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Prevention of Backing Fatalities in Construction Work Zones: Final Report

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16. Abstract
Construction, repair, and maintenance work zones are always hazardous environments, particularly given the dangerous combinations of pedestrian workers and large trucks, bulldozers, rollers, and other moving machinery. Workers are exposed to moving traffic near the work zone with the risk of errant vehicles entering the work zone area. Pedestrian workers are exposed to construction vehicle crashes within the work zone. Between 70 and 80 pedestrian construction workers are struck and killed each year by construction vehicles within a work zone. From 1995 to 2002, 844 worker deaths occurred in roadway work zones, of which 91% were related to motor vehicle traffic or construction equipment. Construction vehicle related deaths were responsible for more than half of these deaths. Dump trucks accounted for 41% of pedestrian-worker deaths and 52% of these involved dump trucks backing up. The American Road & Transportation Builders Association (ARTBA) named run-overs and back-overs as the leading cause of death for roadway construction workers, with over half occurring when workers were struck by construction vehicles or equipment inside the work zone. The purpose of this study was to review current practices and procedures to prevent backing fatalities, identify and analyze appropriate responses, and test commercially available systems for prevention of backing fatalities. Guidelines and recommendations for TxDOT traffic control practices, which incorporate commercially available systems for the prevention of backing fatalities in work zone operations, are also provided in this study.

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Chapter 1. Introduction

1.1 Problem Statement

Construction work zones have always been a hazardous environment due to the dangerous combination of pedestrian workers, congested work zone areas and large moving machinery. Construction zone workers are exposed to highway traffic, as well as equipment within the work zone. The risk from highway traffic is caused from errant vehicles entering the work zone area striking workers caused by failure to provide adequate signs, and sometimes failure to set up a construction work zone properly. Drivers are not given an adequate amount of warning time, and workers are confined to small work areas which make them easy targets for oncoming motorists.

According to Zeyher (2007), between 70 and 80 pedestrian construction workers are struck and killed each year by construction vehicles within a work zone. From 1995 to 2002, 844 worker deaths occurred in roadway work zones, with 91% of these deaths being related to motor vehicle traffic or construction equipment.

Construction equipment within the work zone was responsible for more than half of these deaths. Dump trucks were the leading cause of workers on foot accidents with 41% of the accidents. According to the Washington State Department of Labor and Industries, 2009, 52% of these involved dump trucks backing up. The American Road & Transportation Builders Association (ARTBA) named run-overs and back-overs as the leading cause of death for roadway construction workers with over half-occurring when workers were struck by construction vehicles or equipment inside of the work zone.

1.2 Objectives

The objective of this report is to (1) review current practices and procedures being used to prevent backing fatalities (2) identify and analyze appropriate responses to different scenarios, and work zone site characteristics (3) test commercially available systems for prevention of backing fatalities and (4) provide guidelines and recommendations for TxDOT traffic control practices, incorporating commercially available systems for the prevention of backing fatalities in work zone operations.

1.3 Expected Contributions

The research team will develop recommendations and guidelines to present TxDOT based off of the research conducted throughout this report to aid in the prevention of backing fatalities. The expected contributions include, but are not limited to, the following: 1) A comprehensive review and synthesis of the current practices and procedures being used to prevent backing fatalities in construction work zones, will be conducted, which should help the construction practitioners and safety researchers gain a clear understanding of the state-of-the art/practice; (2) A matrix for evaluation and selecting commercially available systems for prevention of backing fatalities will be developed, which should provide guidance on the use and selection of technology for the prevention of backing fatalities in construction work zones; (3) Guidelines and recommendations will be provided for TxDOT traffic control practices, incorporating commercially available systems for the prevention of backing fatalities in work zone operations. Specifically, an integrated internal traffic control plan, which is the first of its kind and constitutes an integrated engineering, administrative and education, and technology solution, will be carefully developed and documented in detail for the first time.

1.4 Report Overview

The remainder of this report is organized as follows: Chapter 2 presents a comprehensive review of the state-of-the-art and state-of-the-practice literature on backing fatalities, and some of the practices currently used in prevention of construction accidents. Chapter 3 discusses the identification and analysis of appropriate responses including engineering controls, administrative controls, and technology controls. It also collects and reviews the existing backing fatalities data currently available in all TxDOT districts and characterizes these backing fatalities on construction work zones. Chapter 4 presents the identification of commercially available systems for preventing backing fatalities including a review of technology, review of proximity warning systems, as well as some methodology behind this research. Chapter 5 describes the testing of commercially available systems for preventing backing fatalities. Chapter 6 is the recommendations presented to TxDOT for the prevention of backing fatalities. Chapter 7 provides the presentation of guidelines for backing fatalities prevention systems. Finally, Chapter 8 concludes this report with a summary and a discussion of the directions for future research.

Chapter 2. Literature Review

2.1 Introduction

Construction, repair, and maintenance work zones are always hazardous environments, particularly given the dangerous combinations of pedestrian workers and large trucks, bulldozers, rollers, and other moving machinery. Workers are exposed to moving traffic near the work zone with the risk of errant vehicles entering the work zone area. Pedestrian workers are exposed to construction vehicle crashes within the work zone. According to Zeyher (2007), between 70 and 80 pedestrian construction workers are struck and killed each year by construction vehicles within a work zone. From 1995 to 2002, 844 worker deaths occurred in roadway work zones, i.e., over 100 deaths annually (Washington State Department of Labor and Industries, 2009). Of these deaths, 91% were related to motor vehicle traffic or construction equipment, or both. Construction-vehicle-related deaths were responsible for more than half of these deaths. Dump trucks accounted for 41% of pedestrian-worker-related deaths; 52% of these involved dump trucks backing up (Washington State Department of Labor and Industries, 2009). The American Road & Transportation Builders Association (ARTBA) named run-overs and back-overs as the leading cause of death for roadway construction workers, with over half occurring when workers were struck by construction vehicles or equipment inside the work zone (Zeyher, 2007).

The purpose of this chapter is to conduct a thorough review and synthesis of the state-of-the-art and state-of-practice to explore the current knowledge on the prevention of backing fatalities in construction work zones.

The results of this chapter will be a synthesis of guidance and research related to the prevention of backing fatalities in maintenance and construction work zones. This comprehensive synthesis will provide a useful reference for further development of this research.

The information presented in this chapter is organized into the following primary sections: Section 2.2 provides a review of general construction work zone safety characteristics. Section 2.3 presents a review of prevention of backing fatality in construction work zone. Section 2.4 discusses technology controls. Section 2.5 describes integrated engineering, administrative, and technology controls. Section 2.6 presents technology testing. Section 2.7 provides a review summary. Finally, section 2.8 concludes this chapter with a summary.

2.2 Review of General Work Zone Safety Characteristics

A work zone is defined as a section of roadway where construction, maintenance or utility work activities are under way. These zones typically extend from the first Warning sign or Warning vehicle to the End Road Work sign. According to Graham (2006), work zones contain a temporary traffic control (TTC) zone for the traveling public. The TTC consists of advanced warning, transition, activity, and termination areas. The advanced warning area consists of signs, rumble strips, and/or radar transmitters. The next section is the transition area, which consists of channeling devices such as cones and barricades, to divert or contain traffic on the roadway. The third section, the activity area, is where the work takes place. These are implemented because The Manual of Uniform Traffic Control Devices (MUTCD, 2009) described the need for a buffer zone between the traffic control zone and the work zone itself.

The final section is the termination area. In this section channeling devices and signage move traffic back to normal speed and lane configuration. The TTC zone is illustrated in Figure 2.1.

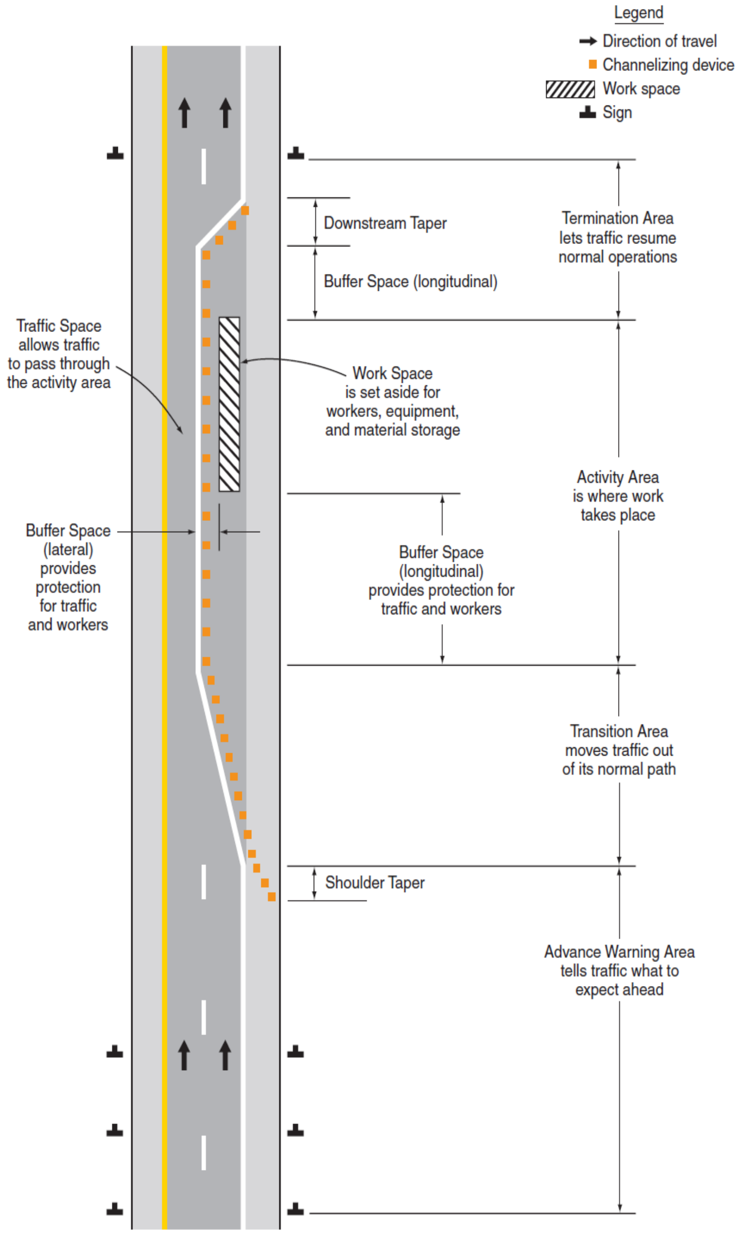


Figure 2.1 Temporary Traffic Control Zone (MUTCD, 2009)

According to the Texas Department of Insurance (2011), incidents occurring in work zones involve a combination of pedestrian workers, highway traffic and heavy equipment. Pedestrian workers being backed over by heavy equipment, accidents involving highway motorists, and equipment rollovers are all life-threatening incidents in the construction zone. The National Institute of Occupational Safety and Health (NIOSH) made specific recommendations to help reduce the number of incidents. Engineers should evaluate the area through surveying to help develop traffic control plans prior to the start of the project. They should design the plans with all of the area hazards in mind and come up with an idea best suited for the project at hand.

Advance warning is a big part in limiting highway traffic incidents, and the best alternative to give these warnings should be evaluated to make sure the best methods are being used. Flaggers should only be used whenever there are no better alternatives, and they should not be used in low visibility conditions. Flaggers should be comprehensibly aware of the Inner Traffic Control Plan (ITCP). After the ITCP has been designed, supervisors should test the review the plan to insure its effectiveness. Once the ITCP is in place in the work zone, supervisors should again test the flow of the work zone to make sure the ITCP is effective.

The Occupational Safety & Health Administration (OSHA) Regulations 1926.200 define the uses and specification of signage in a construction work zone. These specifications could be useful within the work zone for use in the ITCP. The types and specifications of signs are as follows:

- *Danger signs* - Shall be used where immediate hazards exist. Danger Signs shall have red as the predominating color for the upper panel; black outline on the borders; and a white lower panel for additional sign wording.
- *Caution signs* - Shall be used only to warn against potential hazards or caution against unsafe practices. Caution signs shall have yellow as the predominating color; black upper panel and borders: yellow lettering of "caution" on the black panel; and the lower yellow panel for additional sign wording.
- *Exit signs* - Shall be lettered in legible red letters, no less than 6 inches high, on a white field and the principal stroke of the letters shall be at least three-fourths in width.
- *Safety instruction signs* - Shall be white with a green upper panel with white letters to convey the principal message. Any additional wording on the sign shall be black letters on the white background.
- *Directional signs* - Shall be white with a black panel and a white directional symbol. Any additional wording on the sign shall be black letters on the white background.
- *Traffic signs* - Construction areas shall be posted with legible traffic signs at points of hazard.

Bryden and Andrew (1999) analyzed 240 accidents in the New York State Department of Transportation Projects between 1993 and 1997 and discussed the ramifications of their results. 20% of all work zone traffic accidents involve construction vehicles, rather than the traveling public. Public traffic however remains to be the largest part of accidents occurring in work zones. Two thirds of the injuries to pedestrian workers occurred from vehicles intruding into marked work spaces. Bryden et al. (1998) evaluated which methods of traffic control devices should be used in different scenarios to protect the workers and equipment of the work zone, as well as highway traffic which can be impacted by many factors of the work zone. Different traffic control devices such as cones, drums, barriers, signs, sign supports, and other related devices should reach the standards set by a specified code, and the most effective device should be used in the scenario it was designed for. The devices were evaluated under their own subcategory, to be able to maximize effectiveness. One factor was that pavement and debris conditions, although not being a device, can have an impact on the number of accidents, and should be considered in the tests. The results showed that there was a different number of incidents in each category, with there being a high number of accidents accompanied by fatalities with portable concrete barriers, poor pavement conditions, and collisions with construction equipment. Bryden et al. (1998) discusses that a well-designed traffic control plan, integrated with adequate safety training and supervision, can help improve work zone safety.

OSHA (Occupational Safety & Health Administration) (2005) described that transportation incidents and workers struck by vehicles and mobile equipment accounted for the largest part of work-related fatalities according to the Bureau of Labor Statistics. The article considered some tools and considerations used in reducing the amount of injuries and fatalities. Signs, flaggers, barriers, and traffic control devices were used to help reduce the amount of accidents involving motorist traffic when approaching construction zones. To reduce risks in the actual construction zone, the article considered tools such as better lighting, better training, and better protocol for safety procedures such as seatbelts. It is important to have each flagger, spotter, operator trained to know the most efficient ways to work in regard to safety.

2.3 Review of Backing Fatality Prevention in Work Zones

According to Jones (2005), fatalities in work zones are caused by many factors including close proximity to the traveling public and heavy equipment, elevated background noise, and vehicle blind spots. The most common fatal injuries in work zones are caused by construction vehicles, and the most prevalent fatal injuries are caused by backing vehicles, including backing dump trucks and pickup trucks. In the following sections, the prevention of backing fatalities in construction work zones will be comprehensively reviewed.

2.3.1 Identifying Blind Areas

The National Institute for Occupational Safety and Health (NIOSH) conducted research from 1992 to 1998 on data collected from fatalities and nonfatal injuries in construction accidents. The research found that traffic control devices and jobsite management techniques alone, although effective, cannot fully eliminate the risk to workers and accidents that can occur partly due to limited visibility around the equipment. This idea suggests that new technology is also needed to help detect the presence of people in the path of construction equipment and warn the operator of impending accidents (Hefner and Breen, 2003).

The current visibility limitations should be understood in the development of engineering and administrative controls, as well as new technology controls to give researchers and designers a better idea of the solution and/or product that are needed. Worker exposure data can help express these limitations when the areas in which an operator of the equipment cannot see, which then can be used to help select the appropriate technologies to increase situation awareness and minimize the risk of an accident.

According to (Hefner and Breen, 2003), the Center for Disease Control and Prevention awarded Caterpillar Inc. a contract to obtain diagrams of the blind areas around 24 different vehicles used in the construction industry. A blind area is the area around a vehicle or piece of construction equipment that is not visible to the operators, either by direct line-of-sight or indirectly by use of internal and external mirrors. The report illustrated blind areas for heavy equipment, contained descriptions, pictures, and diagrams for each of the machines tested.

Hefner and Breen (2004) illustrated blind areas for different heavy equipment in their 2003 report. To determine these blind areas a series of physical measurements and computer simulations were used. This included a light source placed at the driver's seat and the light measured around the equipment. The computer simulations were conducted by taking measurements around the driver's seat and allowing a computer to determine where the blind areas were. The contract reports and the individual blind area diagrams are provided on the NIOSH website at http://www.cdc.gov/niosh/topics/highwayworkzones/BAD/. The contract report from John Steele is also available from the same website. The Steele contract report is for mining equipment, however some of that equipment may apply to road construction dirt operations.

Blind areas in the test were determined for three planes of elevation: (1) the ground plane; (2) a plane 1500 mm above the ground, which is slightly less than the stature of the 5th percentile operator defined in ISO 3411, but represents the visibility of enough of the head that an operator can identify that there is a person in that area; and (3) a plane corresponding to the height of channelizing devices, which is 900 mm above the ground plane. Polar plots of the recorded data were generated with 5-degree increments and 1-meter intervals up to the 12- or 24-meter test perimeter, depending on the machine size.

The following figures represent some of that data received during the tests under three different plane views, for two different vehicles. Figures 2.2A–2.2C represent a Ford 880 dump truck, while Figures 2.3A–2.3C represent a GMC 3500 HD two-axle, front steer, rear dump truck.

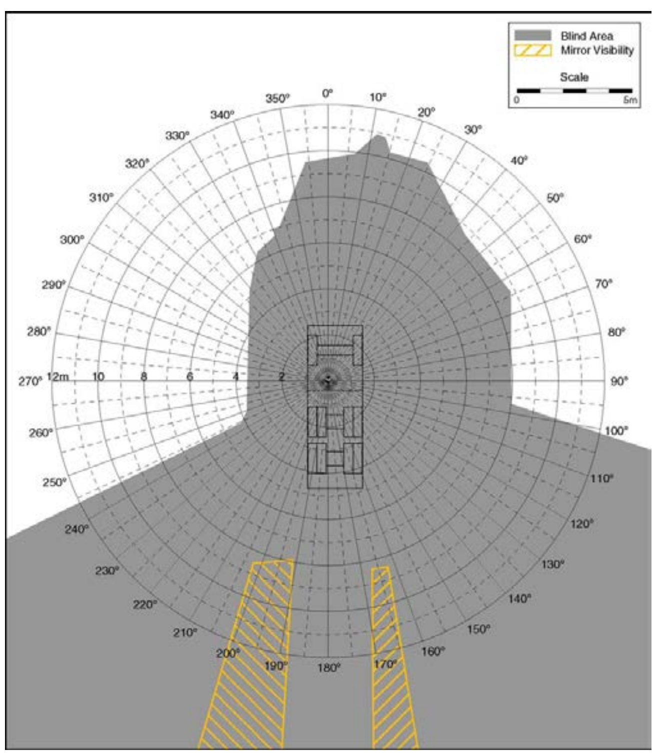


Figure 2.2A Ground Plane View - Ford 880

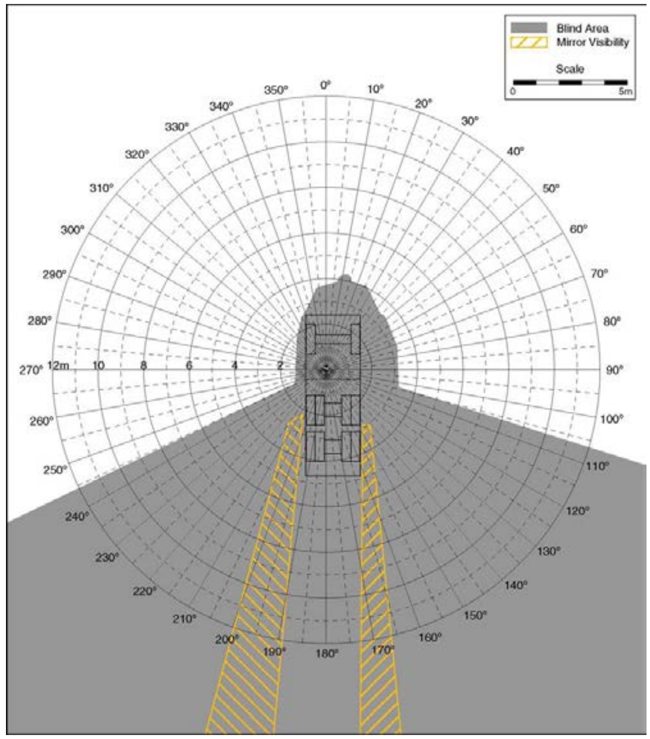


Figure 2.2B 1500mm Plane View - Ford 880

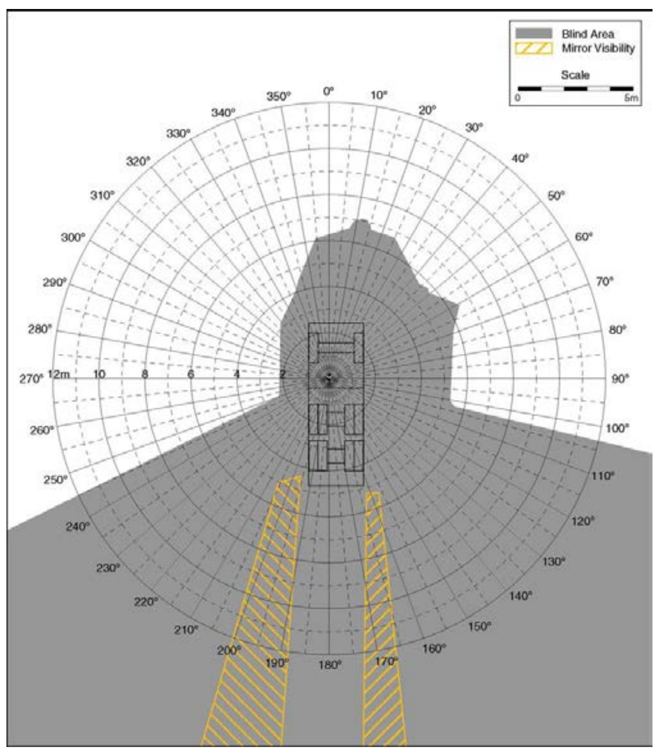


Figure 2.2C 900mm Plane View - Ford 880

Figure 2.2 Ground Plane, 1500mm Plane, and 900mm Plane Views - Ford 880

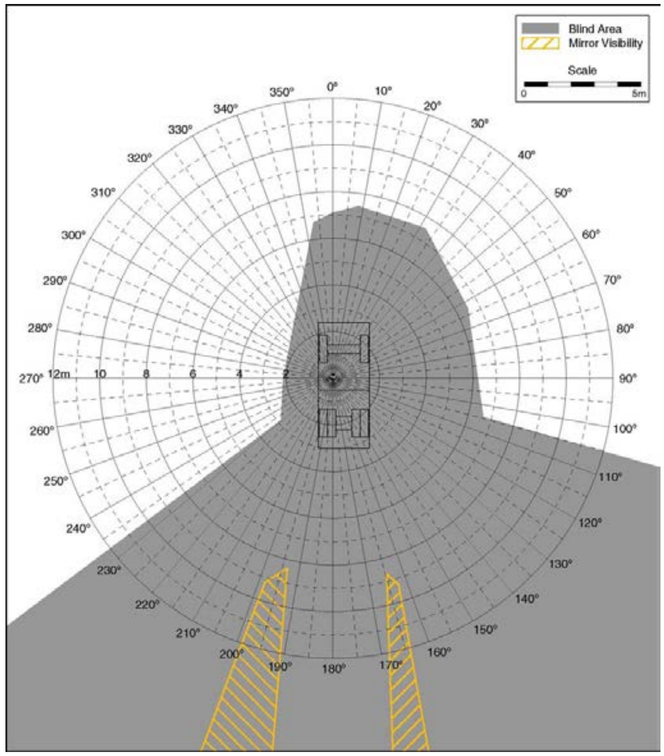


Figure 2.3A Ground Plane View - GMC 3500

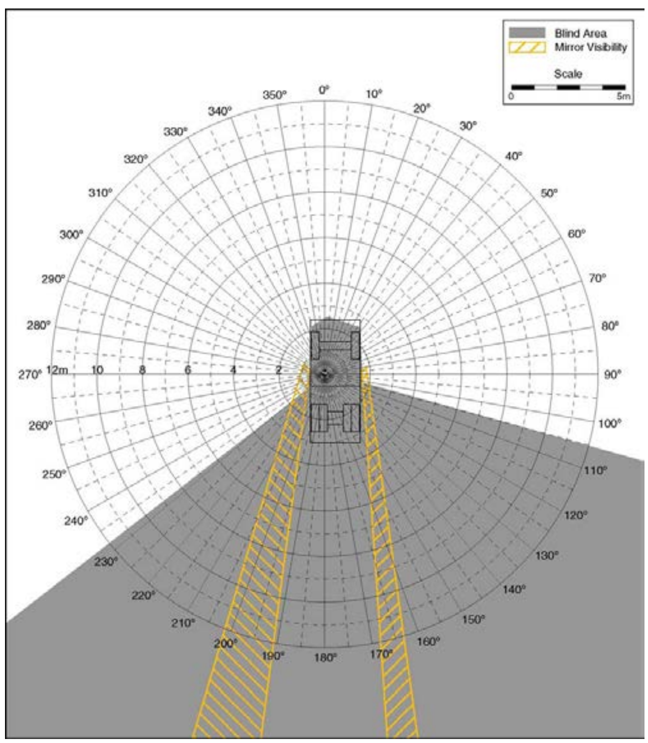


Figure 2.3B 1500mm Plane View - GMC 3500

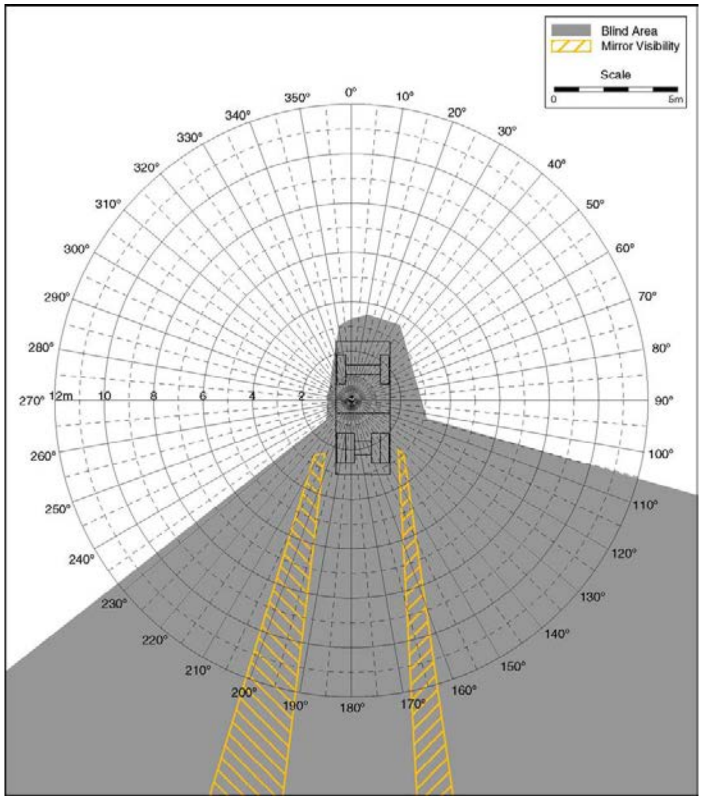


Figure 2.3C 900mm Plane View - GMC 3500

Figure 2.3 Ground Plane, 1500mm Plane, and 900mm Plane Views - GMC 3500

Fosbroke (2009) presented safety concerns about heavy equipment blind areas by studying case studies and blind areas around different heavy machinery. Fosbroke also explained the dangers blind spots create to pedestrian workers in work zones.

