **OK** to continue.

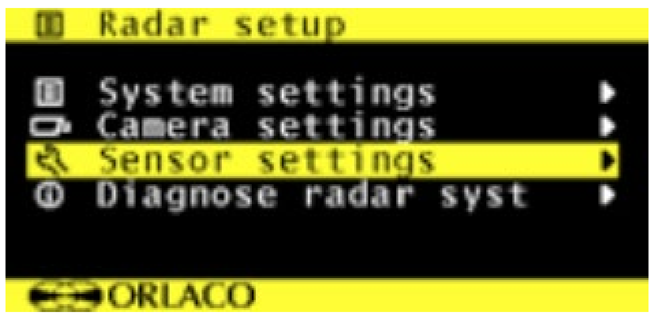


Fig. I-40A: Screen Shot of the Radar Setup Menu

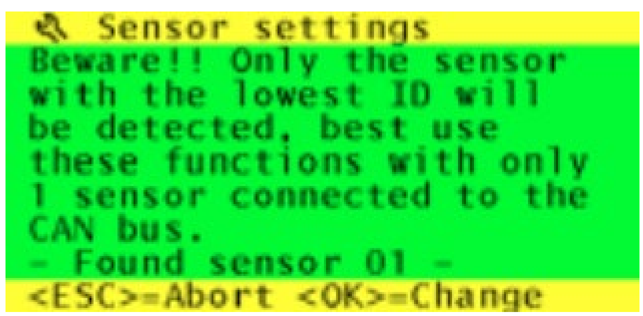


Fig. I-40B: Screen Shot of the Warning Message

Step 5. Change radar direction to appropriate setting based on mounting location. If programming for the first time, the default direction will show up (direction 1). For the current configuration of the AdViSE system the driver-side sensor should be assigned direction 7 (will be referred to as 7 o'clock sensor) and the passenger-side sensor should be assigned direction 5 (will be referred to as 5 o'clock sensor).

Step 6. Change radar type to appropriate setting based on radar configuration used. In the current configuration both the 7 o'clock and 5 o'clock sensors are set as configuration 4, which is single master setting.

Step 7. Change sensor range to desired distance (measurement is in decimeters) default is 60 or 6m. The range can be set from 20 (2m) – 200 (20 m), these are divided into 5 equally sized segments (see **Fig. I-42**). The default detection range is 6m (60).

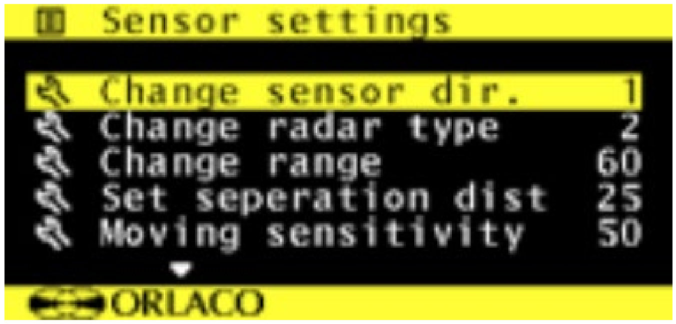


Fig. I-41: Sensor Settings Menu for Steps 5, 6, and 7

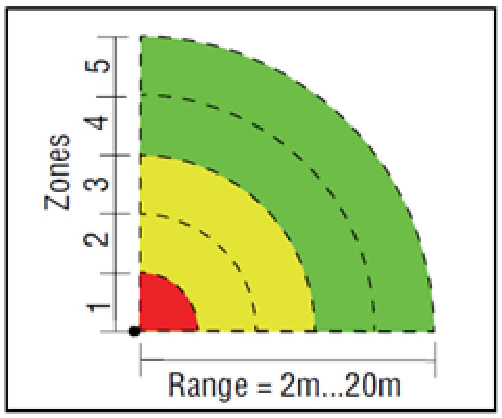


Fig. I-42: A Possible Range Assignment (2 m to 20 m) for the Radar Sensors

When making all the changes the display shows 'busy', then 'success' once completed.

Step 8. Now exit the sensor setting menu (**use the escape button no. 5**) and return to the system setting menu

Step 9. There are 2 alarms/settings that need changed, the 1st is the alarm that comes from the monitor and the 2nd is the one for the external buzzer. Change both to become active at the zone of your preference (one of zones 1-5 showed on **Fig. I-42**).

Step 10. If a rear radar set up is being used 'check' the switch rear radar option in this menu as well and set the block side, speed > off.

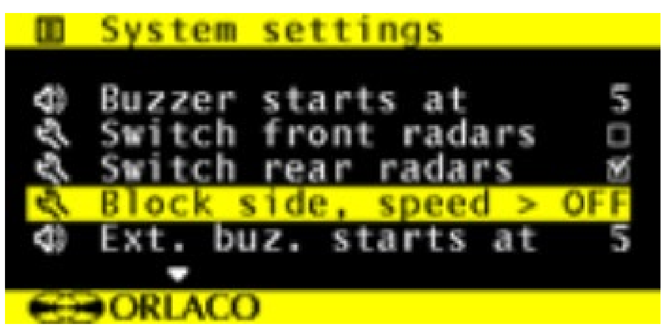


Fig. I-43: System Settings Menu for Steps 8-10

Step 11. Go back to radar setup and enter camera settings, as in **Fig. I-44A**. Match the sensor direction with the desired camera. There can be three (View 1-3) sensor directions connected to one camera. The number indicates the direction where the sensor is looking. For example, setting up Cam 1 (C1) to look at sensor 6 means that camera 1 is looking in the same (rear) direction as sensor 6 and that the monitor will switch to camera 1 as soon as sensor(s) 6 detects an object, as shown in **Fig. I-44B**.

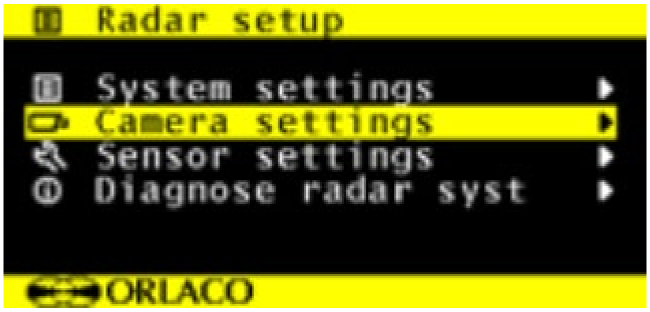


Fig. I-44A: Radar Setup Menu

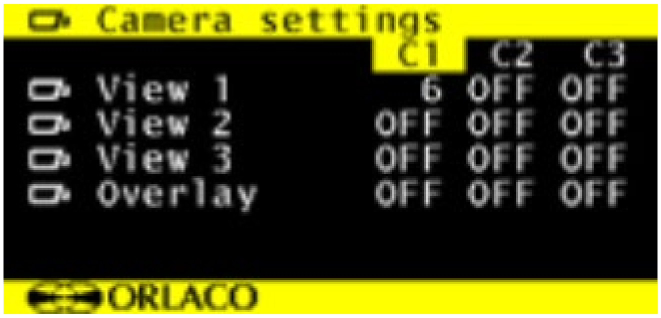


Fig. I-44B: Camera Settings Menu

A radar sensor can be connected as stand-alone (master) or operating in dual mode (as a master/slave pair). The possible configurations are listed in **Table I-6**. For the AdViSE system both sensors are configured as single masters, i.e. setting 4.

Table I-6. Radar Sensor Type

Setting	Meaning
1	Slave to a dual sensor master (setting 2 or 3)
2	Master for corner-rear setup
3	Master for center-rear setup
4	Single master setup
5	Single slave sensor, paired with setting 4

When a sensor direction is matched with a camera the standard visible warning is with colored dots in the above right corner in the monitor, as seen in **Fig. I-45**. For the AdViSE system, the rear camera (C2) should be matched with the views of sensor directions 5 and 7, i.e. View 1 set to 5, View 2 set 2 7, View 3 set to off and overlay set to off.

Fig. I-45: The Radar Detection is Matched with the Rear-view camera

It is possible to change the view to overlay. Please refer to the Orlaco manual for details.

Step 12. **if standby mode is requested**To achieve the black screen except when in reverse the display must be placed in standby mode, enter the power settings menu and turn standby mode to IMM—exit from the service menu and press the enter button. Screen should turn black.

I.3.3.2 Diagnostics

The sensors can fail for various reasons and an error code will be indicated on the display monitor. Possible options are:

1. **S : XX ERROR** The system is expecting a sensor connected to sensor direction XX. Please check connections and sensors or go to diagnostics to check.

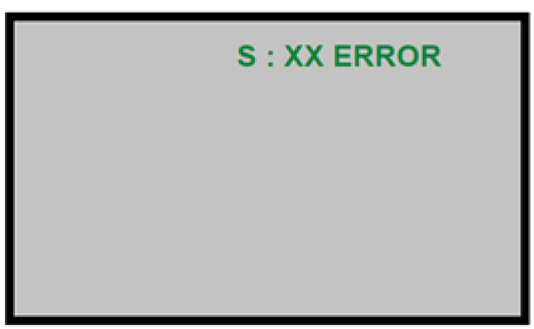


Fig. I-46: Error Code for Connection failure

2. **Error code X●●●●●** The system with multiple sensors connected to different sensor directions is detecting an error and there is a detection of an object on one of the (good) sensors Please check connections and sensor or go to diagnostics to check Error code.

3. **SETUP ERROR** The radar system is active but there is no sensor assigned to any camera view. Please check the total setup of the system.

To go to diagnostics, follow the steps:

Step 1. Open the service menu and go to system settings.

Step 2. Select the Radar setup menu.

Step 3. Select the Diagnose radar syst. Menu, as in **Fig. I-47**. When activating the Diagnose radar syst menu the mode shown is “Zone” (default). With the enter button (8) you can change mode to: Zone, Type, Range and Distance (see **Fig. I-48A**). While in the diagnostics, the status of each sensor will be indicated next to its corresponding ID. See **Fig. I-48B** for interpretation of the sensor status.

Fig. I-47: Diagnose Radar Syst. Menu

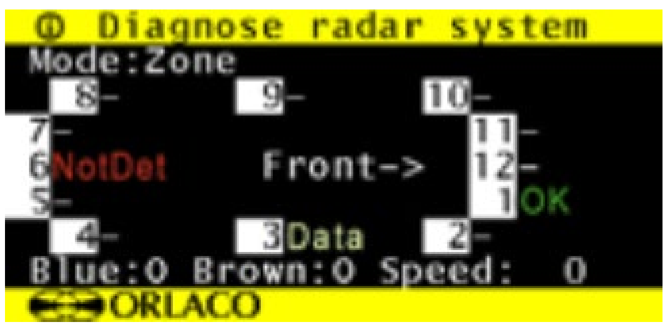


Fig. I-48A: Radar Diagnostic Options

–	Indicates that that specific sensor is not used/ allocated to a camera.
OK	Allocated and connected sensor (OK = no object in range) or the distance to the object in range with colored dots.
Data	Means that data is received from that sensor. However, the sensor is not allocated to a camera.
NotDet	Means that the sensor is allocated to a camera, however, no data is received from a sensor with that ID.
Err01	Means there is no communication between Master and Slave

Fig. I-48B: Interpretations of the Radar Diagnostic Options

I.4 Cost Estimation of the Pilot AdViSE System

Table I-7 provides an inventory of the hardware parts and supplies that have been used to develop the pilot AdViSE system, along with Unit cost of each components (note: Tax is not included in the cost estimation). **Fig. I-49** shows pictures of some key components.

Table I-7. Cost Estimation of the Equipment/Materials Used for the Pilot AdViSE System

Item#	Qty	Description	Unit Price	Picture
1	1	Set Monitor 12'' RLED Serial R6	$1,154	Fig. I-49A
2	1	SRD Interfacing Box	$693	Fig. I-49B
3	1	Multiview Box II	$416	Fig. I-49C
4	4	Camera FAMOS Camera (118Φ) NTSC IR	$502	Fig. I-49D
5	1	Cable 3M UNI 4P Molded	$65	
6	1	Cable 7.5M (24.6 ft) UNI 4P	$75	
7	1	Cable 11M Unit	$77	
8	1	Cable ATVC Camera 6M 7-PIN	$71	
9	1	Cable 15M 4P Molded Connector	$165	
10	1	Cable 15M M12 Green	$127	
11	1	Cable 8M Master-Slave Red	$106	
12	1	Cable 1M UNI 4P Molded Connector	$56	
13	1	A Pair of Radars (for Corner Rear)	$1,871	Fig. I-49E
14	4	Rain Cover for Compact Camera	$25	
15	1	Mascot 8862, 12/24V – DC/DC CO	$398	
16	1	Adapter Cable 4P Male-7P Female	$50	
		Total Cost Estimation	**$7,432**	
TBD		Installation accessories, bracket, etc.	Optional	

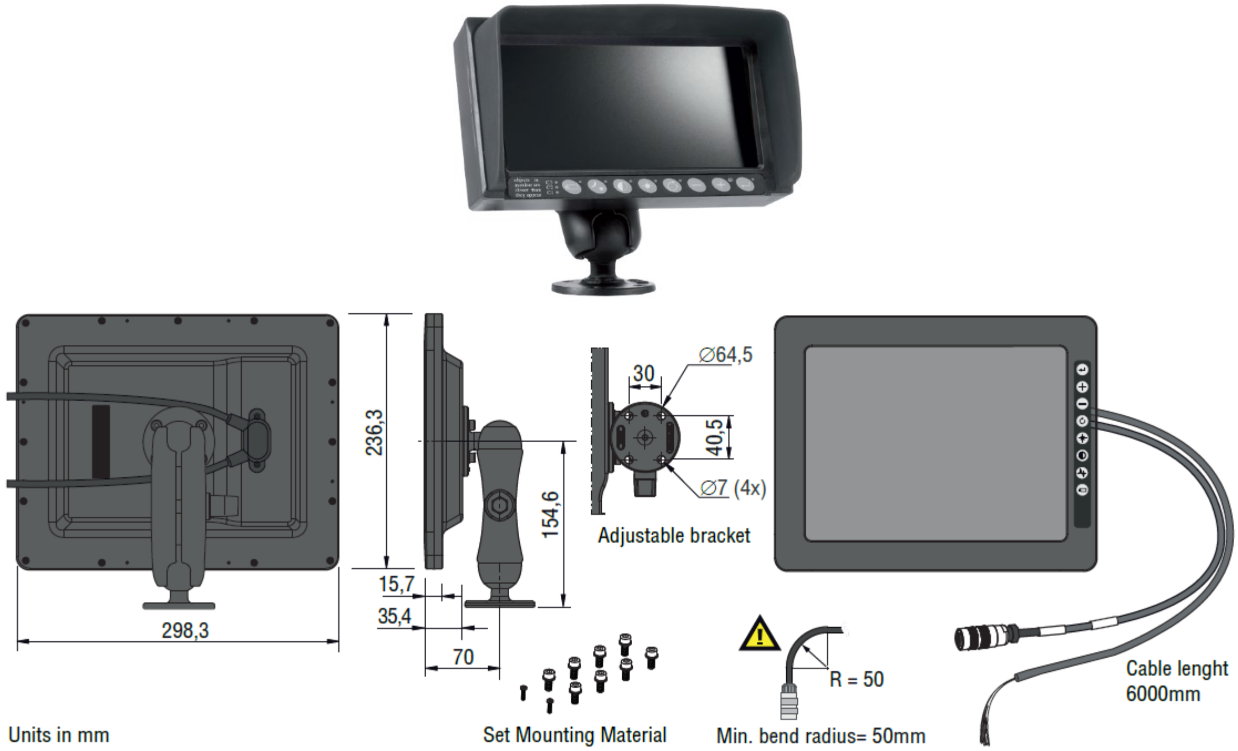


Fig. I-49A: Dimensions of 12” Monitor with CAN Interface

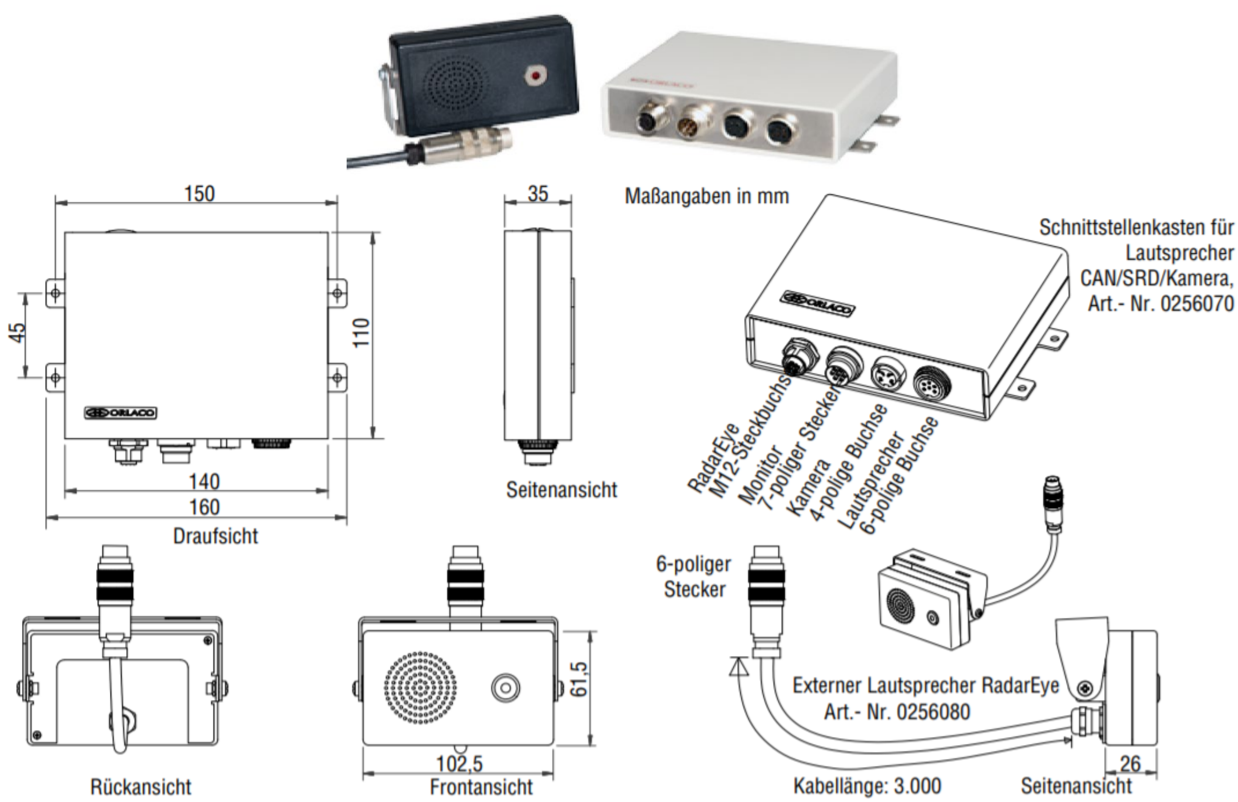


Fig. I-49B: Interfacing Box

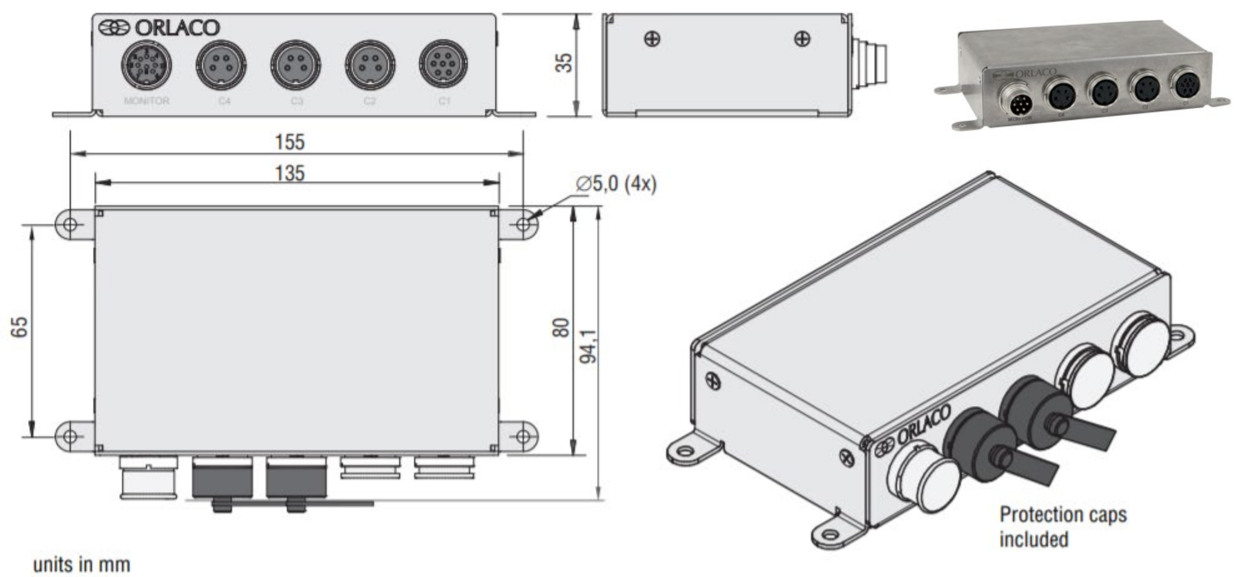


Fig. I-49C: Multiview Box II Serial

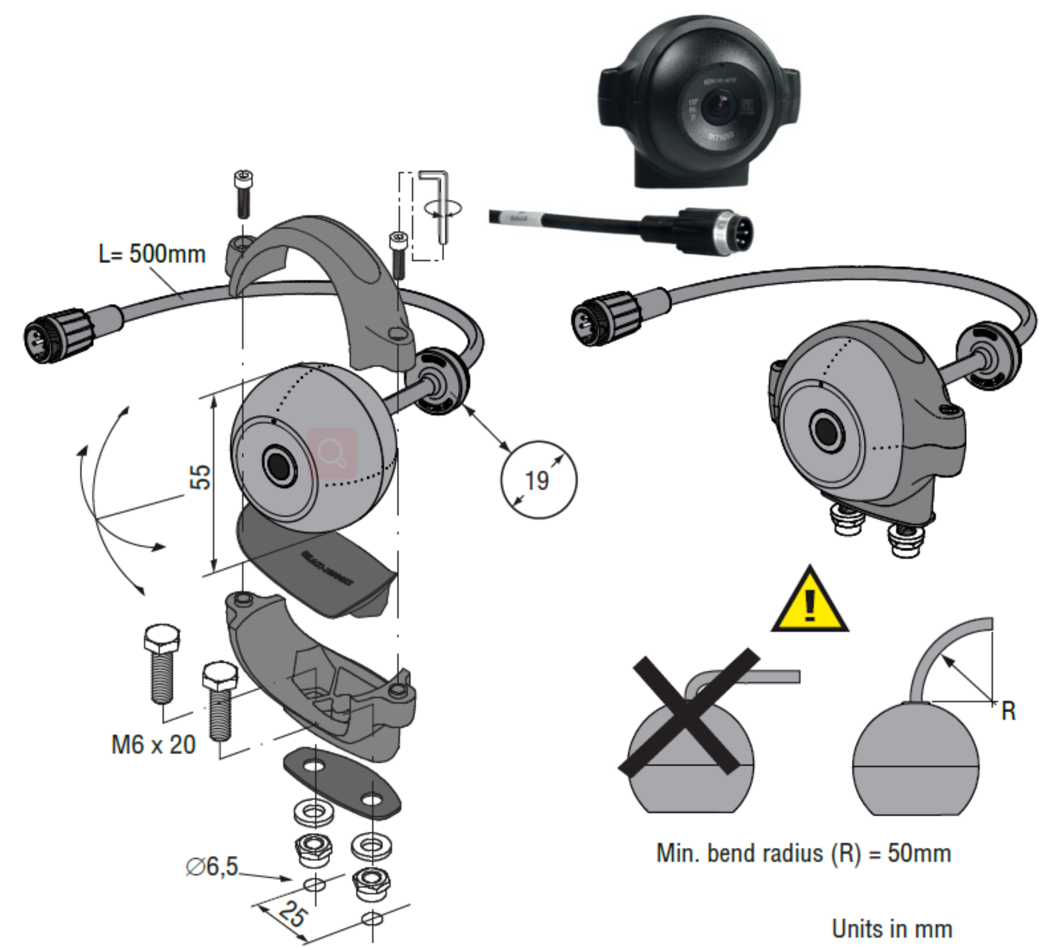
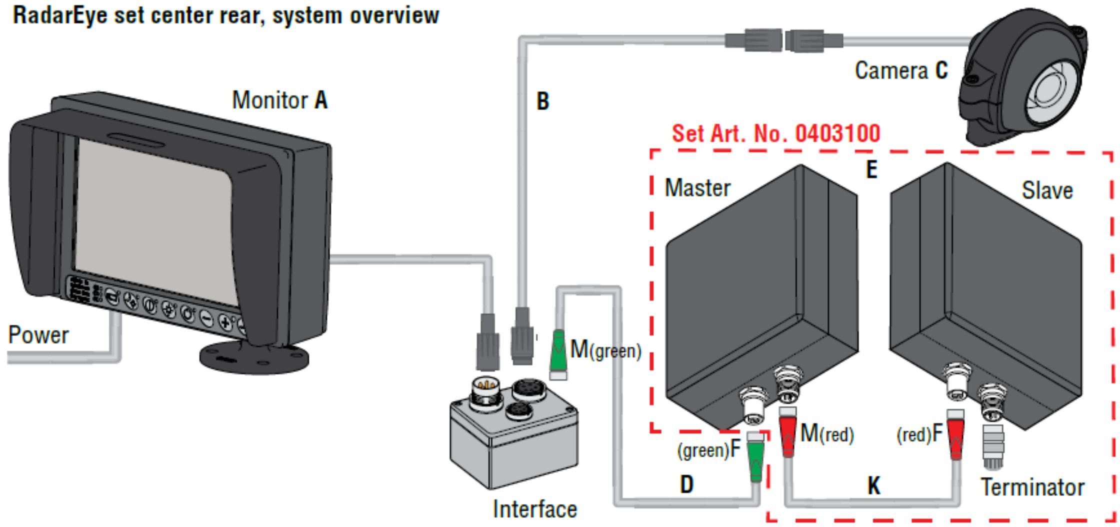
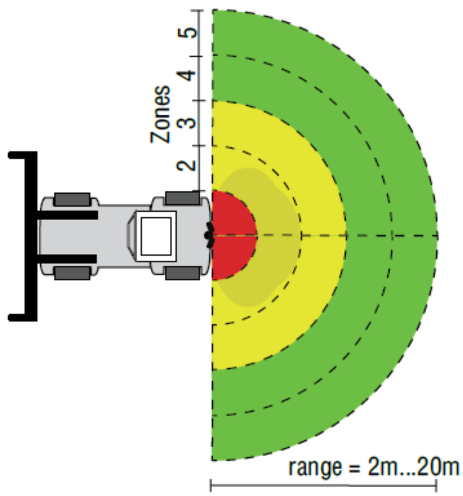


Fig. I-49D: FAMOS Camera





Set SRD Center Rear, Art. No. 0403100
consisting of:
2 x Art. No. 0004320 SRD sensor CAN vertical
1 x Art. No. 0401320 Bracket SRD Sensor center rear
1 x Art. no. 0301080 0,25m M12 M-S Red
1 x Art. No. 0350110 M12 Terminator 120 Ohm

Fig. I-49E: Pair of Radars
(Explanation: A – Monitor, B - Camera Cable, C – Camera, D - Radar Cable, E - Radar Set, center rear, K - Radar connecting cable)

Appendix II: Testing Methodology for Truck Detection System

II.1 Methodological Framework

The flow chart shown in **Fig. II-1** represents the planned testing procedure for the AdViSE system. The procedure starts with installation of the system components which are cameras, radars, and the screen. The testing area can be prepared parallel to the component installation. Once both the procedures are done, different tests based on different components as shown in the flow chart are performed and the data is collected. The collected data from tests is further processed and test results are published. These results are validated by performing surveys that are truly based on system evaluation.