The National Institute for Occupational Safety and Health (2011b) shows blind area diagrams for 13 types of equipment and 41 models; each model has three diagrams measured with ground, 0.9m, and 1.5m level objects. Basically, these diagrams are the same as the output of Hefner and Breen's (2003 and 2004) study, but this website provides an easy-to-follow interface to check blind areas for certain construction equipment types. However, this website does not provide a blind area diagram for any pickup trucks.

Laborers' Health and Safety Fund of North America (2004) discussed the new legislation which Washington adopted in May of 2004 for the safety of work zones. This legislation requires that dump trucks have spotters, rear view video systems, or exit their vehicle to inspect their blind area before backing. The visible area requirements are shown in Figure 2.4.

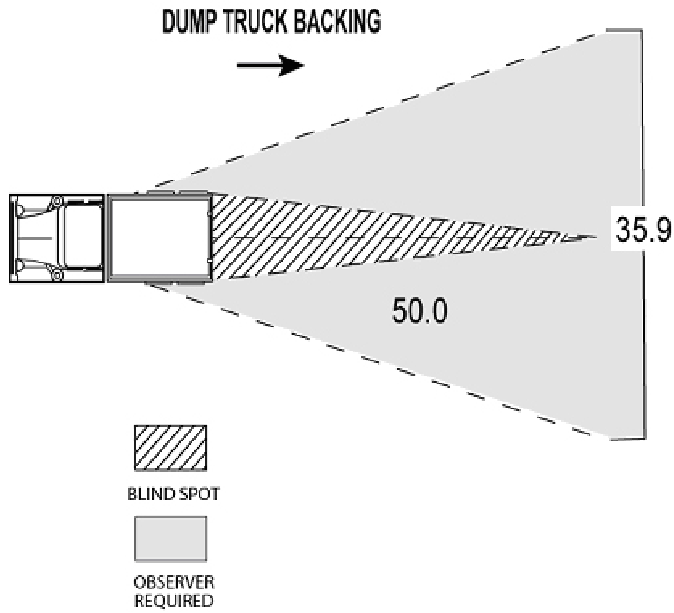


Figure 2.4 Diagram Defining Backing Zone
(Adopted from Laborers Health and Safety Fund of North America, 2004)

2.3.2 Engineering & Administrative Controls

Engineering controls use a logical method to set up, schedule, and execute projects in such a way that minimize danger to pedestrian workers and maximize efficiency. Administrative controls use education and effective overview to insure worker safety and efficiency. These two controls are interconnected because the execution of engineering controls could not be effective without proper training and overview of the workers who will be executing them. With a safe set up and employees with adequate safety training, the execution of safe projects is a much more likely outcome. In this effect, these two solutions are so interdependent and difficult to separate that it is more logical to discuss them together. As a result, they are discussed as one unit in the following section.

According to Zeyher (2007) on average between 70 and 80 pedestrian construction workers are run over and killed each year by construction vehicles, the leading cause being back over incidents. The American Road & Transportation Builders Association (ARTBA) said that before work even begins in a construction zone, that the area should be designed such that a traffic control plan reduces the instances in which a worker can be run over and killed. There should be a set plan of eliminating the risks such as back up only areas designated by cones, as well as the communication between workers on foot and equipment operators should be improved. If a work zone must have a worker on foot in a traffic area, such as a spotter for an equipment driver who is backing up, then one must have a plan in place for where those workers are going to stand, where they are going to go and what kind of communication or signals there will be between the driver of the vehicles and the worker on foot so they know each other's planned movements.

Pratt et al. (2001) discussed work zone safety using NIOSH data collected by undertaking a review of research and by holding a workshop, "Preventing Vehicle- and Equipment-Related Occupational Injuries in Highway and Street Construction Work Zones." Using this data and many case studies, it was determined that nearly as many pedestrian workers are struck by construction vehicles as were struck by the traveling public travelers. Therefore, construction vehicle incidents are a large focus of concern for worker safety. The recommendations given by this report included, but were not limited to, creating a safe work zone layout, the use of temporary traffic control devices, increasing motorist education and speed enforcement, training and illuminating workers more completely, especially flaggers, and the development of an Internal Traffic Control Plan (ITCP). In particular, a case study provided in Table 2.1 (case #13 adapted from Pratt's report) illustrates how the measures recommended by the investigators could have prevented the backing fatality.

Table 2.1 Excerpt of Case Study (Pratt et al. 2001)

Case #13: Construction Laborer Crushed by Asphalt Truck while Paving Interstate Highway
A 34-year-old construction laborer was fatally injured when he was crushed beneath an asphalt-carrying tractor trailer while paving a six-lane interstate highway. The 11-person crew was paving the northbound side of the highway. The high-speed lane and the middle lane had been closed to traffic. Tractor trailers delivering asphalt paving material were queued on the shoulder and partially in the high-speed lane. Two pavers were operating simultaneously in staggered positions in adjacent lanes. Paver #1 was in the far left (high-speed) lane. Paver #2 was in the middle lane staggered some distance behind paver #1, allowing trucks leaving paver #1 to pull into the middle lane to leave. Usually, trucks waited to be signaled to approach the paver, but sometimes drivers backed up as soon as they saw the previous truck leave the paver. At the time of the incident, the driver of the truck next in line for paver #1 had just re-entered the cab of his truck. About a minute later, the victim went over to shovel old asphalt from around the catch basin located approximately 12 feet behind the waiting tractor trailer filled with asphalt. The driver saw a truck pull away from paver #1 into the adjacent middle lane, started backing up, and then heard people yelling and the truck driver working at paver #2 blowing his air horn. He stopped and found that the four left rear wheels had completely passed over the victim. The county medical examiner pronounced the victim dead at the scene. The cause of death was crushing injuries of the head and torso. To prevent similar fatalities, investigators recommended the following measures: - Construction employers should ensure that one person be designated as a spotter to direct trucks backing up within highway construction sites. - Trucking company employers should design, develop and implement a comprehensive safety program that includes, but is not limited to, training for truck drivers in hazard recognition on construction sites and providing back-up alarms on trucks. - Highway paving contractors should design, develop and implement a comprehensive safety program that includes, but is not limited to, training for highway workers in controlling traffic hazards on highway construction sites. - Tractor-trailer manufacturers should consider providing back-up alarms and back-up lights as standard equipment on new vehicles.

Turner et al. (1997) discussed the usefulness of high-visibility clothing and materials in work zones. They used a test work zone to determine the average distance at which drivers saw different color vests and a spectra colorimeter to find the Chromaticity and Luminance Factors of different materials. It was found that florescent yellow-green was the most illuminant, and should have been the most visible; however, the Florescent Red-Orange had the greatest distance of detection. Therefore they concluded that workers, especially flaggers, would benefit most for Florescent Red-Orange vests.

Jones (2005) presented and compared the number of fatalities for the time period of 1995–2002 as well as the breakdown of what type of automobile & what type of scenario caused the fatality. This paper provided a detailed analysis of why the fatalities occur inside work zones as well as procedures to prevent such fatalities in terms of traffic control plans. Specific suggestions on different types of ITCP and how to set up a work zone maximizing safety were also discussed.

In particular, the traffic control plan should be set up and designed to protect the motorist, and to protect motor vehicle entry into the work zone. The principles and guidelines of an ITCP involve reducing the need to back up within a work zone, limiting and controlling pedestrian access points into a work zone, providing traffic flow guidance and diagrams within the work zone to help show the designated movement of equipment and workers, creating buffer zones to protect pedestrians from other vehicles and construction equipment, and creating pedestrian free & vehicle free areas. He also pointed out how spotters should be used and procedures that should be followed in order to be efficient in helping to prevent risks. Spotters should be used whenever a vehicle with restricted view is backing or operating onsite. The spotter can be any worker at the site other than the flagger, and in order to be effective must be in direct line of sight, or some methods of communicating with the driver while being able to see the entire backing area, and able to communicate directions to the driver operating the equipment.

Laborers' Health and Safety (2005) discussed a study done on ITCP contracted with the Centers for Disease Control & Prevention. It considered a case study of a construction worker killed after being ran over by a grader backing up. Several factors were considered involved in an average of around 22 construction deaths every year, similar to the one described in the case study. It was found that the biggest problem in this number is dump trucks backing up mainly because they possess very large blind spots. Backup Alarms, although thought to prevent any kind of risk similar to this case study, have been found to not be enough to always protect pedestrian workers because the alarms are not always working, and on a noisy site, workers hear several back up alarms and get confused about the location of the vehicles. ITCP is a tool that can be used to coordinate the flow of construction vehicles, equipment and workers operating in work zones to prevent vehicular crashes, worker injuries and deaths.

According to the Laborers' Health and Safety (2005),

> Establishing safe construction traffic control principles is the foundation for setting up an effective ITCP. These principles are:
>
> - Isolate workers from equipment
> - Reduce the need to back up
> - Limit vehicle access points to work zones
> - Coordinate truck and equipment movements
> - Provide signs within the work zone to give guidance to pedestrian workers, equipment, and trucks.
> - Design buffer spaces to separate pedestrian workers from errant vehicles and work zone equipment.
> - Inform all on site personnel and workers of ITCP provisions.

Laborers' Health and Safety (2005) also described that ITCPs are not fixed for every scenario and should be adjusted to reflect current conditions and the most effective method. If an independent contractor or someone is entering into the area for work, they should also be briefed on the ITCP and make sure they understand the way they work. It is very important that everyone on the job site knows and understands how the system works, and the designed ITCP.

In addition to an ITCP, the use of backing video devices and the use of spotters may reduce work zone hazards. To make sure the ITCP is being followed there should be people responsible to monitor and make sure it is. Warnings should be given to workers out of position and violations should be treated as violations of standard company policy. Signs should be used only where justified and should not be seen by passing motorists.

Graham et al. (2005) discussed the importance and creation of ITCPs for future projects and what they should include in this document. In this paper, an ITCP is defined as the plans used to control and coordinate the flow of construction vehicles, equipment, and workers within the activity area to create a safer working environment. The components of the ITCP include the traffic control layout, a legend explaining the diagram, and notes explaining portions of the diagram. This is very much like the TTC plan with changes to the specific requirements of each section.

Graham and Burch (2006) presented ITCPs and their purpose, as well as components. By examining several typical highway work zone accidents and 4 active work zones, they came up with suggestions for the setup of ITCPs in work zones. Components of an ITCP consist of:

- The Traffic Control Layout or diagram
- A legend explaining symbols used in the diagram
- Notes explaining portions of the diagram

Figure 2.5 is a diagram showing the layout of an example of a work space and the movement of personnel and vehicles within the work space. It illustrates access points to the work space as well as some parts of the overall work zone. “An ITCP diagram may be the model plan, a modified model plan, or a separate site-specific plan showing the actual work space. The diagram should show critical dimensions related to injury reduction measures” (Graham and Burch, 2006).

Figure 2.6 is a diagram illustrating the ITCP notes. “It contains safety points, injury reduction measures, site-specific provisions, and duties of various contractor personnel. Safety points include pedestrian-free zones, and buffer areas for vehicles such as rollers. Injury reduction measures specify when project safety meetings should be held, use of the ITCP, communication needs, coordination of dump truck arrivals and departures, and reference to general safety requirements” (Graham and Burch, 2006).

Figure 2.7 illustrates an ITCP legend. “The legend explains the symbols used on the ITCP diagram that is being illustrated. Standard symbols on the legend are based on those used in the MUTCD. Additional details on classes of personnel and vehicle types are needed in developing an ITCP for a paving operation. If worker or visitor parking is allowed on site the legend should have a symbol for parking” (Graham and Burch, 2006).

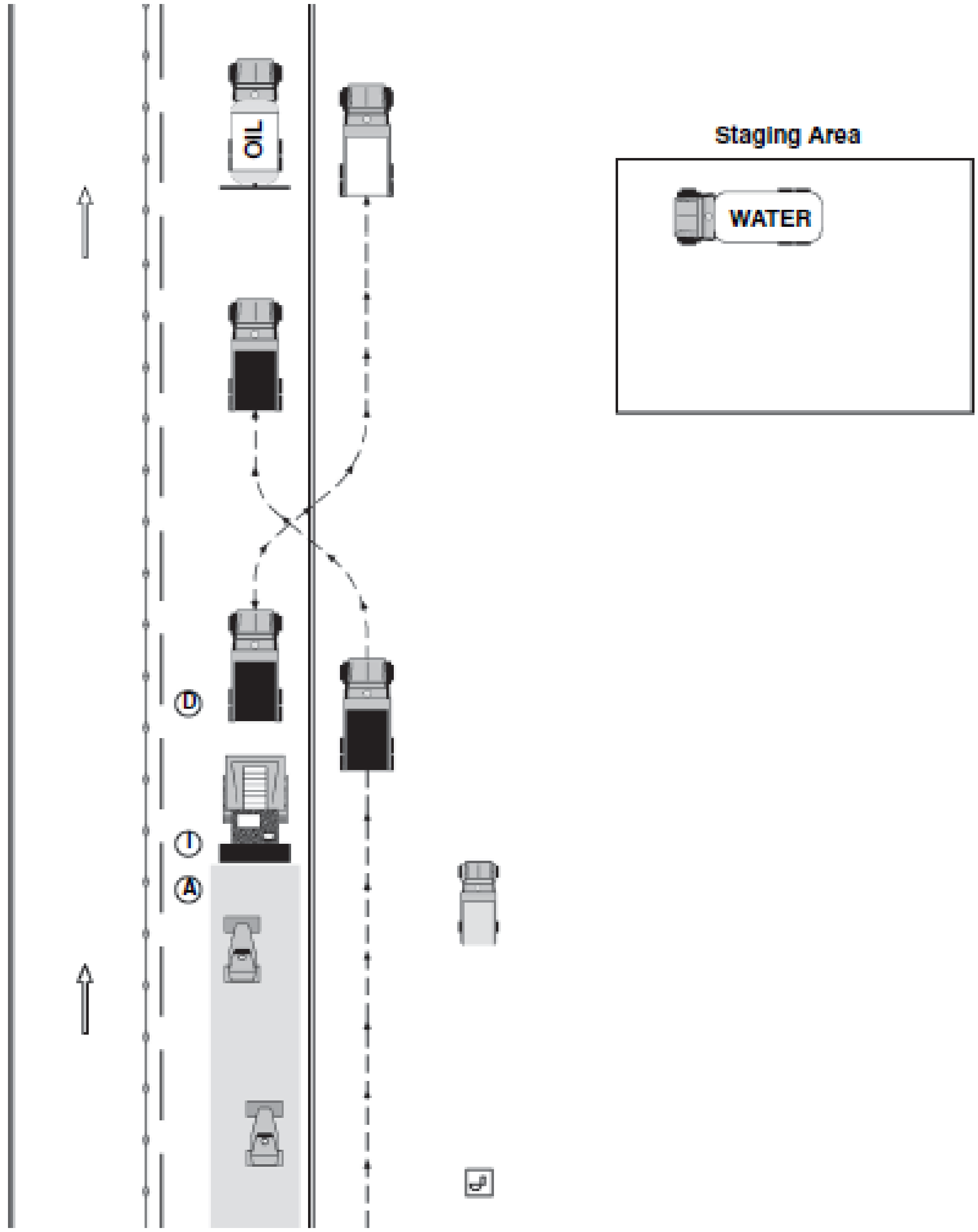


Figure 2.5 Paving Model Plan Diagram (Graham and Burch, 2006)

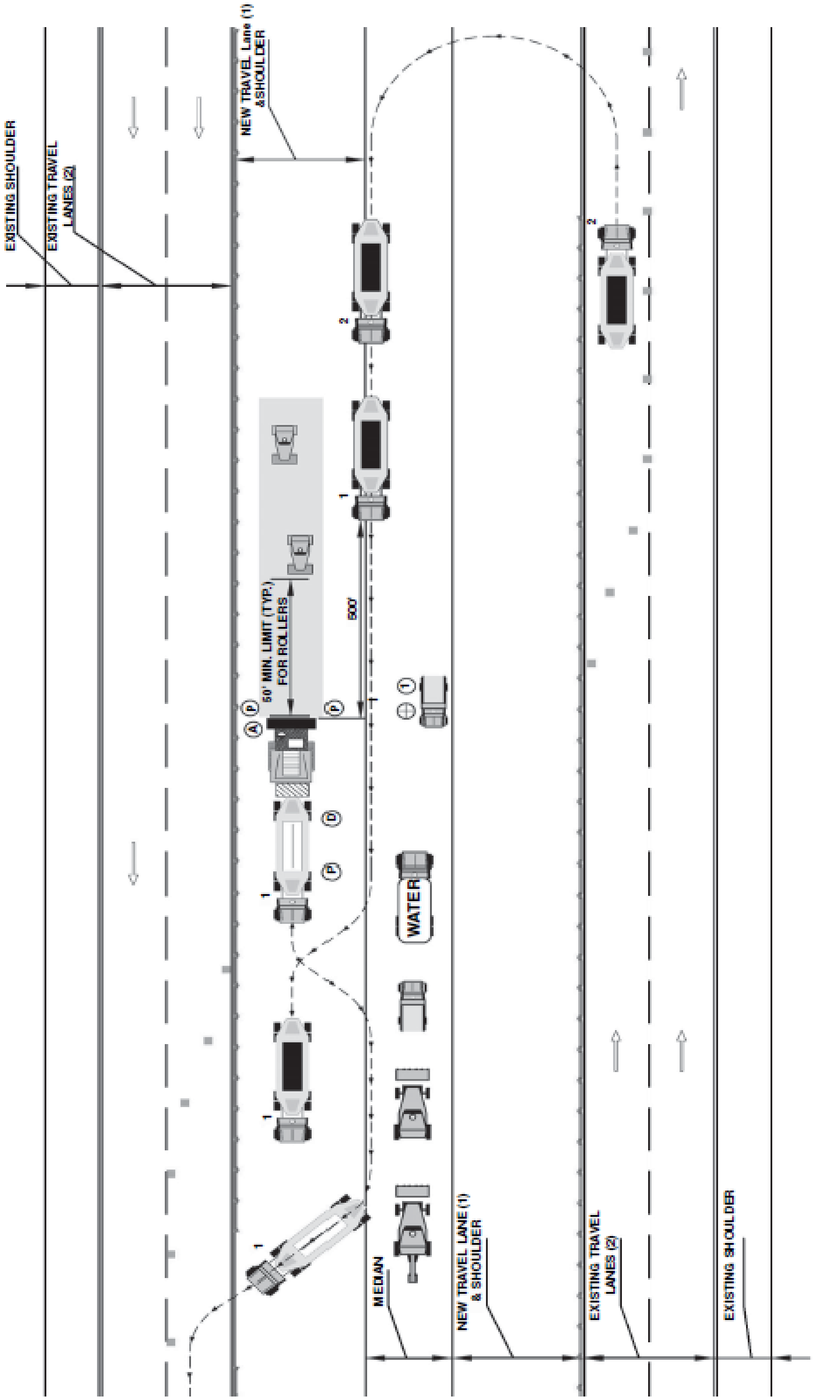


Figure 2.6 ITCP with All Remaining Features (Graham and Burch, 2006)

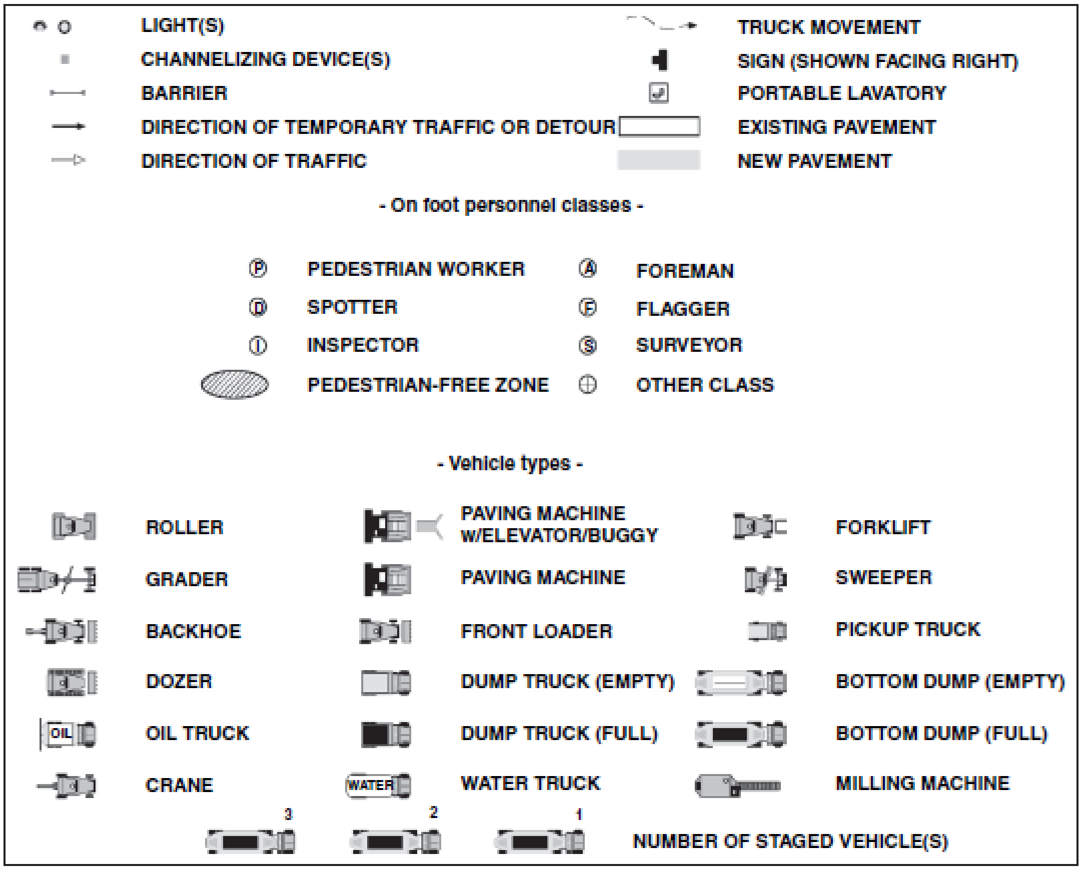


Figure 2.7 ITCP Legend (Graham and Burch, 2006)

Below are the suggestions and some conclusions made by Graham and Burch (2006) for the creation of an ITCP.

Suggestions for ITCP inclusions (Graham and Burch, 2006):

- Reduce the need to back up equipment.
- Limit access points to work zones.
- Establish pedestrian-free areas where possible.
- Establish work zone layouts commensurate with type of equipment.
- Provide signs within the work zone to give guidance to pedestrians, equipment, and trucks.
- Use FAA and Coast Guard principles on vehicle movement, marking, and right-of-way -where applicable.
- Design buffer spaces to protect pedestrians from errant vehicles or work zone equipment.

Suggested steps for creation of ITCP (Graham and Burch, 2006):

Step 1. Review contract documents and model plans.

Step 2. Determine the sequence of construction and choose which, if any, phases should

have site-specific ITCPs.

Step 3. Draw the basic work area layout.

Step 4. Plot pedestrian and vehicle paths.

Step 5. Locate utilities, storage, and staging areas.

Step 6. Prepare ITCP notes.

Six accident reports were reviewed, from which the following conclusions were reached (Graham and Burch, 2006):

1. Back up alarms are insufficient.

2. Spotters should have direct communication with operators.

3. Workers should be privy to specific instructions for the job they are completing; general information about jobs being completed around them, and any changes that have occurred since their last shift and any changes that happen during their current shift.

4. If incidents occur, the safety officer should take in depth reports and insure that in the future the incidents likelihood is reduced.

5. All workers should understand the ITCP and have a good understanding of hazards, potential emergency situations, and how to prevent hazards.

The resulting recommendations were made (Graham and Burch, 2006):

1. A detailed safety plan should be ensured—one that meets or exceeds 29 CFR requirements, with specific documented training for all employees. A competent person who meets 29 CFR standards should be required on site during the work. An ITCP should be required as part of the safety plan.

2. Daily safety meetings should be conducted with all personnel, including truck drivers, inspectors, and others. The ITCP should be discussed, along with updates in operations.

3. Spotters should have direct communication with truck drivers bringing materials to the work site; there should be use of radios or other communication devices to do so.

4. For paving operations a crew member, most logically the screed operator, should be designated to communicate with the rest of the crew when the paving machine is backing up.

5. A crew member should be designated to communicate with the rest of the crew when other equipment is operating in the work area.

6. Truck drivers need instructions on how to enter and exit the work zone and how to maneuver within the work zone. Such instruction could be accomplished by having the designated safety officer go over the ITCP with them before the work begins.

7. All other equipment operators or passenger truck drivers on site should also be made familiar with the ITCP so that they can more safely and efficiently operate within the work area.

8. For night work, light standards should be placed so that lighting is consistent along the work site.

9. All safety apparel should be checked for retro reflectivity for night operations.

10. Desirable operating speeds should be established for vehicles on public roads and in the work space.

11. Seat belts should be required for all vehicles and a seat belt or harness should be required for the rebar setter on PCC paving machines.

12. A specific lock-out or tag-out program should be established for use when there is servicing of machinery.

In particular, Graham and Burch (2006) defined the competent person as follows: according to 29 CFR1926.32, pertaining to definitions, a competent person means one who is capable of identifying existing and predictable hazards in the surroundings or working conditions that are unsanitary, hazardous, or dangerous to employees, and who has authorization to take prompt corrective measures to eliminate them www.access.gpo.gov/nara/cfr/cfr-retrieve.html. The experience and training to recognize and eliminate safety violations and other hazardous situations, because failure to observe safety standards and other safe work practices could result in serious injury or death.

Another article in Washington's State Department of Labor and Industries (2009) evaluated the risks presented to roadway workers on foot and roadway equipment operators. Working in congested areas with low visibility & high speeds can result a number of accidents occurring to workers. Workers on foot are subject to being run over by equipment and highway motorists. Workers on equipment can turn over or be caught up in accidents with other equipment. Currently there is an average of over 100 roadway worker deaths annually, with the trend actually increasing. Incidents occurring with construction equipment were just as high a part as incidents occurring with highway traffic showing that they have a very large impact. 41% of the incidents occurred from dump trucks in which 52% were from the dump trucks backing up. Flaggers within traffic control plans should be adequately trained. Traffic control plans should be designed with maximum safety in mind. Designing them in a way to limit backing up, as well as making zones designated for backing keeping blind spots in mind, helps in reducing chances of accidents. Workers in the construction zone should wear highly visible clothing, be trained in the design of the traffic control plan so they understand what "safe" zones are, and what are not. They should know the procedure to follow to maximize their safety.

The interview with David Fosbroke by MacDonald (2007) discussed the need for an ITCP and how it should be implemented. The need for a safety plan inside work zones was outlined when Fosbroke described that half of the worker fatalities caused by struck-by incidents are killed by construction equipment. The keys to an ITCP, according to Fosbroke, are isolating workers from equipment, reducing the need for backing vehicles, and that all key players over a work site must be present during the ITCP discussions. By studying where equipment blind areas are, Fosbroke was able to determine a method for evaluating how much time workers spent in danger areas. Fosbroke emphasized the importance of ITCP training for all key members of a construction project including the paving foreman, the site superintendent, state inspectors, supervisor, and truck boss. This way all supervisors are able to work together to determine where dangerous areas and safe areas will be and to discuss changes that will happen during construction that could put other parts of the team at more danger. Because of this factor, safety conversations must take place at least every morning to ensure that all members of the crew are aware of changing conditions and how they can avoid danger areas and how they can reduce hazards for other groups of workers.

The review of the California Tailgate Training guide for Vehicles and Heavy Equipment (2007) showed a few key points for training that must be included in any administrative fix for work zone safety. When in a work zone similar to when traveling to or from, vehicles must follow posted speed limits. Before heavy equipment of any kind is moved, steps should be taken including a walk around the vehicle to ensure clearance and, if necessary, a spotter should be used to ensure safety. To insure safety when working near moving vehicles employees must stay alert at all times. This means no distractions including radio. Workers must keep a safe distance and stay off equipment unless necessary. Being visible is important as well which is why employees should wear bright vests or jackets and wear reflective clothing during low visibility conditions. Reflective clothing worn during low visibility conditions will make the pedestrians easier to be seen while working around vehicles, which will make equipment operators more aware if the pedestrian worker disappears from view, possibly into a blind area.

Though the personal responsibility for safety falls to each individual, management must enforce safety rules to ensure the safety of the work zone. This includes checking all operators are properly licensed for the vehicles they use, training workers in specific safety practices related to their jobs, keeping equipment in good condition, and set up a system to control traffic flow, both inside work zones and for public roads passing the work zones.

A case study was conducted to emphasize the importance of these safety rules during training. This study (Vehicles and Heavy Equipment, 2007) illustrated a 36-year-old construction inspector who was backed over by an asphalt dump truck. The dump truck had a back-up alarm that was functioning properly and was only traveling between 5 and 10 miles per hour. This shows that technological controls and controlling speed limits is not enough to prevent accidents. It takes focus on the part of all parties in a work zone. The recommendations made by the Cal/OSHA investigator included:

- Require use of a second person as a spotter when backing heavy equipment with blind spots.
- Minimize the distance heavy equipment needs to back up to gain access to the work area.
- Consider using additional safety devices on heavy equipment to warn workers of a backing vehicle and to warn drivers when someone is in their blind spot.

This illustrates the need for comprehensive Engineering and Administrative controls and the possible need for more technological advances to insure worker safety.

The current Handbook of Safe Practices (2010) for the Texas Department of Transportation (TxDOT) described some safe practices that should be taken to ensure safety of workers. These include that operators shall be responsible for the safe operation of equipment. Particular care shall be exercised in backing. Don’t proceed moving back blindly. All equipment operators shall be assigned a “spotter” when operations require backing without an operational backup alarm or when vision to the rear is obstructed from the operator’s seat. Vehicles should park to eliminate backing when possible. Drivers shall walk around the rear and side of vehicles before backing. It is suggested that workers stay clear of moving equipment especially while backing and it states that all equipment with rear vision permanently obstructed will have a backup alarm. This shows that some important safety rules have been T in effect however they should be more readily enforced. Figure 2.8 displays the current gesturing methods in place for flaggers as illustrated in the TxDOT’s Handbook of Safe Practices (2010).

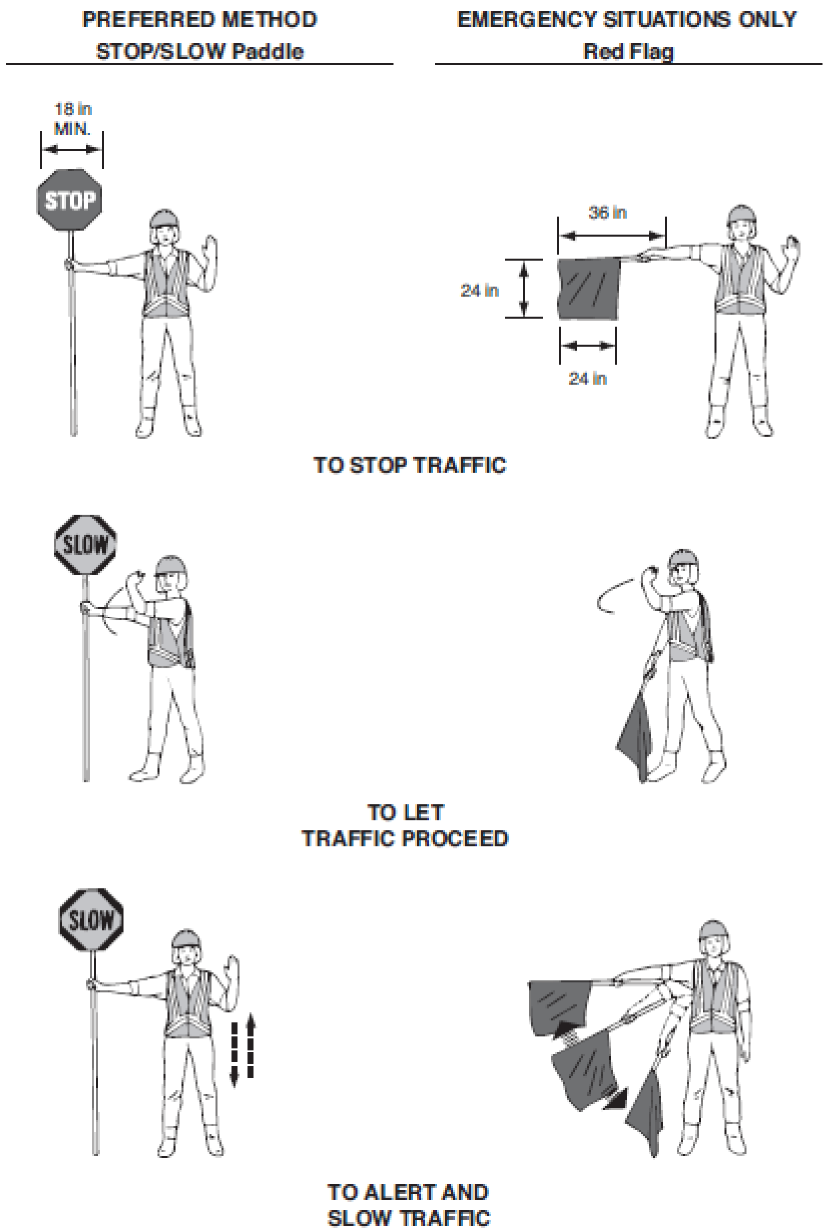


Figure 2.8 TxDOT Flagging Techniques (Handbook of Safe Practices, 2010)

Finally, to develop prevention measures for the backing fatalities for TxDOT, one will need TxDOT-specific backing accidents and fatalities data in the construction work zone. In this effect, the TxDOT district accident form will be very useful in the creation of a form for our ITCP plan. The form in the Bryan’s district is attached below in Figure 2.9.

BRYAN DISTRICT SUPPLEMENTAL VEHICLE ACCIDENT/PERSONAL INJURY REPORT

The following form should be completed by the employee and his/her supervisor within 2 days of a vehicle accident and/or a personal injury when medical treatment is required or there is lost time. Attach the completed form to *Form 487* and/or *Form 20.106* and submit to the District Safety Coordinator. All information should be completed in its entirety. Write "n/a" to answer questions that are not applicable. Use additional sheets to explain any extenuating circumstances. This information is intended to record problems related to safety rules and practices and to determine corrective action deemed necessary.

TO BE COMPLETED BY EMPLOYEE:

Employee Name:		Supervisor's Name	
Accident Date:			

Describe Accident: (What work were you doing; list material, equipment involved)

Cause of Accident: (Explain how and why the accident/injury occurred)

Were Proper Safety Procedures followed according to the Occupational Safety Manual? YES ☐ NO ☐ If YES, why did the procedure(s) fail to prevent the accident/injury?

Were proper safety devices being used? YES ☐ No ☐ If YES, What was used and why did the device(s) fail to prevent the accident/injury?

Describe how this accident could have been prevented:

Would like to discuss the details of this incident further with the District Safety Committee. YES ☐ NO ☐ Your comments may assist the committee in creating recommendations to make our district a safer place to work for all employees.

I UNDERSTAND THAT THIS FORM WILL BE INCLUDED IN MY PERSONEL FILE.

Employee Signature ____________________ Date ____________________

Figure 2.9 An Example of a TxDOT Bryan District Backing Fatality Report Form

2.4 Technology Controls

The development of technology-based solutions to limit blind areas of a driver has led to many different designs and innovations all with one principle in mind: improving the ability to sense what is behind an operator in an area s/he normally cannot see. Some of the more common types of technology controls are sensors, radio frequency detecting sensors, and rear-view camera systems.

Mine Safety and Health Administration (2011) introduced 11 proximity warning system (PWS) manufacturers and links demonstrating their systems which are widely used in the mining industry. Systems includes two radar, three RFID-based, three GPS, and three magmatic-based detection systems.

Oloufa et al. (2002) compared five technology types (infrared, ultrasonic, radar, RFID, and GPS) with five key characteristics which are line-of-sight, response time, cost, reliability, and operation range to select the technology for preventing equipment-related collision on the construction jobsites.

Mazzae and Garrott (2007a) tested commercially-available systems for detecting obstacles present behind backing light vehicles. To do this they tested 11 systems to see how well they performed. These systems included radar and ultrasonic sensors, video systems, and mirrors. The test included static field-of-view measurements, repeatability of static field-of-view measurements, dynamic range measurements, response time measurements, field-of-view measurements for video camera technologies and auxiliary mirrors, and measurements of blind spots behind vehicles. The results of this study showed that "none of the sensor technologies examined, in their current forms, seemed adequately capable of preventing back over crashes with pedestrians" (Mazzae and Garrott, 2007a).

Schaudt et al. (2009) discussed the development and effectiveness of a camera/video imaging system to be used on heavy trucks to help prevent struck-by accidents. The system was tested in a stationary and dynamic situation so that participants could become familiar with the system. They found that response times were lowered significantly and detectability of objects around heavy equipment was increased dramatically using their system.

Rau et al. (2009) discussed the development and effectiveness of a video based struck-by prevention system called an Enhanced Camera/Video Imaging System. The system was tested in a stationary and dynamic situation. They found that it was a promising approach and that it could be an effective tool in preventing crashes and struck-by incidents.

Lee et al. (2010a) investigated the effectiveness of rearview video systems. 45 drivers were selected in this study to examine the usefulness of rearview video systems while backing. It was found the during Straight Line Backing, there was a 46.7% increase in stop rates, in Offset Right Backing a 4.4% increase, and during Alley Dock Backing a 17.8% increase was observed. Also, 90% of the drivers agreed that the system reduced rear blind spots.

Lerner et al. (1997) examined driver reaction times and distances to in this article. By using temporary sensors and video systems inside the cabs of vehicles being driven on a course, reactions and behaviors were monitored to determine factors about how drivers backed. The mean distances and times to collision were found for different speeds at which a driver was backing. This is the most pertinent information for this research project.

Lee et al. (2010b) covered testing procedures for their study of the effectiveness of video systems for preventing backing incidents. It was shown that stop rates in straight-line backing maneuvers were increased by 46.7%. The testing procedure for this test was clearly described and could be useful in the testing of the system created by the current study. Following is Lee's testing procedure (Lee et al., 2010b).

> 1. The participating drivers were asked to read and sign a driver informed-consent form that explained the procedure of the test, the risks and discomforts, the benefits to the driver, the extent of anonymity and confidentiality, the compensation, and their rights, and then confirmed their permission to participate in the test. Each driver was assigned a number that would serve as an identifier for all stages and forms of the test for anonymity purposes.
>
> 2. The drivers were then given a flyer showing diagrams of the three maneuvers that were included in the test, with details for each. Each driver entered an equipped truck, a Sterling day cab tractor with a 34-ft trailer. A second examiner was inside the truck to guide the driver through the maneuvers.
>
> 3. The drivers were asked to perform two sets (with and without a rearview system) of three different maneuvers (straight-line backing, offset right backing, and alley dock backing). To minimize potential bias, the order of the six

maneuvers for each driver followed a pregenerated random number table. Therefore, each driver completed the maneuvers in a different order.

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

5. After completion of all six maneuvers, the drivers were asked to complete a survey to provide their feedback on the system.

Mazzae and Garrett (2007b) tested sensor and visual based systems for backing assistance. The most important findings they had for our study was stopping distances. It can be interpreted from his data that the stopping distance of a passenger vehicle is between 2 and 4 ft per mph. This will be useful when determining a hypothesis prior to testing.

Ruff (2000, 2001a, 2001b) examined RFID and Radar technologies for possible use on large haul mining trucks for the prevention of struck-by incidents and their effectiveness in detecting objects.

- *Video Cameras* - Recent developments have led to cameras being designed with reduced size and cost. Some mines have begun to use the cameras with success. However on large trucks it usually takes multiple cameras in order to be effective. The lenses also must be cleaned, and quite often in bad weather conditions; and the cameras are exposed to a lot of shock and vibrations.

- *Radar* - Radar systems can detect people, rocks, buildings, and foliage. They are especially good at detecting metal objects. An alarm, usually flashing lights and an audible warning, is mounted in the cab of the equipment to warn the operator of an object or person nearby. The advantages of radar include low price, reliable operation in all weather conditions and dusty environments, and reliable detection of large objects such as other vehicles or people. However one problem is that nuisance alarms can be common in which the operator is already aware that there is an object behind his/her equipment that is not posing danger. However, too much trust in the existence of nuisance alarms can be dangerous given that the driver does not actually know what is behind them, and thinks it is just a nuisance alarm and backs up anyways.

- *Radio Frequency Identification (RFID)* - There are different systems available and two were tested that both operate on the same basic principles, but use different communications schemes. Both systems require the use of electronic tags attached to light vehicles, pedestrian workers, other mining equipment, or stationary objects such as utility poles and buildings. Any worker or vehicle entering the mine site must be outfitted with a tag to be protected. The advantages to using RFID include the rare occurrence of false or nuisance alarms, the ability to identify the cause of the alarm through its unique identification code, better detection of objects near the equipment, and the ability to monitor around the entire piece of equipment with just one or two tag readers.

In all, Ruff (2000, 2001a, 2001b) tested seven different systems including three RFID, two Doppler Radar, one Pulsed Radar, and one FMCW Radar. His results can be seen in Table 2.2. It can be seen that RFID systems, have high performance ratings in every area other than cost. It was concluded that no collision warning system can replace the training and caution necessary for operating heavy equipment. However, technology can aid in reducing some of the guesswork required when operating equipment that has extensive blind spots.

Table 2.2 Comparison of Collision Warning System (Ruff, 2001b)

System	Nautilus Buddy	Mintronics Body Guard	AMT CAS	Knapp 201	Sense Tech. Guardian Alert	Preco Preview	Ogden Safety
Phone	1.604.430.8316	1.705.474.4759	61.2.4389.2344	1.800.831.4609	1.800.998.0555	1.800.453.1141	44.1254.679717
Technology	RFID	RFID	RFID	Doppler Radar	Doppler Radar	Pulsed Radar	FMCW Radar
User-Adjustable Zones	Yes	Yes	Yes	Yes	No	No	Yes
Motion Required for Detection	No	No	No	Yes	Yes	No	Yes
Max. Length of Rear Detection Zone as Tested (Person/Pickup in ft.)	50/50	50/50	NA/57.5	22.5/65	25/45	30/27.5	40/40
Coverage Near Outer Dual Tires	Yes	Yes	Yes	Yes	Yes	No	No
Max. Length of Front Detection Zone as Tested (Person/Pickup in ft.)	50/50	50/50	NA/57.5	22.5/65	25/45	30/27.5	40/40
Coverage Near Front Bumper	Yes	Yes	Yes	Yes	Yes	No	Yes
Sporadic Detection at Zone Edges	No	Yes	No	No	No	No	No
All-Weather Use	Yes	Yes	Yes	Yes	Yes	Yes	Yes
False-Alarm Rate in Clear Field	None	None	None	Infreq.	Frequent	Infreq.	Infreq.
Cinder Block Detection	No	No	No	Yes	Yes	Yes	Yes
Multiple Units Needed for Front/Back coverage	No	Yes	Yes	Yes	Yes	Yes	Yes
Two-Way Alarm (for Person Detection)	Yes	No	Yes	No	No	No	No
Cost $US (High = +8,000; Med = 2,000-8,000); Low = -2,000)	High	High	High	Low	Low	Low	Low

Ruff and Hession-Kunz (2001) studied two RFID systems on 2-½-yd front-end loader to evaluate performance with their own criteria for tag reader system and warning system. However, neither RFID systems meet the specification generated because of late response time or size of devices.

In Ruff (2003), the Spokane Research Laboratory of the National Institute for Occupational Safety and Health (NIOSH) was cooperating with the Washington State Department of Transportation (WSDOT) in an evaluation of methods to decrease injuries and fatalities caused when road construction equipment strikes a worker or another vehicle. In a short-term test procedure, they experimented with different camera and sensor systems, first locating the optimum place to mount the system on the truck to not cause false alarms. Once a collection of short-term procedures was completed, they researched a more long-term test procedure. Some factors considered in the long term test procedure were a low probability of a false alarm, reliable detection of a person in a zone starting immediately behind the truck, extending at least 4.6 m (15 ft.) behind the truck and at least the width of the truck, apparent ability of the system to handle harsh conditions, minimal maintenance requirements, favorable impression of the system by the driver, and a feasible mounting configuration. Conclusions made were that in a crowded environment such as a construction zone, the sensors might be very likely to cause many false alarms which might make them less effective than a camera set up. Combining the camera system, as well as the sensors could be very effective but would be expensive. If sensor detection is used, there must be some way of blocking false alarms such as mud, dirt, and other debris that could cause the sensor to go off. Cameras however would work well during the warmer months, but during the winter, or in bad conditions they would be much less effective. In addition, cameras are harder to mount that the sensors, making the installation process more complex and time-consuming.

Ruff (2004a) discussed different electronic devices for warning and prevention of backing incidents in his paper. Three technologies were tested including radar and ultrasonic sensors and video systems. It was found that due to the indiscriminate nature of radar and ultrasonic sensors, nuisance alarms would be frequent. Video systems do allow the driver to determine what is in the blind area however this is a passive system, meaning if the driver does not look, or cannot see something in his screen, there will be no alarm to notify him to stop before a collision. Therefore, a combination was suggested by Ruff; this way if an alarm is to sound, the operator would be able to look in the video screen and determine if it is a nuisance or true alarm.

Ruff (2004b) tested one radar and two RFID systems used in Ruff (2001a) on a 260-ton dump truck. Comparing to the previous test results with radar systems, the test with bigger equipment showed poor results, which were reduced detection range and increased false alarms mainly because of higher system mounting positions. However, RFID systems did not result in a significant difference in results from previous studies.

Ruff (2007) discussed the need for proximity warning systems in mining situations to help prevent struck-by incidents while backing. He studied 4 types of proximity sensors including radar, sonar, infrared, and tag-based systems. It was found that tag-based technology has some of the best features compared to the other systems other than cost. The table of his findings can be seen in Table 2.3. Ruff also looked at blind areas on different construction vehicles and locations for mounting sensors on these vehicles based on their blind areas.

Table 2.3 Proximity Warning Technology Characteristics (Ruff, 2007)

Feature	Sonar systems	Radar systems	Magnetic field tag-based systems	Radio frequency tag-based systems
Adjustable detection ranges	No	Yes	Yes	Yes
Maximum detection range	3m (10ft)	7.6m (25ft) to 17m (55ft) depending on system	18m (60ft)	80m (260ft)
Minimum number of sensor units required for front and rear coverage	4 or more depending on system	2 to 4 or more depending on system	1 or 2 depending on system	2
Two-way alarming	No	No	Yes	Yes
Relative frequency of false alarms	Medium	Medium	Low	Low
Relative frequency of nuisance alarms	High	High	Medium	Medium
Tolerance to mud, just, dirt buildup	Low	Medium	High	High
Installation and setup difficulty	Low	Low	Medium	Medium
Cost per piece of equipment: (High > $10,000 Low < $5,000)	Low	Low to Medium	Medium to High	High

Ruff (2010) tested a camera and advanced video processing system on the stationary equipment conveyor. This system has advantages of low cost, a well-defined hazard zone, and recording availability. Also according to this study, as sensitivity of the system increases, detection zone improves however false alarm rates increase.

The National Highway Traffic Safety Administration (1994) conducted a study of electronic-based rear and side object detection systems. They examined Ultrasonic, Relative Velocity Radar, and Position Radar technologies. They allowed drivers to use these technologies to examine their effectiveness and found that all the system interfaces could be improved. The drivers found that the systems were very useful.

National Institute for Occupational Safety and Health (2011a) studied generic characteristics of 12 technology types with basic sensing methods for each type to help the selection of a PWS system in the mining industry. Table 2.4 provides the advantages and disadvantages of various types of PWS systems.

Table 2.4 Advantages and Disadvantages of Various Types of PWSs (NIOSH,2011a)

Type	Advantages	Disadvantages	Sensing method
Infrared passive	Good for long distance in fog	Accuracy issues with heave snow and rain	Detect object or person presence by heat energy radiation
Infrared active	Good for long distance in fog Measures vehicle speed	Environmental concerns affecting accuracy include temperature, dust, and water sprays	Emits laser beam to ground. Detects reduced time of reflection by objects in path
Capacitive	Compact and easy to install	Needs clean environment	Detects change in capacitance due to object in detection zone
Ultrasonic pulse	Compact and easy to install	All objects trigger alarm Temperature, humidity, air turbulence, target surface smoothness, target size, angle of incidence, and external noise sources cause accuracy problems	Detects change in time-of-flight reflection due to object in detection zone
Radar pulsed	Compact and easy to install	All objects trigger the alarm Snow and ice buildup and angle of incidence accuracy issue	Measures time-of-flight of a pulse that is transmitted and then reflected off of objects in detection zone
Radar Doppler	Compact and easy to install Measures vehicle speed	Cannot detect stopped objects Snow and ice buildup issues	Detects a frequency shift in generated signal due to object in detection zone
RFID passive	Inexpensive and easy to install	Generally short range No range information Orientation sensitivity	A non-powered tag detects generated radio signal
RFID active	Longer range than passive RFID	Requires battery in tag Orientation sensitivity	A battery-powered tag detects generated radio signal
GPS	Accurate Covers wide areas	Only works on the surface	A receiver detects satellite signals and triangulates position, transmits location to other vehicles/personnel via radio
Video camera	Simplicity	Operator must observe monitor Limited field of view	Vehicle operator monitors objects in blind spots on cab-mounted monitor
Magnetic passive	Compact and easy to install	Accuracy issues when metallic objects in field	Detects change in Earth's magnetic field when objects enter detection zone
Magnetic active	Great accuracy over short distance	Only receiver in detection zone triggers alarms	A transmitter provides a marker signal. A receiver measures signal strength and provides alarms

Mazzae and Garrott (2006) tested available back over prevention technologies as they are provided on different vehicle models and after-market technologies. The types of sensors were Ultrasonic, Radar, Video, Convex mirrors, or some combination. They found that sensor-based systems generally exhibited poor ability to detect pedestrians, but video systems had to be watched to be effective. Therefore a combination may be the best solution.

Garrott et al. (2007) studied two types of detection systems; the rearward sensing systems and right-side sensing systems. Three types of evaluations were performed for both the rear and right-side object detection systems including hardware performance measurement, and human factors assessment of the driver/system interfaces, and an assessment of driver subjective reactions to two systems such as the type of alarm to use. In the hardware evaluation, the study tested sensor locations as well as the type of sensor to use. From the study it was found that the cameras and sensor detection systems had a great advantage in safety over vehicles equipped with plane side view mirrors. Factors involved with the video systems are that the cameras are reliable and durable and that there is adequate lighting behind the vehicle so you can see through the camera. Factors involved with the rear detection systems, are the Sensor Reliability, the hardware reliability and that the drivers trust the sensor to guide them in the right direction. If the sensors repeatedly give false alarms, it could build up doubt in the system by the driver which could create more problems. It is early in the stages of the development of these systems, but they are thought to improve the chances of reducing accidents to backing, or in blind spots to the side.