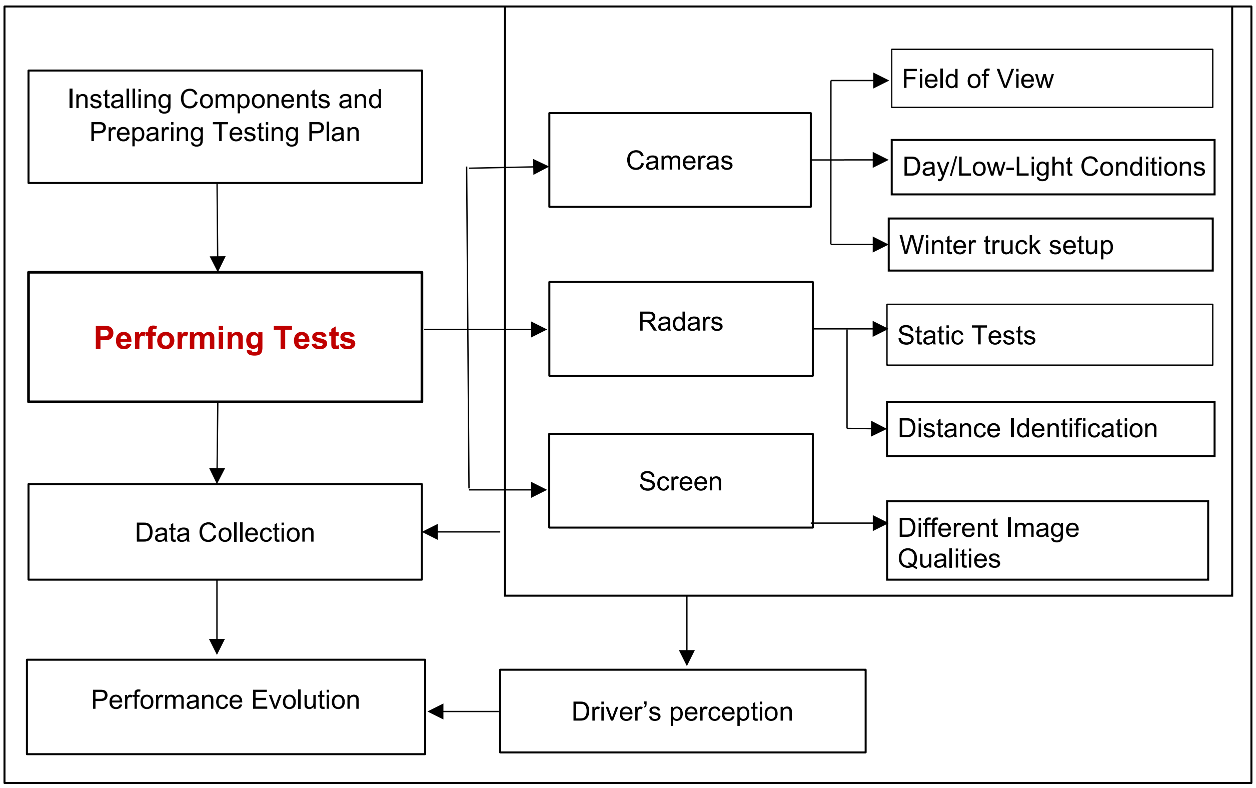


Fig. II-1: Illustration of the AdViSE System Testing Procedure

II.2 Camera Testing Method with Measurable Criteria

II.2.1 Layout of Ground Grid for Measuring Cameras' Fields of View

Fig. II-2 illustrates the concept of the cameras' fields of view, on the basis of which the cameras' detection capability will be tested and possible blind areas will be identified. The purpose is to identify the camera viewable area and blind areas. The test area is designated as an open ground with 1' X 1' grids. Cones (and mannequin, if available) are required as detection objects.

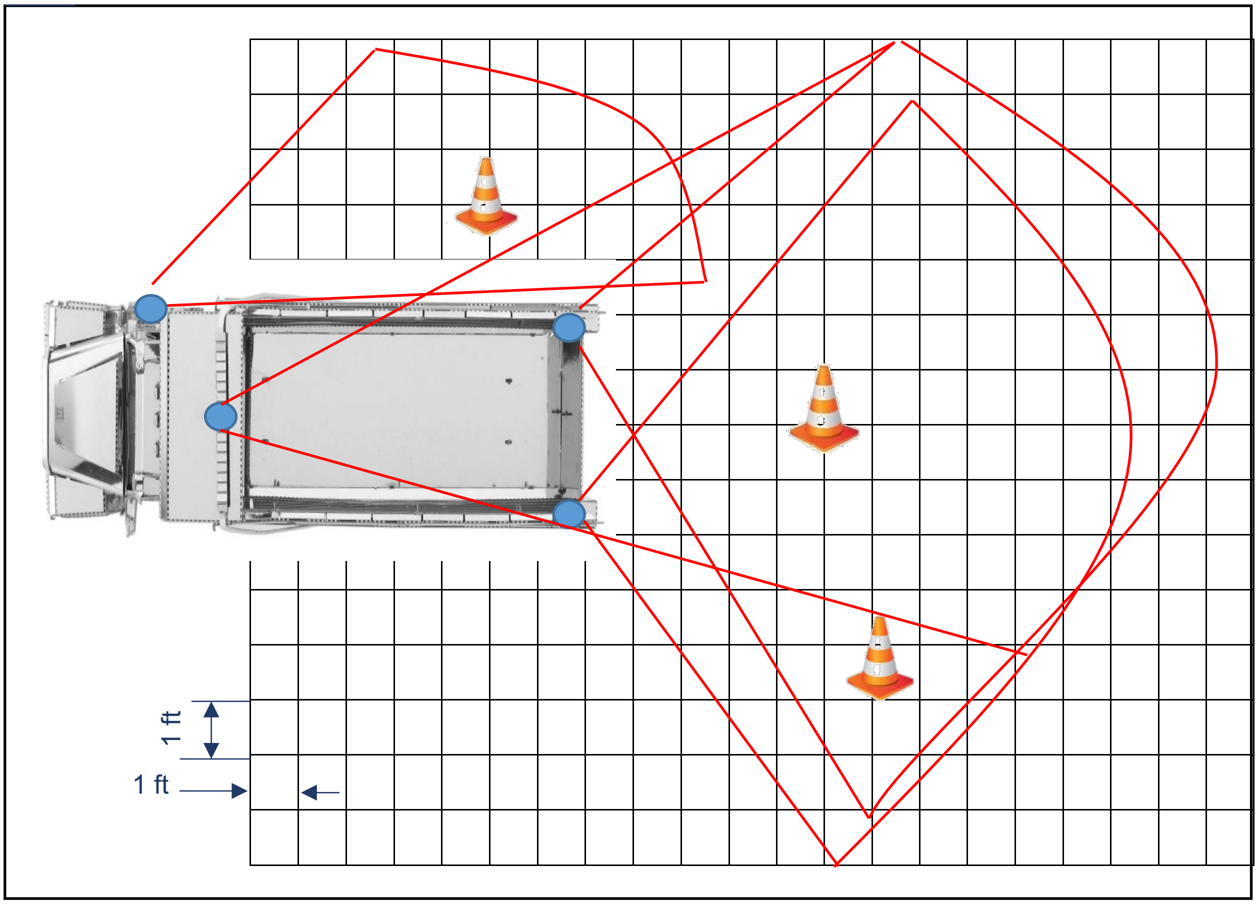


Fig. II-2: Illustration of Cameras' Fields of View

II.2.2 Steps for Measuring Cameras' Fields of View

- Step 1: The testing process starts with marking grids on the ground and the truck is moved onto the grid marked area (**Fig. II-2**).
- Step 2: For rear view camera, place a cone in each grid space, starting with the space immediately below the camera, and check for the visibility of the cone. For side view cameras, place the cones randomly on the edge view points of the visible area and move on to Step 4.
- Step 3: If the cone is detected by the camera through the screen, mark the appropriate grid as visible, if not mark the grid as invisible.
- Step 4: Develop field viewable area as shown in **Fig II-2** by joining the visible points. If the required field of view is unable to detected, change the position of the camera and repeat the procedure from Step 2.
- Step 5: Repeat the procedure from Step 2 through Step 4 against night light conditions.
- Each of the above steps will be video recorded.

II.3 Radar Testing Method Measurable Criteria

II.3.1 Static Testing

The purpose is to identify the radar detection area. The test area can be an open ground with marked 1'X1' girds. Cardboard cylinder, sphere, cones, or mannequins may be used as detectable objects to be arranged at sitting and standing positions.

The testing procedure includes the following steps:

- Step 1: After installation of the radar sensors, the vehicle is brought onto the open ground which is marked with 1'X1' grids.
- Step 2: Objects are placed starting from the row of grids which are located immediately behind the rear bumper and are checked for the triggering of the alarm. The process is repeated and checked for the intensity of identification by the radar.
- Step 3: After one full row of grids are tested the object is moved to the next row.
- Step 4: Repeat steps 2 and 3 for multiple attachments, under different weather conditions and for soiled radar sensors. All collected records are input into data collection sheets for later-on process. **Fig. II-3** and **Table II-2** provide samples of field record data sheet for static testing during different periods of time and under different weather conditions.
- Step 5: Based on the intensity of alarm and number of times did the system identified the object, the area behind the vehicle is divided into five zones as shown in **Fig. II-4**.

Vehicle Rear Bumper

	7	6	5	4	3	2	1	0	1	2	3	4	5	6	7
1															
2															
3															
4															
5															
6															
7															
8															
9															
10															
11															
12															

Fig. II-3: Data Collection Sheet for Static and Dynamic Test

(The number represents the distance in feet)

Table II-1. Static Test Data Processing Sheet

Test No	Zone	Object	Height Of object (ft)	Width of object (ft)	Distance from Truck (ft)	Average Response time in (sec)	Percentage of True Detection	Percentage of False Detection
1								
2	**I**							
3								
1								
2	**II**							
3								
1								
2	**III**							
3								
1								
2	**IV**							
3								
1								
2	**V**							
3								

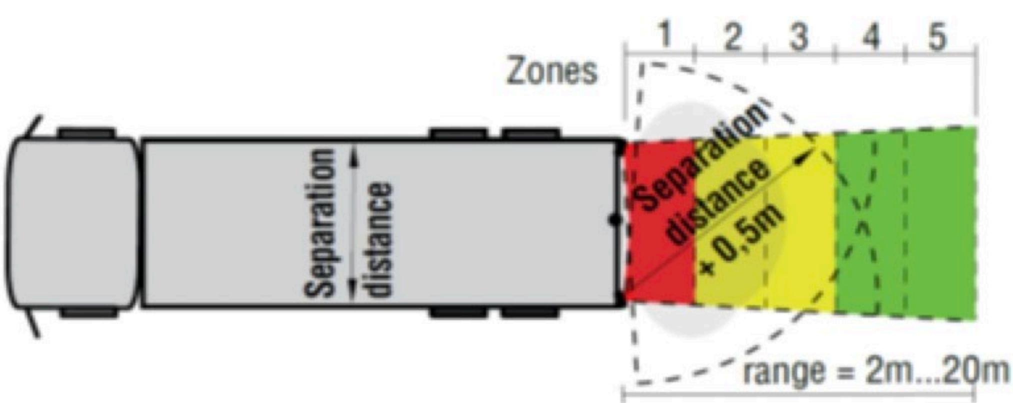


Fig. II-4: Representation of Zones in Static Test

II.3.2 System Testing Method

The purpose is to conduct a real-time testing of the detection system. The test area can be any workzone site. Detection objects may be mannequins and/or persons.

The testing procedure includes the following steps involved in a real-time scenario.

- Step 1: Train drivers about the system.

- Step 2: Identify a work site under ODOT and make necessary arrangements (like spotters).
- Step 3: Test the working of system for identifying the object and alerting the driver to take down the response time.
- Step 4: Repeat the testing process with as many ODOT drivers as possible.
- Step 5: Take a survey from ODOT drivers, resulting in the perceived performance of the system from the drivers' point of view (survey reports to be developed).

II.4 Literature Review of Testing Methods by US DOT and Other State DOTs

Table II-3 summarizes the testing methods by the US DOT and other State DOTs which have been reviewed by the research team and referred when the recommended methods (as described in the sections II.1 through II-3) are proposed for ODOT.

II.4.1 Camera Testing

II.4.1.1 Alignment

What is Alignment?

Alignment is the positioning of the camera. The proposed system contains four cameras covering the blind-spots, dump-bed and one on the either side of the cab.

Why is it necessary?

As mentioned in **Fig. II-5**. the functional requirements of camera are to present the required field of view, in order to have reference while performing activities like backing. This requires alignment activities to be performed so that the position in which the camera is fixed will be justifying its requirements. Also, the selected system has cameras with horizontal angular views of 118° and 80°. By performing the alignment activities, proper utilization of the angular view can be achieved.

How to Align?

There is no pre-defined or pre-performed procedure for this test. It can be performed by trial and error method by placing the cameras at different places which unveils the required spots for the driver's vision. Proper positioning of cameras in commercial vehicles can be achieved by satisfying the following functional requirements (Terzis, A., 2016) of the camera systems:

- Provided fields of view
- Positions compatible with different vehicle variants
- Driver's understanding of depth and speed
- Negative effects from direct light into the cameras
- Problems of soiling
- Cover horizontal field of view
- Cover vertical field of view
- Low impact of glare and flare during regular movements of vehicle
- Proper usage of daylight

Achievement of proper alignment can be tested by checking for the camera positions in accordance to the above proposed requirements.

When is it critical?

This is an initial stage test which helps in positioning of cameras.

Table II-2. Testing Methods Followed by Other State DOT's

DOT	Type of Trucks Tested	Tests Performed	Weather Conditions	Object Use	Reference
US DOT	Commercial Trucks (Medium Sized)	**Radar:** Static and Dynamic tests **Camera:** Video system viewable area **Screen:** Not Performed	Not Performed	**Static Test:** 12-inch, 18-inch, 28-inch, and 36-inch traffic cones, 20-inch-tall PVC pole, 40-inch-tall PVC pole, 1-year-old ATD, 3-year-old ATD, 1-year old child, a 3-year-old child, and an adult male. **Dynamic Test:** 40-inch PVC pole, 1-year-old, and 3-year-old crash dummies, and a toy car, called a "Cozy Coupe®"	Mazzae, E. N. and Garrott, R. W. (2007).
Texas DOT	Dump Trucks, Pickup Trucks, Service Trucks	**Radar:** Static, Dynamic, Dirty Sensor, Pilot test. **Camera:** Not Performed **Screen:** Not Performed *Radar was placed at different positions during the test.	Not Performed	**Static Test:** Person **Dynamic Test:** Mannequin *For static test instead of using a vehicle a wooden frame was used	Fan et al., (2019).
Washington DOT	Dump truck, Sanding truck	**Short Term Tests:** For initial Positioning **Long Term tests:** For testing the reliability of system (static and dynamic) **Camera:** Not Performed **Screen:** Not Performed	**Dump truck**: Winter **Sanding truck:** Summer *No reason	Person	Ruff, T. M. (2003)
Indiana DOT	Dump trucks	**Radar:** Static and dynamic tests (not in grids) **Camera:** Field of View **Screen:** Not Performed	Not Performed	Person	Ferreira-Diaz, C. A et al. (2009).
Michigan DOT	Winter Maintenance Vehicles	**Camera:** Performed real time dynamic test for evaluating relative speeds of three different vehicle types and the warning light activation. **Radar:** Not Performed **Screen:** Not Performed	Winter Conditions	Vehicles (a SUV, a large SUV, and a passenger car)	Zockaie et al., (2018).

DOT	Type of Trucks Tested	Tests Performed	Weather Conditions	Object Use	Reference
New Hampshire DOT	Dump Trucks, Front-End loader	Report based on the surveys made after sample installation to vehicles	All conditions	--------	Hall, A. D., & Roberts, G. E. (2011).
Virginia DOT	Trailer	Grid tests, False alarm test, Driver-In-Loop test.	Not Performed	Objects (Cardboard cylinder, mannequin)	Perez, et al., (2011).
Florida DOT	Large Trucks	**Camera:** controlled tests (No evidence for results shown in report) **Radar:** Not Performed **Screen:** Not Performed ** Majority of the report based on surveys	Not Performed	--------	Kourtellis, et al., (2009).

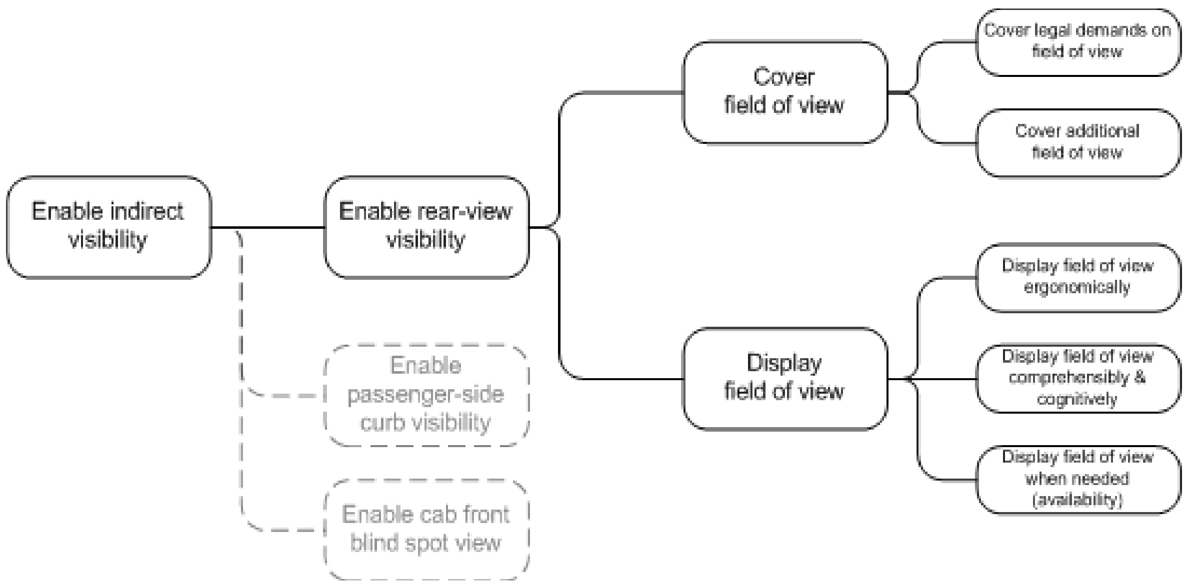


Fig. II-5: Functional Requirements of the Camera

(Fornell Fagerström, K. & Gårdlund, A. (2012))

II.4.1.2 Distance Estimation

What is Distance Estimation?

Capability to estimate the actual distance of the object or vehicle based on the image projected by the camera on the screen.

Why is it necessary?

Many accidents happen due to incorrect estimation of distance of the vehicle or object. It is equally important to know the vicinity of the other vehicles and objects (Megalingam et al., 2016).

How to test?

Schmidt et al. (2015) presented a test for estimating distances while using cameras performed by Bundesanstalt für Straßenwesen (BASt) (**Fig. II-6**), Federal Highway Research Institute, Germany. This can be considered as a reference for the distance estimation test for the cameras. The test procedure followed by BASt is as follows:

A total of 10 male subjects took part in the experiment. All subjects were employees of the BASt. The average age was 51.1 years (SE = 2.4). Of the ten subjects, eight of them had not driven a truck for an average of 11.4 years. 50% of the subjects had experience with the camera-monitor system due to their participation in the CMS car study.

Prior to the experiment, all subjects received a demographic questionnaire which contained questions about visual aids, their last consultation to an ophthalmologist, their truck driving experience and routine use of exterior mirrors. All subjects were active car users and hold a class C or class CE driver's license. About visual function, all participants fulfilled the minimum requirements for visual performance according to Annex 6 of the German Driver Licensing Regulations.

Before starting the experiment, all subjects received the relevant information about the test procedure and data protection regulations. The subjects signed consent forms for participation in the experiment.

Fig. II-6: Explains the Distance Estimation Test Performed by BASt

(Schmidt et al., 2015)

For the evaluation of the CMS, all subjects carried out a test drive at the BASt test facilities as well as in real traffic. The subjects evaluated the CMS based on specified criteria by means of spontaneous statements and questionnaires. To get used to both systems, the subjects first completed an exercise drive at the BASt test facilities. The exercise drive lasted approximately 20 minutes and included scenarios such as straight driving, curves, and straight reversing.

Before the test drive started, the subjects received explanations about the test procedure, an introduction of the truck operation system as well as information about the camera-monitor system.

The total experiment took about 2 hours per subject. In nine out of ten test drives the sun was shining with clear shadow formation. During one of the drives, weather was misty with little sunshine.

The distance estimation was performed at the BASt test facility by means of rear approach to two pylons to the right and left of the end of the vehicle. 4 m was selected for the distance estimation.

The pylons had a height of one meter and the distance between both pylons was 3.20 m. For the distance estimation, half of the subjects first started the rear approach to the pylons using the mirrors and then using the CMS; the other half of the subjects first started with the CMS and then continued with the mirror system. For rear driving using the CMS, the exterior mirrors were folded back.

Proposed Test Procedure

As the main objective of our work is to unveil the blind spot behind the truck to the driver during backing, the distance estimation test may be performed by placing the objects (may be pylons) in all the places that includes all the ocular points.

Pre-Test Procedures

- Select the number of drivers
- Collect details of the drivers like their demographics and medical details like eyesight
- Explain the test procedure to the selected drivers and provide an overview of how to operate the new technologies.

Test Experiment

- Place the pylons (cones) in different measured places in the camera monitoring area.
- Have drivers estimate the distance of the pylons.
- Check for match of the actual and estimated distances.
- Define the vision quality of the camera lens.

Post-Test Procedures

- Gather information regarding the experience of the drivers using the cameras.

Objects Required

- Parking Cones

When is it critical?

- At component level testing, this can be performed at the initial stage of testing.

II.4.1.3 System Viewable Area

What is it?

- The field of view served by the system.

  Why is it necessary?

- To present the area that is displayed by the system around of the vehicle to which it is installed.

  How is it performed?

Mazzae, E. N 2007 and Perez, et al., (2011) performed this test as a grid test by placing the object at different positions behind the vehicle for identifying the camera viewable area.

The field of view can be graphically represented as shown in **Fig. II-7**, which helps the driver in estimating the visible area behind the vehicle when the system is installed which further helps in making decisions.

Objects Required

- Parking Cones

  When is it critical?

- After the camera is installed.

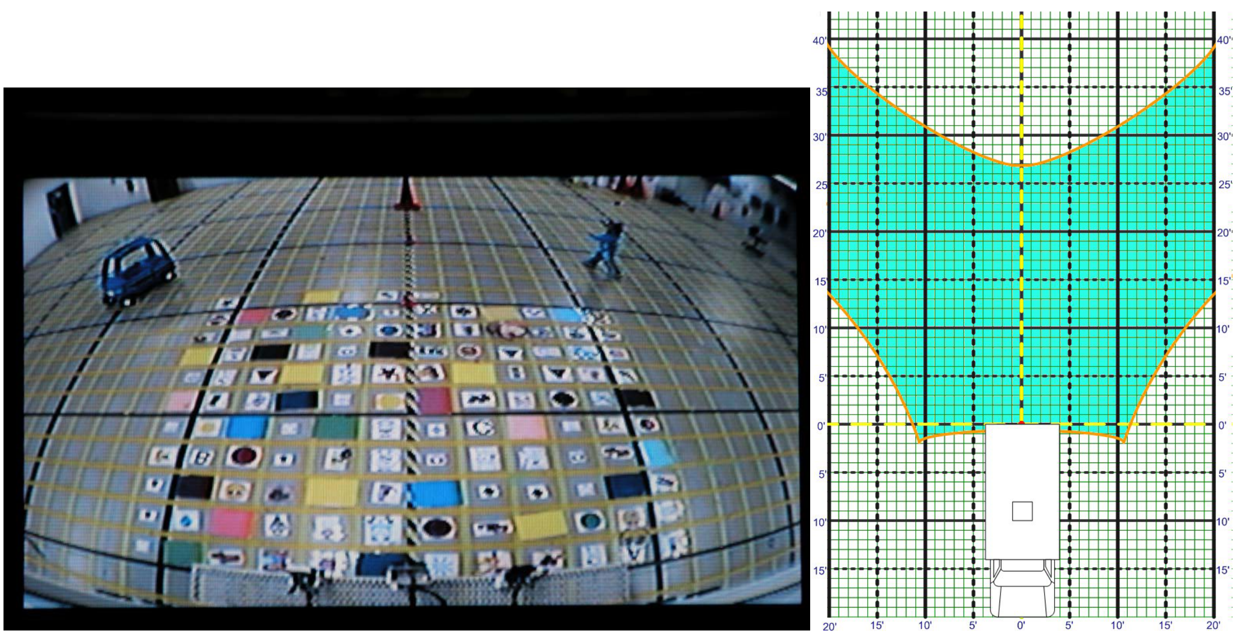


Fig. II-7: Sample view and graphical representation of FOV

(Mazzae, E. N. and Garrott, R. W., 2007)

II.4.2 Radar Testing

Both static and dynamic tests were performed with most concentration on radar. The tests proposed in this section may be incorporated as a part of static and dynamic testing.

II.4.2.1 Objects of Different Shapes

What is it?

This test investigates the effectiveness of the radar for different shapes of objects.

Why is it necessary?

The size of a target as "seen" by radar is not always related to the physical size of the object (Skolnik, 1990). The measurement of the target size as observed by the radar is called the radar cross section, and is given in units of area (square meters). Objects of similar cross-sectional area differ in radar size. For example, a flat plate with an area of 1 square meter would produce a radar cross section of about 1,000 square meters at a frequency of 3 GHz when viewed perpendicularly to the surface (Skolnik, 1990). A cone may be read as having a smaller cross section area as compared to a sphere.

How to test?

This, as a part of static or dynamic testing, was performed by placing objects of different shapes and sizes to assess the presence of an object in the vicinity of the radar.

When is it critical?

This can be tested as a part of system level testing, by using objects of different shapes rather than using a single pole or mannequin.

II.4.2.2 Test for Objects Interference

What is it?

This test addressed the possibility of interference from other attachments of the dump truck. A procedure for drivers to use radars correctly was developed based on the test results.

Why is it necessary?

Different attachments are added to the back of dump truck for tasks such as salt spreading or asphalt dumping. The radar may detect these objects and produce false alarms. This test determined the impact of attachments and produced a procedure on how to adjust the radars for dump truck drivers.

How to test?

Different attachments were installed before performing both dynamic and static tests on the radars.

When is it critical?

This can be tested as a part of system level testing, by placing multiple objects in the vicinity of the test area while performing static and dynamic tests.

II.4.2.3 Static Testing

What is it?

Installed system was tested while keeping both the vehicle and the object behind static.

Why?

This testing approach was performed to validate the operation of the installed system, identify the system detectable area, and take drivers' opinions for analyzing whether to make any changes in the technologies installed.

How to test?

Mazzae, E. N., & Garrott, R. W. (2007) and Ruff, T. M. (2003) performed the static test previously where a person or an object was shifted to different positions while keeping the vehicle static. Based on the procedures used by Mazzae and Garrott (2007) and Ruff (2003), the testing procedure was framed.

The floor of the testing area was marked in the form of grids each of 1 ft^2 where the objects or person were placed to be detected. After marking the grid, the objects were placed on the grid marks located immediately at the back edge of the truck. Each object was tested for detection by both radar and cameras in the row of grids immediately behind the truck. After completion of the test in one row the object or the person moved to the next row and so forth until the system stopped detecting the object.

Testing was performed in different locations in the vicinity of the camera and radar, which contained the targeted area of detection. Different researchers used different modes of identifying the level of detection. Mazzae, E. N., & Garrott, R. W. (2007) defined a symbolic nomenclature as shown in **Fig. II-8** for representing the level of identification of object by the radar.

Fan et al. (2019) represented the identification level by preparing a cumulative chart for tagging the grid with the number of times the object was identified by the radar system as shown in **Fig. II-9**.

Highest Level Warning	●
Intermediate Level Warning	◐ (grey circle)
Lowest Level Warning	○
Inconsistent Warning	⊗
Location Tested But Object Not Detected	·

Fig. II-8: Symbolic Representation of Level of Identification

(Mazzae and Garrott, 2007)

However, the tagging method was found to be more effective as repetitive testing can minimize the effects of false alarms. Repetitive testing is performed by placing the object in the same place for multiple tests. Once the testing process was completed different zones were identified by Fan et al. (2019) based on the intensity and level of detection. The zones included total coverage, reliable area, sporadic area, and proximity detection.

Total coverage included the total detected area irrespective of the number of detections. Reliable area included the coordinates where maximum number (more than nine out of ten trials according to Fan et al., 2019) of detections were identified. Sporadic Area included the grid cells where the lower number (less than nine out of ten trails according to Fan et al., 2019) of detections were identified. Proximity detection included the systems capability to detect the object up to certain distance from the vehicle (3 feet according to Fan et al., 2019).

When is it critical?

After the radar is installed.