Llaneras et al. (2005) focused on developing a driver interface criterion for a rear obstacle detection system, assessed the appropriateness of alternative warning timing algorithms, and evaluated various interface approaches for presenting warning information to drivers. An ideal principle is that in order for a backup warning system to be effective it must capture the attention of an un-alerted driver and provide sufficient advance notice to enable drivers to respond appropriately. A random selection of 48 drivers was used to test the experiment to see the effect of the detection systems. Different timings were tested, as well as different audible noises. It was found that the earlier the warning system alarmed the driver, the better results. Drivers that were alarmed too late were unable to apply the brakes in time to avoid striking the object. In a test where a surprise toy was thrown behind the vehicle, in order to test people's reaction, resulted in that nearly ¾ of the drivers hit the toy even though they were given the warning. This showed that in the case of a surprise, much more a real-life situation that it is very hard for the object to be detected and stop fast enough to avoid hitting it. Staged alarms for the distance from an object were shown to be effective, but also were hard to understand by drivers without proper training.

2.5 Integrated Engineering, Administrative, and Technology Controls

As one can see from the review results of papers/reports mentioned in the above sections, it has been concluded that neither engineering & administrative controls (i.e., internal traffic control plans + spotters + backing safety training), nor the technology controls alone, will completely eliminate the risks to workers. As a result, there is a high need for the engineering, administrative and technology controls to be integrated and work together as the prevention measures for the backing fatalities in the construction work zones. The following will review such integrated solutions.

Fosbroke (2004) discussed a project taken on by many different groups and organizations throughout the states of Pennsylvania, West Virginia, and Washington. Some of the groups included the State Transportation Departments, Construction Companies, Construction Trade Associations, Equipment Manufacturers, the FHWA (Federal Highway Administration), and OSHA. The project worked to develop exposure monitoring system and evaluate injury prevention measures. Fosbroke evaluated some of the types of off-the-shelf technology such as radar, sonar, cameras, and tag-based systems. The study also considered different types of traffic control plans as well as different methods of monitoring to calculate effectiveness. To perform the test, they first needed a way of measuring which method of technology improves the areas in which operators can see the best. Using a light bar method as well as a computer-generated method, they were able to find the blind areas of different types of equipment. The ITCP was also studied, and different designs were studied to find the most effective designs for reducing the chance of an accident. It was found that the best method of reducing the risk of an accident was to consider using a technology used to help eliminate blind areas along with a properly designed traffic control plan to be the most effective. While setting up an internal traffic control plan, Fosbroke (2004) came up with following five questions to ensure a properly set up traffic control plan:

- Can the need for backing be reduced or eliminated?
- Can the number of vehicle access points into the work space be reduced?
- Can pedestrian free zones be established?
- Can the work space accommodate the equipment being used?
- Do any physical features of the site place operators at risk?

The study (Fosbroke, 2004) also brought forth three fatality case studies, which could have been prevented with the addition of a better ITCP as well as eliminating the blinds spots an operator experiences.

Figure 2.10 provides an example of one of the fatality case studies. During a paving operation, the dump trucks entered the work zone, turned around near the paver, and backed to the paver. A victim was struck while the dump truck was backing up to the paver. Fosbroke (2004) suggests that an ITCP could have been used to eliminate the turn-around and minimize the backing distance. It is also possible that if the dump truck possessed some type of technology eliminating the blind spot this fatality could most likely have been prevented.

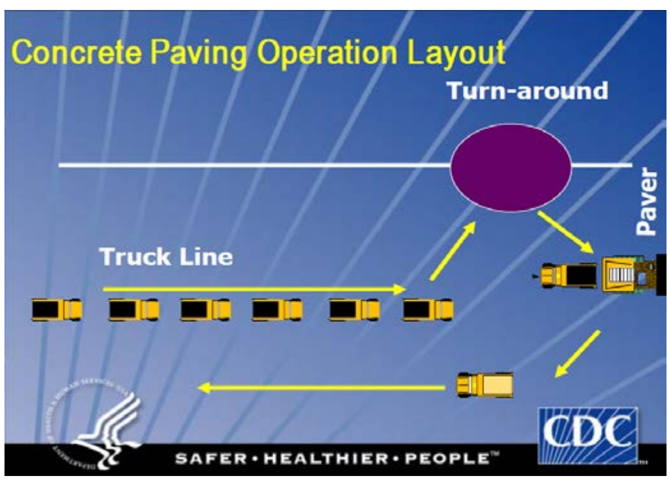


Figure 2.10 Fatality Case Study Diagram (Fosbroke, 2004)

Fosbroke (2006) discussed how to reduce injuries and fatalities due to struck-by incidents involving vehicles, equipment, and tools. He did this by giving field research analysis which showed the danger areas in a work zone. He then presented examples of safety measures such as a sample internal traffic control plan, technologies to warn drivers in a more effective manner, and technologies to warn pedestrian workers and equipment operators of possible struck-by accidents.

An article published in Construction Health and Safety Manual (Ch.28 Backing Up) described blind spots in detail (see Figure 2.11). This article describes how accidents can be caused by blind spots, and how these accidents can be prevented. It listed site planning, spotters, training, and electronic equipment as four primary areas to address in order to prevent these accidents.

Site Planning

- Reduce need for backing.
- Separate foot traffic and equipment operations as much as possible.
- Barricade workers from heavy equipment where possible.

Spotters

- Shall have one job as a spotter and nothing else.
- Must be trained and given oral and written instructions which they understand.
- Must wear a garment—usually a nylon vest—that is fluorescent or bright orange, with two vertical 5-cm-wide yellow stripes on the front and two similar stripes forming a diagonal "X" pattern on the back. These stripes must be retro-reflective and fluorescent. The vest must have an adjustable fit and have a front and side tearaway feature.
- Silver stripes around arms and legs must be worn during night work.
- Must maintain visual contact with the driver, vehicle, and pedestrians near vehicle blind spots at all times.
- Must be able to use clearly understood hand signals to communicate with equipment operators.

Training

- All personnel in work zone must be familiar with blind spots and the hazard they create.
- Workers on foot must make eye contact with equipment operator and signal their intentions before approaching equipment or entering blind spots.
- Drivers must always obey spotters and must stop their vehicle if more than one spotter is signaling at the same time to determine which directions to follow.
- Drivers should remain in their cab if possible to prevent being struck themselves.
- Horns should be blown twice before backing begins.
- If no spotter is present operator should exit vehicle and check blind areas prior to backing.
- Drivers must stop vehicle if any personnel leave their view and may have entered the blind area.

- Spotters must stay alert to better react if a safety hazard is recognized.
- Spotters should understand the limitations of equipment.

Electronic Equipment

- Audible alarms are required for all dump trucks.

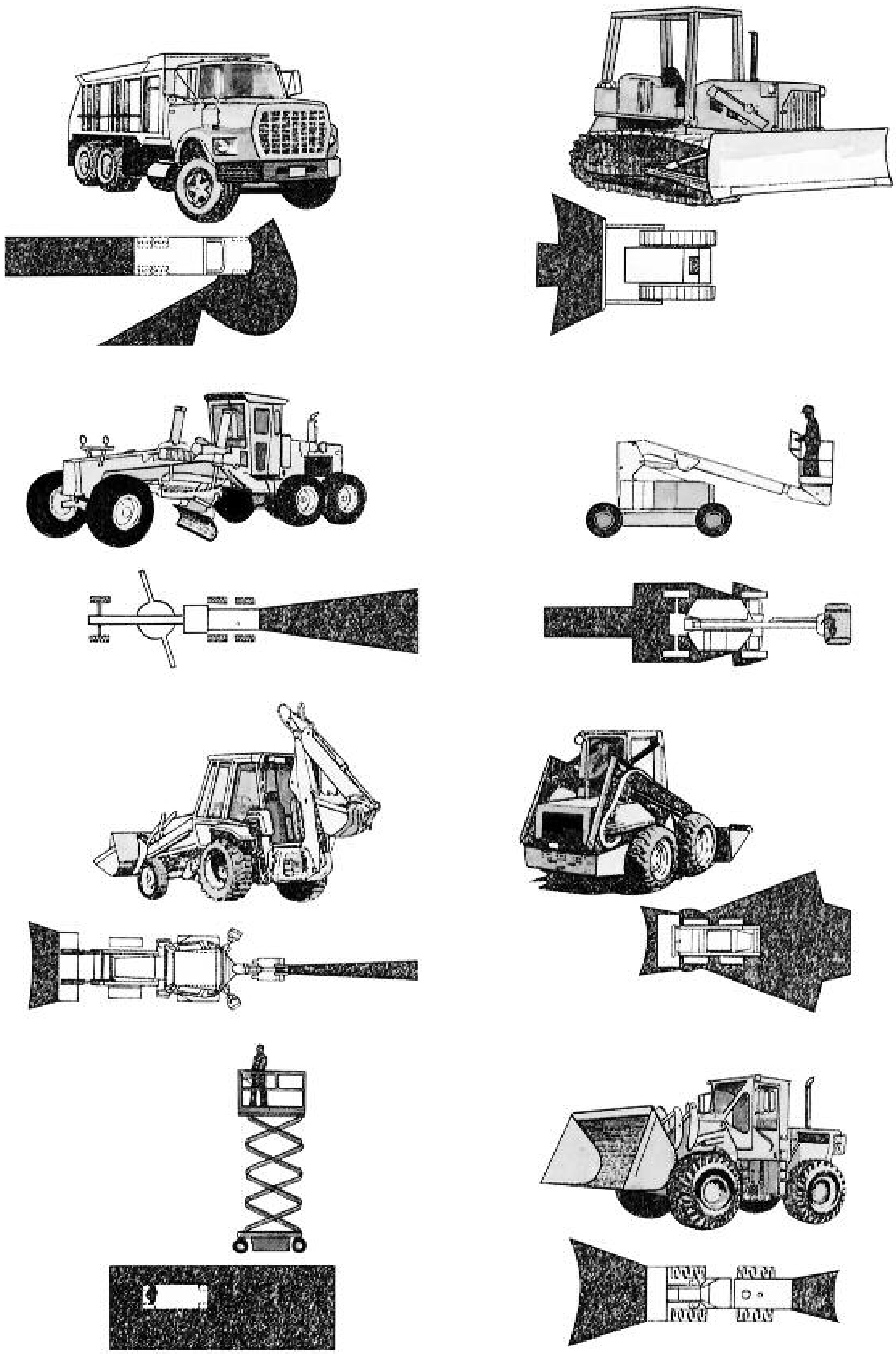


Figure 2.11 Blind Areas around Heavy Equipment
(Construction Health and Safety Manual-Ch.28 Backing Up)

Beaupre et al. (2006) presented findings and recommendations based on workers struck by equipment in work zones between 1992 and 2000. They found that 910 workers died in work zones and 91% of these were vehicle or equipment related. It was found that construction vehicles caused the majority of these fatalities not traffic vehicles. Out of the 258 deaths by construction vehicles, 41% were caused by Dump Trucks. It was also found that out of these, 130 were backing fatalities where 52% were caused by Dump Trucks. Three case studies were presented and a summary of the Fatality Assessment and Control Evaluation (FACE) investigation was included. FACE proposed that trucks be equipped with back-up alarms and that rear sensing technology be examined, strobe lights should be installed on all company trucks, and maintenance should be kept up with. FACE also proposed that heavy equipment should be driven in the forward direction as much as possible. Also, a comprehensive safety plan to be discussed in a pre-work safety meeting on a daily basis, which includes high visibility clothing and head gear for all pedestrians was suggested. Prevention measures for backing accidents are then described as Identifying Blind Areas, Administrative Controls, and Engineering Controls. A summary of Hefner's work (2004) was presented for Identifying Blind Areas. Two keys to Administrative Controls are Backing Safety Program and Internal Traffic Control Plans. The presentation shows that Backing Safety Programs should include (Beaupre et al., 2006):

- Equipment designed to minimize blind areas.
- Equipment inspections/preventative maintenance.
- Layout work areas to avoid backing.
- Use of spotters.
- Training for operators and workers on foot.

  -Operator Training:
    - Avoid having to backup.
    - Do walk around.
    - Be aware of blind areas.
    - Use a spotter.

  -Worker Training:
    - Be aware of equipment blind areas.
    - Stay out of all blind areas and swing radius.
    - Make positive eye contact with operators.
- Use of high visibility vests.
- Use of other backing safety devices (engineering controls).

The proposed ITCP would be defined as "Strategies to control the flow of construction workers, vehicles and equipment inside the work zone." The principles of ITCP are listed below (Beaupre et al., 2006):

- Reducing the need to back up equipment
- Limiting access points to work zones
- Establishing pedestrian-free areas where possible
- Establishing work zone layouts commensurate with type of equipment

- Providing signs within the work zone to give guidance to pedestrians, equipment and trucks
- Designing buffer spaces to protect pedestrians from errant vehicles or work zone equipment

The presentation also included ITCP components, as follows (Beaupre et al., 2006):

Notes Page

- Safety Points
  - No workers in traffic zone
  - Spotter uses hands free radio to talk to trucks
  - No workers on foot between a backing truck and the paver
  - No rollers within 50 feet of the back of the paver
  - Inspectors remain away from paving train and notify spotter before obtaining samples
- Personnel
- Equipment

Legend

- Method Specific

Work Area Diagrams

- Dimensions
- Movement Flow
- Work zone Limits
- Signage

The last part of this presentation included technologies for blind spot intervention which was a summary of Ruff (2003). The testing conclusions were made as follows (Ruff, 2003 and Hefner, 2004):

Sensor systems (radar, sonar, infrared):

- False alarms are possible
- Nuisance alarms can be numerous in crowded work areas

Camera systems:

- Provide view of blind area
- Do not alarm so potential collision may go unnoticed
- May not work in winter conditions
- Good solution for crowded work zones during warmer months

A combination of sensors and a camera may be best solution for warmer months

- Alarm prompts driver to check video

- Video allows driver to check source of alarm

Connolly (2006) discussed dump truck safety and the importance of internal traffic control plans in this article. The suggestions made to be included in an ITCP included: reduce need for backing up, limit access to work zone, establish well marked pedestrian free areas, provide signs inside the work zone to give guidance to pedestrians, equipment, and trucks, and design buffer spaces between workers and pedestrian traffic or work zone equipment. The importance of blind area awareness was also discussed in this article and is described as a safety hazard; especially when backing up. A backing safety program was also suggested. The aspects of this were said to include designing equipment for minimal blind areas, sufficient equipment maintenance, use of spotters, training, and use of high-visibility vests. Training should be for drivers and pedestrian workers about blind areas, and responsibilities when backing. Finally, the article suggested the use of new technologies to help prevent backing accidents.

NIOSH (2000) presented a FACE investigation of a fatal dump truck accident. Upon conclusion of the investigation the following recommendations were made by the investigator (NIOSH, 2000):

- Develop an internal traffic control plan (ITCP) that project managers can use to coordinate the flow of construction vehicles, equipment, and workers operating in close proximity within the activity area, especially on large and multi-contractor jobs.
- Design the workflow to minimize backing heavy equipment.
- Ensure that a person is designated as a spotter to direct trucks that must back up within highway construction sites.
- Consider equipping vehicles with devices to detect the presence of individuals or objects behind backing vehicles.

In addition, EMS providers should:

- Conduct practice runs to road construction sites that have altered the normal traffic patterns.

NIOSH also suggested electromagnetic signal detection systems, among others, as a viable technology for the prevention of backing fatalities.

Washington State’s Safety and Health Assessment and Research for Prevention (SHARP) (2007) presented a case study of a fatal back over incident in which the victim was wearing a high-visibility vest and pants and the truck was found to have a working back-up alarm. SHARP’s 2007 requirements and recommendations include those required by code in Washington State, and others that were recommended for future road construction: (Note that “!” was used in the original document to indicate items required by code):

! If employees are in the backing zone or could reasonably be expected to enter the area, the truck must be backed up only when there is: an observer signaling when it is safe to back up; or has a device such as a video camera that provides the driver with a full view of the area behind the dump truck.

! The employer needs to make sure job assignments do not place a worker in the backing zone of a dump truck or other construction vehicle, unless a spotter / observer is present.

! Dump truck drivers working in construction zones must determine that no one is currently in the backing zone.

! All dump trucks must have an operable automatic back-up alarm.

! Train all site workers (employees and subcontractors) to recognize and communicate to one another about the hazards associated with moving vehicles and equipment in the work zone.

- Backup Collision avoidance systems should be installed on vehicles. Backup collision avoidance systems can help alert drivers of workers on foot in blind spots behind their vehicles.
- The safe coordination of workers-on-foot and construction vehicles is an important part of the work site safety process. Help in managing the process can be accomplished by having an Internal Traffic Control Plan adequately communicated to workers.
- An Internal Traffic Control Plan can help identify critical areas in traffic and pedestrian flow within the work site and help alert workers and site supervisor when additional safety measures are needed such as a spotter / observer or the placement of physical barriers to separate vehicles from workers, for example.

Another article (Watch Your Back, 2003) mentioned that over half of the work zone fatalities are inside of the work zone, and do not involve motorists, many of which are back over accidents due to the blind spots of heavy equipment. Many accidents occur even with backup alarms, and workers wearing reflective clothing. Being able to actually see behind the vehicle was a great addition to these safety procedures. Companies had started using backup cameras to help in preventing accidents. Lake Tahoe Public Works department and AGC ready mix group had installed backup cameras experiencing successful results. AGC ready mix group explained they had not had an accident at all since the addition of their backup cameras. Concluded in this article that the best way to prevent backing accidents was to eliminate the blind spot by adding back up cameras to large equipment.

Cooper et al. (2010) discussed a study done by the Traffic Safety Center (TSC) at the University of California-Berkeley on accident data by Caltrans Fleet. TSC mentioned that there were essentially three approaches that can be taken to eliminate backing crashes.

1. Changes to equipment (e.g., mirrors, backing video, radar/sonar).
2. Adjustments to procedures (e.g., use of cones, circle checks, spotters).
3. Changes in workplace safety policies (e.g., training, accountability).

In 2006, Caltrans backing accidents accounted for 30% of all preventable accidents, which was the single most common accident. After testing, TSC made the following recommendations to Caltran on how to update their safety manuals procedure (Cooper et al., 2010):

- Any time a vehicle is backed, if another Caltrans employee is present, that person will act as a spotter.
- If a vehicle has been stopped or parked for any length of time, the driver shall exit the vehicle and perform a visual inspection.

- In all procedures, the word ‘shall’ will be used rather than ‘should’.

According to the TSC review of the literature, the most effective backing accident prevention systems integrate multiple technologies including video, radar, and back-up alarms, in addition to traditional devices adapted to the special requirements of the backing maneuver. Two potentially powerful tools for eliminating incidents and injuries emerged from their research: enhancement of the Safety Information Management System (SIMS) database to allow a clearer understanding of the scope and magnitude of the problem, and management action to instill and support a strong culture of safety throughout the organization. Employees should be held accountable for the accidents they are involved in, and rules should be enforced.

Some methods to reduce or prevent backing accidents were presented, which include the following (Cooper et al., 2010):

Prior to Job/Planning the Work:

1. Supervisors should plan work projects to minimize the need for backing of vehicles and equipment whenever possible. For example, the forward mode of cone retrieval should be utilized for retrieving lane closures.
2. Design the work space to eliminate or decrease backing and blind spots; when feasible pull trucks into the work zone and let the operation catch up to them.
3. At tailgate safety meetings prior to the job, discuss how and when vehicles will be backing within the work zone and specific measures that will be taken to prevent an accident.

Safety at the Worksite:

1. Workers on foot will be separate from equipment as much as possible: ensure that employees on foot stay out of the work area and in clear view of those who are operating equipment.
2. Minimize the distance heavy equipment needs to back up in order to gain access to the work area.
3. Employees should never move equipment without making positive visual contact with any workers on foot around or near the equipment.
4. In work zones where moving equipment has the potential to strike a worker on foot, employees shall not place themselves in or near the path of backing vehicles and should not enter the work area until it is clear for hand work. One person should be designated as a lookout while vehicles/equipment are moving within the work area.
5. Every backing situation is new and different. Even if you work at the same location several times a day, you should be watchful for changes and any new obstacles.
6. Use a spotter. The driver and spotter should use hand signals instead of verbal ones and make sure they understand each other’s signals. Don’t have the spotter walking backwards while giving instructions.
7. During shoulder or pavement rolling operations, make sure all workers on foot are clear of the work area before moving any vehicles/equipment.

Personal Responsibilities

1. Employees operating vehicles and equipment must be familiar with the blind spots for the particular equipment they are operating. Remember that mirrors can never give the whole picture while backing.

2. Train workers on foot and equipment operators in appropriate communication methods (e.g., using hand signals and maintaining visual contact) to be used when workers on foot are required to be in the same area as equipment.
3. Do a walk-around of your vehicle before entering. Check for obstructions, low hanging trees and wires, and any other potential clearance-related problems.
4. On-foot personnel need to make sure they are a safe distance from vehicles in the work area. Do not stand where the operator cannot see you: a vehicle that has the potential to back up could run you over.

Some suggestions on the proper way to be a spotter, and the proper hand signals are provided in Appendix E of TSC Report, as also shown below in Figure 2.12.

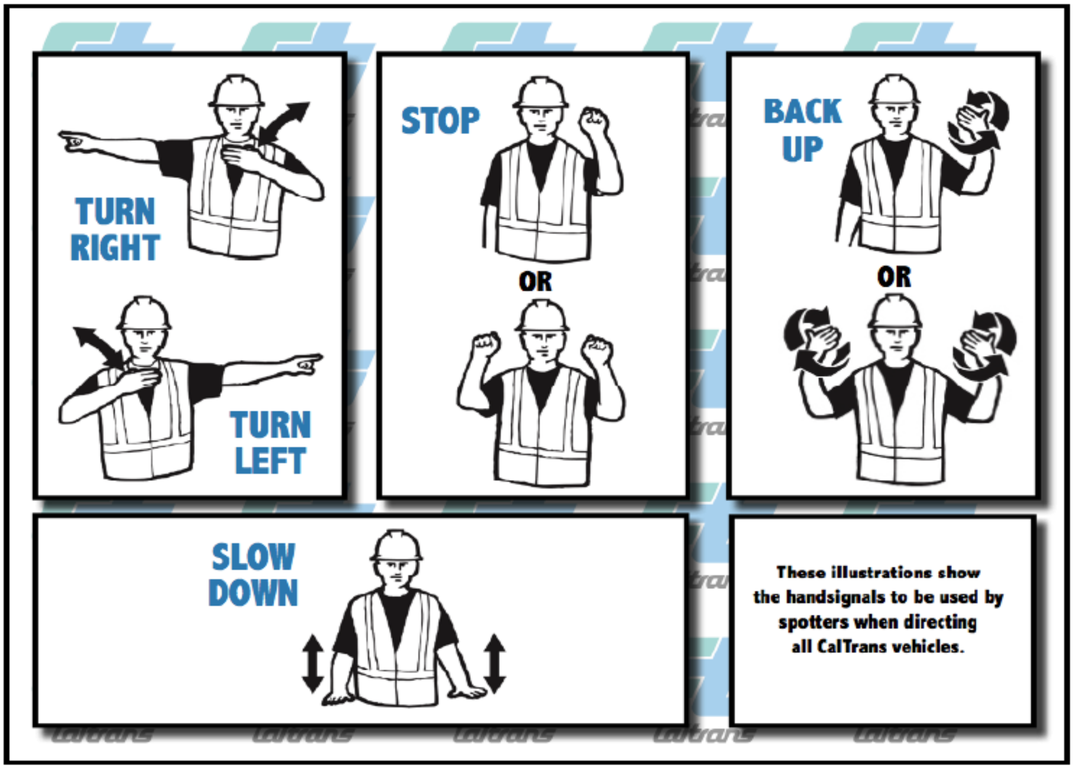


Figure 2.12 Hand Signals Illustration (Cooper et al. 2010)

TSCs findings include:

- A report on highway work zones based on qualitative information obtained from government, labor, industry, academia, and state departments of transportation suggested that the following engineering solutions might effectively reduce backing accidents:

    1. Parabolic mirrors on construction equipment
    2. Individual vibrating alarms that can give workers 8-10 seconds notice of approaching vehicles
    3. Sensing devices that sound an alarm when an object is near the vehicle
    4. Closed-circuit television cameras, mirrors, and devices that stop a vehicle nearing a collision

- NIOSH investigated equipment on job sites to see what backing accident prevention technologies worked best and in 2006 concluded that back-up video systems are very helpful and work best when used in conjunction with a radar system that alerts the driver that something may be behind the vehicle and directs his attention to a monitor.
- Back-up warnings that alerted drivers approaching known obstacles were more successful in preventing backing incidents than warnings that sounded in response to a surprise event. However, some argue that audible alarms do not always protect workers outside vehicles due to malfunctions and work site noise.

FACE (2006) offered suggestions to prevent an occurrence such as the one that occurred in 2006 where a construction worker was backed over and killed by an asphalt truck. Later it was found that the backup alarm had not been installed properly, and that the worker had walked into the path of the oncoming asphalt truck. Their recommendations include the following:

1. Employers should ensure that backing procedures are in place for the use of mobile construction vehicles, a spotter is designated to direct backing, and drivers are in communication with workers on foot.
2. Employers should develop, implement and enforce procedures that minimize exposure of workers on foot to moving construction vehicles and equipment.
3. Employers should develop and implement specific training on equipment blind areas for mobile equipment operators and workers on foot.
4. Employers should consider installing aftermarket devices (i.e., camera, radar, and sonar) on construction vehicles and equipment to help monitor the presence of workers on foot in blind areas.
5. Employers and companies performing any type of final assembly on construction vehicles should ensure that safety equipment is installed in accordance with the manufacturer’s specifications and operates as intended
6. Manufacturers of heavy construction equipment, such as dump trucks, should explore the possibility of incorporating new monitoring technology (e.g., radio frequency identification (RFID) tags and tag readers) to help monitor the presence of workers on foot in blind areas.
7. The U.S. Department of Labor, Occupational Safety and Health Administration (OSHA) and State OSHA Plans should consider a rulemaking effort to improve the safety regulations and require new safeguards for employees on roadway construction worksites.

The Fatality Assessment and Control Evaluation (FACE) for Wisconsin (2001) reported a fatality in which a 20-year-old construction laborer died from being run over by dump truck in a work zone. The work zone had been cleared of road traffic, and so there were no effect that high pedestrian area traffic could have. The investigation reported that the truck was equipped with rear view mirrors on both sides, as well as a backup alarm. The victim was backed over while he was bent over driving stakes into the ground. The truck was backing up and steered left to avoid a grader that was smearing the gravel he had just dumped. It was discovered the operator had been watching his mirrors, and the backup alarm activated, however he was unaware as well as the victim of the danger that presented him. From this accident investigators were able to provide some recommendations to help prevent a risk of an accident like this occurring again, which include the following:

- Develop an internal traffic control plan (ITCP) that project managers can use to coordinate the flow of construction vehicles, equipment, and workers operating in close proximity within the activity area (FACE for Wisconsin, 2001).
- Managers should show diagrams, and different methods of portraying the designed ITCP to their workers as well as ensuring the importance of safety and how that can be accomplished with the ITCP designed for that scenario.
- Design the workflow to minimize backing heavy equipment (FACE for Wisconsin, 2001)
- Companies should carefully evaluate environmental and economic barriers to forward operation and select work operations that allow forward movement.
- Ensure that a person is designated as a spotter to direct trucks that must back up" (FACE for Wisconsin, 2001). The spotter should have clear instructions from the ITCP coordinator, and know the proper way of communicating with the operator.
- Consider equipping vehicles with devices to detect the presence of individuals or objects behind backing vehicles" (FACE for Wisconsin, 2001). Some types of technology include electromagnetic signal detection systems, infrared detection systems, ultrasonic detection systems, and video cameras.

Communication among everyone in the work site should be a top priority.

2.6 Review Summary

Based on the comprehensive literature review of the state-of-the-art and state-of-practice, current strategies employed by the industry and various DOTs to prevent backing fatalities include: 1) Engineering and administrative controls (including ITCP, spotters, and training); and 2) Technology controls (including several potential electronic devices).

Table 2.5 provides a summary of the literature review conducted from these perspectives in this technical memorandum, which can also be used to the general points of each piece of literature reviewed by the research team.

In summary, it can be concluded that any single control is insufficient. Training alone will not prevent all incidents because working in a dangerous environment will always allow for human error to cause injury. Hence, there is a need for engineering controls such as an ITCP (i.e., site planning) to be in place to make the work zone less hazardous. However, even with a safer work zone and better training, technology is the last line of defense to insure the safety of all workers in a work zone. Therefore, integrating technology controls along with site planning, and training can greatly reduce the risk of fatal construction accidents especially caused by backing.

Table 2.5 Summary of Literature Reviewed

	Blind Areas	Engineering & Admin Control	Technology Control	Integrated Control
Beaupre et al. (2006)		✓	✓	✓
Bryan District (2010)		✓		
Bryden and Andrew (1999)	✓			
Bryden et al. (1998)		✓		
Connolly (2006)		✓		
Construction Health and Safety Manual (2011)	✓	✓		
Cooper et al. (2010)	✓	✓	✓	✓
FACE (2001)		✓	✓	✓
FACE (2006)		✓	✓	✓
Fosbroke (2004)	✓	✓	✓	✓
Fosbroke (2006)		✓	✓	✓
Fosbroke (2009)		✓		
Garrott et al. (2007)			✓	
Graham and Burch (2006)		✓		
Graham et al. (2005)		✓		
Handbook of Safe Practices, TxDOT (2010)		✓		
Hefner and Breen (2003)	✓	✓	✓	✓
Herner and Breen (2004)		✓		
Jones (2005)	✓	✓		
Laborers' Health and Safety (2004)			✓	
Laborers' Health and Safety (2005)		✓	✓	✓
Lee et al. (2010a)			✓	
Lee et al. (2010b)			✓	
Lerner et al. (1997)			✓	
Llaneras et al. (2005)		✓	✓	✓
MacDonald (2007)	✓	✓		
Mazzae and Garrott (2006)			✓	
Mazzae and Garrott (2007a)			✓	
Mazzae and Garrott (2007b)			✓	
MSHA (2001)			✓	
MUTCD (2009)		✓		
NHTSA (1994)			✓	
NIOSH (2000)	✓	✓	✓	✓
NIOSH (2011a)	✓		✓	

	Blind Areas	Engineering & Admin Control	Technology Control	Integrated Control
NIOSH (2011b)	✓			
Oloufa et al. (2002)			✓	
OSHA Fact Sheet (2005)	✓	✓		
OSHA Regulations 29CFR (2005)		✓		
Pratt et al. (2001)		✓		
Rau et al. (2009)			✓	
Ruff (2000)			✓	
Ruff (2001a)			✓	
Ruff (2001b)			✓	
Ruff and Hession-Kunz (2001)			✓	
Ruff (2003)			✓	
Ruff (2004a)			✓	
Ruff (2004b)			✓	
Ruff (2007)			✓	
Ruff (2010)			✓	
SHARP (2007)	✓	✓	✓	✓
Schaudt et al. (2009)			✓	
Texas Department of Insurance (2011)	✓	✓	✓	✓
Turner et al. (1997)		✓		
Vehicles and Heavy Equipment (2007)		✓	✓	✓
Washington State Department of Labor and Industries (2009)	✓	✓		
Watch Your Backing (2003)		✓	✓	✓
Zeyher (2007)	✓	✓		

2.7 Summary

A comprehensive review and synthesis of the current and historic research and current methods of preventing backing fatalities has been discussed in the preceding sections. These methods include engineering controls, administrative controls, and technology controls, as well as the integration of the three, in hopes of creating the safest work environment possible. The research is intended to provide a solid reference and assist in the development of new methods in hopes of creating a safer work environment. It also gives a very solid background on the terminology used in a construction work zone, the blind areas that the large equipment faces, as well as the principles of an internal traffic control plan.

Chapter 3. Identification and Analysis of Appropriate Responses

3.1 Introduction

The purpose of this chapter is to identify useful and effective means for the Texas Department of Transportation (TxDOT) to improve backing safety in work zones using information and data collected in Chapter 2 (Literature Review). Though this chapter has many characteristics similar to the literature review, it is focused on TxDOT and which engineering, administrative, and technology controls can be implemented efficiently and effectively in Texas whereas the literature review focuses on the current state-of-practice and on the identification of traffic control devices and preventative treatments for backing fatalities in construction work zones as a whole.

In this chapter, the existing backing fatality data and related characteristics will be presented first, and then four basic approaches will be addressed for improving backing safety in Texas: Engineering Controls, Administrative Controls, Training, and Technology Controls. The results will include a comprehensive analysis of current backing prevention methods and the limitations of these methods. A case study will be examined to show how the implementation of new protocols, planning, and equipment could improve the safety of work zones.

3.2 Characterization of Backing Fatalities

The existing backing fatalities data currently available in all TxDOT districts has been collected and reviewed and these backing fatalities in construction work zones are also characterized. Due to confidentiality issues, only the data in Table 3.1 is provided here.

As a result, the research team will focus more on the comprehensive identification and analysis of appropriate responses, as well as testing commercially available systems for prevention of backing fatalities in construction work zones as we move forward with the project.

Table 3.1 TxDOT Backing Fatalities Data

TEXAS DEPARTMENT OF TRANSPORTATION				
Backing Fatalities - (1938 - Current Year)				
#	District	DOI		Description
1	19 - Atlanta	6/30/10	Y	Fatality- Employee was crushed by belly dump truck.
2	14 - Austin	1/15/06	Y	Crushed by Pneumatic Roller while performing inspection.
3	05 - Lubbock	8/2/93	Y	EMPLOYEE WAS BACKED OVER BY THIRD PARTY VEHICLE
3	01 - Paris	7/18/91	N	STANDING IN ROADWAY AND BACKED OVER BY TXDOT TRUCK
4	09 - Waco	7/9/86	Y	While walking between laydown machine & dump truck, dump truck backed up hitting employee and knocking him to ground and rolling over him.
5	09 - Waco	8/29/79	N	TOLD DRIVER TO BACK THE DISTRIBUTOR AND THEN WALKED BEHIND THE DISTRIBUTOR OUT OF MIRROR VIEW OF THE DRIVER
6	13 - YOAKUM	7/9/79	Y	Employee was inspecting a contract asphalt operation. He was standing behind his pickup when a sub-contractor's dump truck backed up and pinned him between the two vehicles.
7	5 - LUBBOCK	2/4/70	Y	Employee was backed over by a contractor's spreader truck.
8	1 - PARIS	6/12/69	Y	Employee was measuring across the roadway when a sub-contractor's dump truck backed over him.
9	12 - HOUSTON	11/4/68	N	Employee was flagging for a patching crew when he walked behind one of the department owned trucks and was run over.
10	18 - DALLAS	11/4/68	Y	Employee walked behind a third party truck loaded with hot mix and was run over.
11	15 - SAN ANTONIO	1/20/65	Y	Employee was checking and writing haul tickets for base material which was being dumped on highway construction project when a third party dump truck which was backing up to dump load of material ran over him.
12	18 - DALLAS	1/4/65	N	Employee had dismounted from truck to pick up plate of metal debris on shoulder of road. Driver of truck backed up for piece of metal to be loaded when employee somehow fell under the path of the rear wheels of the moving truck.
13	1 - PARIS	5/29/62	N	Another employee was backing up a tractor with sheep-foot roller attached, the tractor stopped for a moment and employee stepped into disconnect roller, tractor backed over him.
14	21 - PHARR	8/16/58	Y	Employee was knocked down and run over by contractor's tractor.
15	9 - WACO	3/5/56	N	Leveling asphalt surface on highway and truck backed over head and chest.
16	22 - LAREDO	2/17/56	N	Employee supervising rolling operation, turned around and truck backed over him crushing him.
17	10 - TYLER	4/23/54	N	Was walking along pavement and a truck backing up knocked him to pavement.
18	1 - PARIS	9/24/51	N	Was making adjustment on asphalt distributor. Right foot was caught by rear truck wheels, throwing man underneath distributor. Distributor and truck were in motion.
19	12 - HOUSTON	7/24/51	Y	Truck backed into and ran over body of employee after he had issued haul ticket to driver.
20	13 - YOAKUM	6/2/48	Y	Employee was patching asphalt pavement when struck from rear by truck.
21	8 - ABILENE	5/30/47	Y	Dump truck backed over employee.
22	14 - AUSTIN	8/21/46	Y	Employee was laying string on road surface to guide asphalt shot when stuck and run over by loaded truck.
23	10 - TYLER	10/23/41	N	Employee stepped behind maintainer to get out of way of car and maintainer backed over employee.

3.3 Engineering Controls

Internal Traffic Control Plans (ITCP) are used to create structure and order in a work zone for safety and efficiency purposes. The goal of an ITCP is to prevent fatal incidents by reducing dangerous situations within a work zone. The ITCP should be designed to include buffer zones between the traveling public, the pedestrian workers, and trucks/equipment within the work zone. An ITCP will direct the movements of workers and equipment entering, moving within, and exiting a work zone. The ITCP is developed to reduce the need for backing movements as much as possible. This directly reduces the possibility of back-over fatalities. The ITCP is to be developed to keep workers-on-foot separate from heavy equipment as much as possible and to include designated worker-only and pedestrian-free zones whenever possible. The ITCP should assign signage to direct the movement of pedestrians, vehicles, and equipment within the work zone and should limit access to the work zone.

The ITCP can be changed by the safety officer or related competent person as needed while a project progresses, and these changes must be communicated to all other personnel who received an ITCP upon beginning work on the project. Even when the ITCP is not changed, the changing environment and new safety concerns should be discussed with workers **at least once per shift** to keep the workforce apprised of possible hazards that may not have been present during their last shift.

Creating the ITCP necessitates certain considerations; a few important issues are listed below that must be included during this planning.

- Areas where worker-equipment interaction occurs should be minimized.
- Buffer zones between workers and public traffic/heavy equipment should be maximized.
- Backing situations should be minimized.
- Vehicle access points into work zone should be reduced.
- Keep the length of the work zone appropriate to the work in progress.
- Design and implement the plan in accordance with safety management principles that call for a hierarchical approach to prevention of worker injuries.

The creation of an ITCP is a key component to the improved safety of work zones. An ITCP should contain a minimum of three parts including a traffic control diagram, a legend explaining this diagram, and notes explaining the details of the diagram and work zone. The creation of the ITCP takes place in 6 steps (Graham and Burch, 2006).

1. Review the contracts and model plan for the project.
2. Decide the sequence of events in the project and choose which phases of work need an ITCP.
3. Create a basic design of the work zone.
4. Designate storage, utility, and staging areas.
5. Design vehicle and pedestrian paths throughout the work zone.
6. Create the ITCP notes.

All recommendations presented below in this section were made based on a comprehensive literature review, completed in Chapter 2, over the following references (Jones 2005, Laborers' Health and Safety 2005, Graham et al. 2005, MacDonald 2007, Fosbroke 2004, Fosbroke 2006, Connolly 2006).

3.3.1 Internal Traffic Control Plan Diagram

The ITCP diagram should contain schematic diagrams depicting the movement of construction workers and vehicles within the work space. Diagrams should contain separate illustrations for all paving, trenching, and dirt spread operations. The diagrams must be modified to assure compatibility with the overall ITCP, and to address site-specific conditions. Routes should be identified and marked to allow workers and work vehicles to safely enter, do the job at hand and exit the work zone safely.

An example of this plan has been provided in Figure 2.6 in Chapter 2. The diagram shows a layout of an example work space and the movement of personnel and vehicles within the work space. It illustrates access points to the work space as well as some parts of the overall work zone. Also, the diagram illustrates the movements of a truck within a work zone. The truck enters the work site on one lane and performs a U-turn to enter a dumping area. After traveling down the construction area, the truck will enter in front of the roller, pull up straight, and back straight up a short distance in order to dump material right in front of the loader, and then pull off on the side. A design such as the one described minimizes the amount of backing, and technical backing by allowing the truck operator to back straight up to the loader, and not from a very long distance. The maximum safe distance a dump truck should back is dependent on many variables including weather conditions, speed of backing, activity of area, and many more. For this reason, no testing has been done to determine a certain safe distance. Therefore, the goal is to minimize or eliminate backing all together and a quantified distance is not available. However, workers are able to stand on the left side of the setup and are not subjected to being backed over.

3.3.2 Legend

The legend should clearly label all parts of a traffic control plan diagram including heavy equipment paths and areas such as pedestrian free, or backing free, zones. Some of the movements and objects that are represented by symbols include the following:

- Lights and channelizing devices
- Barriers
- Direction of highway traffic, and traffic within the work zone
- Sign locations
- Worker locations, with a different symbol for each worker
- Different equipment within the work zones

An example of such a legend can be seen in Figure 2.7 in Chapter 2.

3.3.3 Internal Traffic Control Plan Notes

The proper implementation of the ITCP should lead to more effective injury prevention. The ITCP notes should be used as a guide for all personnel on the site to make sure the implementation of this plan is correct. This means that all personnel, private contractors included, working on the project must be made comprehensively aware of the ITCP when they enter the work zone. Current updated notes are important so that changes throughout the course of the project are reflected and are easily referenced to see how safety could be affected. This updating should be done frequently to reflect current working conditions, to alter any tasks that were previously conducted, and to ensure workers continuously understand the job taking place. This is especially important for supervisors, inspectors, and independent contractors such as dump truck drivers to insure all members of the project are in consensus on how the work zone will be set up to insure a high level of safety. Preconstruction safety meetings should be held by all foremen, supervisors, and inspectors to insure the cohesion to the ITCP notes and to ensure all workers within the site understand the notes which have been presented to them.

The ITCP notes should contain site-specific safety measures, explanations for contractor duties (in reference to safety), and other safety points. These points include such measures as pedestrian-free zones and buffer zones in which zones are clearly depicted, so there is no question with workers who are unfamiliar with the work zone. The notes should also contain specifics such as safety meeting frequencies, truck arrival times, and internal speed limits for the work zone.

3.4 Administrative Controls

Section 3.4 discusses the recommendations which should be made to improve workers safety based on Administrative Controls. These include safety meetings, the use of safety officers, the implementation of regulations and guidelines, and the proper training of employees. These recommendations were made after a comprehensive review of the following references which was done in Chapter 2, a literature review (Vehicles and Heavy Equipment 2007, Handbook of Safe Practices 2010, Ch.28 Backing Up, Beaupre et al. 2006, SHARP 2007, Cooper et al. 2010, FACE 2006).

3.4.1 Safety Meetings

Safety conversations should take place every day in order to continue to remind workers of the steps to increase their safety and to adapt to current changing conditions which can affect safety. All key players over a work site should be present during the meetings, especially those in charge, in order for them to better guide construction laborers. Higher management personnel should monitor and make sure all rules are followed. These rules and guidelines should be presented at safety meetings in order for the workers to understand what it is expected.

3.4.2 Safety Officers

Every work zone should be assigned a traffic control supervisor who is knowledgeable on the type of project at hand and who will be able to carry out many tasks throughout the construction process. These tasks include, but are not limited to, reviewing the Traffic Control Plan and offering suggestions, coordinating activities at the work site, and determining traffic routes within the work zone. They should avoid assigning collateral duties to workers which can distract them from focusing on their safety responsibilities. The supervisors should be made responsible for daily documentation of hazards, how hazards were mitigated, maintain lines of communication of this data between individuals responsible for different aspects of work zone safety. The safety officer and work-zone supervisors should decide how to demarcate traffic routes within the work zone, whether by using cones or other means, and include a plan for communicating between vehicle operators and workers-on-foot about where they are. They should evaluate the effectiveness of the ITCP throughout the project and look for ways of improving the setup to increase safety. The traffic control supervisor should be authorized to temporarily halt work until unsafe conditions related to temporary traffic control have been eliminated.

3.4.3 Regulations & Guidelines for Workers

Guidelines and expectations should be presented to workers during safety meetings to inform them of what to expect during different scenarios. Warnings should be given to workers outside of these guidelines and violations should be treated as violations of standard company policy. These guidelines and expectations are described in the following section labeled training because the first step in implementing safety guidelines and regulations is to ensure workers understand the purpose of such guidelines and have been trained to properly abide by them.

3.5 Training

The training of all workers on any construction site is the first step to keeping the job site safe. Properly trained employees are much more likely to follow company policy and standard safety policies. The following are safety policies which should be explained to each employee to ensure they follow safety protocol and understand the importance of such. It is key that all supervisors understand all of the following protocols as well so that they may enforce and teach them to workers and so that they may follow these protocols themselves. These procedures were developed by the study of numerous case studies (Pratt et al. 2001) and should help reduce the chance of fatalities in work zones if personnel understand and follow them properly.

3.5.1 Workers on Foot

- Must be trained to recognize and avoid the hazards of working on foot around equipment and in dynamic work zones
- Workers must not cross directly in front of, or behind, dump trucks as they have large blind areas in those areas.
- Workers should make eye contact with heavy equipment and large truck operators before entering an area near the equipment or truck.
- If workers must stand near heavy equipment, they should stand in front of, or on the operator side of the vehicle so the operator can easily see the worker.
- Workers should be knowledgeable and properly trained in the tasks that they are required to do and should report to an officer if they do not feel their skills are enough to perform their tasks safely.
- Must never place themselves under or behind running equipment without direct contact and instruction from the equipment operator.
- All workers must understand the environment around them and therefore, must be aware of the ITCP set up for the work zone.

- Should be vigilant around heavy equipment and trucks in the work zone and should stand clear when possible
- Should be equipped with high visibility clothing to insure detection by other workers on site and heavy equipment operators

3.5.2 Spotters

- Should know how to understand and use hand signals to communicate with equipment operators and other workers in the work zone
- Should be assigned whenever backing maneuvers are regularly expected and should not have any other jobs during this time
- Should be placed in a location where they are visible to equipment and vehicle operators.
- Should only direct one backing vehicle at a time.

3.5.3 Flaggers

- Must have the skills and knowledge to understand the traffic flow, the work zone setup, and proper placement of channelizing devices
- Shall be assigned an area to be responsible for monitoring operations
- Should direct only traffic moving in one direction at busy, noisy, construction sites
- Should be present when work is being performed on the sides of roadways normally open to the public
- Should be authorized to recommend to traffic control supervisors that operations be halted in his or her immediate work area.
- In the event of multiple flaggers, should be trained to communicate effectively with one another by sight, or with two-way radios.

3.5.4 Equipment Operators

- Must always use provided safety equipment such as safety belts when operator their equipment
- Must understand the ITCP to insure their movements remain in designated areas at all times
- Must understand the workspace, and current conditions to better reflect the movements that are safe for them to make
- Operators must understand hand signals for use when communicating with workers on the ground, especially when in backing maneuvers.
- When being directed by a spotter, operators should keep constant view of the spotter and if direct view is interrupted, the operator must come to a complete stop to regain contact with the spotter.

- If an equipment operator believes there is a possibility of pedestrian workers being in the area where they are making maneuvers, they must keep positive visual contact with these workers during the maneuver.
- Employees should report equipment problems to the designated competent person who should be given the authority to shut down unsafe equipment without repercussion.
- Should carry out pre-inspection checks on the equipment they are operating
- Should use spotters in an effective manner, and communication with a two-way radio
- Operators should never allow passengers on their vehicle without proper safety constraints in use. i.e. safety belt
- Horseplay should never be tolerated in or around moving equipment.
- Operators should never move equipment without making positive visual contact with any workers on foot or near the equipment.
- If no spotter or visual backing aid is in use, equipment operators must exit their vehicle and walk around the back to ensure no pedestrian workers or obstructions are present.
- Before backing, operators should blow the horn of their vehicle twice to warn workers on site of their intention to back.
- Employers should ensure that equipment operators are trained to check work areas for the presence of pedestrians in the machines path before changing the direction of travel.
- Employers should ensure that backup alarms, horns, and other safety equipment on construction machinery are functional and tested daily. Equipment that has nonfunctioning backup alarms, horns, or other safety equipment should be removed from service until it is repaired.
- Employers should train equipment operators to properly use safety equipment such as safety belts and make sure they understand the limitations of their machine. If the equipment is equipped with a rollover protective structure, operators should know to keep their safety belt fastened and how to react during a rollover event.

3.6 Technology Controls

Technology is an option which when used correctly can greatly reduce the number of run-overs and back-overs in construction work zones. Back-up cameras, sonar, radar, and the Global Positioning System are all devices that can help detect and avoid pedestrian workers- Tractor-trailer manufacturers should consider providing back-up alarms and back-up lights as standard equipment on new vehicles. Each type of device has its pros and cons and each device should be researched and considered for each task to see the best type of device that can be used. The type of device should be considered under each scenario to determine its effectiveness at all times and not just in certain situations.

Commercially available technologies will be identified in Chapter 4 and tested in Chapter 5. Result findings will be presented, and a recommendation will be made on how to incorporate engineering, administrative, and technology controls for the fatalities in Chapter 6 and guidelines for backing fatalities prevention systems will be presented in Chapter 7.

3.7 Case Study

Table 3.1 presents a case study (Pratt et al. 2001) of a backing fatality incident.

Table 3.2 Case Study (Pratt et al. 2001)

Construction Laborer Crushed by Asphalt Truck While Paving Interstate Highway
A 34-year-old construction laborer was fatally injured when he was crushed beneath an asphalt-carrying tractor trailer while paving a six-lane interstate highway. The 11-person crew was paving the northbound side of the highway. The high-speed lane and the middle lane had been closed to traffic. Tractor trailers delivering asphalt paving material were queued on the shoulder and partially in the high-speed lane. Two pavers were operating simultaneously in staggered positions in adjacent lanes. Paver #1 was in the far left (high-speed) lane. Paver #2 was in the middle lane staggered some distance behind paver #1, allowing trucks leaving paver #1 to pull into the middle lane to leave. Usually, trucks waited to be signaled to approach the paver, but sometimes drivers backed up as soon as they saw the previous truck leave the paver. At the time of the incident, the driver of the truck next in line for paver #1 had just re-entered the cab of his truck. About a minute later, the victim went over to shovel old asphalt from around the catch basin located approximately 12 feet behind the waiting tractor trailer filled with asphalt. The driver saw a truck pull away from paver #1 into the adjacent middle lane, started backing up, and then heard people yelling and the truck driver working at paver #2 blowing his air horn. He stopped and found that the four left rear wheels had completely passed over the victim. The county medical examiner pronounced the victim dead at the scene. The cause of death was crushing injuries of the head and torso.

This fatality was preventable using many of the previously stated controls.

- The implementation of an internal traffic control plan could have designated when the driver should have backed toward the paver.
- A designated spotter should always be used where backing maneuvers are expected to be frequent.
- The designation of the area between the trucks and the paver should have been designated as a pedestrian free zone.
- Pedestrian workers should not place themselves directly behind trucks without making positive contact with the truck driver.
- Truck drivers should check behind their vehicles before backing if there is a possibility of pedestrian being in the area behind their vehicles.

- A technology should be introduced which warns equipment operators when there is a pedestrian worker directly behind their vehicle when backing either by visual contact using cameras or by another form of detection.

With these protocols and technologies in place, this backing fatality could have been prevented.

3.8 Summary

The objective of this chapter is to identify and present effective means of improving backing fatalities. It is separated into four major components; Engineering Controls, Administrative Controls, Training, and Technology Controls. It provides a more in depth look at each component, and how they can affect the safety in a work zone, as well as some effective procedure for maximizing the efficiency of each one.

Chapter 4. Identification of Commercially Available Systems for Preventing Backing Fatalities

4.1 Introduction

The use of audible automatic reverse signal alarms is a common practice within the heavy construction equipment industry. In addition, many technologies, such as those based on radar and radio frequency identification (RFID), have been developed and tested to provide hazard warnings with either operators or workers to prevent collisions within blind areas of construction equipment. Despite their benefits that the aforementioned technologies can bring to the construction work zone, these systems also have a few limitations. Primarily due to the various construction equipment characteristics, there is no panacea in terms of technology that will work for all types of construction equipment. For example, dump trucks and dozers have significantly different blind areas that require different criteria for a proximity warning system selection. Secondly, rapidly changing sensing technologies require more generic criteria to be adapted easily, when new devices are made available. Based on the existing limitations, the main objectives of the study in this chapter are: (1) To select construction equipment types which most frequently cause backing accidents; (2) To establish a generic proximity warning systems (PWS) selection criteria for selected equipment types; and (3) To select appropriate proximity warning systems for selected vehicle types.

In recent years, many studies have evaluated various sensing technologies and tested commercially available proximity warning systems for different types of vehicles. A proximity warning system consists of a type of sensor that detects the presence of an object, an interface that provides an audible and/or visual alarm to the equipment operator and wiring between the two. Potential sensor technologies include ultrasonic echo detection, infrared reflection, radar (radio detection and ranging), video cameras, and radio-frequency identification systems. This section will review characteristics of sensing technologies and proximity warning system.