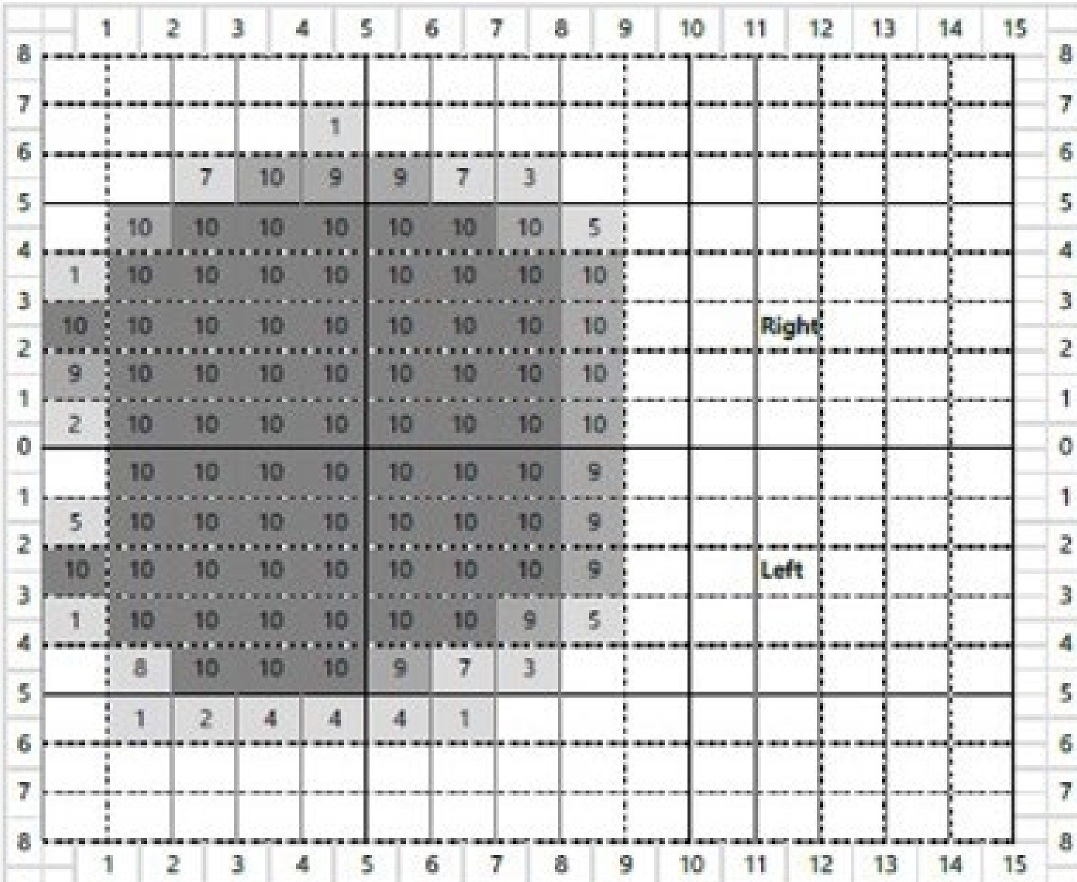


Fig. II-9: Representation of Detection Zone by Tagging (Fan et al., 2019)

<u>II.4.2.4 Dynamic Testing</u>

<u>What is it?</u>

Cameras and radars were tested with the vehicle moving while the object behind remained static.

<u>Why?</u>

This testing approach was performed to verify that the installed system was operational, and also to take drivers' opinions and make any necessary changes in the technologies installed.

<u>How to test?</u>

<u>II.4.2.5 Grid Test</u>

Like the static testing, this testing procedure required marking the grid cells on the ground with an area of 1 ft^2. The same objects were used for this test as well. The only difference for this test is that the vehicle was under motion while the object remained static.

Mazzae and Garrott (2007) performed dynamic tests with two different methods. One method kept the vehicle static while moving the object, while the other kept the object static while moving the vehicle. The tests were performed with different objects (human and non-human) and with the vehicle backing up at different speeds as described in **Table II-3.**

Table II-3. Usage of Different Speeds in Dynamic Testing In Two Ways
(Mazzae and Garrott 2007)

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

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

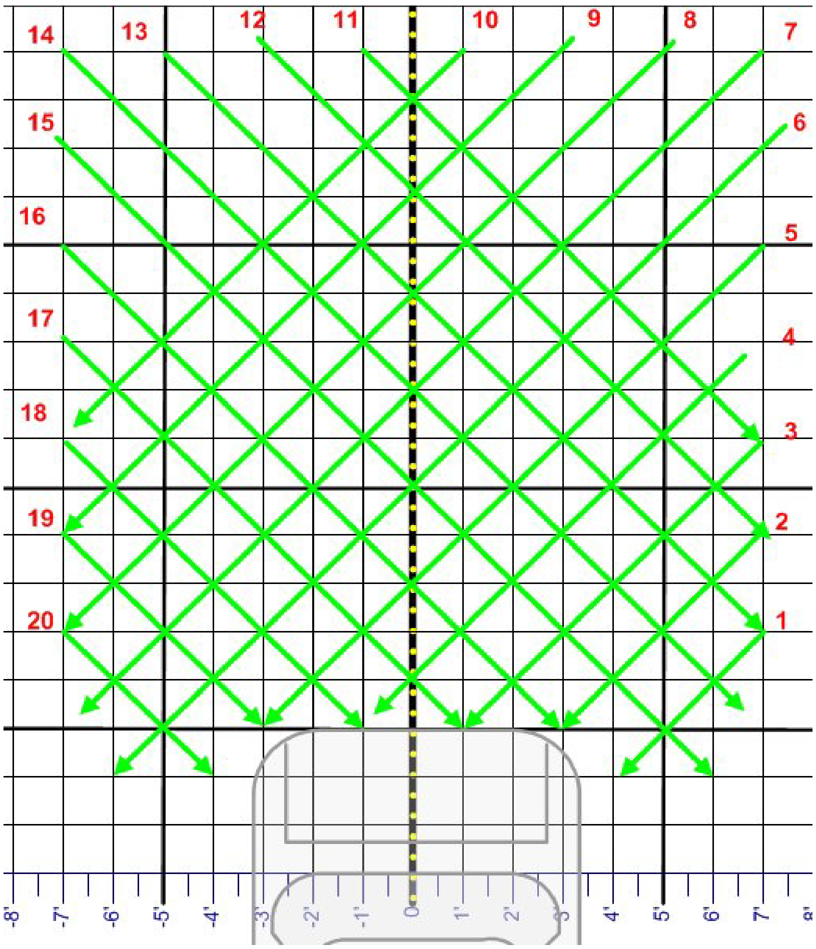
	Child, 1-yr-old		Child, 3-yr-old			Adult Walking
	Walk	Towed Ride-On T	Walk	Run	Pedaled Ride-On Toy	(Outdoors)
Eagle Eye	3-7	3-9	4-10	2-4, 6	2-11	4-6
HaoDi	5	8	4	4-5	7	7
Hindsight 20/20	8	8	8	8	9	9
Vorad Backspotter	8-11	9-12	8-14, 16	9-12, 14-15	8-11, 13-14	5-18

Mazzae and Garrott (2007) also tested for identifying different paths on which the system can detect the movement of the objects. The paths which were identified are shown in **Fig. II-10**.

The latter was performed on a cone and a car, keeping the vehicle moving and the detectable distance was noted as shown in **Table II-4**.

Fan et al., (2019) performed the dynamic testing on a mannequin following the same method of tagging the grid cells with the number of times which the object has been detected. However, there was little change from the static testing. In dynamic testing Fan et al., (2019) incorporated the distance measuring method linking with the static testing as shown in **Fig. II-11**. Here, the object was placed at a position behind the vehicle and the vehicle started backing towards the object. When the alarm was triggered, the distance at which the object was detected was measured. This test was repeated in different number of trials (5 according to Fan et al., 2019). The number of times the object was detected was tagged to the grid cell and the reduction in the detection zone was identified (**Fig. II-12**).

The detection zone can be identified once the process of tagging the grid cells is completed. The numbers in the highlighted box in **Fig. II-13** represent that the object was detected 3 times at 4 meters from the tail end of the vehicle and one each time at 5 meters and 6 meters. The number of trials performed here are 3+1+1 = 5. The distance is represented by the edge cells. The cells in red color represent the non-detection zone and the cells in the grey color represent the detectable distance.



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

Fig. II-10: No. of Paths Identified by Different Systems (Mazzae and Garrott, 2007)

Table II-4. Detectable Distances while the Vehicle is Moving (Mazzae and Garrott, 2007)

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

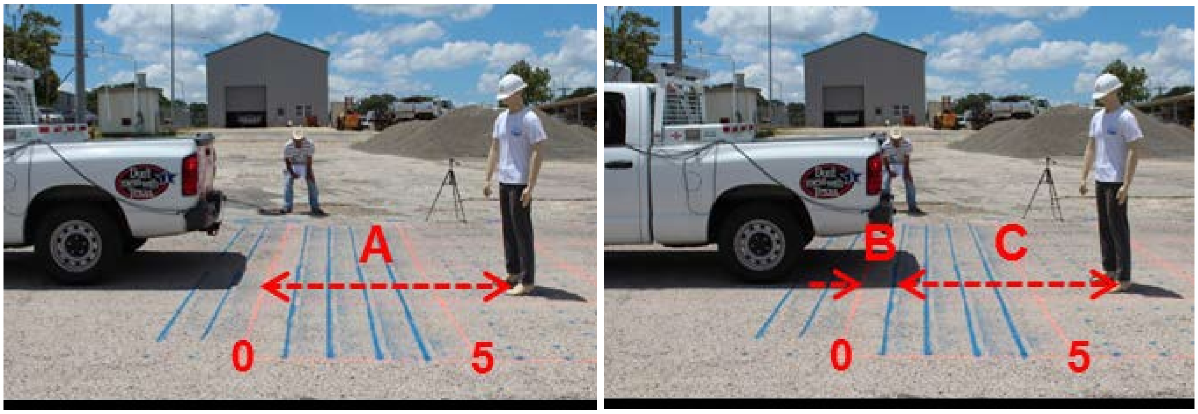


Fig. II-11: Dynamic Testing Based on Distances (Fan et al., 2019)

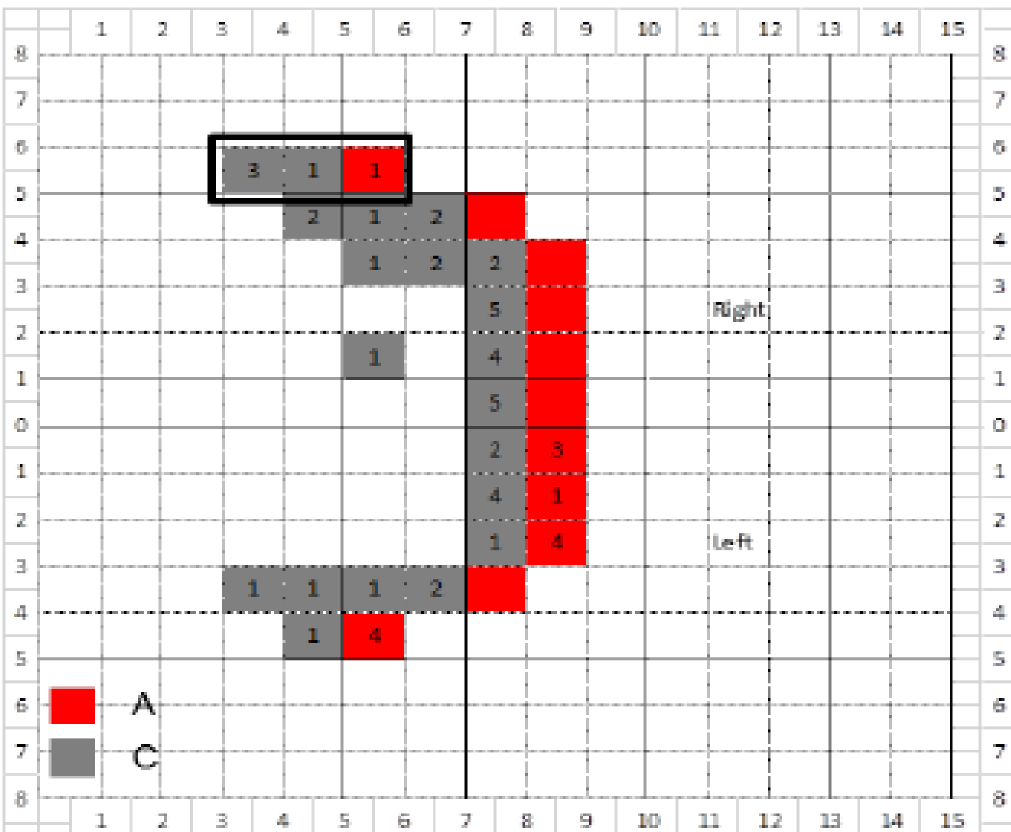


Fig. II-12: Cumulative Record Sample (Fan et al., 2019)

II.4.2.6 Non-Grid tests

Zockaie et al., (2018) performed real-time dynamic tests by fixing the component to the vehicles and his test results are based on the surveys given by the drivers who used the system.

When is it critical?

After the radar is installed.

II.4.2.7 Soiled Radar Testing

What is it?

Testing the radar when its external surface is covered with mud.

Why?

To find the impact of soiling on the radar's ability to detect objects, as construction working zones are often filled with dust.

How to test?

Both the static and dynamic tests are performed by using the soiled radars. Fan et al., (2019) repeated the static tests by soiling the radar systems as shown in **Fig. II-13**.

When is it critical?

This can be performed as a part of system testing.

When is it critical?

After installation of the radar.

Fig. II-13: Normal and Soiled Radar Sensors (Fan et al., 2019)

II.4.3 Screen Testing

II.4.3.1 Alignment

What is it?

Test for proper positioning of screen for convenient and faster observation.

Why is it necessary?

When the driver sits in the driver seat, movement of the head changes the field of view and movement of the eyes changes direction of line of sight (the line which connects the midpoint between the two pupils and the point of fixation that is observed) (International Organization for Standardization, 2008).

In monitoring tasks, the driver actively moves the eyes to seek information (International Organization for Standardization, 1999). Therefore it is necessary to properly position the screen.

How to Align?

International Organization for Standardization (2008) recommended certain suitable positions which are safe for a driver to observe while concentrating on driving. Different angles as shown in **Fig. II-14** were suggested with a labelling of A, B and C. The zone which lies between 15° in horizontal and vertical views on either side for the driver is the most recommended zone and is highly preferable for faster reaction.

The zone which is represented by B is safe but not highly recommended, and the zone represented by C is not at all recommended for positioning of the screen.

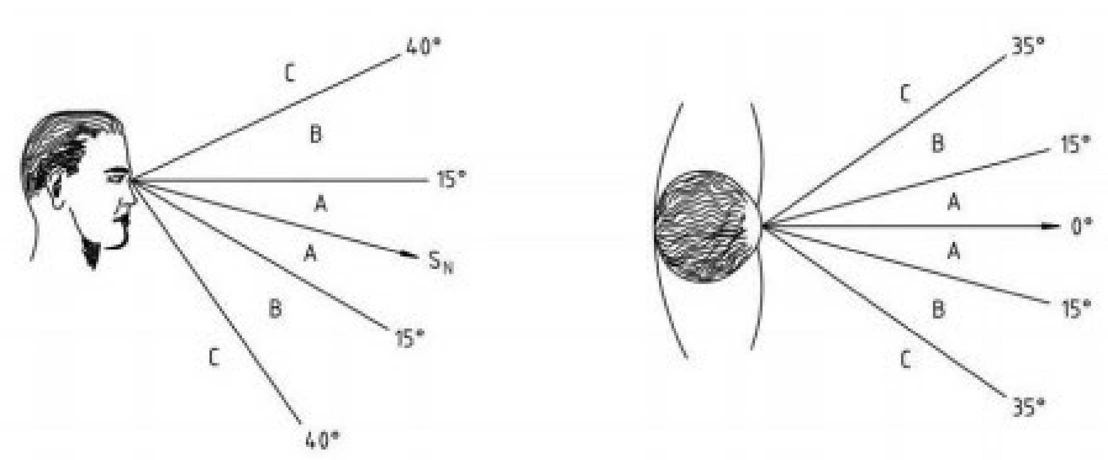


Fig. II-14: Suitable Positions for Field of View While Monitoring

(International Organization for Standardization, 2008)

Size of Screen:

According to Fornell Fagerström, K., & Gårdlund, A. (2012) the size of the screen is another factor to consider when positioning. A larger screen may be placed at a significantly farther distance while a smaller screen may be placed nearer. Fornell Fagerström and Gårdlund (2012) recommended certain positions shown in **Fig. II-15** based on the above-mentioned requirements.

When is it critical?

As a part of component testing, testing for alignment of screen must be performed in the initial stage of installation.

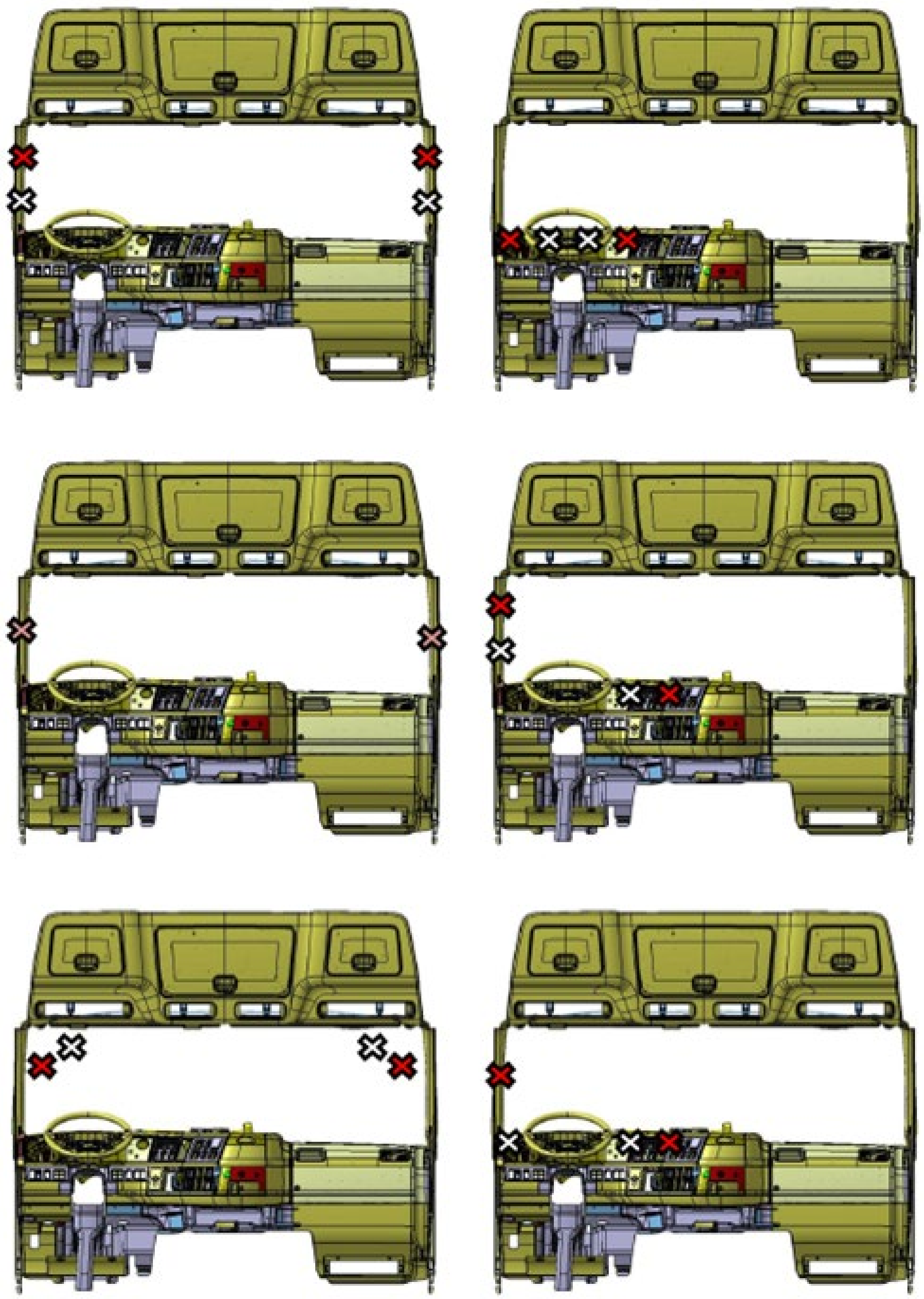


Fig. II-15: Recommended Positions to Place the Screen
(Fornell Fagerström and Gårdlund 2012)

II.4.3.2 User Interface

Image reproduction

For the evaluation of the image reproduction the following technical properties were examined by Schmidt et al. (2015).

What is it?

This test compared to the colors of items displayed on the monitor and in a conventional mirror against their original colors.

Why is it necessary?

This experimental test helped analyze the color rendering ability of the screen (even in different lighting conditions) and making some operational cautions for the driver.

How is it performed?

(a) Color rendering: As shown in **Fig. II-16**, this test was performed simply by placing several colored pencils in front of the camera and comparing the colors displayed on the screen with the original colors (Schmidt et al., 2015).

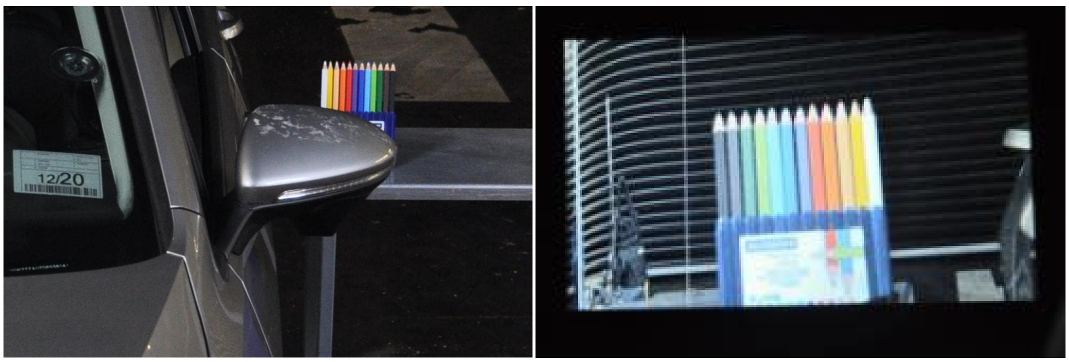


Fig. II-16: Color Range and Monitor Color Rendering (Schmidt et al., 2015)

(b) Behavior in glare: Schmidt et al. (2015) performed the test (**Fig. II-17**) by comparing the images produced in the screen and mirror due to the lighting that is projected on the camera from a vehicle behind.

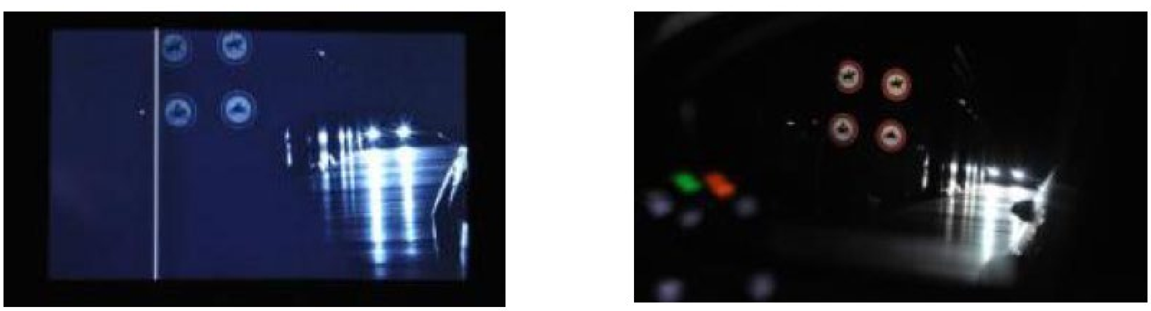


Fig. II-17: Glare Observed in Screen (left) and Mirror (right) (Schmidt et al., 2015)

(c) Behavior in extreme cold: The test for behavior in extreme cold condition that is shown in **Fig. II-18** was performed by Schmidt et al. (2015) at a temperature of -20°C (-4°F) by waving a hand in fort of the camera and recording the image observed in screen and the mirror.

Fig. II-18: Difference Observed in Hand Movement Screen (left) and Mirror (right)

(Schmidt et al., 2015)

(d) Effects of soiling: Fig. II-19 shows the test that was performed by soiling the mirror and the camera. Schmidt et al. (2015) performed this test in different steps by creating different stages of soiling by using materials like pollen, dust, dirt in water or salt and produced the images for different stages which proved the camera system is more clear under soiled conditions.

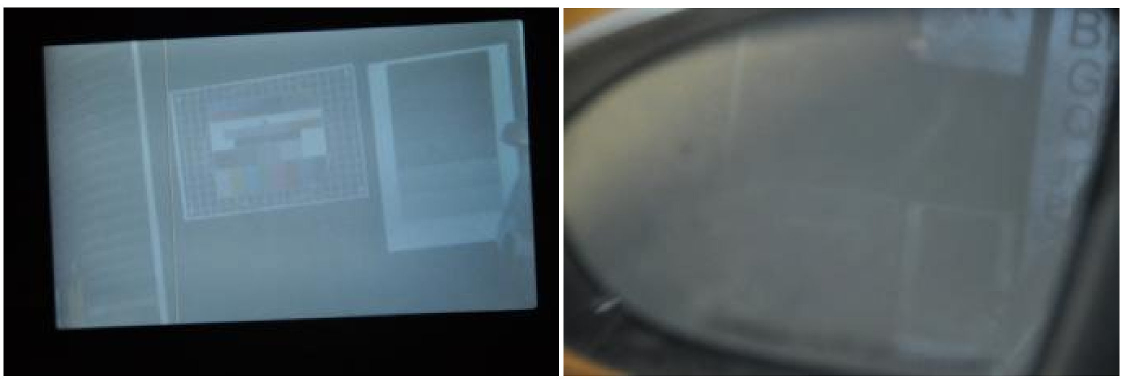


Fig. II-19: Images Displayed by Soiled Camera (left) and Soiled Mirror (right)

(Schmidt et al., 2015)

When is it critical?

After alignment and installation of cameras and the screen.

Appendix III: On-Site Tests of the Pilot AdViSE System

III.1 Testing Site and Criteria Measuring Viewing/Detecting Capabilities

The on-site tests were conducted at the ODOT Hilliard Outpost Garage (4400 Currency Drive, Columbus, OH 43228). **Fig. III-1** shows the testing site where the ground was marked with a 1'X1' grid, and demonstrates the layout of cones in each detection zone. The tests of the AdViSE system followed the methodological framework as described in Section II.1. The objective of the tests was to identify the zones of camera visibility and the zones of radar detection of the installed AdViSE system. The field of view (or FOV) of the cameras was divided into different zones using the criteria described in **Table III-1**. **Fig. III-1** represents the image quality criteria based on which different zones were identified during the on-site tests. The zones of radar detection were defined using the criteria as described in **Table III-2**. The representation of radar detection zones was adopted from the camera manual given by Orlaco. The AdViSE system produces audible alerts and displays color-based indications on the screen when an object is detected via the radars. As illustrated in **Fig. III-2** the indications are dots varying from 5 through 1 for objects at closer proximity to farther proximity respectively.

Table III-1. Criteria of Zones Based on Image Viewing Quality on the Monitor

Zone	Image Quality	Color Symbol
1	Best	Red
2	Acceptable and identifiable	Yellow
3	Acceptable but not clear	Yellow
4	Unacceptable	Green
0	Not in FOV boundaries or invisible	Black

Table III-2. Criteria of Zones Based on Object Detection Ability

Zone	Detection ability	Color Symbol
1	5 of5	Red
2	4 of 5	Yellow
3	3 of 5	Yellow
4	2 of 5	Green
5	1 of 5	Green

Specifically, the following tests are performed:

- Identify different zones of the camera's coverage in daylight and low-light (dawn) conditions in terms of the quality of visibility, with the use of a parking cone.
- Identify the radar coverage zones, in terms of the proximity of the object, with a human subject as target object.

During the radar coverage test, both radars operated separately. The human subject moved on the test grid in two different postures, standing and crouching, and zones were identified.

Fig. III-1: Testing Site with Layout of the Cones Measuring Camera Viewing Capability

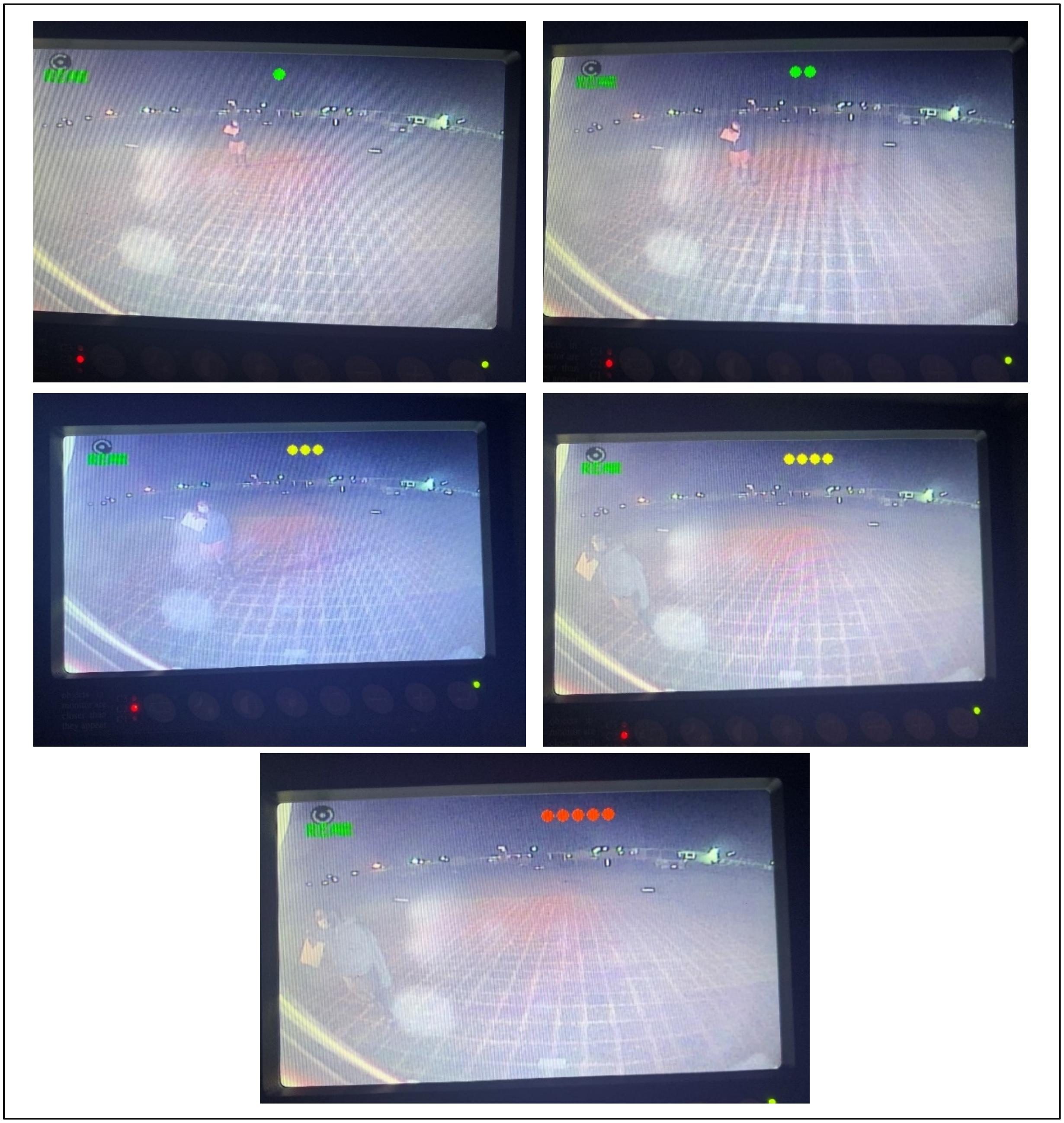


Fig. III-2: Radar Detection Zones as Displayed in the Monitor Screen

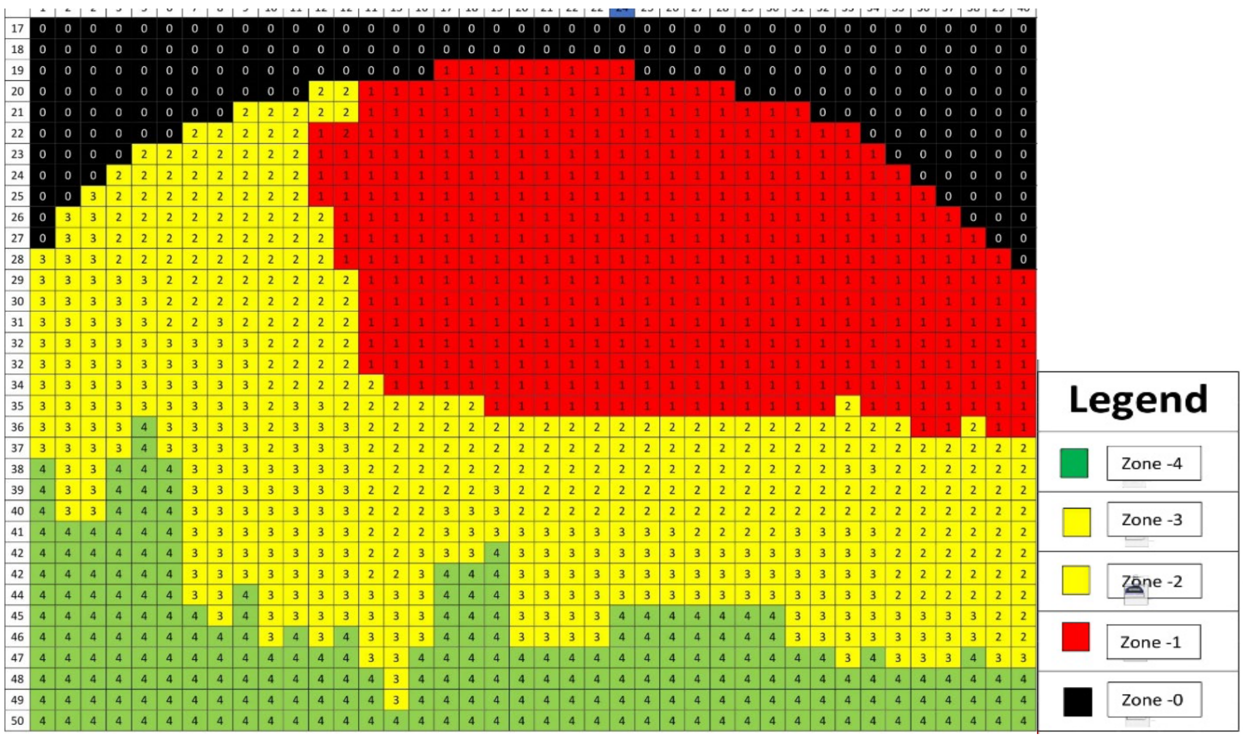
III.2 Visibility Zones of Camera

The area within the field of view of the camera was divided into four zones, assigning each zone a number from 1 through 4. The cone was placed in each cell on the grid within the approximate FOV determined during the tests. Based on the cone's viewing quality on the screen, each cell was identified as a zone, based on the criteria as described in **Table III-1**.

The best viewing quality (zone 1) was assigned when the white stripes on the cone were clearly visible and distinguishable. The worst viewing quality (zone 4) was assigned when the cone was visible but none of the color patches (white or orange) are distinguishable. Note that cases where the cone was partially visible with the stripes clearly separated, such as the cones on the left of the screen in **Fig. III-1**, were still rated as zone 1.

III.2.1 Rear Cameras

The zones of visibility for the rear camera are identified in two different lighting conditions, as shown by **Fig. III-3**. Each cell on the grid is color-coded for different zones.



17	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	0	0	0	0	0	0	0	0	0	0	0
18	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	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	2	2	2	2	2	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
23	0	0	0	0	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0
24	0	0	0	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0
25	0	0	3	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
26	0	3	3	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0
27	0	3	3	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0
28	3	3	3	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
29	3	3	3	3	3	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
30	3	3	3	3	3	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
31	3	3	3	3	3	2	2	3	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
32	3	3	3	3	3	3	3	3	3	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
32	3	3	3	3	3	3	3	3	3	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
34	3	3	3	3	3	3	3	3	3	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
35	3	3	3	3	3	3	3	3	3	2	3	3	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1
36	3	3	3	3	4	3	3	3	3	2	3	3	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	2	1	1
37	3	3	3	3	4	3	3	3	3	2	3	3	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
38	4	3	3	4	4	4	3	3	3	3	3	3	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	2	2	2	2	2	2
39	4	3	3	4	4	4	3	3	3	3	3	3	3	2	2	2	2	2	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
40	4	3	3	4	4	4	3	3	3	3	3	3	3	2	2	2	3	3	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
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42	4	4	4	4	4	4	3	3	3	3	3	3	3	2	2	3	3	3	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	2	2
42	4	4	4	4	4	4	3	3	3	3	3	3	3	2	2	3	4	4	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	2	2
44	4	4	4	4	4	4	3	3	4	3	3	3	3	3	3	3	4	4	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	2	2
45	4	4	4	4	4	4	4	3	4	3	3	3	3	3	3	3	4	4	4	3	3	3	3	4	4	4	4	4	4	4	3	3	3	3	3	3	3	3	2	2
46	4	4	4	4	4	4	4	4	4	3	4	3	4	3	3	3	4	4	4	3	3	3	3	4	4	4	4	4	4	4	3	3	3	3	3	3	3	3	2	2
47	4	4	4	4	4	4	4	4	4	4	4	4	4	3	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	4	3	3	3	4	3	3
48	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
49	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
50	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4

Fig. III-3: Field Data Collection Sheet for Rear Camera under Low-Lighting Conditions

These discrete observations were converted into an AutoCAD drawing to identify continuous zones. The drawings created for the rear camera during low-lighting conditions in AutoCAD are shown by **Fig. III-4** and **Fig. III-5** for low and daylight conditions.

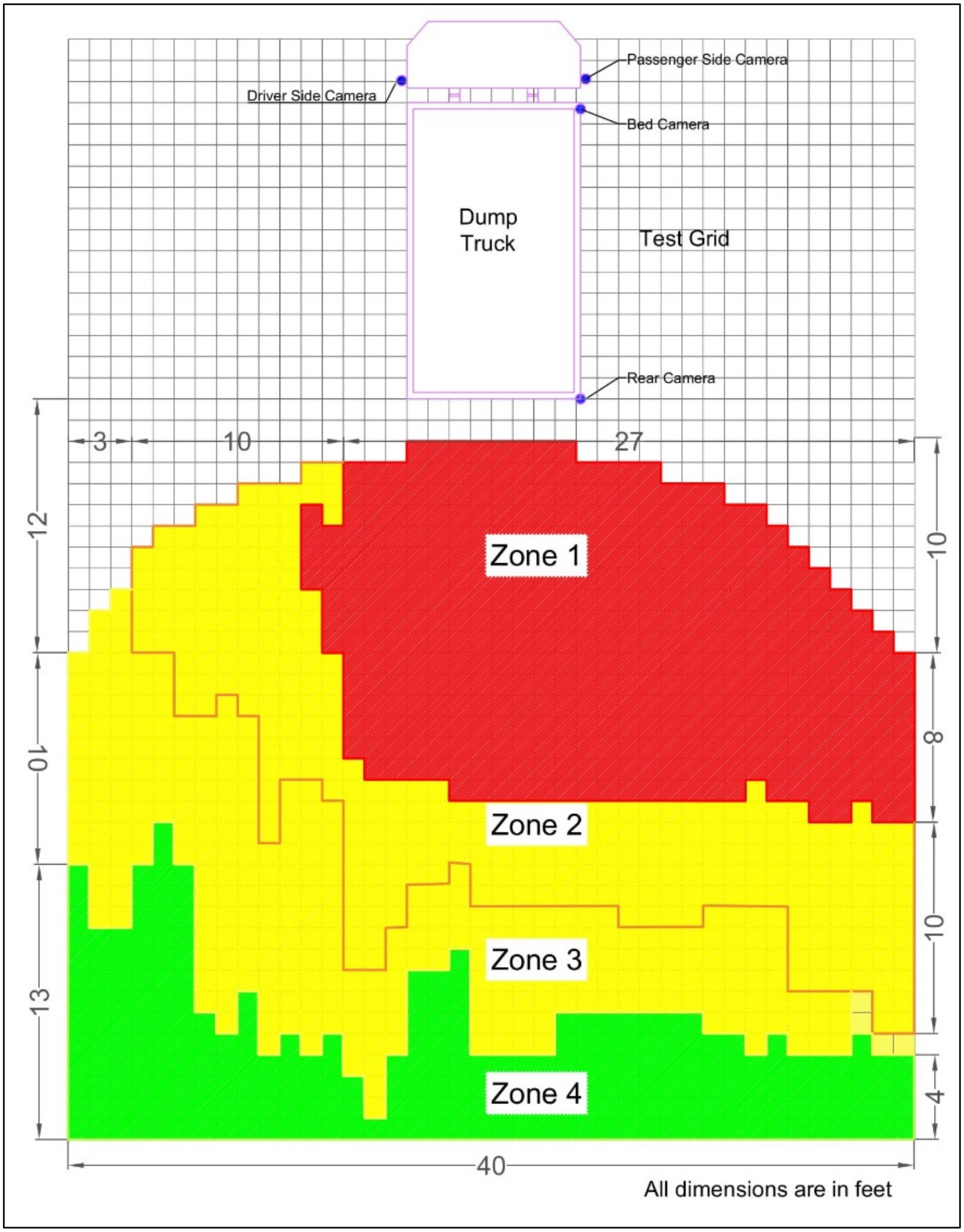


Fig. III-4: Identified AdViSE's Zones of Visibility for Rear Camera under Low-Lighting Conditions Represented in AutoCAD

The lengths of different zones are measured for the installed cameras of the AdViSE system in daylight and low-light conditions (shown in **Table III-3**).

Table III-3. Identified Lengths of AdViSE's Rear Camera Zones of Visibility

Zones of Visibility	During daylight (in feet)		During low light (in feet)	
	Driver Side	Passenger Side	Driver Side	Passenger Side
Zone-1	18	19	4	22
Zone-2	8	8	10	7
Zone-3	12	12	5	2
Zone-4	17	16	13	4

Critical FOV boundaries for different zones were identified using the AutoCAD drawing as shown in **Fig. III-5** and **Fig. III-6** for low and daylight conditions.

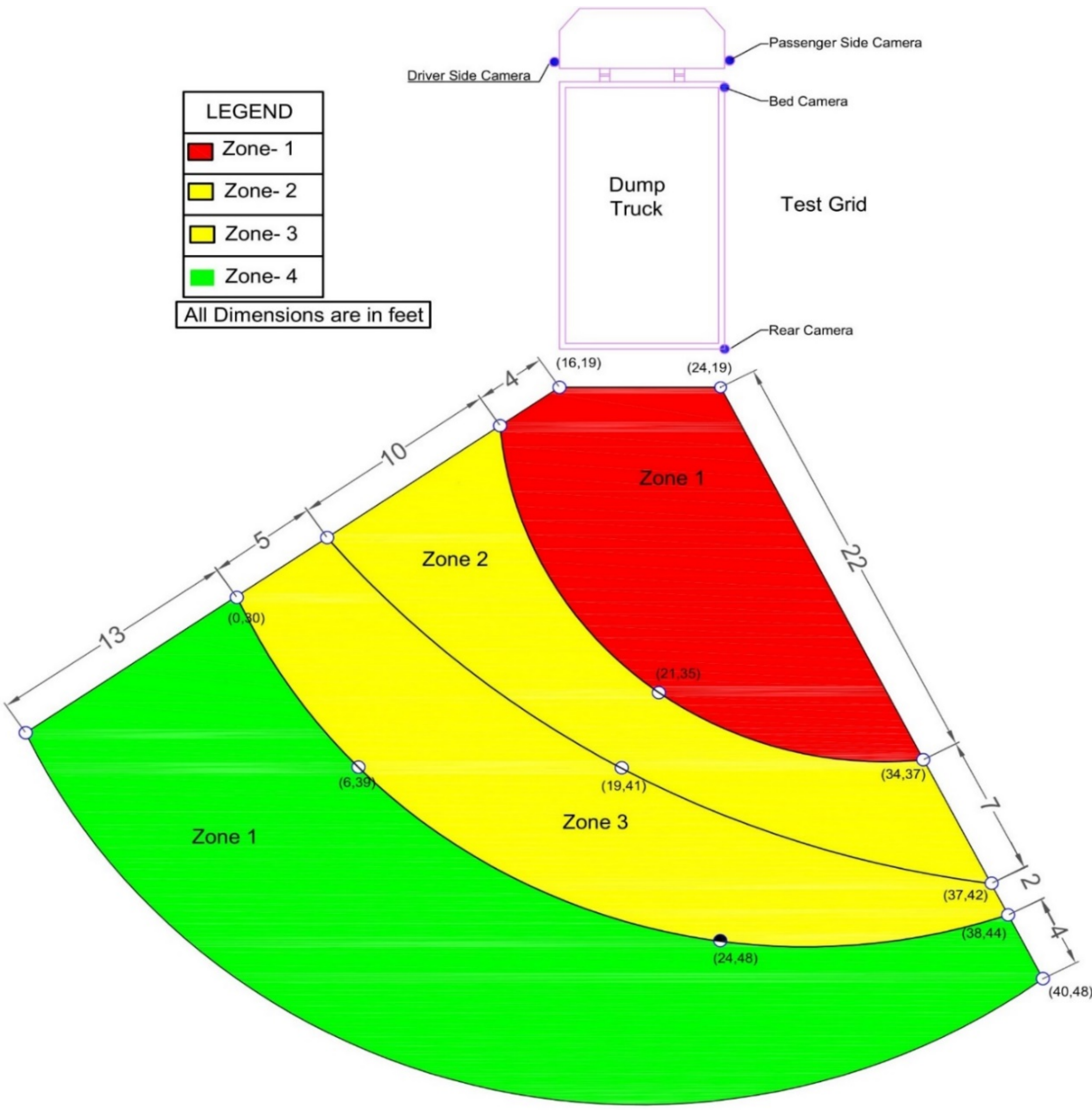


Fig. III-5: Critical FOV Boundaries of Visibility Zones for Rear Camera on Low-Lighting

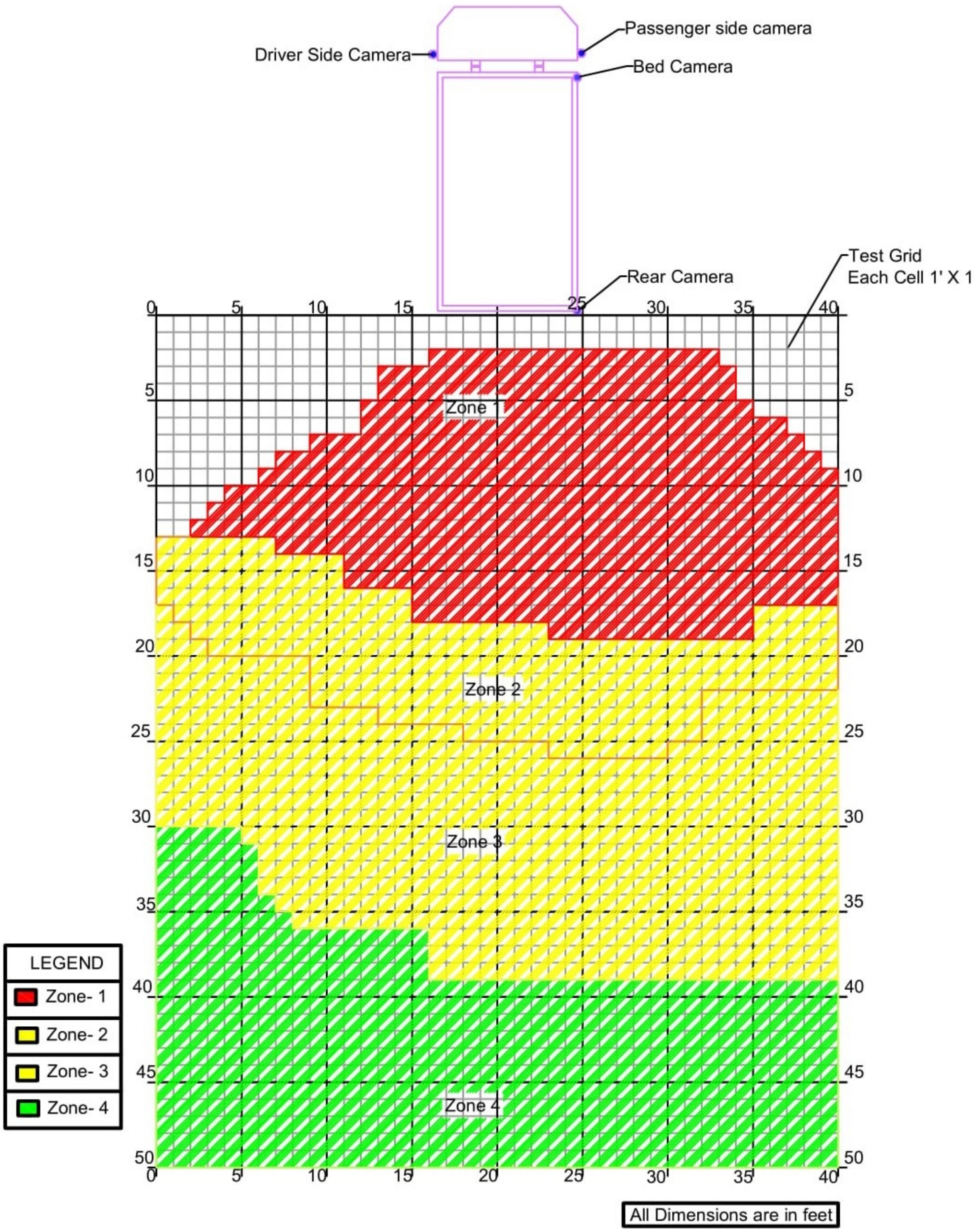


Fig. III-6: Identified AdViSE's Visibility Zones for Rear Camera on Daylight (Represented in AutoCAD)

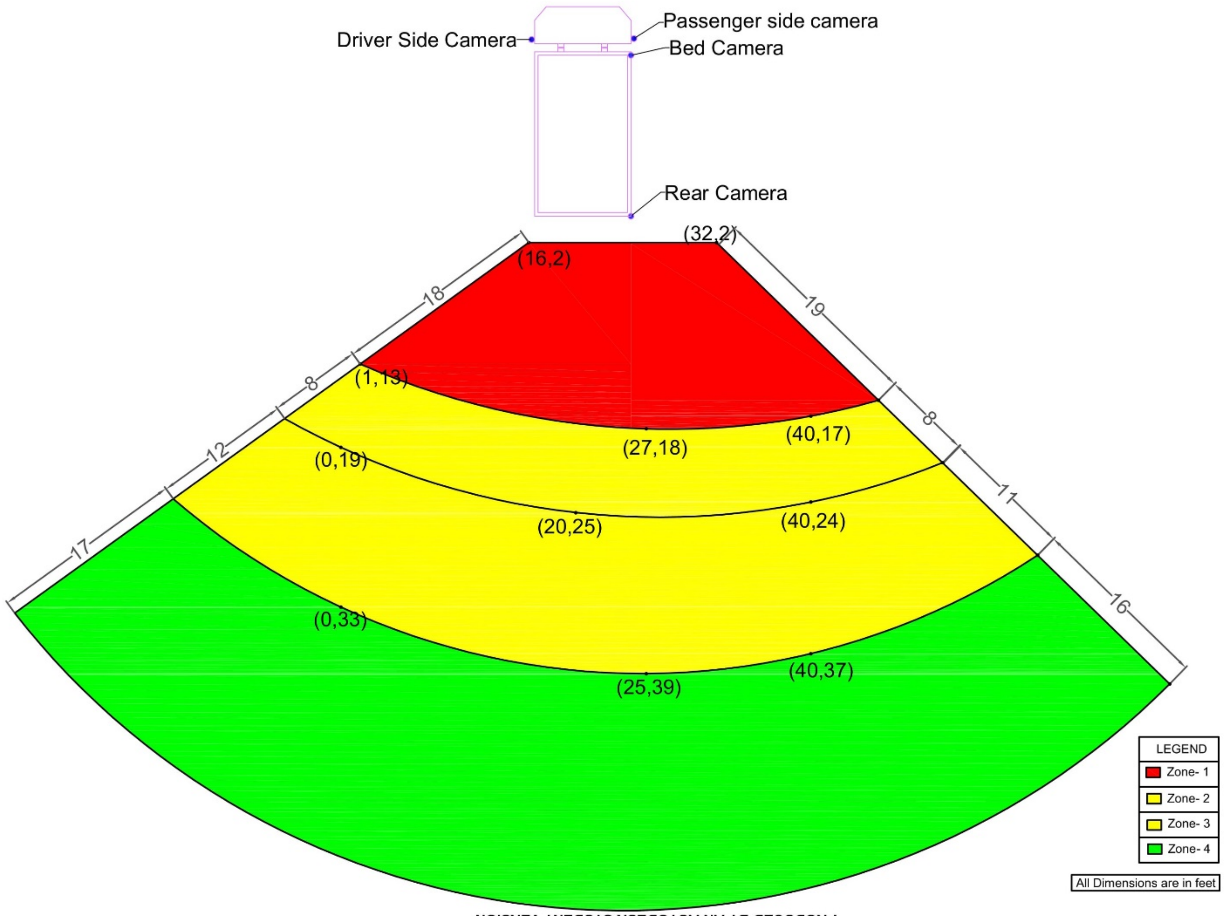


Fig. III-7: Critical FOV Boundaries of Visibility Zones for Rear Camera under Daylight Conditions

III.2.2 Passenger Side Camera

The procedure adopted for the passenger side camera is same as that of the rear camera. **Fig. III-8** and **Fig. III-9** represent the data collection sheet reproduced in AUTOCAD. Likewise, for the rear camera, the zones of visibility are identified during the low-light and daylight conditions and the lengths are measured (shown in **Table 3**). Critical fields of view (FOV) are identified for both the cases as shown in **Figure 10** and **Figure 11**.