4.2 Technology Review

Sensing technologies reviewed include infrared, ultrasonic, radar, RFID, global positioning system (GPS), and video camera technologies. Oloufa et al. (2002) compared five sensing technology types with five key characteristics; line-of-sight, response time, cost, reliability, and operation range to select the technology for preventing equipment-related collision on the construction jobsites. Ruff (2000, 2001a, 2004b, 2007) provided qualities of two technology types, radar, and RFID methods. The author mentioned that one of major concerns of radar systems is relatively frequent false alarms, which make the equipment operator start ignoring alarms. Regarding RFID systems, these papers pointed out that despite creating very few false alarms, the RFID method has the disadvantage of increasing the potential of collisions with obstacles that are not outfitted with a RFID tag. The National Institute for Occupational Safety and Health (NIOSH, 2008) studied generic characteristics of seven sensing technology types with basic sensing methods of each type to aid the selection of a PWS system in the mining industry. Table 4.1 identifies the various types of sensing technologies applied to work zones, and the pros and cons of each type.

Table 4.1 Characteristics of Sensing Technologies

Technology	Characteristics		Reference
Infrared	Pros	- Good for long distance in fog - Very low cost, small size, fast response	Oloufa et al. (2002), NIOSH (2008)
	Cons	- Accuracy issues with heavy snow and rain - Measures vehicle speed (Active) - Not very reliable, very short range	Oloufa et al. (2002), NIOSH (2008)
Ultrasonic	Pros	- Compact and easy to install - Low cost, small size, fast response	Oloufa et al. (2002), NIOSH (2008)
	Cons	- All objects trigger alarm - Accuracy issues with temperature, humidity, air turbulence, target surface smoothness, target size, angle of incidence, and external noise sources - Not highly reliable, short range	Oloufa et al. (2002), NIOSH (2008)
Radar	Pros	- Compact and easy to install - Measures vehicle speed (Doppler) - Effective in detecting people and smaller vehicles - High reliability	Oloufa et al. (2002), Ruff (2004), NIOSH (2008)
	Cons	- All objects trigger the alarm (Pulsed) - Cannot detect stopped objects (Doppler) - Accuracy issues with snow and ice buildup and angle of incidence - High implementation cost - Relatively high false and nuisance alarm rates - Not effectively detect objects, such as plastics, dry wood, or objects with large flat surfaces	Oloufa et al. (2002), NIOSH (2008)
RFID	Pros	- Easy to install - Relatively low cost, no line-of-sight issue - Not affected from harsh environment	Oloufa et al. (2002), Ruff (2000), NIOSH (2008)
	Cons	- Orientation sensitivity - No range information (Passive) - Requires battery in tag (Active) - Life of battery, magnetic interruption - Do not generate false alarms - More expensive than radar systems - Increases the potential of collisions with obstacles that are not outfitted with a tag	Oloufa et al. (2002), Ruff (2000,2001,2004,2007), NIOSH (2008)
GPS	Pros	- Covers wide areas	Oloufa et al. (2002), NIOSH (2008)
	Cons	- Only works on the surface - High cost, need for open space	Oloufa et al. (2002), NIOSH (2008)
Video cameras	Pros	- Simplicity	NIOSH (2008)
	Cons	- Operator must observe monitor - Limited field of view - Only works in daytime or with sufficient light	NIOSH (2008)
Magnetic	Pros	- Compact and easy to install - Great accuracy over short distances (Active)	NIOSH (2008)
	Cons	- Accuracy issues when metallic objects in field - Only receiver in detection zone triggers alarms	NIOSH (2008)

4.3 Proximity Warning Systems Review

Collision warning systems consist of a sensor and operator interface that detects nearby objects and provides equipment operators with hazard warning on objects in blind spots. Many commercially available systems were tested in the mining industry as well as construction and automotive industries. This system review will aid in determining evaluation factors and collecting data for commercially available PWS systems. Ruff (2000, 2001b) applied six radar systems, three Radio-Frequency Identification (RFID) systems and one ultrasonic system on a 50-ton dump truck, a Komatsu 210M. According to the results, the RFID system, which is a tag-based system, had longer detection ranges and no false alarm rates, but is relatively expensive and hard to install than other systems. Radar and ultrasonic based systems showed that sporadic detection areas existed at the boarder of detection areas. In addition, Ruff (2001b) recommended that proximity warning system (PWS) detection zone need to cover the entire width of the equipment with approximately 12-15 meters (39-49 feet) detection length for large dump trucks and cover the tires at the rear.

Ruff (2001b) tested one radar and two RFID systems used in Ruff (2000, 2001a) on a 260-ton dump truck. Compared to previous test results of the radar system, the test with the larger equipment showed poor results. This accounted for reduced detection range and increased false alarms mainly because of a higher system mounting position. However, RFID systems did not result in significant differences from Ruff (2000, 2001b). In addition, Ruff (2004) pointed out the importance of supplemental systems, such as a video camera, to help equipment operators recognize the cause and exact location of objects without the driver leaving the cab. Ruff and Hession-Kunz (2001) studied two RFID systems on a 2-½-yard front-end loader to evaluate performance with their own criteria for a tag, a reader system, and a warning system. However, both RFID systems did not meet specifications generated because of late response times or size of devices. Mazzae and Garrott (2007) selected 11 commercially available systems for light vehicles and evaluated the performance with field of view of video cameras, detection range of radar systems, and response times. This study showed that cameras had a wider range of view than the detection range of radar systems tested and only three systems met the International Organization for Standardization's (ISO) recommended response time of 0.35 seconds. However, the ISO recommendation has been changed to 0.5 seconds (ISO, 2010). Ruff (2007) applied two radar, one RFID, and one magmatic-based tag systems on various mining equipment types. In this study, one radar system was tested in an active mining site for 7 days and resulted in 18% false and 42% nuisance alarm rates. According to this study, most false alarms were caused by small objects such as ruts or rocks. Nuisance alarms (an alarm from objects of which the operator is already aware) are unavoidable, but it might be tolerated by incorporating a video camera which allows the source of the alarm to be verified. Ruff (2007) also suggested that sensor systems: (1) Detect a minimum of 6 meters (20 feet) length for dump trucks to provide sufficient time to brake; (2) Have low false alarm rates, not detecting objects under 30 centimeters, which are considered as causes of false alarms; (3) Be easy to install; (4) Provide an effective alarm; (5) Handle harsh environmental conditions; and (6) Cost under US$15,000 per truck.

Ruff (2010) tested one camera and advanced video processing system on a stationary equipment conveyor and concluded that as sensitivity of the system increased, detection zone was improved, and false alarm rates increased.

4.4 Methodology

Methodology is divided into two major categories: equipment selection and proximity warning system selection. It is not practical to establish specific sensor selection criteria for all existing types of construction equipment. Therefore, it is important to select test bed equipment types which are dominant in causing backing accidents to be the focus of our research. From accident analysis and blind area data analysis, two test bed equipment types were selected. In addition due to the rapidly changing sensing technology market, developing generic sensor selection criteria is important because the same criteria can be consistently used to select new sensing systems in the future when new technologies are developed. Proximity Warning Systems were selected based on analysis of PWS selection matrix and a PWS list. The PWS selection matrix is the generic sensor selection criteria for selected test bed vehicles. PWS list is a collection of commercially available sensor systems with specific data. In order to evaluate PWS selection matrix and PWS list, selection of common evaluation factors was necessary. The following diagram (Figure 4.1) illustrates the overall process of this study, which is described in detail subsequently.

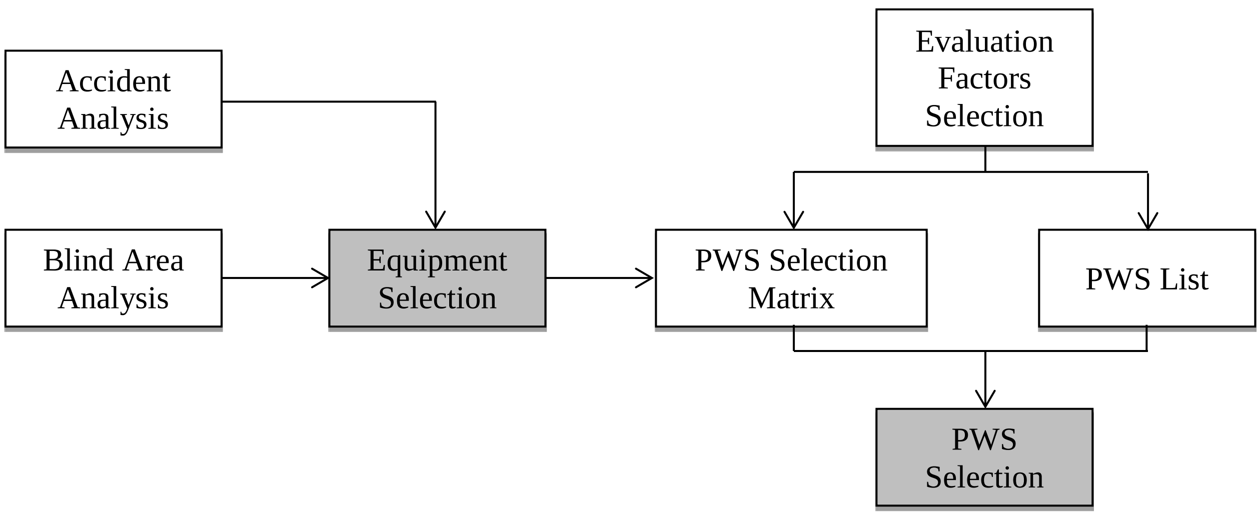


Figure 4.1 Process Diagram

4.4.1 Equipment Selection

4.4.1.1 Accident Analysis

The goal of the accident analysis is to find equipment types which are the leading causes of backing accidents. An example of a database which was utilized in this study is the Liability Accidents Cost Report by Year which is available through the Texas Department of Transportation (TxDOT) safety database and includes backing accidents from 2001 to 2011. Data analyzed characterize backing accidents using the following attributes: Claim number, Date Accident & Time, District/Division, Vehicle Type, Fiscal Year, Equip number, Injury Cost, Property Cost, Expense Cost, and Total Cost. Based on the TxDOT dataset, number of backing accidents by equipment types is analyzed. The goal of the accident analysis is to find equipment types which are the leading causes of backing accidents.

As can be seen Figure 4.2, out of 503 total accidents, 316 accidents (62.8%) were caused by pickup trucks and 61 accidents (12.1%) were caused by dump trucks. Since the majority of accidents were caused by pickup and dump trucks, almost 75% of total accidents, it is important to carefully examine these two equipment types to minimize current backing accidents.

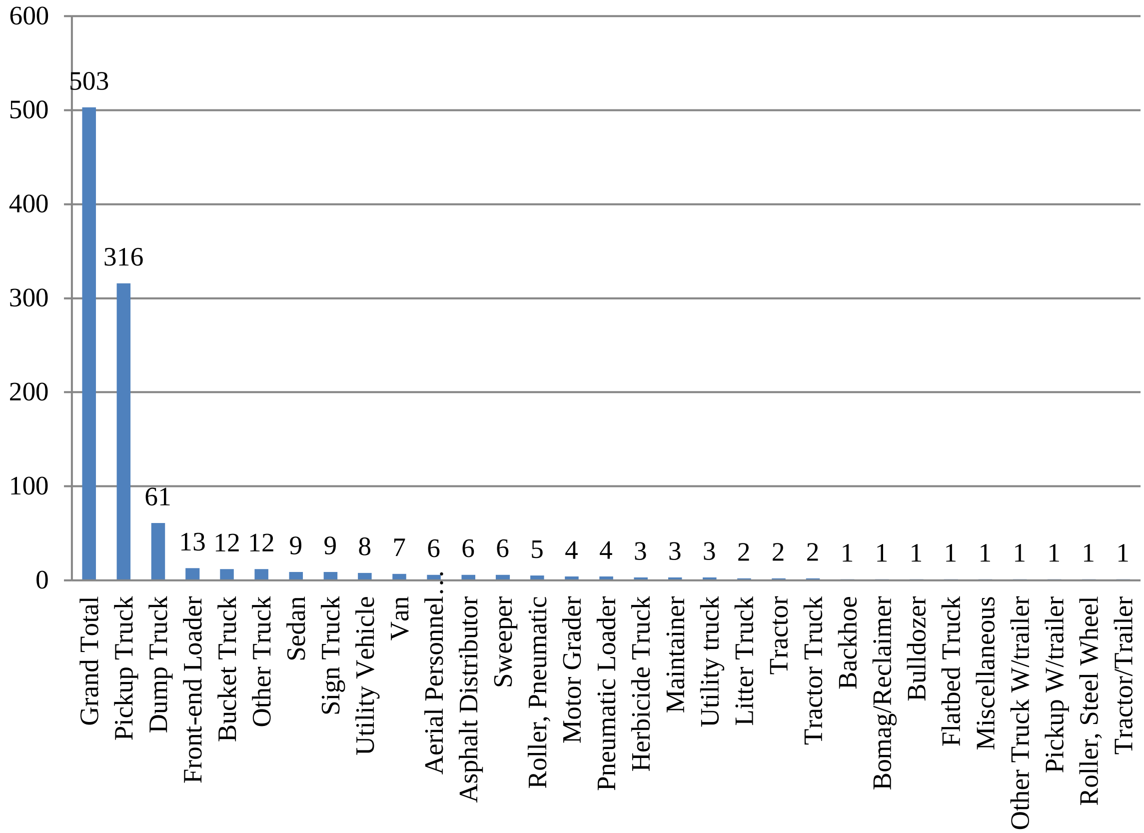


Figure 4.2 Number of Backing Accidents by Equipment Type

4.4.1.2 Blind Area Analysis - A Revisit

Blind areas differ by equipment types and enable the understanding of visibility limitations around construction equipment. It is therefore important to study blind areas of various construction equipment types to select proper sensor systems for each equipment type. Both Hefner and Breen (2003) and Ruff (2007) mentioned the importance of blind area analysis. According to Hefner and Breen (2003), a blind area can be used to help select the appropriate technologies such as radar systems, radio signal detection systems etc. that can help minimize the risk to workers. Ruff (2007) also explained that blind area plots can be used as a guide to determine the effective placement of monitoring devices. The National Institute for Occupational Safety and Health, NIOSH (2011) provides blind area diagrams for 13 types of equipment and 41 models, which measured objects from the ground level, 0.9 meters (3 feet), and 1.5 meters (5 feet) (NIOSH, 2011). For further analysis, blind area diagrams of eight different construction equipment types with 1.5-meter (5 feet) level objects were selected, which are considered most widely used in construction work zones. Figure 4.3A–4.3H shows blind area diagrams of the eight types of construction equipment: dump truck, pickup truck, excavator, scraper, grader, dozer, loader, and backhoe and loader. In addition, a percentage of the blind area was calculated using Equation 1 to compare the blind area of selected equipment types and Area Analysis.

$$\textbf{\textit{Equation (1) Percentage of Blind Area}}\ (\%) = \frac{\textbf{\textit{Blind Area}}\ (m^2)}{\textbf{\textit{Total area of 12m radius circle}}\ (m^2)} \times \mathbf{100}$$

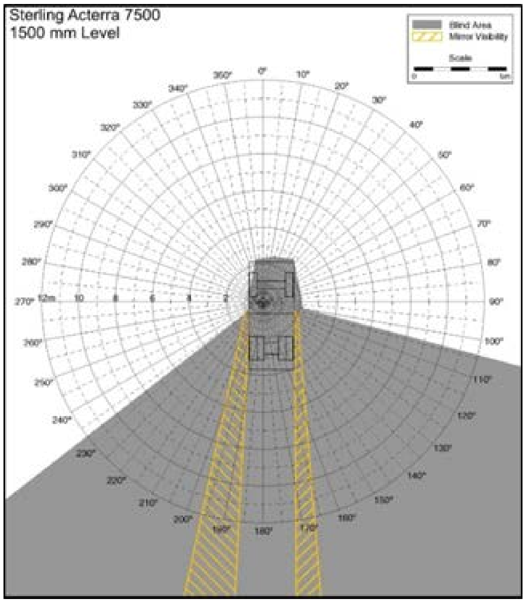


Figure 4.3A Dump truck (33%)

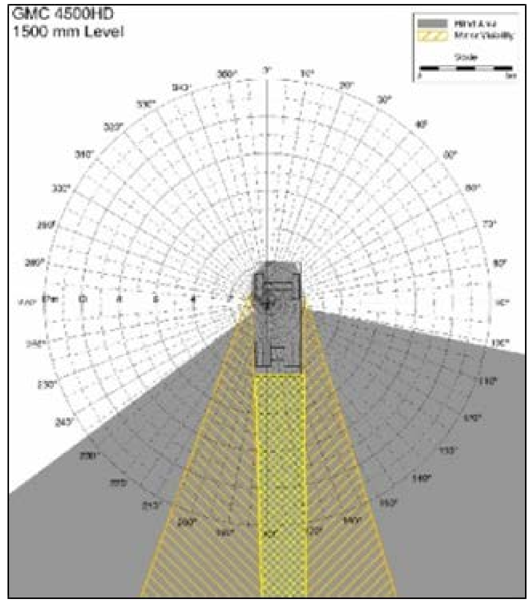


Figure 4.3B Pickup truck (22%)

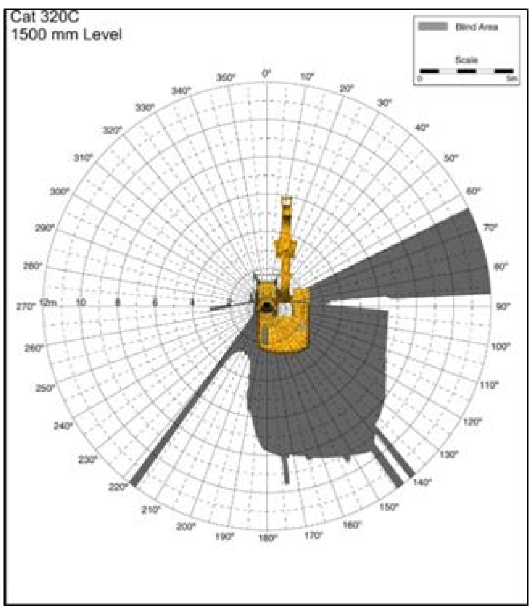


Figure 4.3C Excavator (21%)

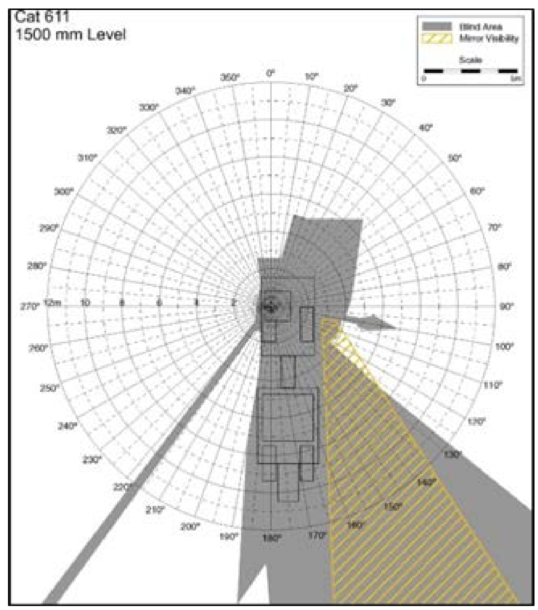


Figure 4.3D Scraper (18%)

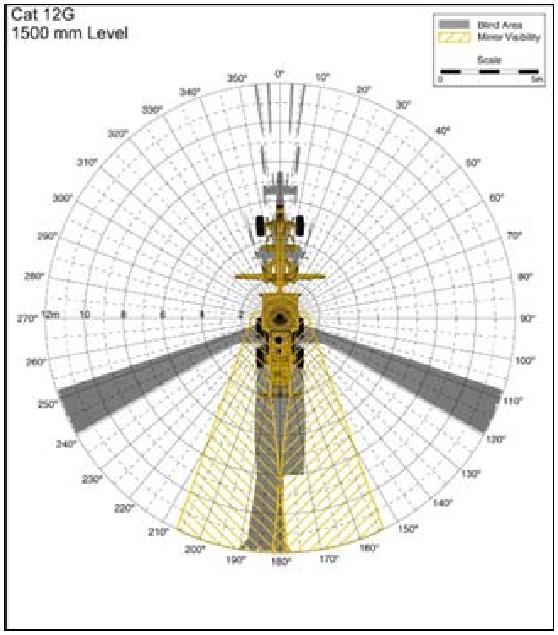


Figure 4.3E Grader (11%)

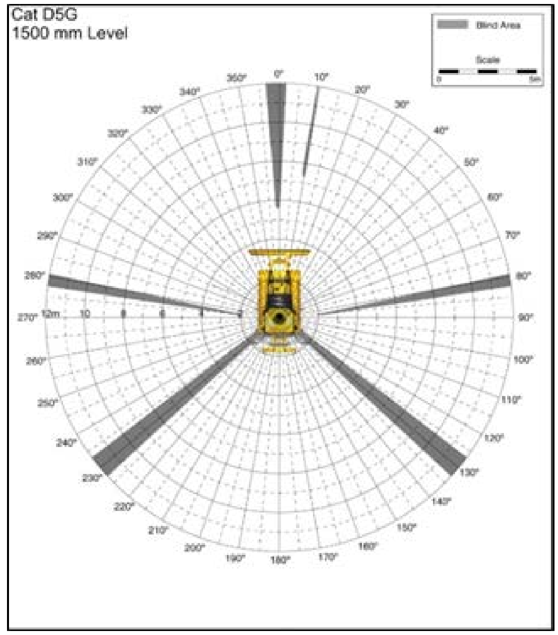


Figure 4.3F Dozer (8%)

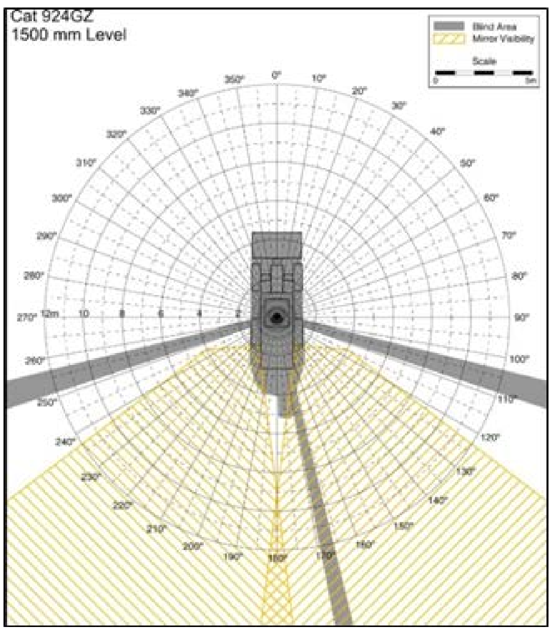


Figure 4.3G Loader (8%)

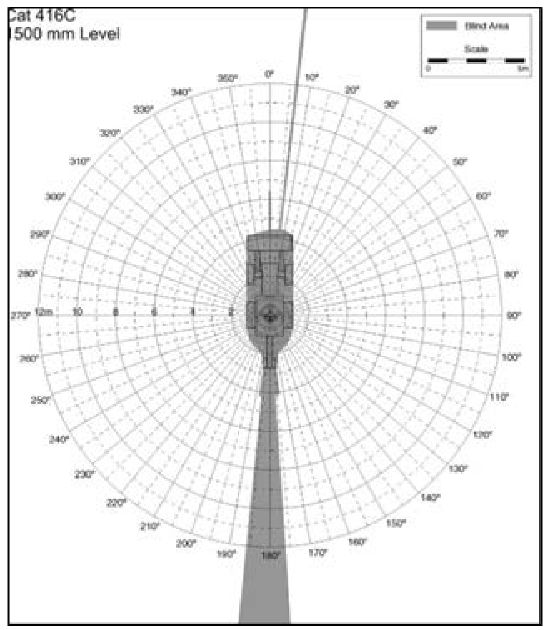


Figure 4.3H Backhoe and Roller (6%)

Figure 4.3 Blind Area Diagrams of Eight Construction Equipment Types

As can be observed in Figure 4.3A, the dump truck has the largest blind area (33%), followed by the pickup truck (22%), excavator (21%), scraper (18%), and grader (11%); the backhoe and roller has only 6% of blind area. In the case of the blind area diagram of the pickup truck, the original diagram was modified to reflect line of sight through back mirror without a dump bed. After calculating the percentage of blind area, eight equipment types were classified into three classes, high, medium, and low. High indicates over 20% blind areas, medium is between 10% and 20%, and low is below 10%. As a result, dump trucks (33%), pickup trucks

(22%), and excavators belong to the high class, and scrapers and graders belong to the medium class, and dozers, loaders, and backhoes and rollers are classified into the low class.

From the accident analysis, pickup trucks (62.8%) and dump trucks (12.8%) were determined to be the leading cause of backing accidents in the state of Texas. In addition, the blind area analysis also showed that dump trucks (33%) have the highest percentage of blind area followed by pickup trucks (22%). In conclusion, pickup trucks and dump trucks were selected for proximity warning system selection.

4.4.2 Proximity Warning System Selection

4.4.2.1 Evaluation Factor

Developing evaluation factors is one of the most important processes to provide generic criteria for the sensor system selection. Evaluation factors selected are a basis of PWS selection matrix and PWS list. 19 evaluation factors were collected from 17 academic papers and two ISO standards. Among the 19 factors, eight evaluation factors were selected which were used more than five times in previous studies. The eight factors are 'For use in all weather', 'Response time', 'Technology', 'Camera as supplemental method', 'Cost', 'Level of effort in mounting', 'Maximum range of rear detection zone', and 'False-alarm rate in clear field'. Table 4.2 shows eight evaluation factors selected.