Table III-4. Identified Lengths of AdViSE's Zones of Visibility for Passenger Side Camera

Zones of Visibility	During daylight (in feet)	During low light (in feet)
Zone-1	11	7
Zone-2	4	4
Zone-3	4	4
Zone-4	9	14

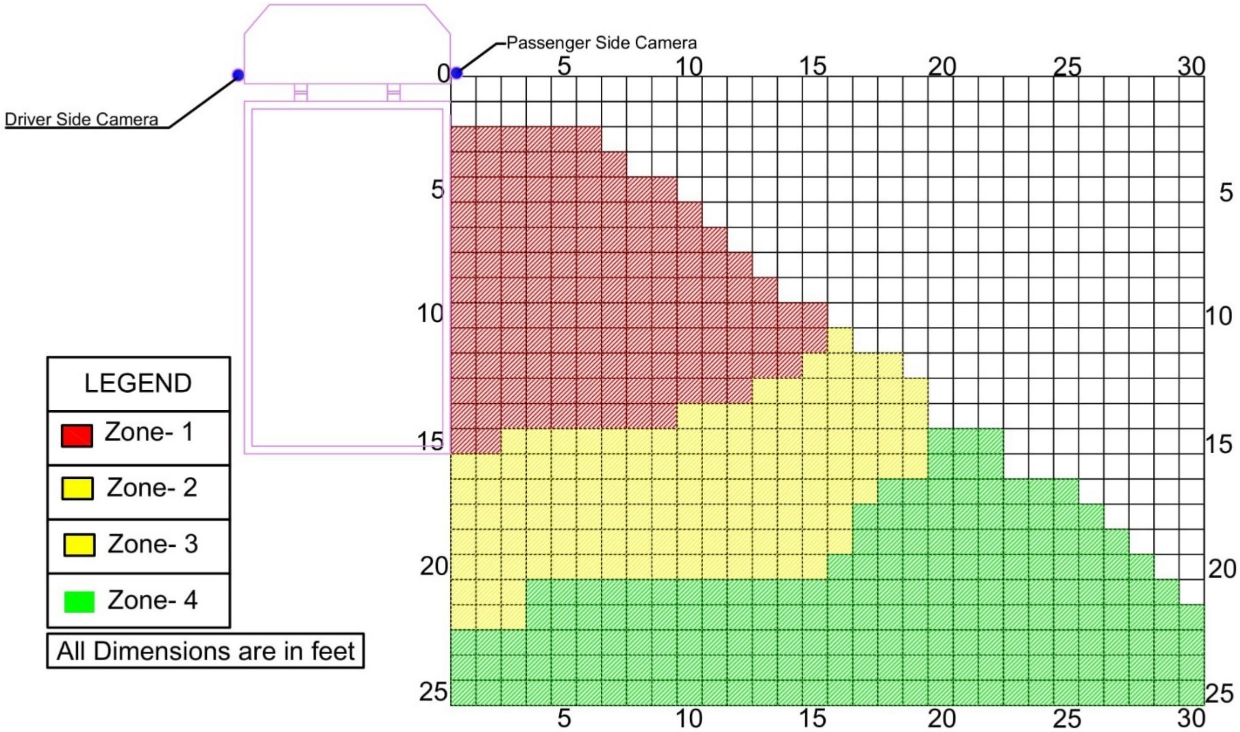


Fig. III-8: Identified AdViSE's Zones of Visibility for Passenger Side Camera under Daylight Conditions (Reproduced in AutoCAD)

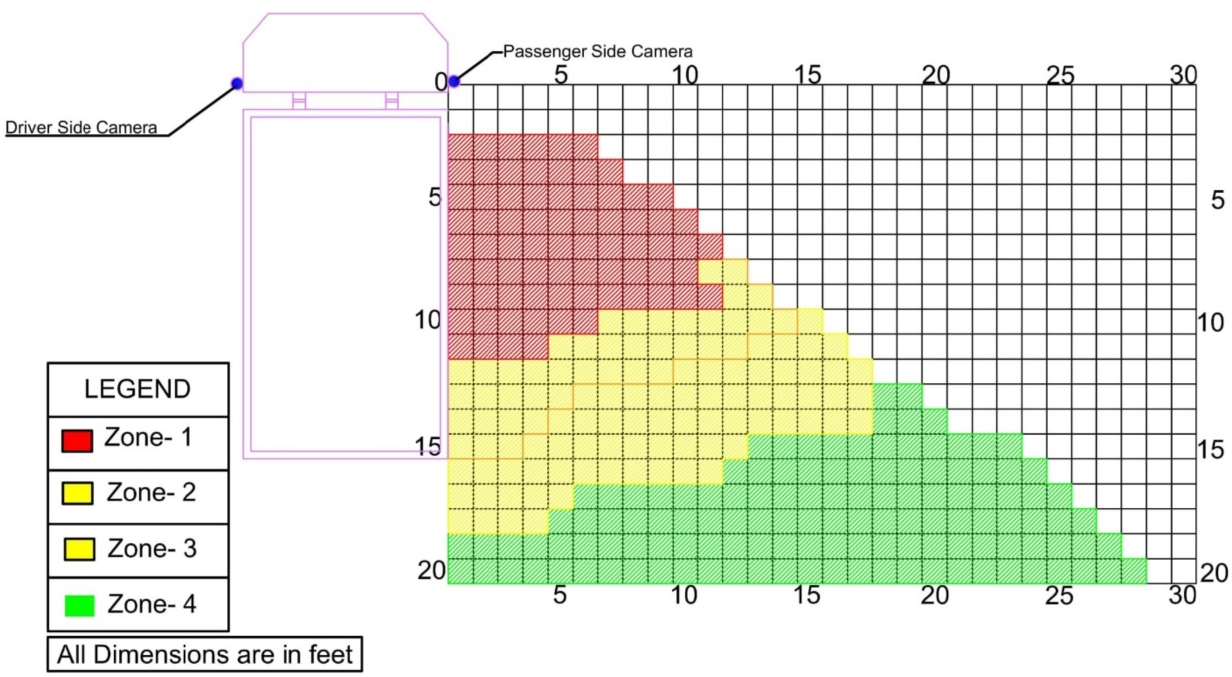


Fig. III-9: Identified AdViSE's Zones of Visibility for Passenger Side Camera under Low-Lighting Conditions (Reproduced in AutoCAD)

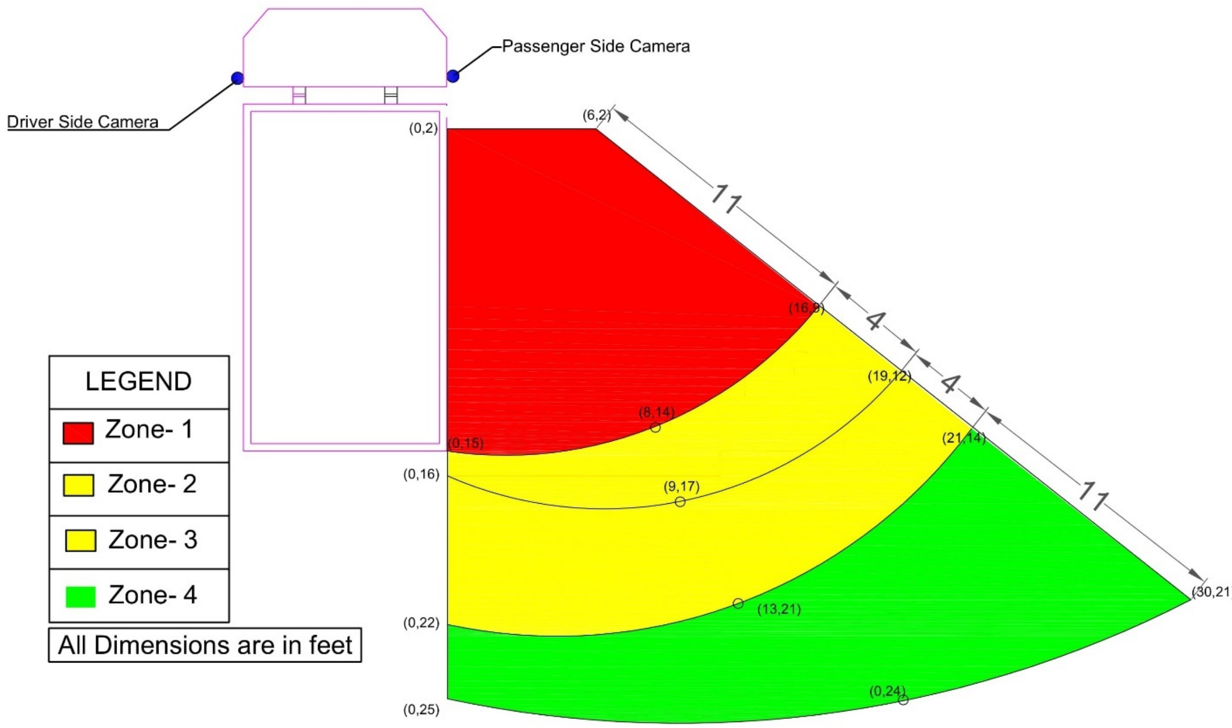


Fig. III-10: Critical FOV Boundaries of Visibility Zones for Passenger Side Camera under Daylight Condition (Reproduced in AutoCAD)

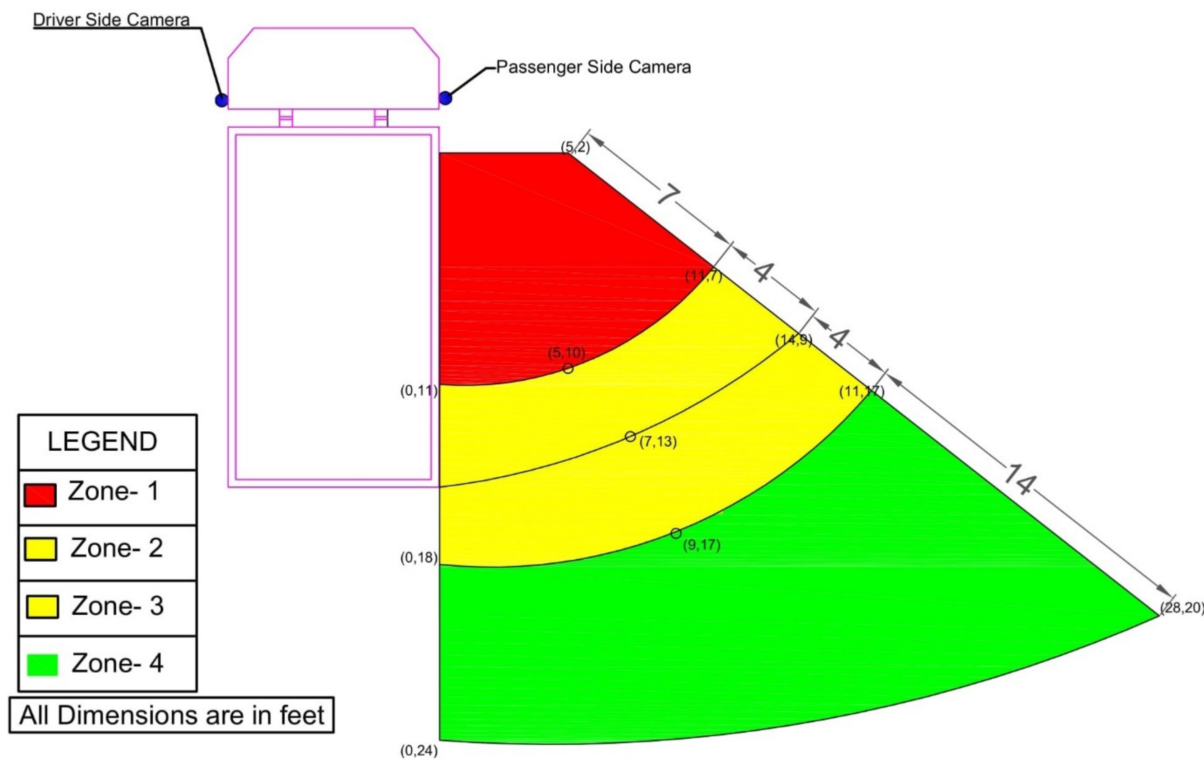


Fig. III-11: Critical FOV Boundaries of Visibility Zones for Passenger Side Camera under Low-Lighting Condition (Reproduced in AutoCAD)

III.2.3 Driver Side Camera

Fig. III-12 and **Fig. III-13** represents the data collection sheet reproduced in AutoCAD. The zones of visibility are identified during the low-light and daylight conditions and the lengths are measured (shown in **Table 4**). Critical fields of view (FOV) are identified for both the cases as shown in **Figure 14** and **Figure 15**.

Table III-5. Identified Lengths of AdViSE's Zones of Visibility for Driver Side Camera

Zones of Visibility	During daylight (in feet)	During low light (in feet)
Zone-1	18	12
Zone-2	2	2
Zone-3	1	6
Zone-4	11	12

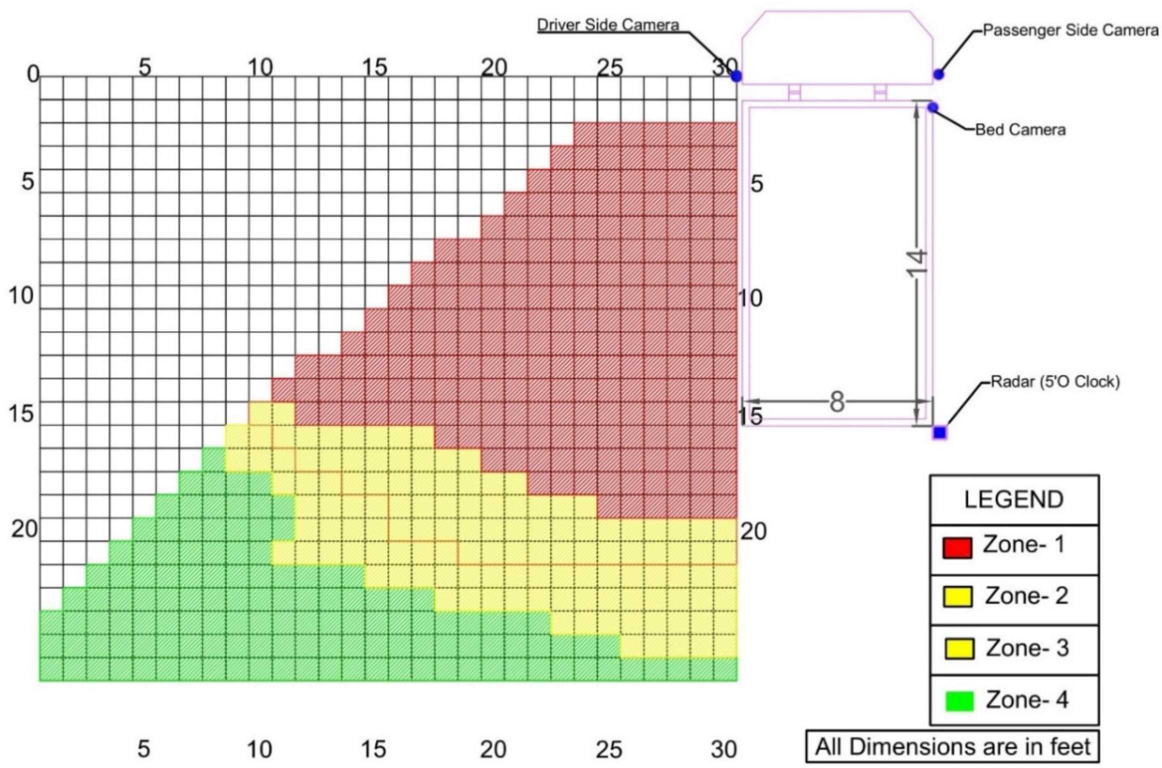


Fig. III-12: Identified AdViSE's Visibility Zones for Driver Side Camera under Daylight Condition (Reproduced in AutoCAD)

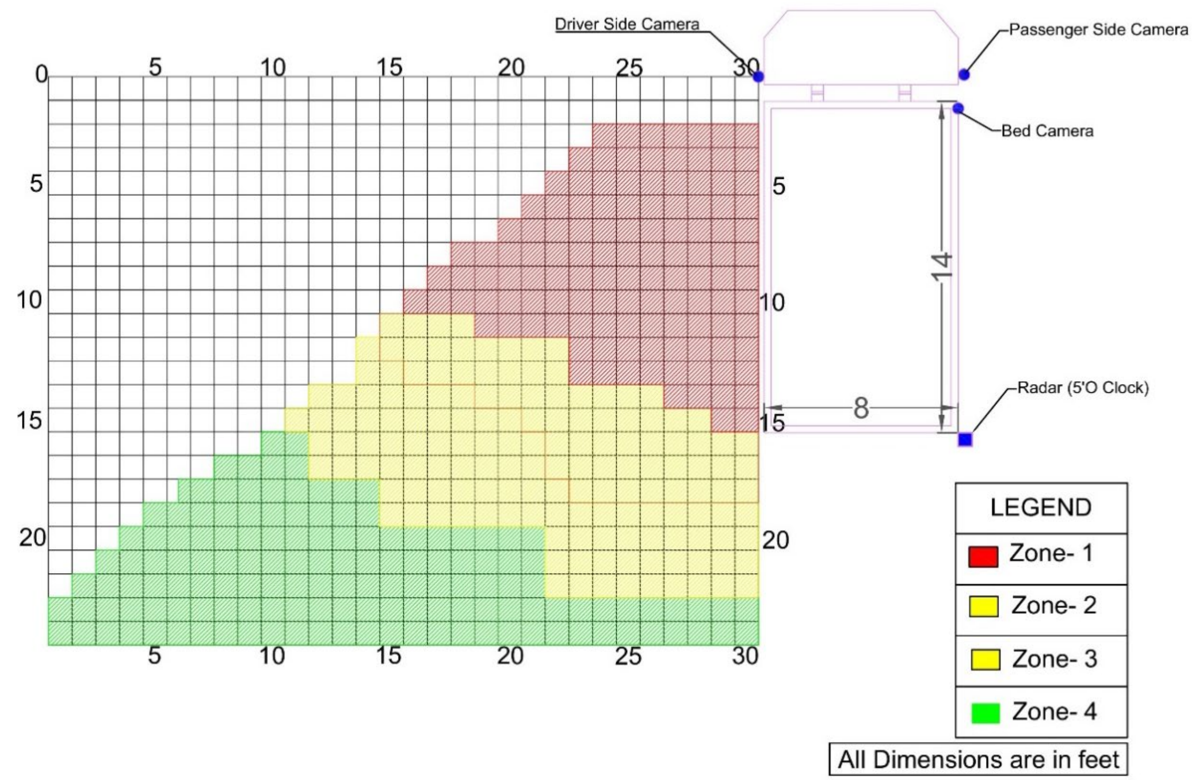


Fig. III-13: Identified AdViSE's Visibility Zones for Driver Side Camera under Low-Lighting Condition (Reproduced in AutoCAD)

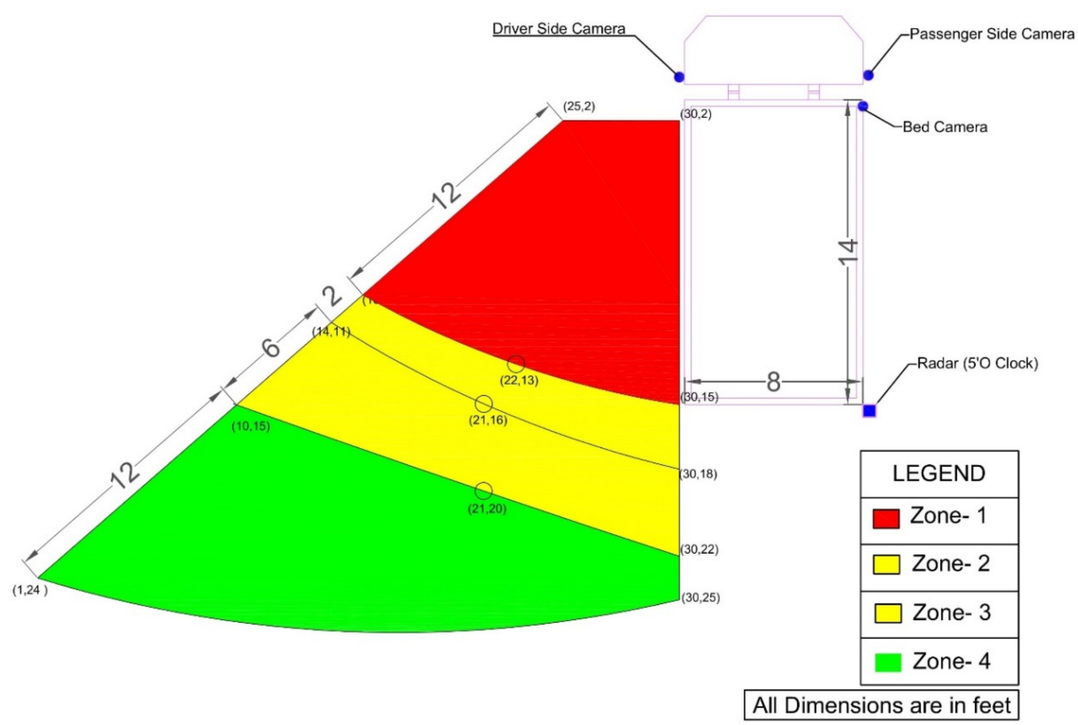


Fig. III-14: Critical FOV Boundaries of Visibility Zones for Passenger Side Camera under Low-Lighting Condition (Reproduced in AutoCAD)

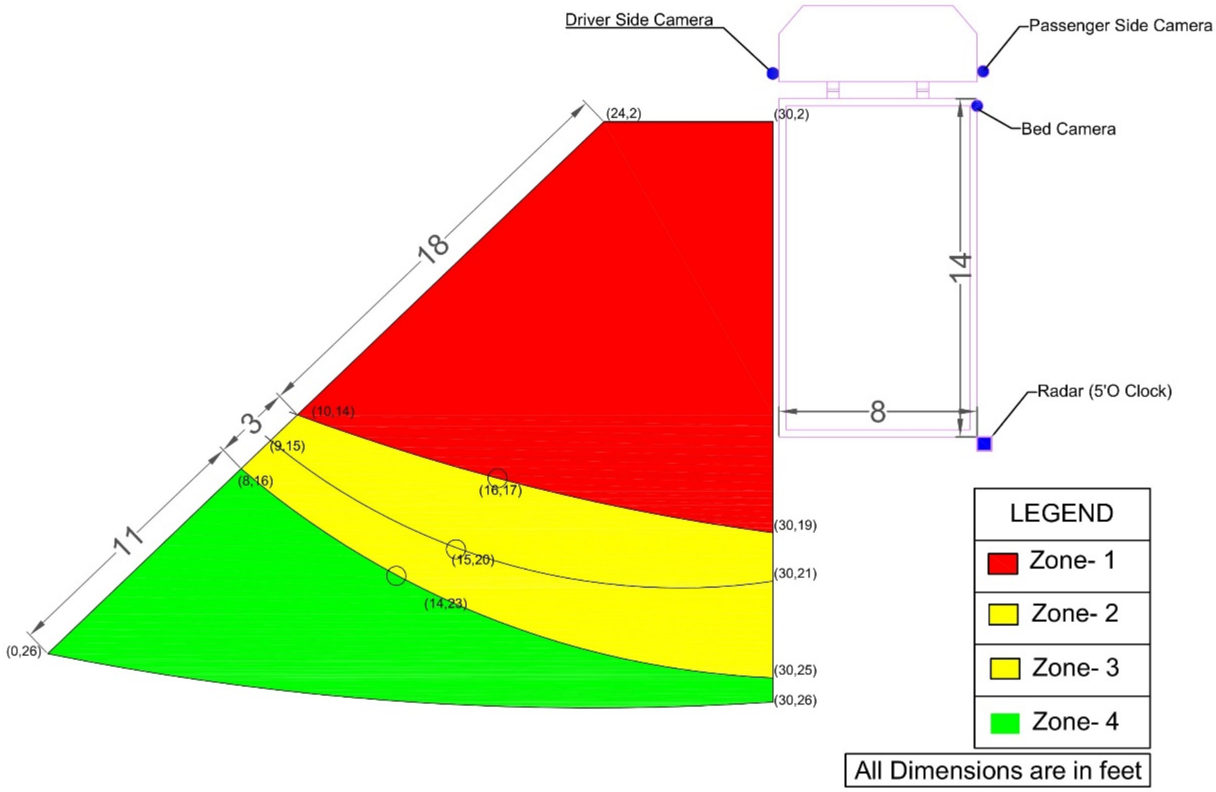


Fig. III-15: Critical FOV Boundaries of Visibility Zones for Passenger Side Camera under Daylight Condition (Reproduced in AutoCAD)

III.2.4 Dump Bed Camera

The dump bed camera monitors the bed of the dump-truck. However, this camera also covers the passenger side of the truck to an extent and some portion of the dump bed immediately behind the cabin of the truck is still found to be a blind spot. **Fig. III-16** and **Fig. III-17** represent the FOV of the dump bed during low-light and daylight conditions. The lengths of the zones identified (shown in **Table III-6**) are the zones identified to the passenger side of the truck.

Table III-6. Identified Lengths of AdViSE's Zones of Visibility for Dump Bed Camera

Zones of Visibility	During daylight (in feet)	During low light (in feet)
Zone-1	16	11
Zone-2	8	2
Zone-3	6	11
Zone-4	26	23

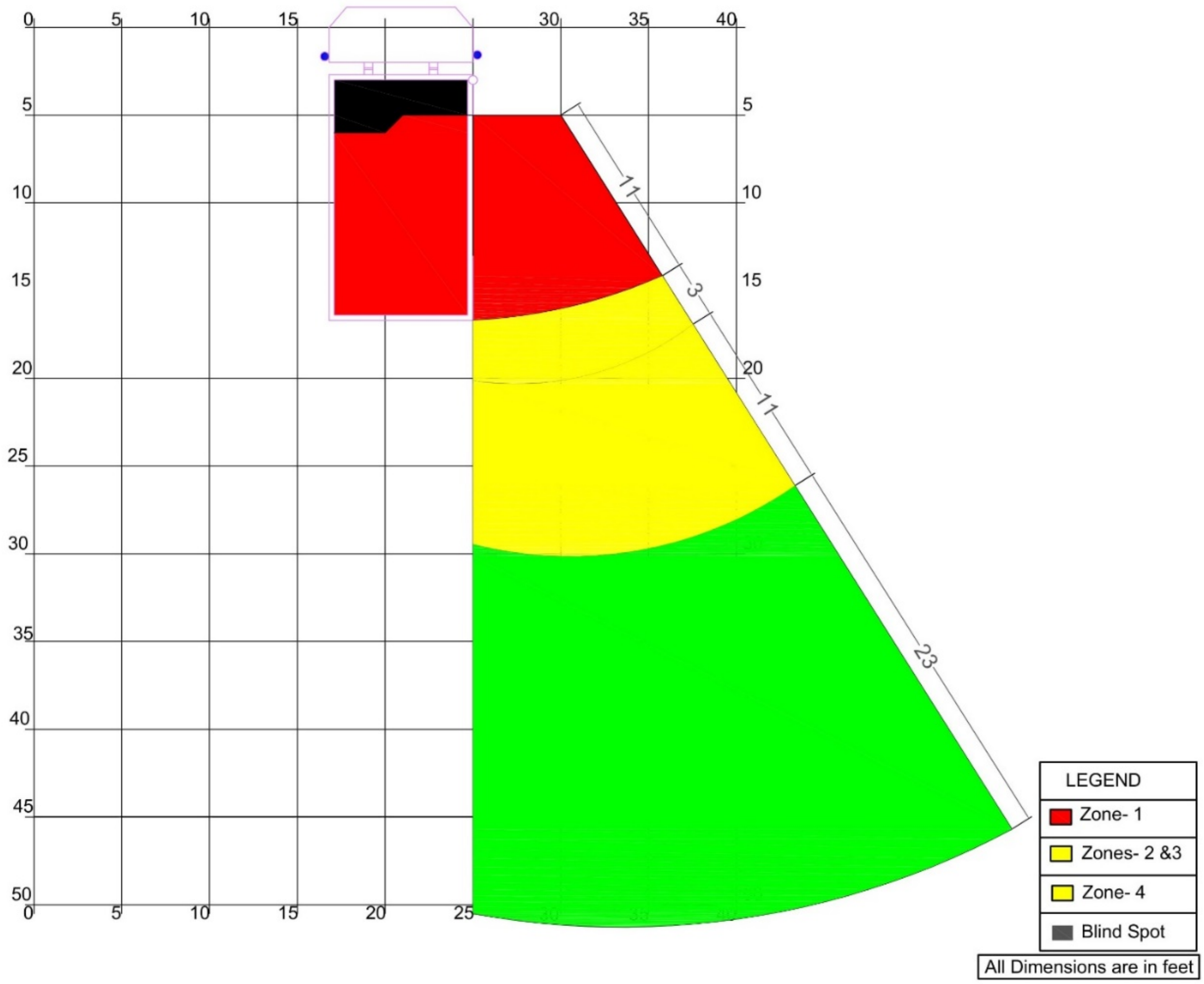


Fig. III-16: Dump Bed Camera's FOV Boundaries of Visibility Zones under Low-Lighting Conditions (Reproduced in AutoCAD)

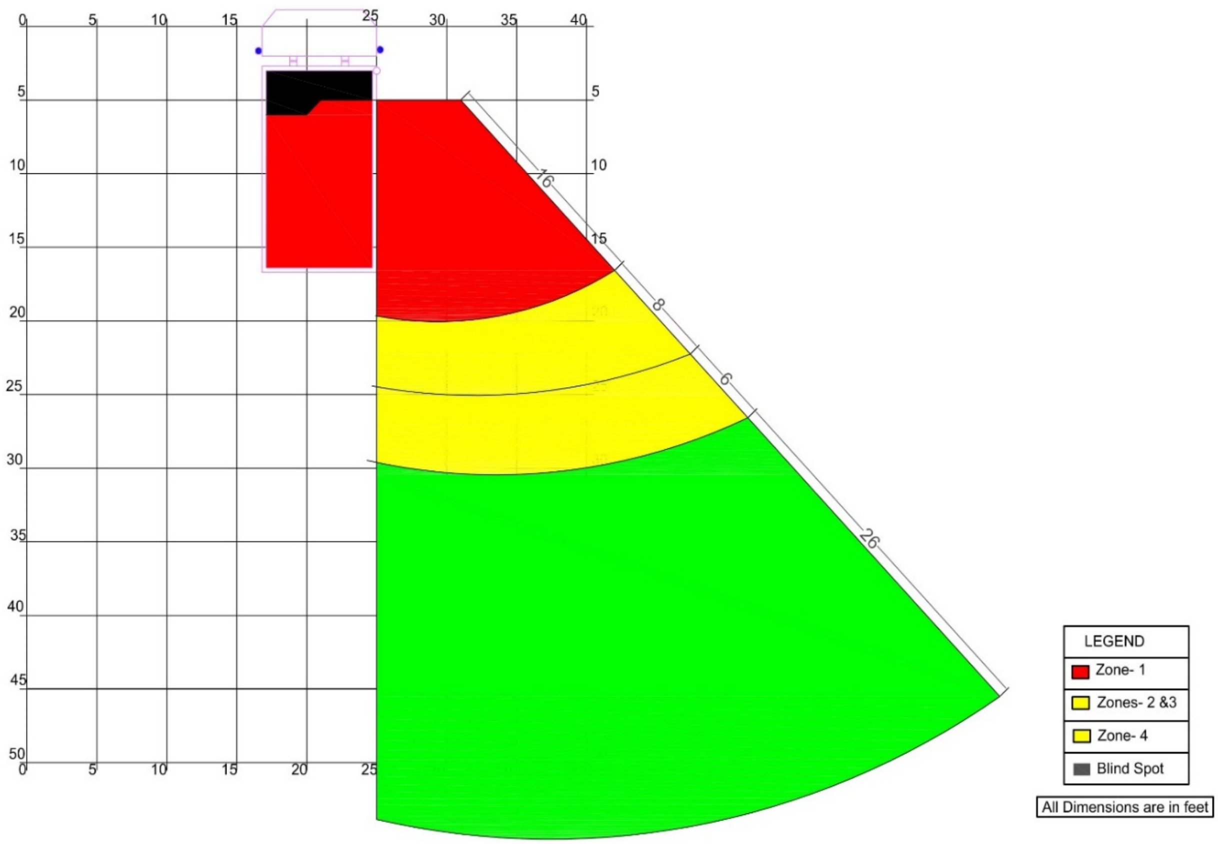


Fig. III-17: Dump Bed Camera's FOV Boundaries of Visibility Zones under Daylight Conditions (Reproduced in AutoCAD)

III.2.5 Zones of Camera Visibility with Additional Set-up

An additional blind spot in the camera detectable area is observed when the dump truck is provided with the additional set-up which is used for pouring asphalt and salt. **Fig. III-18** and **Fig. III-19** represents the illustration of the additional blind spots created due to the asphalt and salt pouring set up.

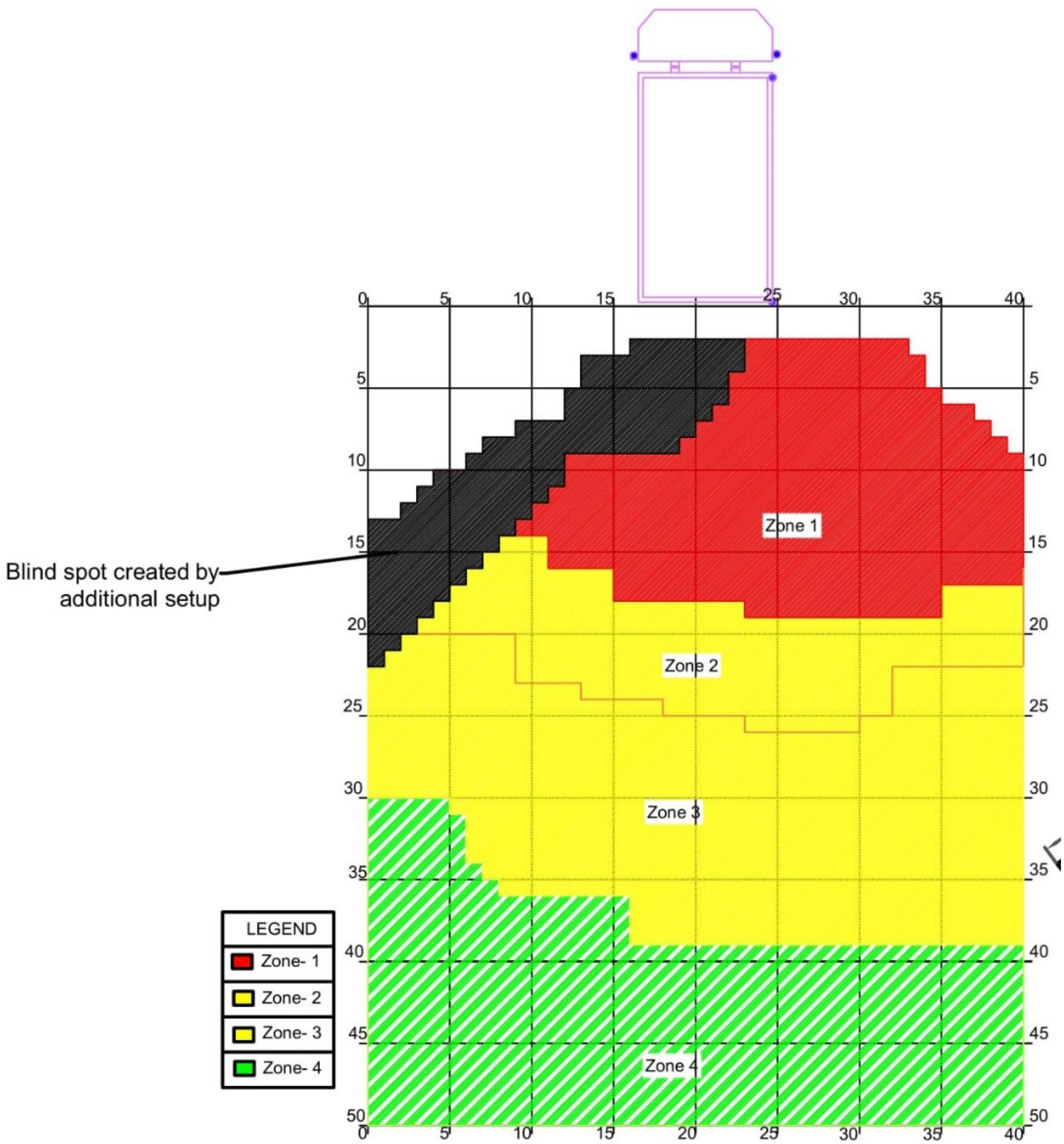


Fig. III-18: Identified Additional Blind Spot in the FOV of the AdViSE's Rear Camera (Reproduced in AutoCAD)

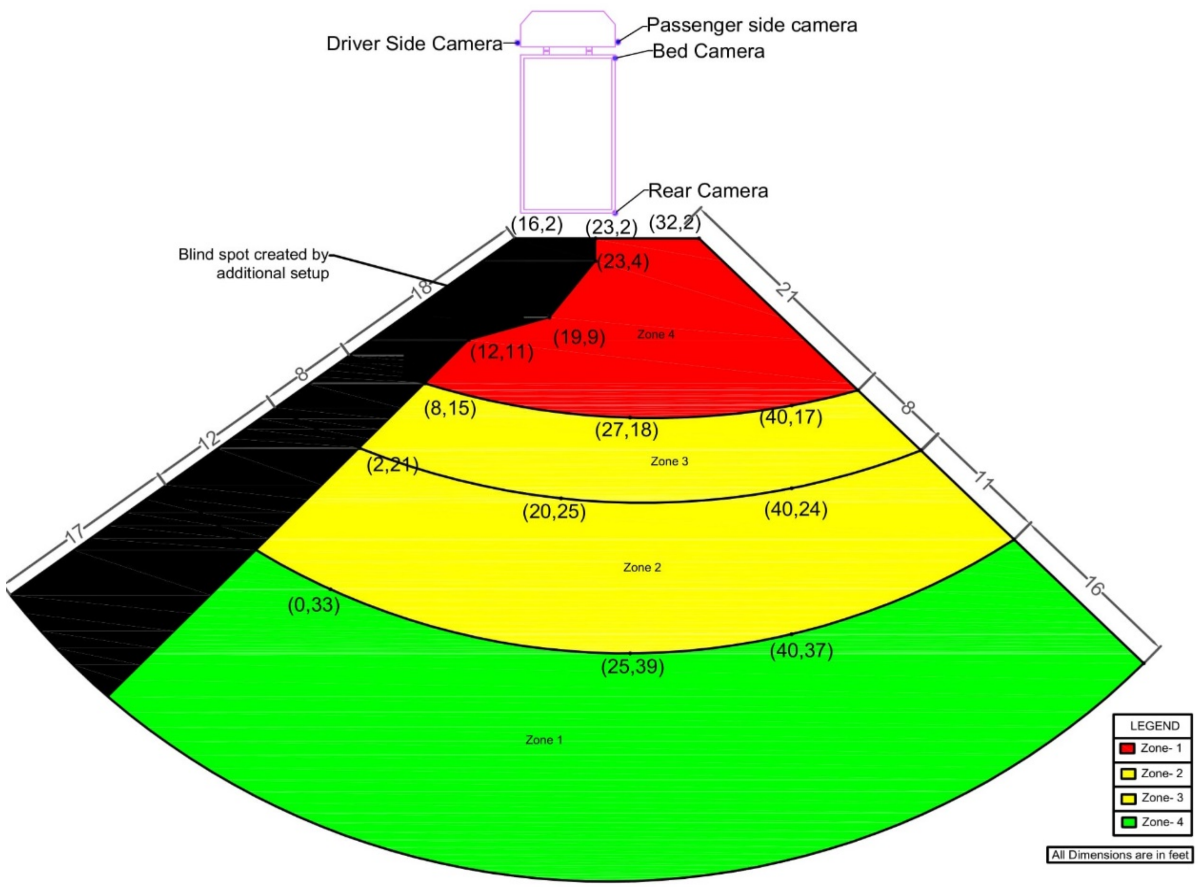


Fig. III-19: FOV Boundaries of Visibility Zones for Rear Camera along with the Blind Spot Created by the Additional Set-up

III.3 Detection Zones of Radars

The radars on the driver side and the passenger side are designated as 7 o'clock and 5 o'clock, respectively. Using the audible alert and the display, different coverage zones of the radar detection are identified.

III.3.1 Radar at 7 O'Clock

Fig. III-20 represents the data collection sheet for the 7 o'clock radar. The data is regenerated in AutoCAD (shown in **Fig. III-21**). Critical detection zones are obtained as shown in **Fig. III-22** by trimming uncertain zones.

Table III-7. Identified Lengths of AdViSE's Detection Zones for Radars

Zones of detection	Radar at 5 O'Clock (in feet)	Radar at 7 O'Clock (in feet)
Zone-1	2	3
Zone-2	4	3
Zone-3	3	4
Zone-4	4	2
Zone-5	7	5

	1				5					10	11				15			18		20					25					30			33		35					40
1																																								
3													5	5	5	5	5	5	4	4	4	3	3	3																
																	5	5	5	5	5	4	4	4	4	3	3	3	3											
5																5	5	5	5	5	4	4	4	3	3	3	3	3	2	2	2	2	1							
															4	4	4	4	4	4	4	4	4	3	3	3	3	2	2	2	2	2	1							
														4	4	4	4	4	4	4	4	3	3	3	3	3	3	2	2	2	2	2	1							
														4	4	4	4	4	4	4	3	3	3	3	3	3	3	2	2	2	2	1	1							
														3	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	2	1	1							
10														3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	2	1	1	1							
													3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	2	2	1	1	1	1							
												2	3	3	3	3	3	3	3	3	3	2	2	2	2	2	2	2	1	1	1	1	1							
												2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1							
												2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1							
15											1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1							
											1	1	1	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1							
											1	1	1	1	1	1	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1								
											1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1									
											1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1											
20												1	1	1	1	1	1	1	1	1	1	1	1	1	1	1														
														1	1	1	1	1	1	1	1	1	1	1	1															
																1	1	1	1	1	1	1	1	1	1															

Fig. III-20: Field Data Collection Sheet for 7 O'Clock Radar

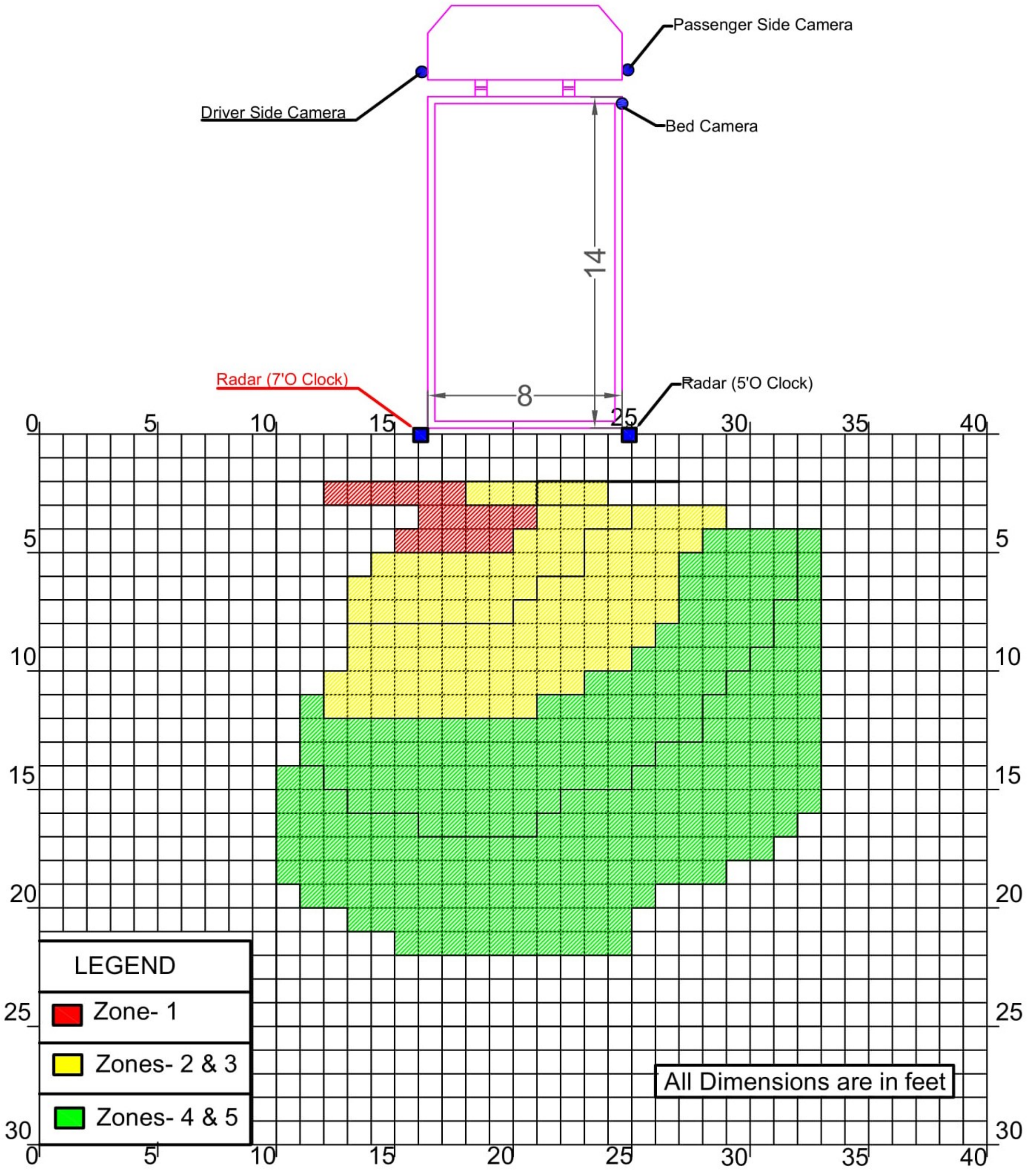


Fig. III-21: Identified AdViSE's Detection Zones for 7 O'Clock Radar

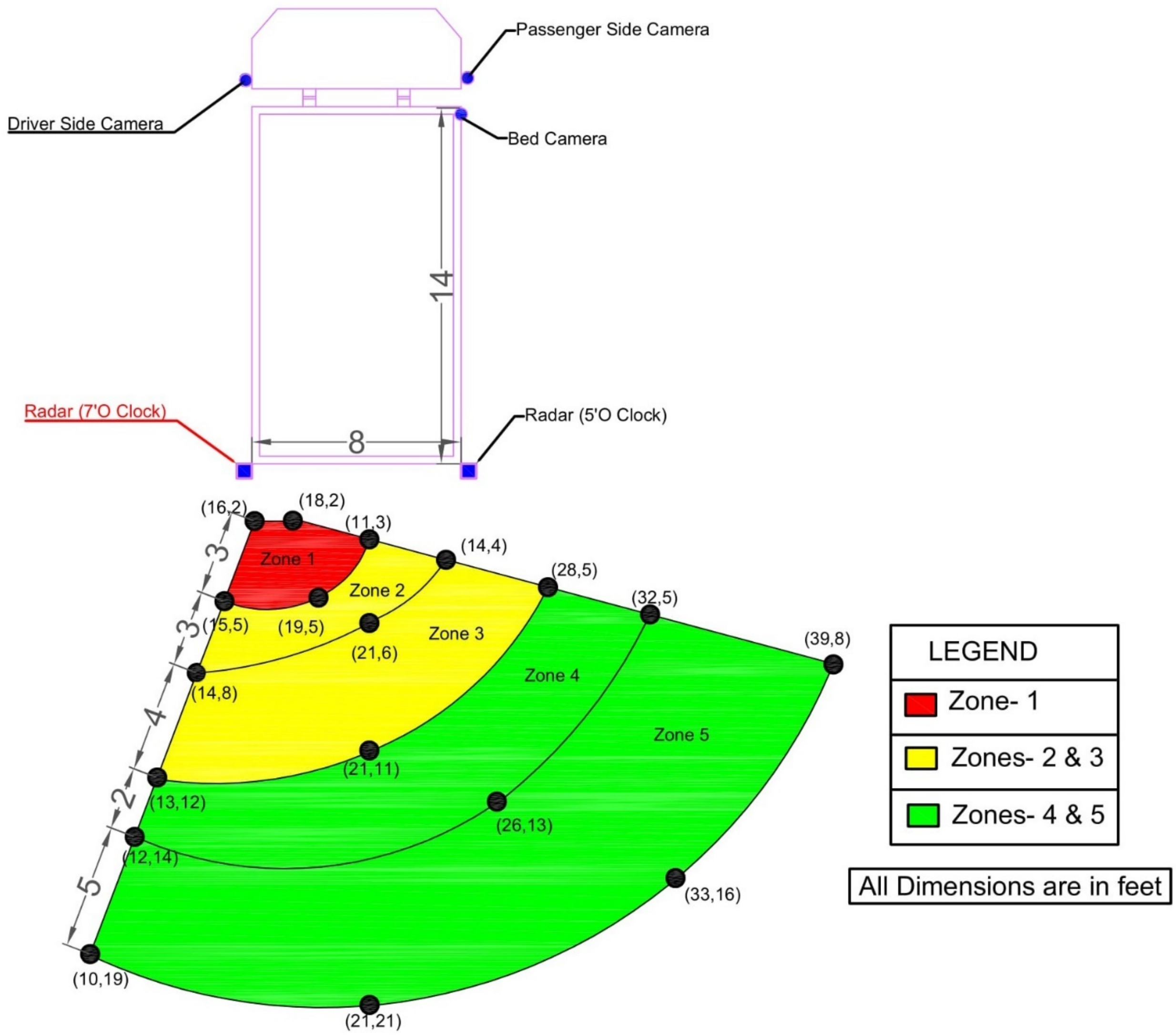


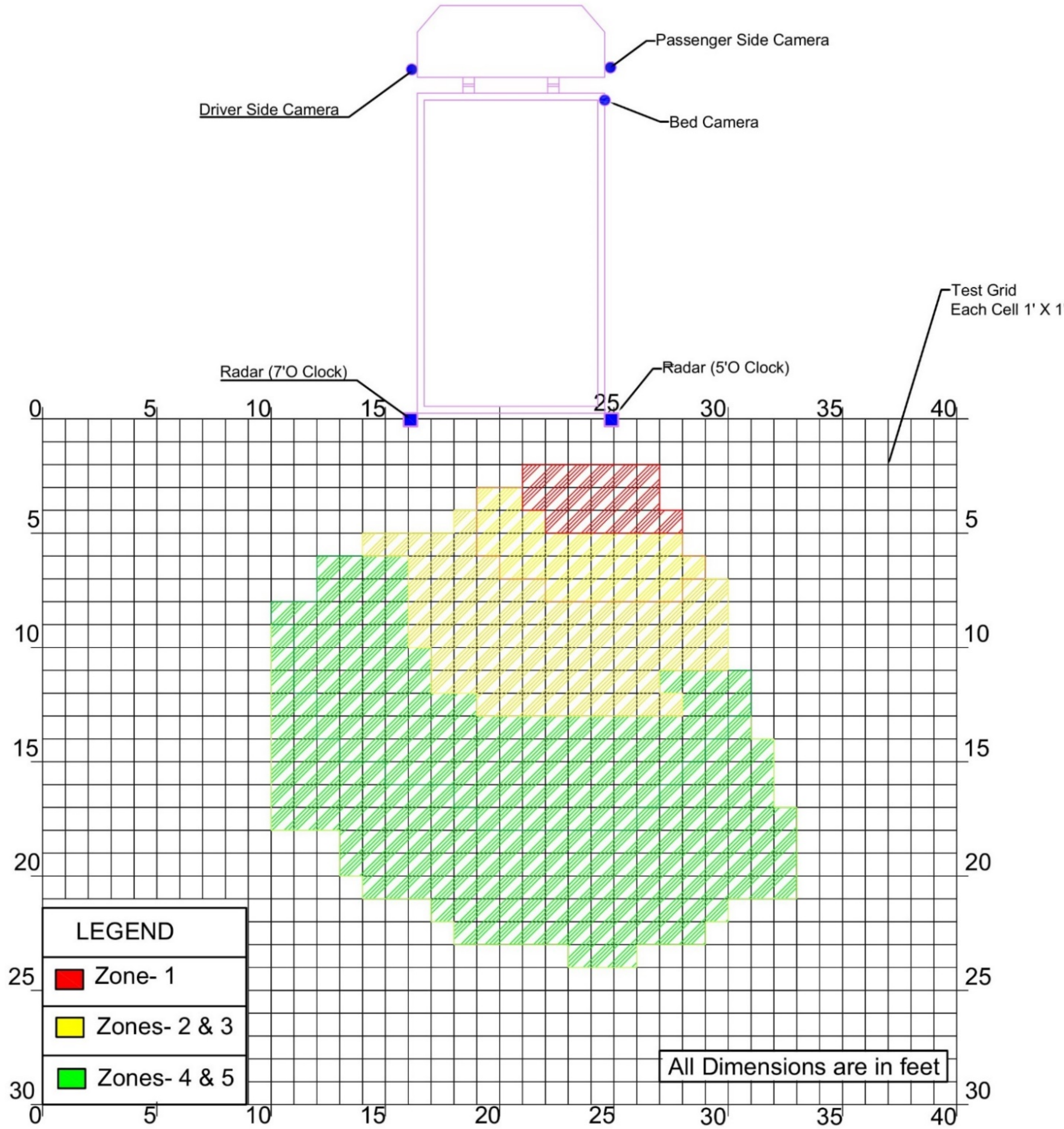
Fig. III-22: Critical Detection Zones for 7 O'Clock Radar

III.3.2 Radar at 5 O'Clock

Fig. III-23 represents the data collection sheet for the 5 o'clock radar. The data is regenerated in AutoCAD (shown in **Fig. III-24**). Critical detection zones are obtained as shown in **Fig. III-25** by trimming uncertain zones.

	1				5					10	11				15			18		20					25					30			33		35					40
1																																								
3																						5	5	5	5	5	5													
																				4	4	5	5	5	5	5	5													
5																			3	4	4	4	5	5	5	5	5	5												
															3	3	3	3	3	4	4	4	4	4	4	4	4	4												
													2	2	2	2	3	3	3	3	4	4	4	4	4	4	4	4	4											
													2	2	2	2	3	3	3	3	3	3	4	4	4	4	4	4	3	3										
											2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3										
10											1	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3										
											1	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	3	3	3										
											1	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	2	2	2	2									
											1	1	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	2	2	2									
											1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1									
15											1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1								
											1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1								
											1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	1	1	1	1	1								
											1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	1	1	1	1	1	1	1							
														1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1							
20														1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1							
															1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1							
																		1	1	1	1	1	1	1	1	1	1	1	1	1										
																			1	1	1	1	1	1	1	1	1	1	1											
																								1	1	1														
25																																								

Fig. III-23: Field Data Collection Sheet for 5 O'Clock Radar



Fig, III-24: **Identified AdViSE's Detection Zones for 5 O'Clock Radar (Reproduced in AutoCAD)**

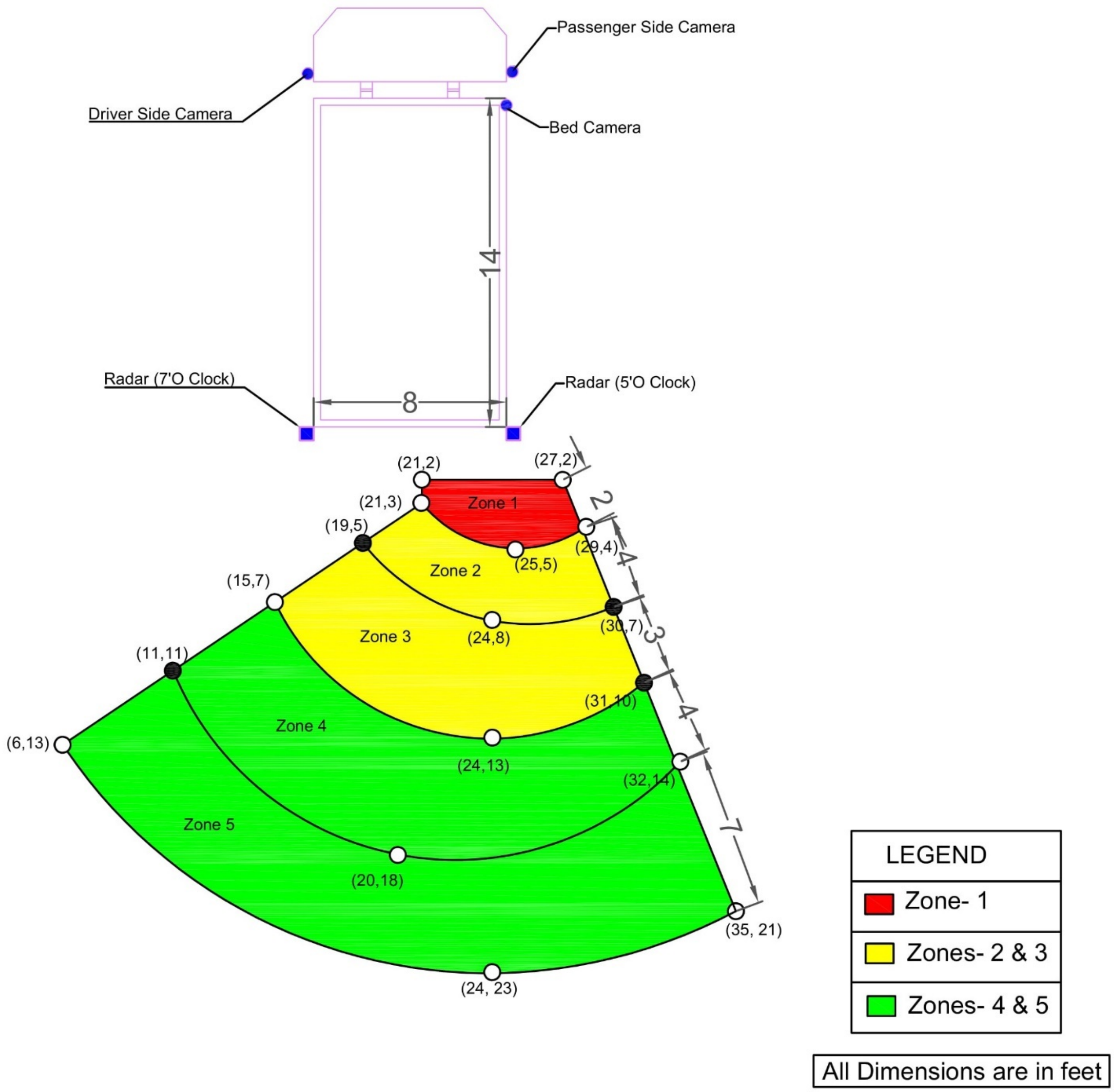


Fig. III-25: Critical Detection Zones for 5 O'Clock Radar

III.4 Key Findings about the AdViSE System

III.4.1 360-Degree View of the AdViSE's Detection Areas

Based on the on-site tests of the AdViSE system as described in the above sections, all detection outcomes are presented together in a single diagram to illustrate the 360-degree view of the camera, radar, and mirror detectable areas with blind spots. **Fig. III-26** and **Fig. III-27** show the 360-degree views under low-light conditions and daylight conditions, respectively.

Compared with **Fig. III-28**, an illustration of mapping potential solution with backing accident causes, the 360-degree views of the AdViSE detection areas could cover the blind areas present in trucks without the system.