Table 4.2 Evaluation Factors

Evaluation Factors	**Number of Citations**	**Evaluation Factors**	**Number of Citations**
System size	2	Level of effort in mounting	5
For use in all weather	7	Total coverage near rear tires	3
Voltage and current value	1	Maximum range of rear detection zone	12
System activation	2	Total coverage near bumper	3
Self-test capabilities and failure indication	2	Sporadic detection at zone edges	3
Response time	7	False-alarm rate in clear field	8
Technology	19	Nuisance-alarm rate	4
Camera as supplemental method	5	Two-way alarming	1
Cost	8	Staged alarming by the distance	3
User-adjustable zones	3		

NOTE: False-alarm = an alarm when no obstacle exists
Nuisance-alarm = an alarm from objects of which the operator is already aware

4.4.2.2 PWS Selection Matrix

Based on eight evaluation factors, a generic PWS selection criterion (PWS selection matrix) was generated for pickup and dump trucks. The criterion was developed from ISO standards, recommendations in previous studies, and our research team's assessment. Technology selection for both equipment types is limited to ultrasonic and radar methods since other systems have the following challenges. The main limitation of tag-based systems such as methods using RFID and magmatic tags are that both vehicles and workers have to be equipped with specific devices. In dynamic construction work zones there will be a management challenge to make all workers wear a tag to be detected by a sensor installed in the vehicle. In a similar way, the global positioning system (GPS) is only proper to avoid collisions among vehicles because workers cannot carry GPS. In addition the video camera system cannot generate alarms, so it is recommended to be used as a supplemental method with other selected sensor systems. Developing rear detection range criteria is deeply related to the vehicle's reverse speed which determines the braking distance of the vehicle. According to ISO 12155 (ISO, 1994), the average reversing speed of commercial vehicles is 5 kilometers per hour (3.1 mph). Therefore a developed rear detection range criterion was based on 5 kilometers per hour of vehicle reverse speed. Recommended rear detection range of a pickup truck is 3 meters (10 feet), and 6 meters (20 feet) for a dump truck. False alarm rates in clear field should ideally be zero since frequent false alarms will make operators ignore warning alarms. A cost criterion for a pickup truck should be under $3,000 and $10,000 for dump trucks. All types of sensor systems should be durable and operational in any weather conditions such as rain, snow, and dust. According to ISO 17386 (ISO, 2010), response time should not exceed 0.5 seconds. Installation hours will depend on the proficiency of the installer, but it was concluded that 4 hours for pickup and 8 hours for dump truck for a first user when following a system installation guide book should be appropriate. A video camera is not necessary for pickup trucks because an operator has sufficient visibility through the back mirror, but it is recommended for dump trucks because an operator cannot see objects through the back mirror due to the dump bed. Table 4.3 shows the PWS selection matrix for pickup and dump trucks.

Table 4.3 PWS Selection Matrix

Evaluation Factors	**Pickup Truck**	**References**	**Dump Truck**	**References**
Technology	Radar, Ultrasonic		Radar, Ultrasonic	
For use in all weather	Yes	Ruff (2007)	Yes	Ruff (2007)
Maximum range of rear detection zone	3m (10ft)	ISO (2010)	6m (20ft)	Ruff (2007)
Response time	500m/s	ISO (2010)	500m/s	ISO (2010)
False-alarm rate in clear field	None		None	
Cost	Under $3,000		Under $15,000	Ruff (2007)
Level of effort in mounting	Less than 4hours		Less than 8 hours	
Camera as supplemental method	Not necessary		Recommended	

4.4.2.3 Proximity Warning System List

PWS list is a collection of commercially available sensor systems. Based on eight evaluation factors, specific data were collected from direct contact with vendors and test results of previous papers. Seven systems and ten models were accessed. For example, HindSight 20-20 system has three different models. Figure 4.4 summarizes commercially available sensor systems and their specific data.

Systems	Preview		Guardian Alert	Sensor Vision	Hindsight 20-20			Buddy	AMT	Becker CAS
Model	Workzone	HighResolution		Ogden radar	HS-30 + CS-561	HS-100F + CS-561	HCS-700 (HS-345NL)		CAS-CAM /RF	CAS-430
Technology	Pulsed radar		Doppler radar	FMCW Radar	Pulsed Ultrasonic			Tag-based	Tag-based	Tag-based
Maximum length of rear detection zone	3m (10ft)	1.8 - 6m (6 – 20ft)	2.7 - 3.6m (9 – 12ft)	1.5 - 24m (5 – 78ft)	2.4m (8ft)	2.4m (8ft)	2.7m (9ft)	18m (60ft)	0 - 80m (0 – 260ft)	0 - 100m (0 – 328ft)
False-alarm rate in clear field	None		Frequent	None	None			None	None	None
Cost (*)	$659 ($1,985)	$766 ($2,093)	Below $2,000	Below $2,000	$266 ($585)	$130 ($489)	$409 ($806)	Between $5,000 and $10,000	Over $10,000	$45,000 ($60,000)
For use in all weather	Yes		Yes	Yes	Yes			Yes	Yes	Yes
Response time	0.50sec		NA	0.48sec	0.20sec			NA	0.30sec	0.25sec
Level of effort in mounting	4-6hours		Low	Specialist required	1hour			Medium	Medium	Specialist required (One day)
Camera as supplemental method	Optional		No	No	Optional			Optional	Yes	Optional
Note	Direct contact		[5]	[5] Not approved by FCC	Direct contact			[5]	[7] Not approved by FCC	Direct contact

NOTE: (*) = cost including a camera system, NA = not available
FCC = Federal Communication Commissions

Figure 4.4 PWL List

Among the seven systems, two systems, Sensor Vision and AMT, have not been approved by the US federal Communication Commissions (FCC). As can be seen Figure 4.4, maximum rear detection zones range from 2.4 meters to 100 meters (7.9 to 328 feet). For some models such as High Resolution and Guardian Alert, the user is allowed to adjust the maximum detection ranges. Except for Guardian Alert system, the other six systems have no false-alarms in a clear field. The false alarm rate data of Guardian Alert was collected from a paper published in 2001, so it is possible this fact has been improved. Cost data showed that ultrasonic systems are the cheapest and tag-based systems are relatively expensive. System cost ranges from $130 to $60,000 and cost in parenthesis is including a camera system. All systems investigated are durable in any harsh weather conditions and provide staged warning alarms by the distance, mostly three stages. In addition, most sensor response times meet ISO standard 0.5 seconds except for two absence data. Two systems, Sensor Vision and Becker CAS, require a specialist to install the systems. Lastly, five systems have their own video camera systems which can be incorporated with their main sensor systems.

4.5 Results

Based on PWS selection matrix and PWS list developed, three systems were chosen as appropriate sensors for the pickup truck. Figure 4.5 describes how three sensors were selected and the others were discarded.

Systems	Preview		Guardian Alert	Sensor Vision	Hindsight 20-20			Buddy	AMT	Becker CAS
Model	Workzone	HighResolution		Ogden radar	HS-30 + CS-561	HS-100F + CS-561	HCS-700 (HS-345NL)		CAS-CAM /RF	CAS-430
Technology	Pulsed radar		Doppler radar	FMCW Radar	Pulsed Ultrasonic			Tag-based	Tag-based	Tag-based
Maximum length of rear detection zone	3m (10ft)	1.8 - 6m (6 – 20ft)	2.7 - 3.6m (9 – 12ft)	1.5 - 24m (5 – 78ft)	2.4m (8ft)	2.4m (8ft)	2.7m (9ft)	18m (60ft)	0 - 80m (0 – 260ft)	0 - 100m (0 – 328ft)
False-alarm rate in clear field	None		Frequent	None	None			None	None	None
Cost (*)	$659 ($1,985)	$766 ($2,093)	Below $2,000	Below $2,000	$266 ($58[illegible])	$130 ($[illegible]89)	$409 ($806)	Between $[illegible] and $10,000	Over $10,000	[illegible] ($60,000)
For use in all weather	Yes		Yes	Yes	Yes			Yes	Yes	Yes
Response time	0.50sec		NA	0.48sec	0.20sec			NA	0.30sec	0.25sec
Level of effort in mounting	4-6hours		Low	Specialist required	1hour			Medium	Medium	Specialist required (One day)
Camera as supplemental method	Optional		No	No	Optional			Optional	Yes	Optional
Note	Direct contact		[5]	[5] Not approved by FCC	Direct contact			[5]	[7] Not approved by FCC	Direct contact
			False Alarm Rates	FCC	Detection Zone			Tech. Cost	FCC	Cost

NOTE: (*) = cost including a camera system, NA = not available
FCC = Federal Communication Commissions
Figure 4.5 PWS Selection for Pickup Trucks

Sensor Vision and AMT systems were discarded because they have not been approved by the US federal Communication Commissions (FCC). Due to the technology and cost criteria, two tag-based systems, Buddy and Becker CAS, were discarded and HS-30 and HS-100F models were discarded due to the short rear detection zone. Also, Guardian Alert system was discarded because of frequent false alarm rates. As a result, Work Zone, High Resolution, and HCS-700 sensor systems were selected for the pickup truck.

Similarly for dump trucks, Sensor Vision and AMT systems were discarded because they have not been approved by the US federal Communication Commissions (FCC). Two tag-based systems, Buddy and Becker CAS, were discarded due to technology criteria. Because of rear detection zone criteria, 6 meters (19.7 feet) for dump truck, five models were discarded. As a result, only High Resolution was selected for dump trucks, displayed in Figure 4.6.

Systems	Preview		Guardian Alert	Sensor Vision	Hindsight 20-20			Buddy	AMT	Becker CAS
Model	Workzone	HighResolution		Ogden radar	HS-30 + CS-561	HS-100F + CS-561	HCS-700 (HS-345NL)		CAS-CAM /RF	CAS-430
Technology	Pulsed radar		Doppler radar	FMCW Radar	Pulsed Ultrasonic			Tag-based	Tag-based	Tag-based
Maximum length of rear detection zone	3m (10ft)	1.8 - 6m (6 – 20ft)	2.7 - 3.6m (9 – 12ft)	1.5 - 24m (5 – 78ft)	2.4m (8ft)	2.4m (8ft)	2.7m (9ft)	18m (60ft)	0 - 80m (0 – 260ft)	0 - 100m (0 – 328ft)
False-alarm rate in clear field	None		[illegible]	None	None			None	None	None
Cost (*)	[illegible]	$766 ($2,093)	Below $2,000	Below $2,000	[illegible] ($585)	[illegible] ($489)	[illegible] ($806)	Between $5,000 and $10,000	Over $10,000	Avg $45,000 ([illegible])
For use in all weather	Yes		Yes	Yes	Yes			Yes	Yes	Yes
Response time	0.50sec		NA	0.48sec	0.20sec			NA	0.30sec	0.25sec
Level of effort in mounting	4-6hours		Low	Specialist required	1hour			Medium	Medium	Specialist required (One day)
Camera as supplemental method	Optional		No	No	Optional			Optional	Yes	Optional
Note	Direct contact		[5]	[5] Not approved by FCC	Direct contact			[5]	[7] Not approved by FCC	Direct contact
	Detection Zone		Detection Zone, False Alarm Rates	FCC	Detection Zone			Tech.	FCC	Tech. Cost

NOTE: (*) = cost including a camera system, NA = not available
FCC = Federal Communication Commissions

Figure 4.6 PWS Selection for Dump Trucks

Based on PWS selection matrix and PWS list, three sensor models—WorkZone, HighResolution, and HCS-700—were selected for pickup trucks while only the HighResolution sensor system was selected for dump trucks.

4.6 Validation

In order to validate the selection of evaluation factors, 20 experts who are working in safety or sensor related industry or academia were asked to select their top five sensor-based proximity warning system criteria. Recognition-based measure, which provides a collection of lists to select their preference among the list, was used for the survey. The selection list is from the evaluation factors seen in Table 4.3 and Table 4.4 shows the result of the survey.

Table 4.4 Result of Proximity Warning System Selection Criteria Survey

Evaluation Factors	Number of Responses	Rank	Number of Citations	Rank
For use in all weather	15	1	7	5
Cost	11	2	8	3
Maximum range of rear detection zone	11	2	12	2
Response time	9	4	7	5
System activation	8	5	2	15
Two-way alarming	8	5	1	18
False-alarm rate in clear field	7	7	8	3
Self-test capabilities and failure indication	6	8	2	15
Level of effort in mounting	5	9	5	7
Technology	3	10	19	1
Camera as supplemental method	3	10	5	7
Nuisance-alarm rate	3	10	4	9
Staged alarming by the distance	3	10	3	10
Total coverage near bumper	2	14	3	10
User-adjustable zones	2	14	3	10
System size	1	16	2	15
Voltage and current value	1	16	1	18
Total coverage near rear tires	1	16	3	10
Sporadic detection at zone edges	0	19	3	10

Of the 20 experts, 15 responded ‘For use in all weather’ factor is important criteria to select sensor-based proximity warning system. Half of respondents considered ‘Rear detection area’ and ‘Cost’ as one of evaluation factors, and followed by ‘Response time’, ‘System activation’, and ‘Two-way alarming’. There were only three respondents who selected ‘Technology’ as an important criterion, which is the most referenced evaluation factor during the evaluation factor development. It is possible because ‘Technology’ factor is relatively broad concept compared to other factors and researchers did not provide characteristics and application of each sensing technology, for example tag-based systems are normally more expensive than radar and ultrasonic systems. In addition, people were interested in how the sensor system is activated, which users can customize such as reverse mode only or all mode activation. Overall, among top nine ranked factors from the survey six factors were the same as researchers evaluated from Section 4.4.2.1 Evaluation Factors.

4.7 PWS Summary

The generic sensor selection criteria will be useful to select proper sensor systems by different types of construction equipment because these generic criteria can be used regardless of passing time or technological changes. While further study must still be done to test as many equipment as possible, this study focused on equipment types which show the leading cause of backing accidents in the state of Texas and had the highest percentage of blind areas. Pickup trucks (62.8%) are the dominant equipment type causing backing accidents in the state of Texas (as shown in the TxDOT accidents dataset), followed by dump trucks (12.1%). In addition, blind area analysis showed that dump trucks (33%) have the highest percentage of blind areas, followed by pickup trucks (22%). In conclusion, pickup trucks and dump trucks were selected for the PWS selection analysis.

In order to select proper sensor systems for both equipment types, the generic PWS selection criteria and commercially available PWS list were generated based on nine evaluation factors. Specific data for PWS selection matrix and PWS list collected from related publications and specifications from commercially available systems. As a result, three sensor systems for pickup and one sensor system for dump trucks were selected based on the developed evaluation criteria. This study identified promising sensor systems for pickup and dump trucks based on generic sensor selection criteria. Because this study was limited to two vehicles types, it is recommended that a larger study with more equipment types be conducted.

4.8 Summary

This chapter worked to identify commercially available systems that can be used to prevent backing fatalities in construction work zones. In an effort to do this, a technology review was conducted in order to review which types of technology could be effective in the construction setting. The technologies reviewed included: infrared, ultrasonic, radar, RFID, GPS, and video camera technologies. The methodology of how the systems were to be reviewed was developed and divided into two major categories equipment selection, and proximity warning system selection. In order to understand the factors affecting construction work zone accidents, research was done on the blind areas of different types of equipment as well as the frequency of different types of work zone accidents. To review the proximity warning systems, the following eight evaluation factors were considered: ‘For use in all weather’, ‘Response time’, ‘Technology’, Camera as supplemental method’, ‘Cost’, ‘Level of effort in mounting’, ‘Maximum range of rear detection zone’, and ‘False-alarm rate in clear field’. Using this criterion, suitable systems for pickup trucks, and dump trucks were selected, and compared using tables, and validation for reassurance purposes.

Chapter 5. Testing of Commercially Available Systems for Prevention of Backing Fatalities

5.1 Introduction

According to the Census of Fatal Occupational Injuries (CFOI) data (2009), the construction industry was responsible for 18.3% of all work-related fatalities in 2009, which were 834 of 4,551. 834 fatalities indicate that fatal occupational injury rate equals about 9.7 per 100,000 construction workers while the 2009 annual fatal occupational injury rate was 3.5 for all industries. Among the 834 construction industry fatalities, machinery and vehicle related fatalities accounted for 34.3%, or 284 of 834. Table 5.1 compares the total and construction industry's fatalities from 2003 to 2009 as well as showing machinery and vehicle related fatalities within the construction industry. Also CFOI data indicates dump trucks and pickup trucks as the main causes, about 25%, among all construction equipment types.

Table 5.1 CFOI Fatalities Data from 2003 to 2009

	Number of Fatalities						
	2003	2004	2005	2006	2007	2008	2009
All Industries	5575	5764	5734	5840	5657	5214	4551
Construction	1131	1234	1192	1239	1204	975	834
Machinery or Vehicle	397	407	416	422	386	336	286
Pickup trucks	67	64	71	74	65	37	59
Dump trucks	29	47	37	48	32	14	27

To minimize backing fatalities, many object detection technologies such as radar, ultrasonic, and radio-frequency identification-based systems have been tested and applied within the construction and mining industries. These sensor-based object detection technologies provide hazard warnings to either operators or workers to prevent collisions within blind areas of construction equipment. However, it is common practice that every construction equipment type has limited possible sensor installation locations. Also due to the lack of an appropriate sensor performance measurement framework, developed specifically for construction safety practices, there is a need to develop a construction industry-specific testing and reporting protocol to evaluate sensor system performance. The main objectives of the study in this chapter are to (1) study possible sensor locations for typical construction vehicles, such as pickup and dump trucks; (2) examine sensors' performances at realistic installation locations, heights and widths, to provide users with realistic detection ranges of sensors which would aid in saving workers' lives; and (3) test sensor systems in realistic environments (dynamic test and dirty sensor test) to evaluate the performance of sensor-based proximity warning systems.

5.2 Background

5.2.1 Review of Sensor Installation

Ruff (2000, 2001) tested several types of proximity warning systems including radar and tag-based systems on the Komatsu 210M (50-ton-capacity) haul truck in the mining industry. Installation height tested was 68 inches at the rear light bar. According to the studies (2000, 2001), most sensor-based systems should be tilted downwards at 5 to 10 degrees in order to work effectively except for tag-based systems, which are not influenced by installation heights. In addition, Ruff (2004) applied two sensor systems, one radar and one tag-based system, selected from previous studies (2000, 2001) to the Caterpillar 793B (260-ton-capacity) haul truck. Because of higher installation placement, the sensor was tilted downwards at 15 degrees and the detection range was smaller than previous results. Ruff (2007) pointed out sensors' installation height and angle as influential factors on detection ranges as well as the calibrated sensitivity of the sensor which users cannot change. Ruff (2007) also mentioned that as sensitivity increases, the detection range increases but generates frequent false and nuisance alarms which lead operators to ignore alarms. However, Ruff's studies did not provide any concrete results for detection range changes according to different sensor's installation heights. Also, since haul trucks tested in mining industry were too big to be applied to typical construction equipment, additional tests for construction industry equipment are required.

Mazzae and Garrott (2006, 2007a, 2007b) in consecutive studies of National Highway Traffic Safety Administration (NHTSA), tested several sensors, video, and mirror systems on SUV-type vehicles, light vehicles, and medium trucks. The authors conducted controlled static and dynamic tests with various objects including different types of traffic cones, PVC poles, dummies, children, and human males. However, they did not consider sensor's installation heights or widths, which might lead to sensors' performances. In addition, dump and pickup trucks were not considered, which are frequently related to backing fatalities in construction work zones.

Wierwille et al. (2008) tested camera systems on a truck with different locations to see different improvements of visibility. The authors pointed out that lines-of-sight were different from installation heights, widths, and angles.

5.2.2 Review of Test Bed Designs

Two federal agencies, the National Institute of Occupational Health and Safety (NIOSH) and the National Highway Traffic Safety Administration (NHTSA), sponsored proximity warning systems tests in the mining and automotive industry, respectively. In addition, the National Institute of Standards and Technology (NIST) assisted in the development of the Intelligent and Automated Construction Job Site (IACJS) test bed and the International Organization for Standardization (ISO) published minimum requirements of Maneuvering Aids for Low Speed Operation (MALSO) devices for light-duty vehicles.

NIOSH pointed out the blind area of heavy mining and construction equipment as the primary cause of back-over accidents and examined blind areas of 13 types of equipment and 41 models (2011). A series of tests were performed by Ruff (2000, 2001, 2007) to evaluate several types of sensor systems including radar and tag-based systems on 50 and 260-ton-capacity mining haul truck based on evaluation factors such as false-alarm (an alarm when no obstacle exists) rate, level of effort in mounting, maximum range of rear detection zone, and cost. In addition, Ruff designed test procedures for determining the detection characteristics of a proximity warning system including test obstacles, test setup, test procedures, and recording data. Ruff only conducted a type of dynamic test, which measured sensor detection area with a stationary vehicle and a person walking 3 mph in a 2.5 feet squared dimensioned measurement grid.

In NHTST, Mazze and Garrott (2006, 2007) tested several sensors, video, and mirror systems on SUV-type vehicles, light vehicles, and medium trucks. To evaluate sensor systems performance, the authors measured static field-of-view, repeatability of static field-of-view, dynamic detection range, and response time for selected back-over avoidance sensor-based systems. A one-foot-square measurement grid was used for the tests and special devices applied to control an object speed in the dynamic test and measure sensor systems response times.

Saidi et al. (2011) developed the Intelligent and Automated Construction Job Site (IACJS) test bed. The authors defined construction tasks which require improvement through automation, selected available technologies from the literature review, and evaluated alternative technologies performances using the test bed. In their research, rebar mapping 3D imaging technologies were evaluated for performance and productivity. This research also mentioned that test beds should: (1) enable innovation, (2) enable evaluation in a controlled testing environment, (3) provide an environment for demonstrations, (4) evaluate technology readiness and mitigate risk, and (5) enable deployment of technology to the field.

ISO (2010) described functional and requirements of sensor systems regarding system activation, driver interface, dynamic performance of object detection, monitoring range coverage, and self-test capabilities and failure indication.

Although there are many studies that develop test bed designs for work zones and the construction industry. There has been little research in construction industry-specific test bed protocols to evaluate sensing technologies which can minimize construction equipment-related backing accidents.

5.3 Tested Proximity Warning Systems

Based on the research findings in Chapter 4, Identification of Commercially Available Systems for Prevention of Backing Fatalities, a pulsed ultrasonic system and three pulsed radar systems were selected for the test. A sensor-based proximity warning system consists of a sensor or set of sensors which detects the presence of an obstacle within a detection zone, a display that provides an audible and/or visual alarm to the operator and wiring between the two. The three pulsed radar systems consist of a single sensor whereas an ultrasonic system has two sensors. The following subsections provide key features of each system. A detailed sensor specification and installation schema is provided in Appendix B.

5.3.1 System 1: HCS-700

Manufacturer: HINDSIGHT 20-20, http://hindsight20-20.com

HCS-700 system is an ultrasonic-based sensor system and uses 40 kHz low frequency sound waves to detect the objects within the detection zone. As illustrated in Figure 5.1, two sonar sensors detect objects behind the vehicle and both visual and audible warnings are generated on the monitor in the cap. This system has 'U' shaped detection zones and 9 feet maximum detection range. Also, key features of HCS-700 system are described in Table 5.2.

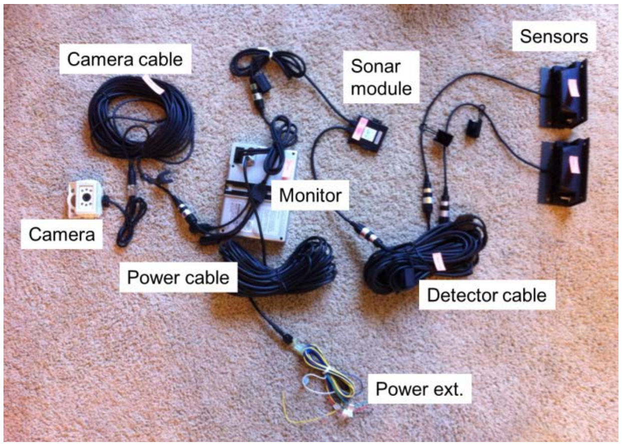


Figure 5.1 HCS-700: Major Component (Left) and Two Ultrasonic Sensors (Right)

Table 5.2 HCS-700: Key Features

Technology	Ultrasonic	**Frequency**	40 kHz
Size	2*5 (inches)	**Response time**	250ms
Cost (*)	US$409 (US$809)	**Detection distance**	9 feet
Number of sensors	2	**Camera**	Yes

(*) cost including a camera system in Feb. 2012

5.3.2 System 2: WorkZone

Manufacturer: PRECO ELECTRONICS, http://www.previewradar.com

WorkZone system is a radar-based system and utilizes 5.8 GHz super high frequency pulsed radar signals to detect objects within a predefined detection zone. As shown in Figure 5.2, single radar sensor detects objects behind the vehicle and both visual and audible warnings are generated on the monitor in the cap. This system also has ‘U’ shaped detection zones and 10 feet maximum detection range. Key features of WorkZone system are described in Table 5.3.

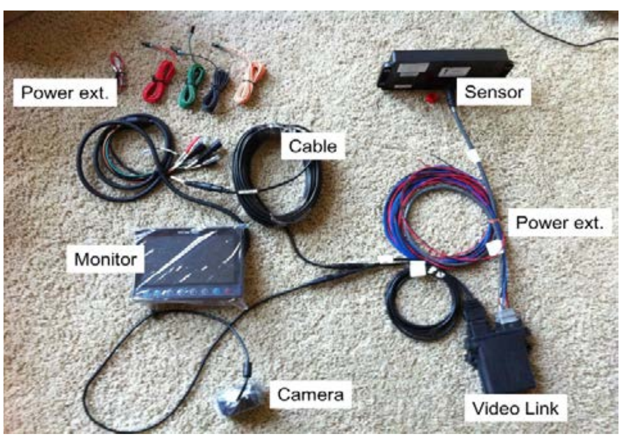


Figure 5.2 WorkZone: Major Component (Left) and a Pulsed Radar Sensor (Right)

Table 5.3 WorkZone Key Features

Technology	Pulsed Radar	**Frequency**	5.8 GHz
Size	4*9 (inches)	**Response time**	500ms
Cost (*)	US$659 (US$1,985)	**Detection distance**	10 feet
Number of sensors	1	**Camera**	Yes

(*) cost including a camera system in Feb. 2012

5.3.3 System 3: HighResolution

Manufacturer: PRECO ELECTRONICS, http://www.previewradar.com

HighResolution system is a radar-based system and uses 6.3 GHz super high frequency pulsed radar signals to detect objects within a detection zone. As shown in Figure 5.3, single radar sensor detects objects behind the vehicle and both visual and audible warnings are generated on the monitor in the cap. This system has 'V' shaped detection zones and 20 feet maximum detection range. Key features of HighResolution system are described in Table 5.4.