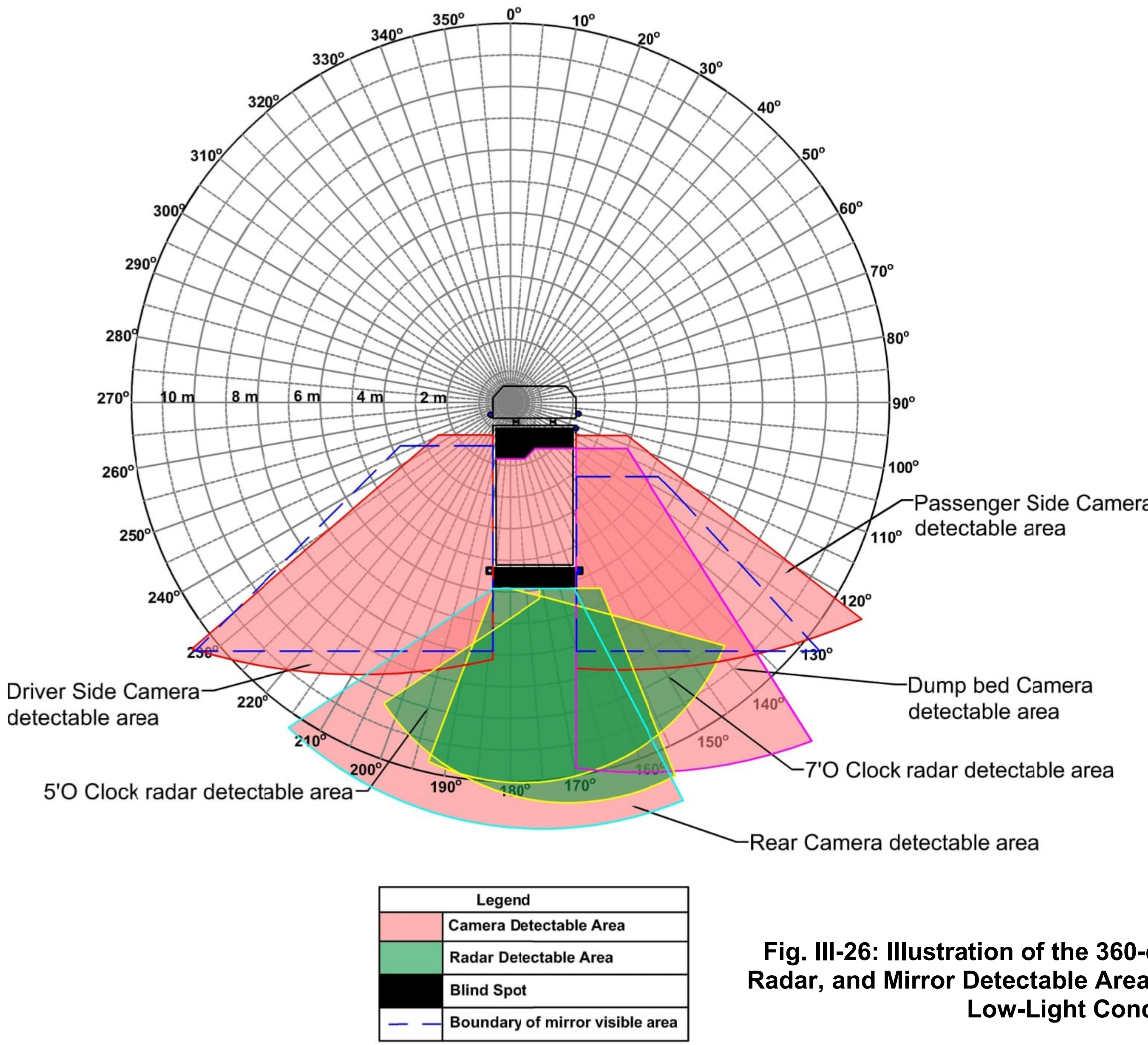
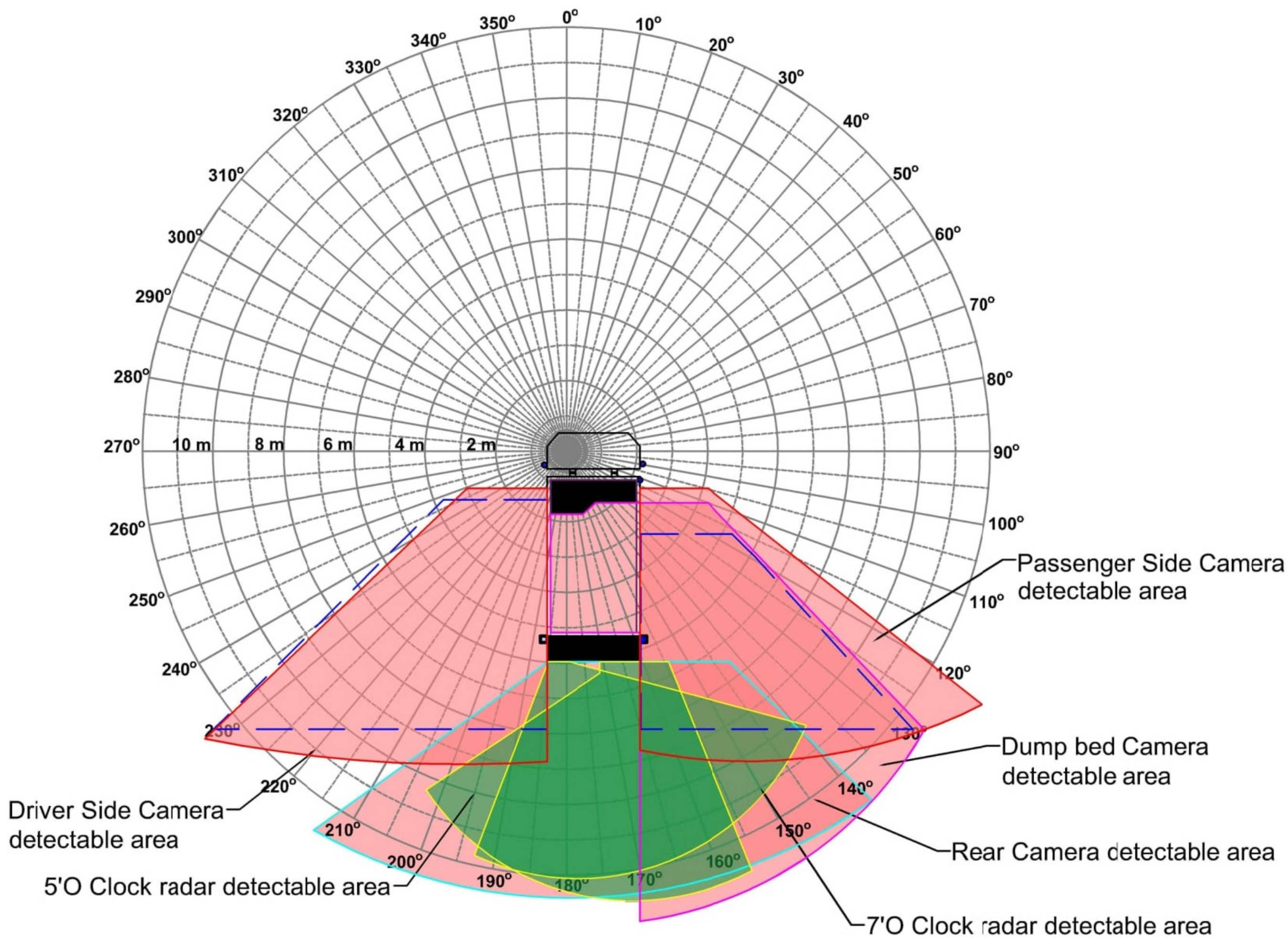


Fig. III-26: Illustration of the 360-degree View of Camera, Radar, and Mirror Detectable Areas with Blind Spots under Low-Light Conditions



Legend	
	Camera Detectable Area
	Radar Detectable Area
	Blind Spot
— —	Boundary of mirror visible area

Fig. III-27: Illustration of the 360-degree View of Camera, Radar, and Mirror Detectable Areas with Blind Spots under Day Light Conditions

III.4.2 Reduced Truck Blind Area Compared with Traditional Measures

To understand how the AdViSE system could outperform the traditional solutions in reducing the truck blind areas, some traditional measures which have been developed in practice to prevent backover crashes are summarized as follows. *Based on the discussion in Section III.3.1, the AdViSE has obvious advantages to overcome weaknesses of the typical traditional safety solutions in terms of reduced dump truck blind areas.*

III.4.2.1 Mirrors

Mirrors (such as side mirrors and rear mirrors) can reduce blind areas and enlarge visible areas from the operator's position. They are not the most effective means of increasing truck drivers' visual range. However, supplemental mirrors have the potential to significantly reduce blind-side and backovers (Blower, 2007; Pratt et al., 2001). However, conditions such as rain, dirt on the mirror and windows, driver inattention, driver attending to another visual task, and time pressures may impact the mirror use (Cook et al., 2011).

III.4.2.1 Backing Warning Technologies

Providing drivers with a complete rear view of their trucks may overcome visibility problems when backing through work zones (Ferreira et al., 2017). Blind spot detection and collision-warning systems have been developed to assist in detecting objects or people and giving warning using technologies of cameras, sensors (such as ultrasound sensors, radars), back-up alarms, and back-up lights (Cooper et al., 2009; Ruff, 2004). Construction machines and vehicles equipped with multiple closed-circuit cameras provide a wide-angle view of the rear, thus improving the blind-spot monitoring. Radar systems can help to detect people, vehicles, buildings, and other equipment in back of construction vehicles and equipment (Fan et al., 2014; Ruff, 2006). Sensor-based systems for proximity warning in combination with other devices, such as cameras, would allow the operator to better check the source of any alarm (Ruff, 2006). However, without appropriate design and selection of cameras and sensors with appropriate ingress protection ratings, problems/issues may occur in cold and snowy conditions (Ruff, 2004). Back-up alarms which are easier to hear over construction noise along with flash lighting can also help to prevent backovers (Fan et al., 2014; Schneider, 2008).

III.4.2.3 Lighting

Lighting should be installed at a work zone to ensure proper illumination for the workspace. The glare should be controlled to avoid blinding the crews and passing traffic (Pratt et al., 2001).

III.4.2.4 Spotter

When available, operators should use a spotter to direct truck backing up on construction sites. The driver and spotter should use hand signals instead of verbal ones and make sure they understand each other.

III.4.2.5 Training

Operators, safety personnel, and instructors should be trained to increase their awareness about the limited-visibility or blind areas around construction vehicles and equipment. The NIOSH blind area diagrams help drivers recognize which areas around construction vehicles can be seen. Workers should also be trained in hazards and adaptations for low-visibility conditions such as night time (Pratt et al., 2001).

III.4.2.6 High Visibility Apparel

Workers should wear high-visibility apparel. Similarity in colors of safety vests and nearby construction equipment makes it more difficult to identify persons at a safe distance from the truck (Ferreira et al., 2017). Meanwhile, high-visibility hats, arm bands, and vests with strobes can increase visibility (Pratt et al., 2001).

III.4.2.7 Automatic Operation

In case of distraction or error by the driver or the backover victim, automation in the backing safety system could trigger a safety warning to avoid crashes (Graham and Dearth, 1984).

III.4.2.8 Traffic Flow Control

A well-designed traffic control plan both inside work zones and for public roads passing the work zones can help improve work zone safety (Bryden, 2007). The traffic control plan should include traffic control devices, signals, and message boards to instruct drivers to follow paths away from work zones, and devices including cones, barrels, barricades, and delineator posts can be also used inside work zones. Temporary traffic control prior to construction should be set up in case motorists ignore warning signs and devices when work starts. Missing traffic control devices outside work zones lead to the potential for motorists to inadvertently enter the work space or exit the highway in the wrong place (Pratt et al., 2001).

III.5 Other Findings and Discussions

III.5.1 Blind Spot behind the Truck

During the static tests, it was discovered that two feet immediately behind the dump truck fall into a blind spot not detectable by the AdViSE cameras, as shown in **Fig. III-28**. This blind spot forms a triangular cross-section from its side view, as shown in **Fig. III-29** and **Fig. III-30.** However, mechanics and drivers believe that this blind spot will not have an impact during regular use of the truck.

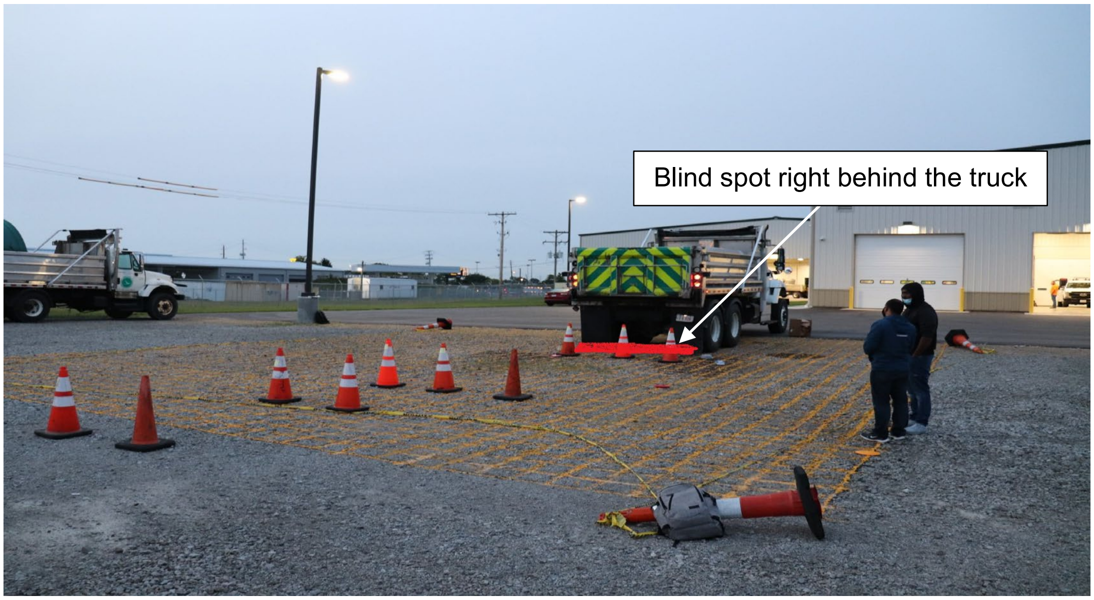


Fig. III-28: Blind Spot Located Right behind the Back of the Dump Truck

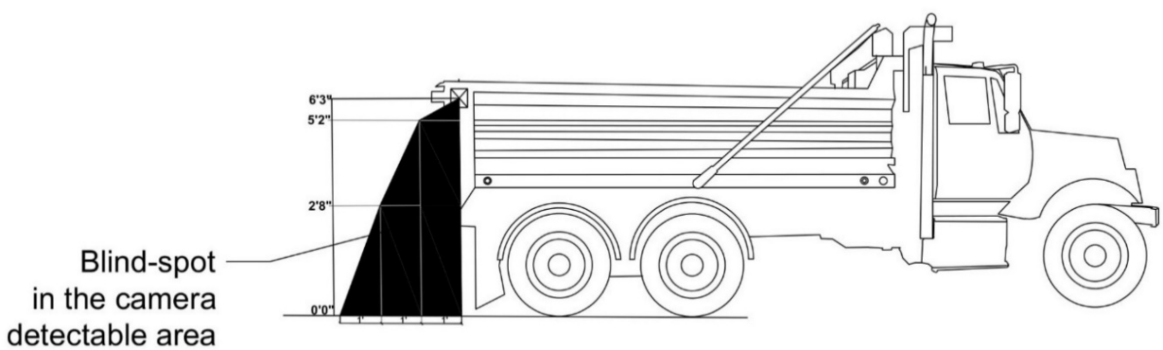


Fig. III-29: Illustration of the Side View of the Camera Blind Spot

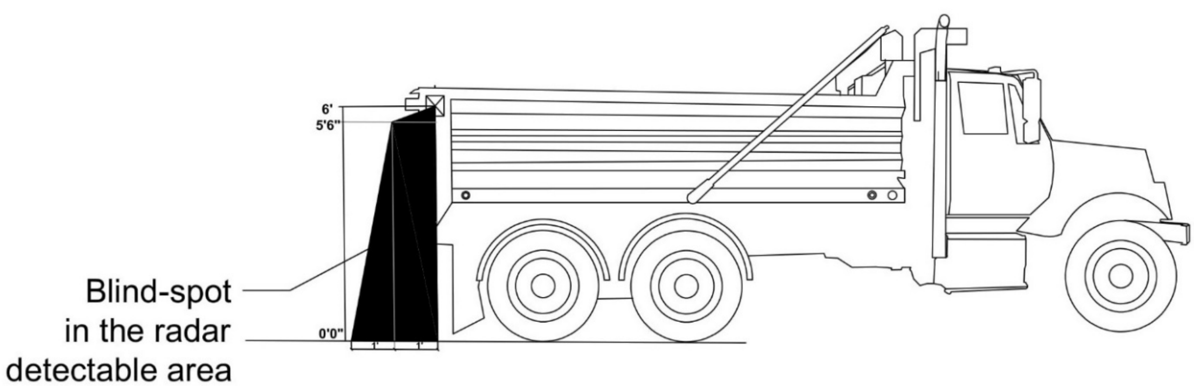


Fig. III-30: Illustration of the Side View of the Radar Blind Spot

III.5.2 Low-Lighting Impacts

The camera visibility tests were performed before dawn. The lamp posts beside the test grid provided lighting during these tests. **Fig. III-31** shows the images of the lamp posts that are on either sides of the test grid.

Fig. III-31: Photos Showing the Lamp Posts on Either Side of the Vehicle

A light post on the driver side of the truck created a shadow putting the passenger side in complete darkness, so a light tower was added on the passenger side for the low-light tests (shown in **Fig. III-32**).

Fig. III-32: Photos Showing the External Light Used for Zones Identification from the Passenger Side Camera

III.6 Post-Testing Survey and Analysis

III.6.1 Design of the Survey Questionnaire

The University of Cincinnati's research on identifying the best practices for decreasing dump truck backing accidents has led to an installation of a camera-radar system to a testing truck. Site measurements have identified some limitations of the installed system. So far, the limitations identified include **blind spots behind the truck**. This survey is specifically designed for acquiring inputs from drivers and mechanics of ODOT.

The purpose of this survey is to:

1. Find out impact of identified limitations and collect information on how to best deal with the identified limitations.
2. Find out if there are other limitations of the installed system.

Before answering the questions, please carefully review Figures 1, 2 & 3, which represent the field of view of the cameras and the blind spot of the rear camera.

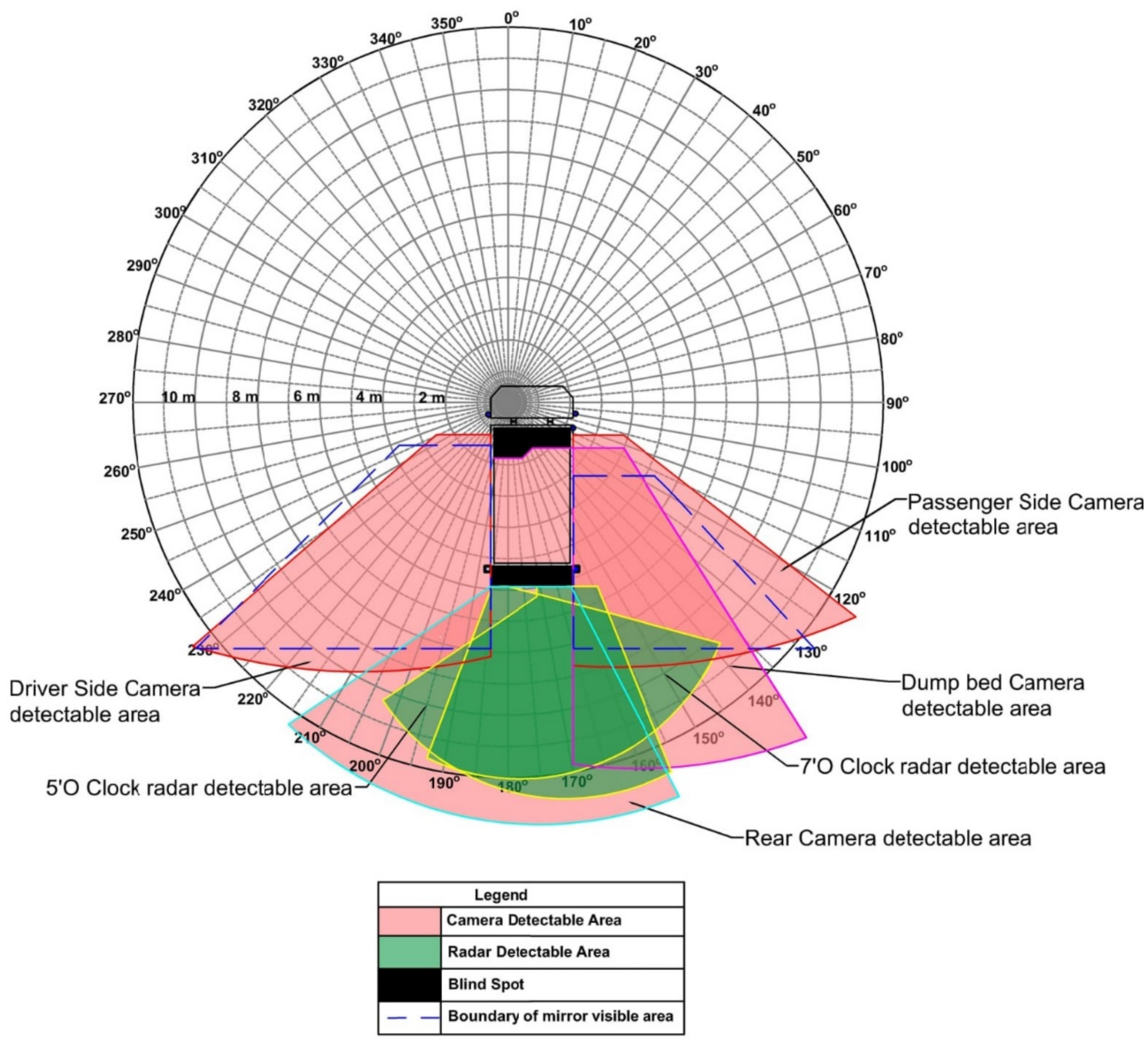
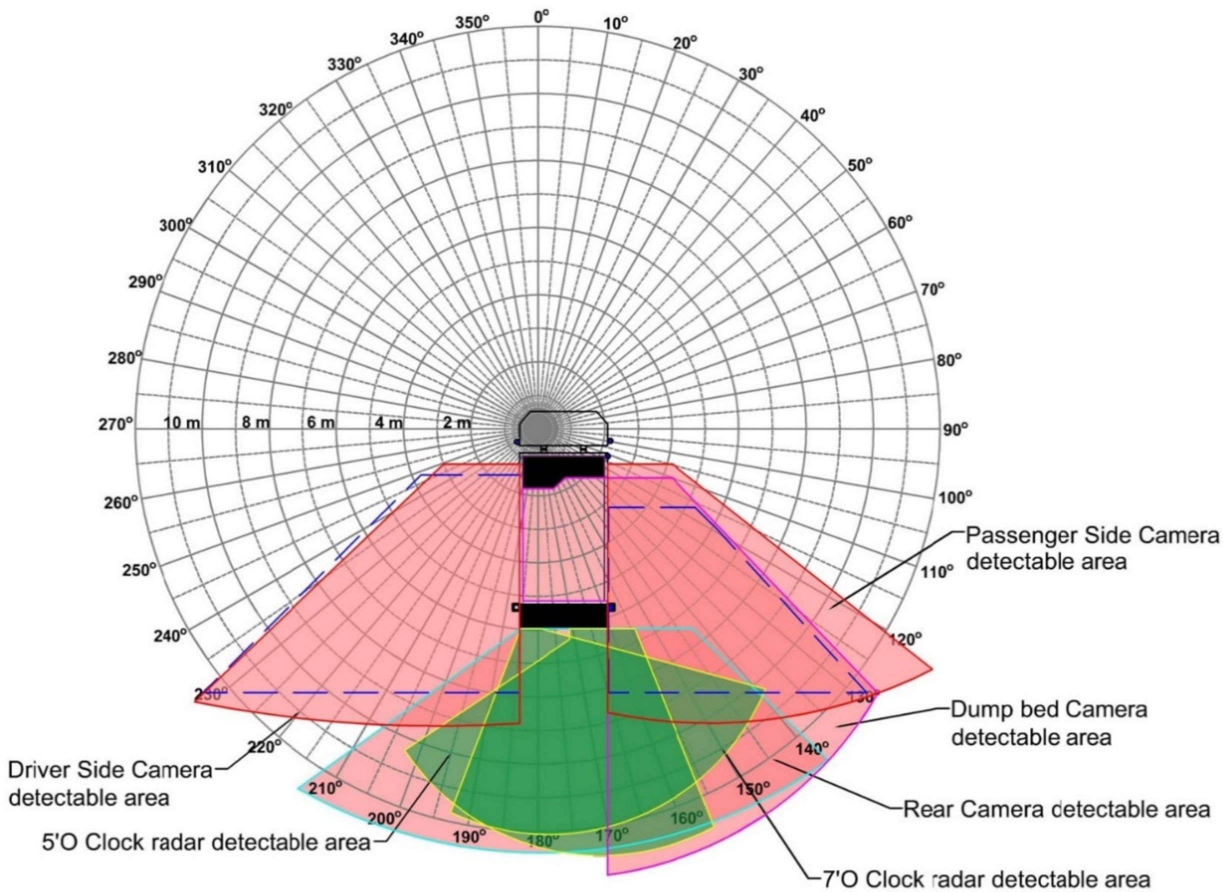


Figure 1: Illustration of the 360-degree view of camera, radar, and mirror detectable areas with blind spots under low-light conditions



Legend	
	Camera Detectable Area
	Radar Detectable Area
	Blind Spot
	Boundary of mirror visible area

Figure 2: Illustration of the 360-degree view of camera, radar, and mirror detectable areas with blind spots under daylight conditions.

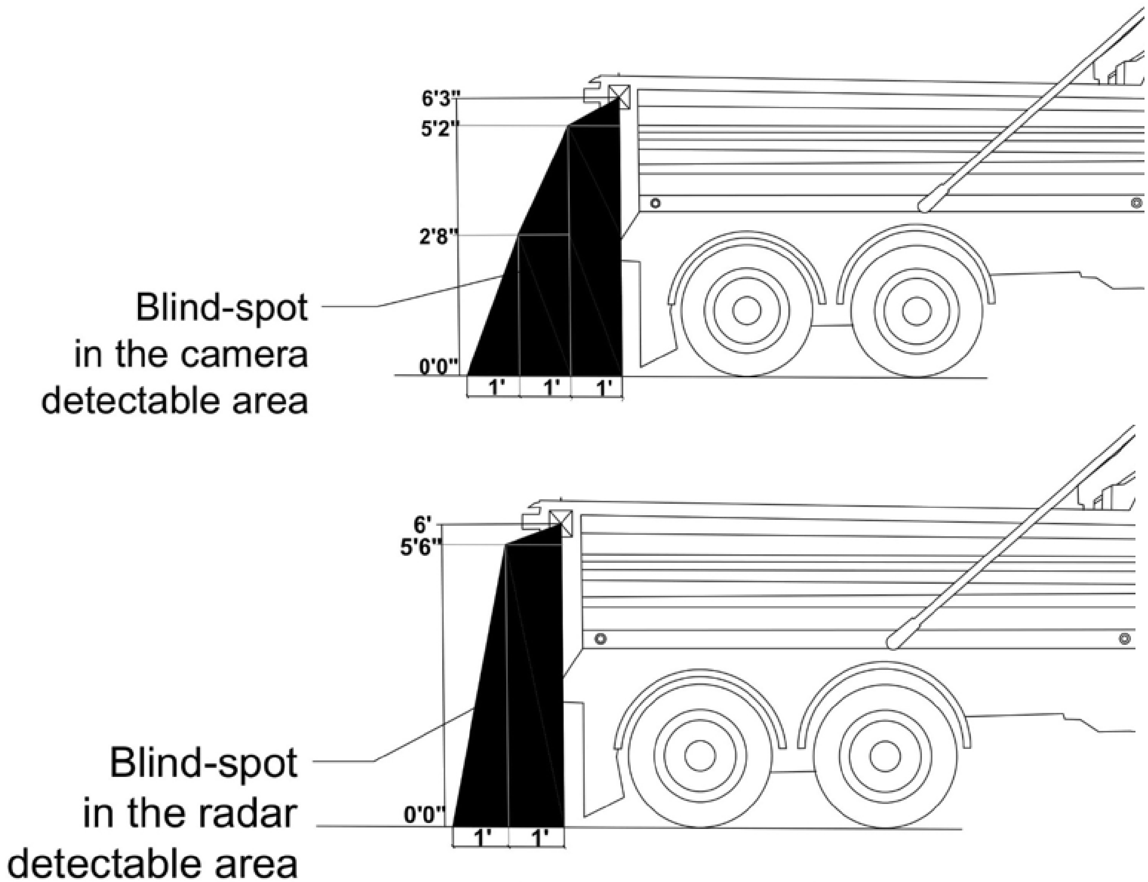


Figure 3: Illustration of the side-view of the truck with the blind spot of the rear camera

If you have any questions about the survey, please contact the PI (Prof. Heng Wei) of this research project by email at: weihg@ucmail.uc.edu

RESPONDER CONTACT INFORMATION

Name:

Phone number:

Email address:

IMPACT OF IDENTIFIED LIMITATIONS & SUGGESTIONS TO DEAL WITH THEM

1- Please review the coverage provided by AdViSE (you may also refer to Figures 1, 2 and 3), **please indicate below how helpful is the installed AdViSE system for reducing backing accidents** in the following operations **(1: Not helpful at all, 5: very helpful**)?

a) Paving (N/A, 1, 2, 3, 4, 5)
b) Snow clearing operations (N/A, 1, 2, 3, 4, 5)
c) Ditching (N/A, 1, 2, 3, 4, 5)
d) Sweeping (N/A, 1, 2, 3, 4, 5)
e) Litter removal (N/A, 1, 2, 3, 4, 5)
f) Other opera: please indicate ___________ (N/A, 1, 2, 3, 4, 5)

2- Given the current **blind spots behind the truck as shown in Fig. 3, can you rate the possible negative impacts of the blind spots** on the following maintenance operations (**1: No impact, 5: very high negative impact**)

g) Paving (N/A, 1, 2, 3, 4, 5)
h) Snow clearing operations (N/A, 1, 2, 3, 4, 5)
i) Ditching (N/A, 1, 2, 3, 4, 5)
j) Sweeping (N/A, 1, 2, 3, 4, 5)
k) Litter removal (N/A, 1, 2, 3, 4, 5)
l) Other: please indicate ___________ (N/A, 1, 2, 3, 4, 5)

3- Please comment on how the **blind spots behind the truck may or may not be a concern for** the various maintenance operations as indicated above **and suggest ideas on how to deal with the concerns**.

OTHER LIMITATIONS

4- Other than the limitations related to the **blind spots behind the truck**, please indicate if you have observed while using the truck in the various maintenance operations any of the following as a potential limitation of the installed system. Please ALSO indicate the maintenance operation that is affected most by the limitation. **(Use the following numbers to indicate the maintenance operation: 1- Paving, 2- Snow clearing operations, 3- Ditching, 4-Sweeping, 5- Litter Removal, 6- other- please indicate)**

a) Performance during icy conditions (1, 2, 3, 4, 5,6)
b) Performance during rain (1, 2, 3, 4, 5,6)
c) Performance during salt application (1, 2, 3, 4, 5,6)
d) Display clarity (1, 2, 3, 4, 5,6)
e) Distraction caused by numerous displays (1, 2, 3, 4, 5,6)
f) Distortion of images (1, 2, 3, 4, 5,6)
g) Adaptation speed of the cameras at very fast changes of the light conditions (1, 2, 3, 4, 5,6)
h) Glare caused by bright displays
m) Potential for developing "bad" safety habits due to over reliance on the technology (e.g. ignoring or reducing shoulder check) (1, 2, 3, 4, 5,6)
n) Others: Please indicate: _______________________ (1, 2, 3, 4, 5,6)

Questions related to MAINTENANCE WORKS – FOR MECHANICS ONLY

5- Please indicate what kind of **maintenance/cleaning** operations are performed currently on the dump truck and **how often** such operations are carried out (i.e., dump truck regular washing procedure, check-up and service routine, what psi is the power washing system?).

S. No	Maintenance/Cleaning Operation	Time Interval

III.6.2 Analysis of the Survey Outcomes

The Post-testing surveys, which were developed based on the AdViSE system's coverage, provided exciting facts. These were designed to get the maximum feedback of drivers with less time involved. Two-thirds of the respondents provided their contact information, while the remaining third did not. The respondent sheets were analyzed to know the drivers' ability to understand the coverage and the drivers' understanding of the developed AdViSE system's benefits.

III.6.2.1 Questions related to Coverage and Blindspot:

Firstly, the survey asked respondents to rate the AdViSE system's coverage for different dump truck operations on a scale of 1 through 5, with one being 'not helpful at all' and five being 'very helpful.' The survey results show that most respondents found the AdViSE system's coverage to be 'very helpful' for paving operations with an average score of 5 points, followed by sweeping operations with an average score of 4.33, as shown in **Fig. III-33**. Next, an average score of 2.67 points was given to litter removal, followed by two average points for snow clearing and ditching operations. Some responses towards pothole operations were given the lowest score of 1.67 points on average.

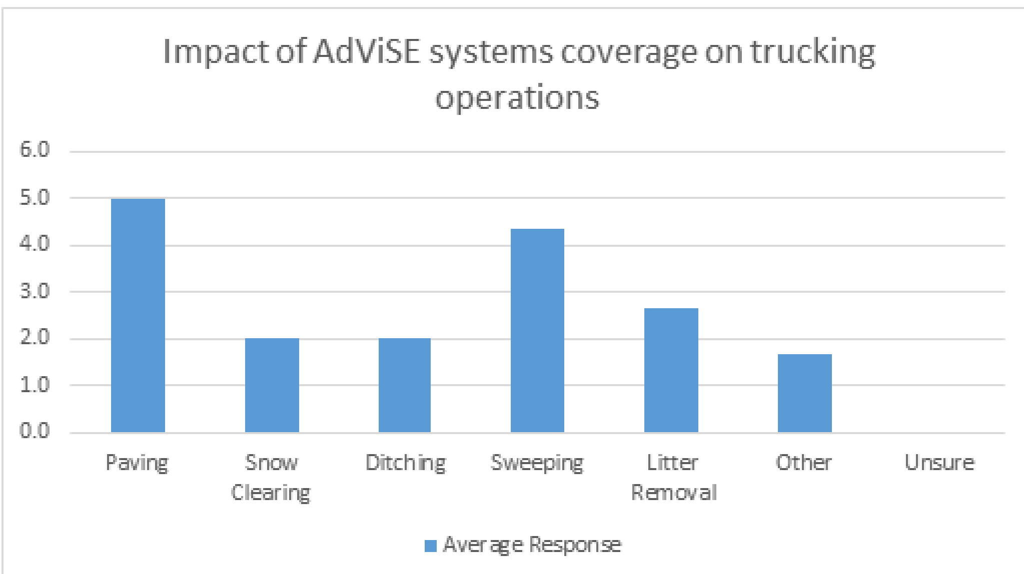


Fig. III-33: Survey Responses to the AdViSE's Impacts on Truck Operation Coverage

Secondly, the survey questionnaire concentrated on the impact of the blind spot observed during the testing of AdViSE system on different dump truck operations, and the respondents were asked to rate the system on a scale of 1 through 5 in the same way. As shown in **Fig. III-34**, there is a considerable impact of the blind spot on certain operations like paving and sweeping, which received an average score of 2.33 points from the respondents. This was followed by snow clearing, ditching, and litter removal operations with an average score of 1.67. Some respondents felt that there is also an impact on pothole operations, which fell under the 'other' category.

The survey also asked for suggestions regarding the blind spot of the system, however respondents replied that they were confident that the blind spot is not a concern.

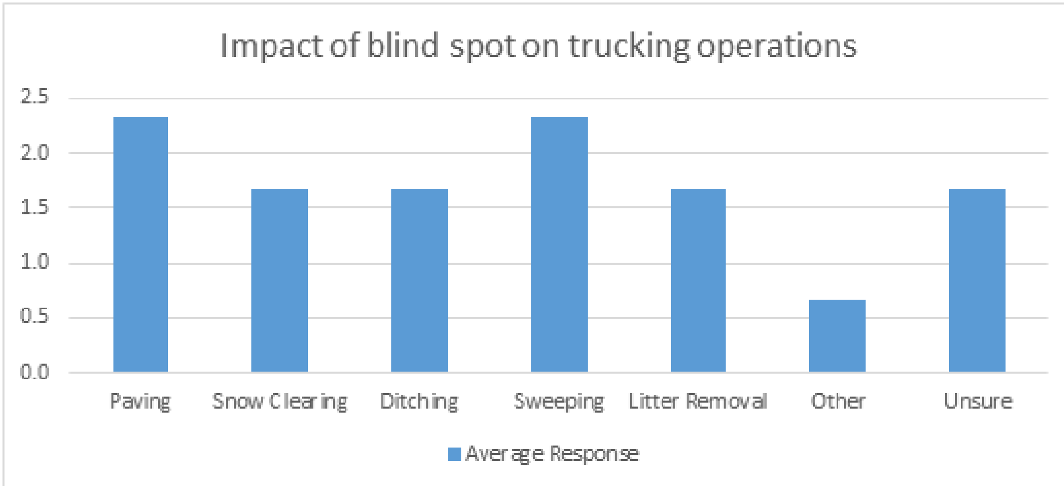


Fig. III-34: Survey Responses to the AdViSE Impacts on the Truck Blind Spots

III.6.2.2 Questions on other limitations:

The survey also asked the respondents to mention any other observed limitations of the system with different trucking operations, and the responses are shown in **Table III-8**. The table's vertical index represents the limitations, and the horizontal index of the table represents the trucking operations. The fractions in the table represent the fraction of respondents who mentioned that there might be a limitation for each operation.

Table III-8. Survey Responses to Other Limitations of the AdViSE System Observed by Drivers under Different Operations

Function/ Application		Paving	Snow Clearing	Ditching	Sweeping	Litter removal	Others	Unsure
Perfor-mance	Icy Conditions					1/3		1/3
	Rain	1/3			1/3		1/3	1/3
	Salt Application					1/3		1/3
Display	Clarity	1/3			2/3		1/3	1/3
	Distraction	1/3			2/3		1/3	1/3
	Distortion				1/3			1/3
	Adaptation					1/3		1/3
	Glare	1/3						1/3
Potentiality for developing bad safety habits						1/3		1/3
Others					1/3			1/3

Some questions which are intended for mechanics are also included in the survey. As the survey is taken only from the drivers, no response is identified for the questions based on maintenance and cleaning operations.

III.7 Benefit-Cost Analysis Method for Future Study

III.7.1 Previous Studies of Impact of a Rearview Video System on Backing Accident Reduction

The research team's literature review found out a number of previous studies which analyzed the impacts of rearview camera or video systems on backing accidents reduction. For example, Mazze et al.'s study (2008) through a research project funded by USDOT found that the likelihood of a rearview video system preventing a backing crash <u>depends on several conditions</u>, most notably the location and movement (or path) of the obstacle. Other previous studies also suggested similar results.

Hurwitz et al.'s research (2010) has shown that even for the average drivers in a variety of accident-prone scenarios, i.e., moving objects including children in the rear area, 88% of those drivers who looked at the rear view system had avoided the backing accident. **Table III-9** summarizes the relevant findings from some previous studies.

Table III-9. Summary of Previous Studies of Rearview Video System on Accident Impact

Accident reduction %	Type of truck	System	Source
100 -130 / year to 80/year (Around 20%-38%)	Dump Truck	Radar + Cameras	Cooper, D. L., Duffy, S., Orrick, P., & Ragland, D. R. (2010). Develop Methods to Reduce or Prevent Backing Crashes. California PATH Program, Institute of Transportation Studies, University of California at Berkeley.
40%	Regular trucks	Rear View Cameras	Kourtellis, A., Lee, C., Lin, P. P. S., & Lu, J. (2009). *Evaluation of the Effectiveness of Rear-View Camera Systems as a Countermeasure for Truck Backing Crashes: Lessons Learned from Actual Field Deployment* (No. 09-1569).
51.9%	Winter Maintenance Trucks	Rear View Cameras	Zockaie, A., Saedi, R., Gates, T. J., Savolainen, P. T., Schneider, B., Ghamami, M., ... & Zhou, C. (2018). Evaluation of a Collision Avoidance and Mitigation System (CAMS) on Winter Maintenance Trucks (No. OR 17-103). Michigan. Dept. of Transportation. Research Administration.

As shown in **Table III-9**, the cited studied indicated a range of accident reduction rate at 38 - 52%, while 88% of the average drivers opt to look at the rear-view system in an effort to avoid the backing accident (Hurwitz et al., 2010). On the other hand, no field research was performed to determine with certainty the percent reduction in accidents that ODOT should anticipate with the use of AdViSE. Accoridingly, we had to rely on previous research studies (see referecnes listed in **Table III-9**).

Though we know that ODOT drivers are skillful and will be trained to use the AdViSE system effectively to significantly reduce backing accidents, we used a more conservative 50% reduction rate in the BCA study. The step-by-step BCA procedure is described in details below.

III.7.2 Benefit-Cost Analysis of the AdViSE System

A Benefit-Cost Analysis (BCA) attempts to identify and express a proposed system's benefits in simple economic terms. One effective way of performing a BCA is a simple payback method. The simple payback method determines the number of years needed for the annual benefits generated from using the proposed system to pay for the cost of the system using the following equation:

Simple payback = (Cost of proposed system) /(annual benefits resulting from the system)

The economic benefits of AdViSE result from the avoided annual cost of dump truck backing accidents. Thus to be able to calculate the Simple payback, both the cost of the system and the annual cost of backing accidents need to be calculated as described in the next sections.

Step 1: Cost of AdViSE Alternatives

The costs of the various alternatives of AdViSE as obtained from the manufacturer are provided in **Table III-10**. It should be noted that the costs in Table III-10 are per truck.

Table III-10. Costs of the AdViSE Configuration Alternatives

Item	Full-Equipped (4 Cameras + 2 Radars) (i.e. the Pilot System)	Semi-Equipped (2 Cameras + 2 Radars)	Simple-Equipped (2 Cameras Only)
Cost	$7,432/ truck	$6,148/ truck	$3,224/ truck
Improved Function	Remove blind spots: left (driver) side, right (passenger) side, rear areas and dump bed; audible warning	Remove blind spots: right (passenger) side, and rear area; audible warning.	Remove blind spots: right (passenger) side and rear area.

Step 2: Determine average number of ODOT dump truck backing accidents per year

The crash data was obtained from ODOT safety division as shown in **Table III-11** and **Table III-12**. The crash data obtained indicate different types of severities, i.e., fatal, injury, and physical damage only (PDO). Based on the data shown in those tables, the following items are calculated:

- Number of ODOT back up accidents (year 2019) = 132
- % of backing accidents caused by dump trucks based on District 6 data = 7/19 = 36.84%
- Number of ODOT back up accidents caused by dump truck/year **(a)** = 36.84%×132 = 48.63

Table III-11. Ohio Dump Truck Backing Accidents

Year	Injury	PDO	Grand Total
2017	11	108	119
2018	1	114	115
2019	11	121	132
2020	4	72	76
Grand Total	**27**	**415**	**442**
Total (years 2017 – 2019)	23	343	366
Proportion	6.30%	93.70%	

Table III-12. Backing Accidents in District 6, ODOT (Year 2019)

Total Accidents Reported : **19**			
Dump truck involved accidents: **7 (36.8%)**		Fatal Accidents: **0%**	
Pick-up truck involved accidents: **9 (47.36%)**		Non -Fatal Accidents: **0%**	
Other vehicles involved: **3 (15.78%)**		PDO: **100%**	
Accident in details			
Sl. No	Date	Type of truck	Severity
1	3/14/2019	Dump Truck	No Injury - PDO
2	2/21/2019	Dump Truck	No Injury - PDO
3	11/13/2018	Pick-up Truck	No Injury - PDO
4	5/7/2019	Pick-up Truck	No Injury - PDO
5	3/12/2019	Dump Truck	No Injury - PDO
6	4/22/2019	Pick-up Truck	No Injury - PDO
7	3/18/2019	Dump Truck	No Injury - PDO
8	2/10/2019	Dump Truck	No Injury - PDO
9	6/6/2019	Pick-up Truck	No Injury - PDO
10	9/5/2018	Pick-up Truck	No Injury - PDO
11	7/10/2018	Tractor	No Injury - PDO
12	6/28/2018	Dump Truck	No Injury - PDO
13	6/13/2018	Pick-up Truck	No Injury - PDO
14	6/20/2018	Pick-up Truck	No Injury - PDO
15	6/15/2018	Sweeper	No Injury - PDO
16	1/28/2018	Dump Truck	No Injury - PDO
17	1/14/2018	Pick-up Truck	No Injury - PDO
18	6/21/2018	Pick-up Truck	No Injury - PDO
19	10/13/2017	Van	No Injury -PDO

Step 3: Determine percent of various types of backing accidents

Based on data in **Table III-11**, the percentage of various accident types resulting from backing accidents data for year 2019 is listed in **Table III-13.**

Table III-13. Percentage of Accident Types in Ohio (year 2019)

Improper Backing	Fatal	Injury	PDO
#	0	11	121
%	0.00% (**b**)	8.33% (**c**)	91.67% (**d**)

Step 4: Calculate ODOT Cost of different types of accidents

Table III-14 was obtained from ODOT's "Crash Cost Annual Adjustment" report and contains accidents cost data in terms of comprehensive societal costs associated with different types of crashes (i.e., fatal, injury, PDO) based on 2019 prices. An inflation percentage of 3% was used to determine the accidents costs in 2021 prices as indicated in **Table III-15**.

Table III-14. Comprehensive Societal Costs of Crashes by Accident Type (2019)

Accident type	Fatal	Injury	PDO
Comprehensive Societal Cost	$6,295,122	$115,733	$10,964

Table III-15. ODOT Comprehensive Societal Cost of Accidents by Type (2021 Prices)

Accident type	Fatal	Injury	PDO
Comprehensive Societal Cost 2021	$6,483,976 (**e**)	$119,205 (**f**)	$11,293 (**g**)

For every type of accident, and by multiplying the ODOT's cost (**e/f/g**) by the average annual number of ODOT dump truck backing accidents (**a**) and percentage of backing accidents (**b/c/d**), we can obtain the Annual ODOT dump truck Backing Accident Cost (*h/i/j = a*(b/c/d)*(e/f/g)*) **as shown in Table III-16.** By adding h, I, and j, the total annual ODOT dump truck backing accidents' cost can be determined as $986,520.

Table III-16. Total Annual ODOT Dump Truck Backing Accident Cost (per year)

Accident type	Fatal	Injury	PDO
Total Annual ODOT Backing Accident Cost (per year)	$0 (**h**)	$483,094 (**i**)	$503,426 (**j**)

The annual benefits associated with AdViSE result from the avoided ODOT annual cost of backing accidents and depend on the anticipated % reduction in dump truck backing accidents resulting from the use of AdViSE. In this analysis, as previously discussed we assumed a "conservative" 50% reduction with proper use and training based on previous studies. Thus the anticipated **total annual** ODOT benefits from AdViSE is = 0.50 × 986,520 = $493,260.

Step 5: Complete the BCA analysis and calculate the simple payback

In order to conduct the BCA, and since the cost provided in Table III-10 are "per dump truck", the annual benefits associated with AdViSE should also be calculated per dump truck. ODOT has currently 853 tandem dump truck. However, not all dump trucks are regularly used and thus it is logical to assume that the accident rate per truck is not constant among all trucks and that trucks that are more regularly used are responsible for the majority of accidents.

Thus, in order to calculate the annual benefits of AdViSE system per truck we have to make some assumptions regarding the % of ODOT trucks that are regularly used and that typically cause all of ODOT backing accidents and should be the prime candidates for AdViSE installation. Based on Feedback from ODOT district 6 personnel, we assumed 50% of ODOT trucks are regularly used and thus cause the majority of backing accidents. Based on this assumption we calculated the annual benefit of AdViSE system per truck as ($493,260/(50%*853)= $1,156.53/truck.

Finally, the payback periods for the various alternatives are calculated as shown in **Table III-17** by dividing the costs of the various alternatives of AdViSE per truck provided in Table III.10 by the anticipated annual benefits per truck ($1,156.53/truck).

Table III-17. Payback Period (years) for AdViSE System Alternatives

Assumed % accident reduction rate	50%
Assumed % of regularly used dump trucks that cause the majority of ODOT backing accidents and that will be equipped with AdViSE	50%
Payback: AdViSE Alternative I: Fully-Equipped (4 Cameras + 2 Radars)	6.43 years
Payback: AdViSE Alternative II: Semi-Equipped (2 Cameras + 2 Radars	5.31 years
Payback: AdViSE Alternative III: Simply-Equipped (2 Cameras Only)	2.79 years

Appendix IV – Manuals

IV.1 AdViSE User Manual

AdViSE User Manual

(Version 1.0)

Date: January 4, 2021

Keyboard Layout

- Different functionalities of the AdViSE system can be accessed and navigated through the keyboard buttons embedded on the 7-inch or 12-inch monitor.
- The buttons are embedded horizontally on the 7-inch monitor and vertically on the 12-inch monitor, but identical in terms of functionality, as shown in Fig. **IV-1**.

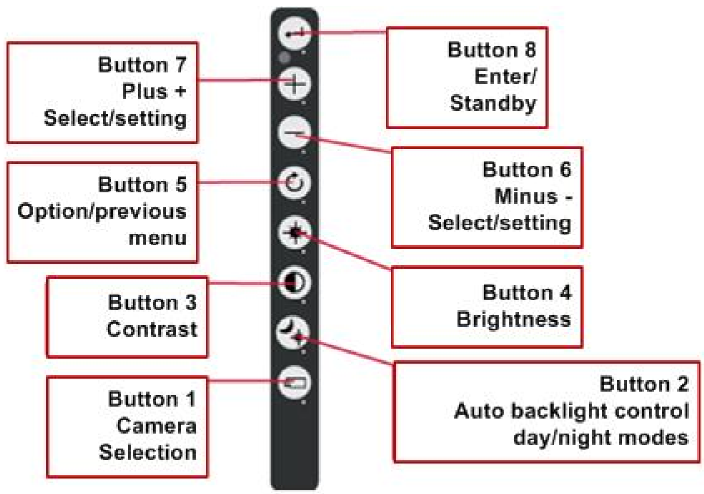


Fig. IV-1A: Menu Buttons on the 12-inch Monitor

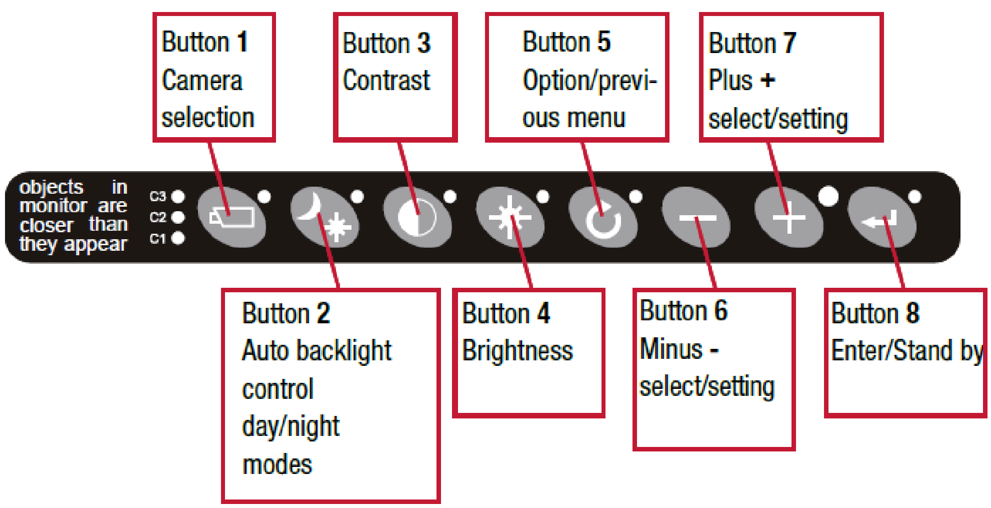


Fig. IV-1B: Menu Buttons on the 7-inch Monitor

Keyboard Functionality

- The keyboard buttons can be used to adjust the display quality, switch between camera views, and activate the radar sensors. Their various functionalities are summarized below:

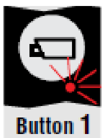
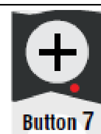
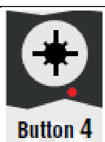
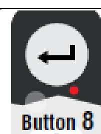
	**Button 1, Camera Selection** Manual selection of camera views		**Button 5, Option/Previous menu** Return to previous menu
	**Button 2, Auto back-light control**		**Button 6, Minus** Move to next or to left
	**Button 3, Setting Contrast**		**Button 7, Plus** Move to previous or right
	**Button 4, Setting Brightness**		**Button 8, Enter** Select or activate option

Fig. IV-2: Functionality of the keyboard buttons

Default Display

- Upon power ON, the monitor shows a quad-view on the split screen, meaning it will show images from all the four cameras installed, as shown in Fig. **IV-3**.
- The camera view can be changed using the manual camera selection button (**see Manual Camera Selection**)

Fig. IV-3: Default Split-Screen View with Four Cameras

DUMP – Dump-bed view	**REAR** – rear-camera view	**DRIVER** – driver-side camera view	**PASS** – passenger-side camera view

Manual Camera Selection

- Press the manual camera selection (button 1) once.
- The camera LED will flash to indicate that manual camera selection is enabled (**Fig. IV-4**).
- Use the minus (button 6) and plus (button 7) buttons to select the desired camera.
- Press button 1 again to disable manual camera selection.
- Available buttons are shown in **Fig. IV-5**.

- When manual camera selection is active, the trigger wire for reverse/radar is not functional; i.e., the radar will show proximity alert whenever an object is in its detection zone.

Fig. IV-4: Red LED under Button 1 indicating Manual Camera Selection Enabled.

Fig. IV-5: Available Camera Views

Rear-view Camera and Radar

- Once the vehicle is put into reverse gear, the monitor view is switched to rear camera and the radar sensors are activated.
- If an object is detected on the rear of the vehicle, the monitor will display color-coded dots (indicating proximity of the object), as shown in **Fig. IV-6**.

Fig. IV-6: Rear-view Camera and Radar Sensor Indicator on the Monitor When the Vehicle is in Reverse

Proximity Detection

- The number of dots will increase, and the color of the dots will gradually turn from Green to Red, as an object approaches within the detection range of the radar sensors.
- There will also be an audible alert (tone) with the pitch and frequency of the tone increasing with closer proximity.
- The detection zone is divided into 5 zones with each zone displaying as a different combination of color-coded dots on the screen.

Fig. IV-7A: Single Green Dot Indicating Zone 1 (Furthest from the Sensor)

Fig. IV-7B: Two Green Dots -- Zone 2

Fig. IV-7C: Three Yellow Dots - Zone 3

Fig. IV-7D: Four Yellow Dots -- Zone 4

Fig. IV-7E: Five Red Dots Indicating Zone 5 (Closest to the Sensors)

Display Adjustment

Adjust Backlight Brightness

- Press button 2 to switch between the automatic backlight mode (ABC), the LCD backlight day setting, or the LCD backlight night setting.
- In the day and night mode the brightness of the backlight can be manually set using the minus and plus buttons (buttons 6 & 7).
- These settings are not camera dependent and therefore apply for all cameras.

Adjust Contrast

- Press button 3 to enter this option
- The contrast can be set using the minus and plus buttons (buttons 6 & 7).
- Must be set for each camera individually. Use the camera selection button to select a camera (see details in **Manual Camera Selection**)

Adjust Brightness

- Press button 4 to enter this option
- The brightness can be set using the minus and plus buttons (buttons 6 & 7).
- Must be set for each camera individually. Use the camera selection button to select a camera (see details in **Manual Camera Selection**)

IV.2 AdViSE Maintenance Manual

According to the recommendation of Orlaco (the provider of major physical parts of the AdViSE system), the following maintenance items are raised to draw attention to the users:

Orlaco cameras, sensors and cables are protected by IP69 and IP67 ingress protection and can be pressure washed. However, we recommend avoiding direct high pressure around the area where the cameras and radars are installed while cleaning the exterior of the dump truck with pressure wash.

At normal weather conditions, the camera lens and radar surface should be cleaned with wash clothes during truck's regular cleaning cycles.

The debris (snow, ice, mud, etc.) from extreme weather conditions can occlude the camera lens and hinder the detection ability of the radar sensors. In such conditions, the lens and radar surface should be wiped clean with a cloth at the beginning of each shift. Additional cleaning may be needed during work zone operations.

While cleaning the interior (cab) of the truck, caution should be taken to not loosen any cable connections between the interface box, monitor, etc. and the cameras and sensors.

In addition to air and moisture, certain chemicals such as de-icing agents can corrode the cable connectors over time. Therefore, in every six months the cable connectors should be checked and replaced if necessary.

At the beginning of a shift, the operator should verify that the AdViSE system functions properly. The following should be checked:

- The monitor displays all camera views. Refer to the AdViSE user manual (**section IV.1**) for instruction on how to manually select camera views.
- The radar sensors are able to detect objects. In case of detection failure, an error message will be shown on the monitor (see Fig. I-47). In such case, the cable connection of the interface box to the radar sensors should be examined.