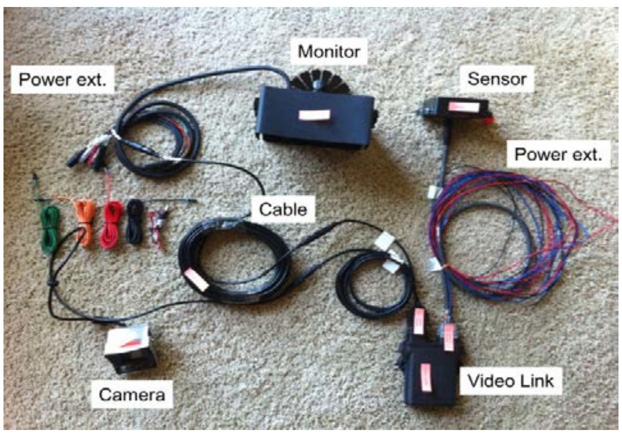


Figure 5.3 HighResolution: Major Component (Left) and a Pulsed Radar Sensor (Right)

Table 5.4 High Resolution: Key Features

Technology	Pulsed Radar	**Frequency**	6.3 GHz
Size	4*5 (inches)	**Response time**	500ms
Cost (*)	US$766 (US$2,093)	**Detection size**	20 feet
Number of sensors	1	**Camera**	Yes

(*) cost including a camera system in Feb. 2012

5.3.4 System 4: WorkSight

Manufacturer: PRECO ELECTRONICS, http://www.previewradar.com

WorkSight system is also a radar-based system and uses 5.8 GHz super high frequency pulsed radar signals to detect objects within a detection zone. As shown in Figure 5.4, a single radar sensor detects objects behind the vehicle and both visual and audible warnings are generated on the monitor in the cap. This system has 'U'+'V' shaped detection zone, which is a combination shapes of WorkZone and HighResolution, and 20 feet maximum detection range.

Although this system is compatible with a camera system, researchers did not purchase the video system to avoid duplicated purchase. The performance of camera system is expected to obtain from the test of the other three sensor systems combined with the camera system. Key features of WorkSight system are described in Table 5.5.

Figure 5.4 WorkSight: Major Component (Left) and a Pulsed Radar Sensor (Right)

Table 5.5 WorkSight: Key Features

Technology	Pulsed Radar	**Frequency**	5.8 GHz
Size	4*9 (inches)	**Response time**	500ms
Cost*	US$1,769.50	**Detection size**	20 feet
Number of sensors	1	**Camera**	No

** cost in Jul. 2012*

5.4 Sensor Installation

Seven typical construction vehicles, three dump trucks, two pickup trucks, and two service trucks, were measured to evaluate proper installation locations for four types of sensor systems at the Texas Department of Transportation (TxDOT) Maintenance Office, in Austin, Texas. Because sensor-based proximity warning systems were designed to aid low speed backing maneuvers, the rear of each vehicle was checked to see the possible sensor mounting positions, which were finally determined from the evaluation with the maintenance manager and vendors.

5.4.1 Dump Trucks

In order to see the possible sensor mounting position for dump trucks, three typical dump trucks were measured. According to the TxDOT maintenance manager, 90% of their dump trucks are six- or ten-yard dump trucks. Figure 5.5 describes rear views of three types of dump trucks (6 yards, 10 yards, and F-450) and proper installation positions for four sensors.

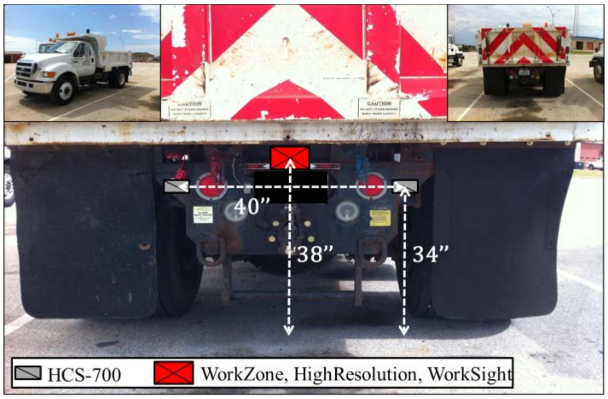


Figure 5.5A 6 Yards Dump Truck

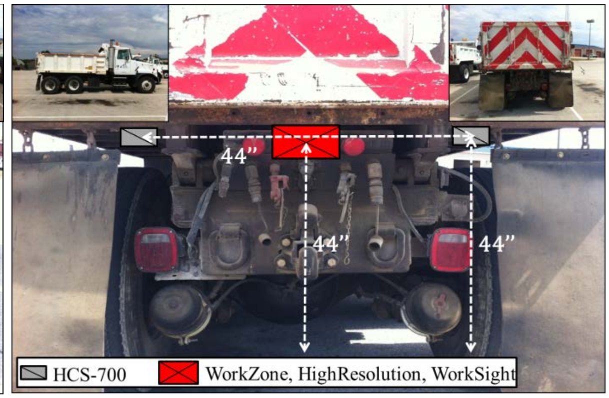


Figure 5.5B 10 Yards Dump Truck

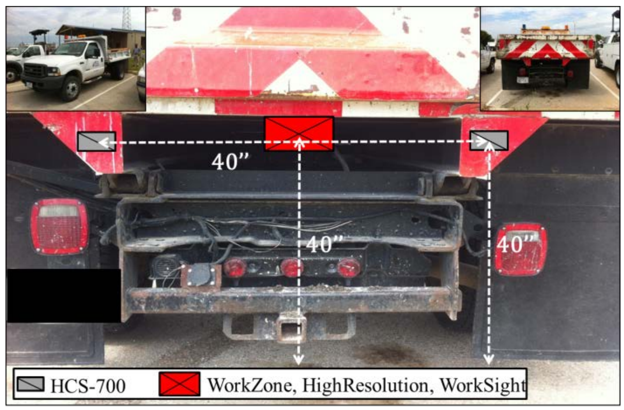


Figure 5.5C F-450 Dump Truck

Figure 5.5 Sensor Installation Survey on Three Types of Dump Trucks

As can be seen in Figure 5.5A, two sensors of HCS-700 system can be installed to the steel plate just outside the brake lights on the 6 yards dump truck. Three single sensor systems (WorkZone, HighResolution, and WorkSight) should be attached to the bottom of the bed in the middle. Because three single sensors have a socket at the back of the sensors, they need a bracket to be hung on. In case of the 10 yards dump truck (Figure 5.5B), all four sensor systems need to be attached to the bottom of the bed with brackets. Figure 5.5C shows that HCS-700 system can be installed on the triangle plates and other three single sensor systems should be hung on the bottom of the bed with brackets. From the installation assessment with three dump trucks, installation heights and widths of HCS-700 system range from 34 inches to 44 inches and from 34 inches to 44 inches, respectively. Installation heights of three single sensor systems range from 38 inches to 44 inches in the center.

5.4.2 Pickup Trucks

Two types of pickup trucks, Chevrolet-1500 and RAM-1500, were surveyed and Figure 5.6 demonstrates the rear view of two pickup trucks and installation dimensions.

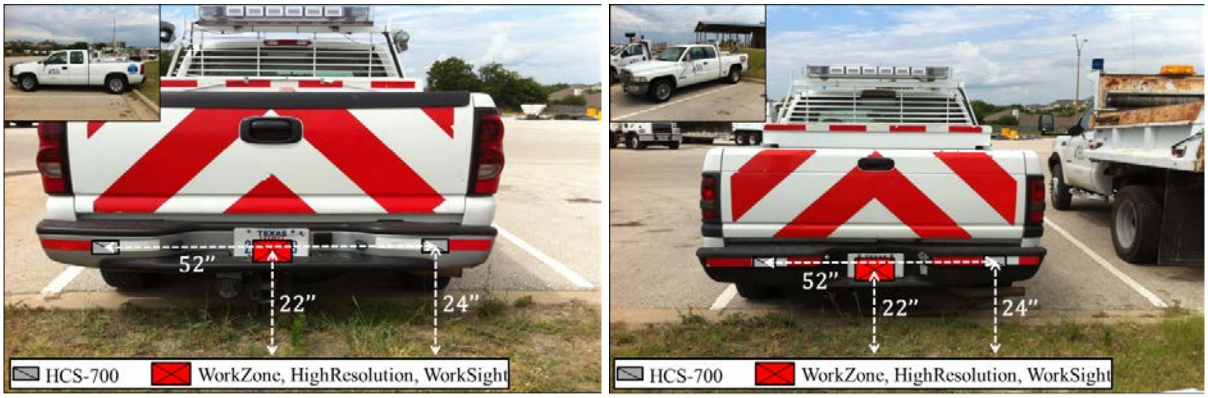


Figure 5.6A Chevrolet-1500 *Figure 5.6B RAM-1500*

Figure 5.6 Sensor Installation Survey on Two Types of Pickup Trucks

As can be seen in Figure 5.6, there was no ideal location for the single sensor systems for both pickup trucks because of the tailgate and license plate. According to Texas Transportation Code – Section 502.404, Operation of Vehicle without License Plate or Registration Insignia (2007), operators need to display two license plates at both front and rear of the vehicle. Therefore, sensor systems cannot cover the license plate. In case of system HCS-700, two sensors can be attached to the rear bumper with relatively flexible width. Also, HCS-700's two sensors might be installed the bottom of the bumper (14'' high) to avoid possible contacts on dumpers from the other vehicles. Even though single sensor systems (WorkZone, HighResolution, and WorkSight) do not seem to have proper areas for sensor installation, the researchers assumed that sensors could be installed immediately behind the license plate for the purpose of the field tests.

5.4.3 Service Trucks

Since service trucks are modified dynamically to meet their purposes, sensor locations will vary according to their design. Two service trucks were evaluated to find proper installation locations for four sensor systems. Figure 5.7 shows the rear of a service truck and possible system installation positions.

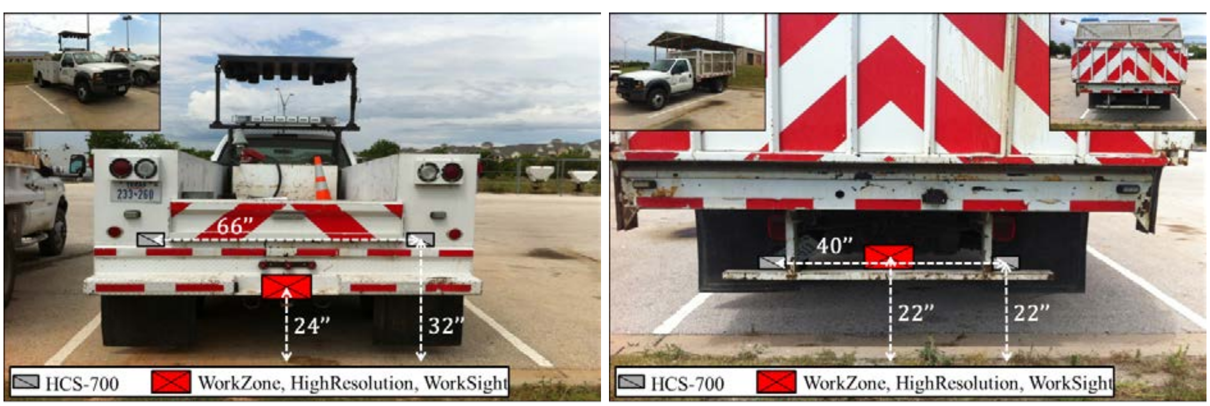


Figure 5.7A Service Truck I *Figure 5.7B Service Truck II*

Figure 5.7 Sensor Installation Survey on Two Types of Service Trucks

Table 5.6 summarizes installation heights and widths of the four sensor systems for seven different vehicles. Installation height and width of HCS-700 system range from 14 inches high and 40 inches wide to 44 inches high and 66 inches wide. For the other three single sensor systems, the installation heights range from 22 inches to 44 inches in the middle of the vehicles. The measurement results will be used to design the static test.

Table 5.6 Summary of Sensor Installation Survey with Seven Construction Vehicles

No.	Vehicle type		HCS-700		WorkZone		HighResolution		WorkSight	
			Height (inch)	Width (inch)	Height (inch)	Width (inch)	Height (inch)	Width (inch)	Height (inch)	Width (inch)
1	Dump truck	6 yards	34	40	38	Center	38	Center	38	Center
2		10 yards	44	44	44	Center	44	Center	44	Center
3		F-450	40	40	40	Center	40	Center	40	Center
4	Pickup truck	Chevrolet-1500	24	52	22	Center	22	Center	22	Center
5		RAM-1500	24	52	22	Center	22	Center	22	Center
6	Service truck	Type I	32	66	24	Center	24	Center	24	Center
7		Type II	22	49	22	Center	22	Center	22	Center

5.4.4 Summary of Findings

- Each vehicle has the limited space for sensor installation. Since construction vehicles are frequently modified for the unique purpose, it is strongly recommended to evaluate possible sensor mounting positions with operators and vendors to maximize sensor performance.
- The survey of pickup truck showed that there is no proper space for single sensor systems installation because of a tailgate, license plate, and trailer connecting device located in the middle of the rear of pickup truck (see Figure 5.8).

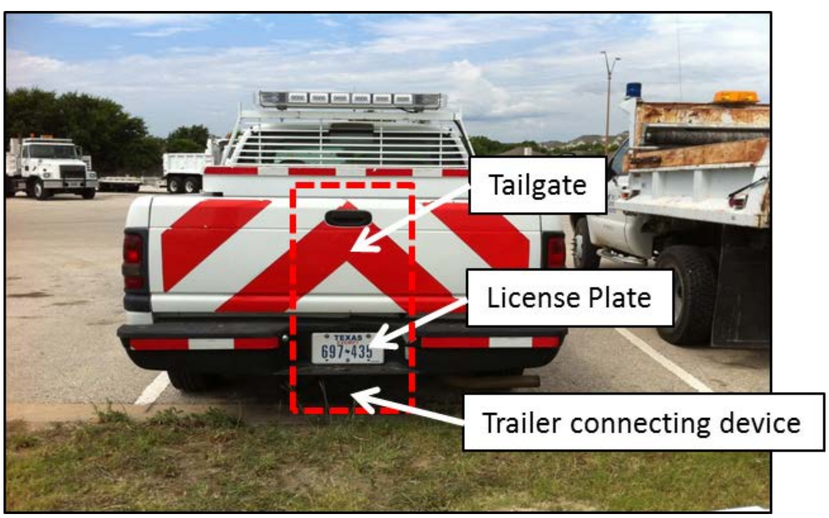


Figure 5.8 Rearview of Pickup Truck

- To hang on sensors, 'L' shape brackets are required for four sensor systems. In HCS-700 system package, two 'L' shape brackets are included, but to install other three sensor systems, brackets are not provided and TxDOT Austin maintenance office created them for the installation (see Figure 5.9).

Figure 5.9 “L” Shape Bracket to Hang on the Sensor

5.5 Static Test

5.5.1 Test Overview

The main objective of the static test is to study the sizes of detection areas for four selected sensor systems at different sensor installation locations. All tests were performed at the J.J. Pickle Research Campus in Austin, Texas. A wooden frame was built and used to install sensor systems (see Figure 5.10) instead of actual vehicles, and a DC 12 voltage car battery was used as a power source instead of connecting wires to actual vehicle power source. The frame was created to place sensors at various heights and widths. In order to record an accurate detection range, 18 feet by 30 feet measurement grid was set up using nylon strings with each cell at 1 foot by 1 foot.

Figure 5.10 Frame and Measurement Grid Setup for Static Tests

Based on sensor installation survey, each sensor system was tested with three different heights, 24 inches, 36 inches, and 48 inches. In case of HCS-700 system, a 12-in. installation height was also tested, and additional tests were conducted at three different widths—40 inches, 52 inches, and 64 inches—because this sensor system consists of two sensors. A total of 15 tests were performed and Table 5.7 summarizes the series of tests. Weather conditions such as temperature and humidity were recorded for each test because air density might impact the performance of sensors using pulsed signals. In addition, a human male participated as the object to be detected by the sensor systems.

Table 5.7 Summary of Static Test Plan

Test No.	System Type	Height (inch)	Width (inch)	Temperature (°F)	Humidity (%)	Trials
1	HCS-700	12	52	82	57	NA
2		24	52	85	57	10
3		36	52	84	58	10
4		48	52	91	45	10
5		36	40	89	50	10
6		36	64	79	74	10
7	WorkZone	24	Center	85	55	10
8		36	Center	86	57	10
9		48	Center	80	66	10
10	HighResolution	24	Center	83	39	10
11		36	Center	90	34	10
12		48	Center	93	41	10
13	WorkSight	24	Center	85	65	10
14		36	Center	95	43	10
15		48	Center	86	59	10

5.5.2 Test Procedure

The static test process was designed based on two previous test bed designs developed by Ruff (2000, 2001, 2007) and Mazzae and Garrott (2006, 2007a, 2007b). The detection area was determined by having a person walk towards the stationary proximity warning system installed in the wooden frame and Figure 5.11 describes the basic scenario of the static test. After installing a sensor system at the specific installation position, the person moved toward the sensor in a line parallel to the longitudinal centerline of the sensor. When the alarm was triggered the first time, the cell was recorded on the data collection sheet. Similarly, when the alarm stopped, the cell just passed was recorded as the other end point of detection range in the straight line. To minimize response time impact of each sensor system, the subject stayed at least one second in each cell to implement the static test. In this scenario, cells between two end points were assumed within the detection range. By repeating the same scenario along with the other lines, the detection range of the sensor system was obtained. This process was repeated ten times for each test.

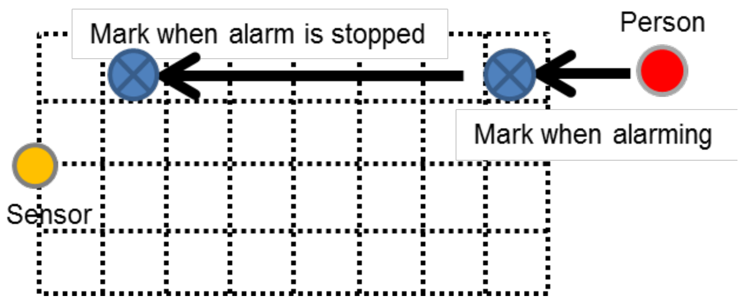


Figure 5.11 Basic Procedure of Static Test

5.5.3 Data Collection

During the test, manual results were recorded on the data collection sheet whether or not an alarm is activated in the cells and then converted into cumulative (Figure 5.12A) and individual results (Figure 5.12B). In the cumulative result, cells with 10 indicate that the areas were detected ten times out of ten trials and cells with 4 indicate that the areas were detected four times out of ten trials. From the cumulative results, reliable detection (90% accuracy or above) and sporadic detection area (less than 90% accuracy) were also determined. In addition, researchers understood that a detection area was slightly different for each trial from individual results.

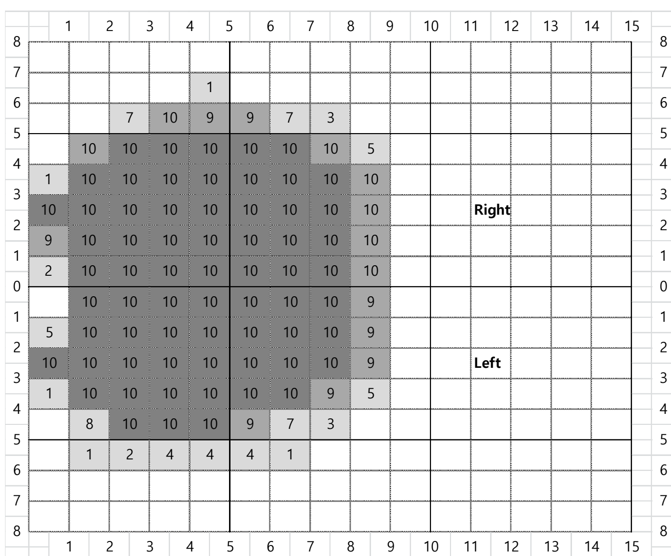


Figure 5.12A A Sample of Cumulative Record

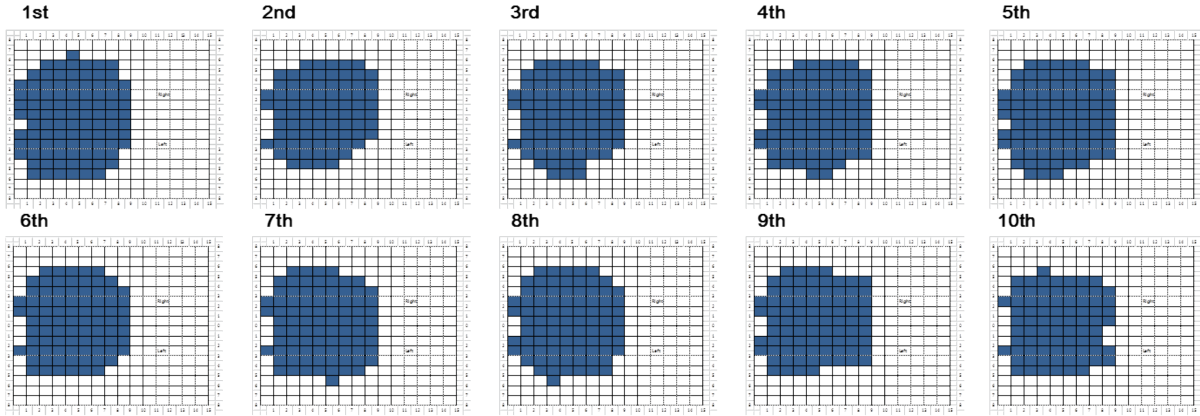


Figure 5.12B A Sample of Individual Record

Figure 5.12 A Sample of Data Collection

5.5.4 Results

To assess the performance of four sensor systems, following factors observed:

- Total Coverage: This coverage indicates number of cells total detected by a sensor system, which is the summation of reliable and sporadic detection areas.
- Reliable Area: This area is number of cells detected more than nine times out of ten trials and reliable area percentage indicates a ratio of total coverage and reliable area. This area will be used to determine the size of detection zone.
- Sporadic Area: This area indicates number of cells detected less than nine times out of ten trials and sporadic area percentage indicates a ratio of total coverage and sporadic area.
- Close Proximity Detection: This factor will evaluate sensor system's close proximity detection capability within 3 feet of vehicle and along the vehicle width (8 feet).

The following subsections will show static test results of each sensor system with the above four performance evaluation factors. Only cumulative results will be presented; individual results can be found in Appendix C.

5.5.4.1 System 1: HCS-700

HCS-700 system, which consists of two ultrasonic sensors, was tested with four different heights and three different widths to compare detection range variance in accordance to different sensor installation positions. Figure 5.13 describes test results diagrams with the size of detection zone and capability to detect close proximity areas. A dashed blue box and arrows in each figure indicate approximate width of pickup truck and installation position of sensors, respectively. In addition, the close proximity area, which is colored with yellow, was defined to evaluate the capacity to detect within 3 feet long and vehicle wide (8 feet) zone.

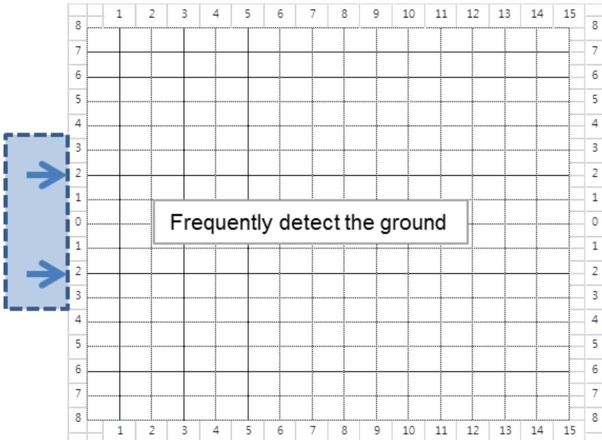


Figure 5.13A Test 1 (H: 12'' W: 52'')

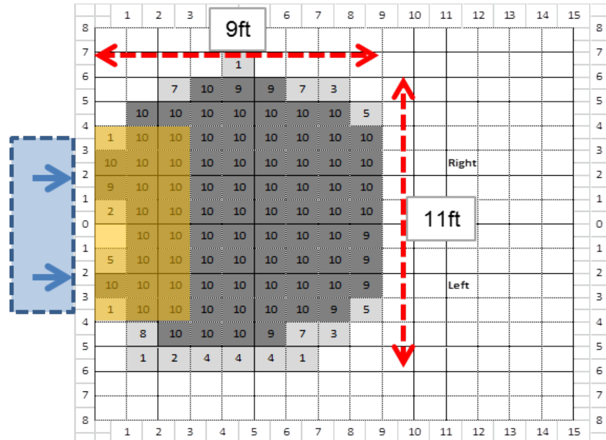


Figure 5.13B Test 2 (H: 24'' W: 52'')

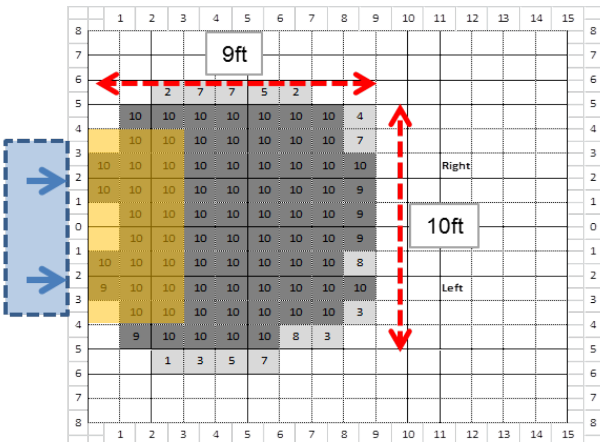


Figure 5.13C Test 3 (H: 36'' W: 52'')

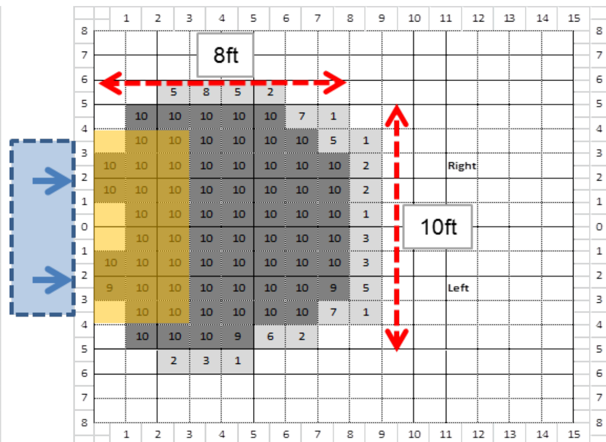


Figure 5.13D Test 4 (H: 48'' W: 52)

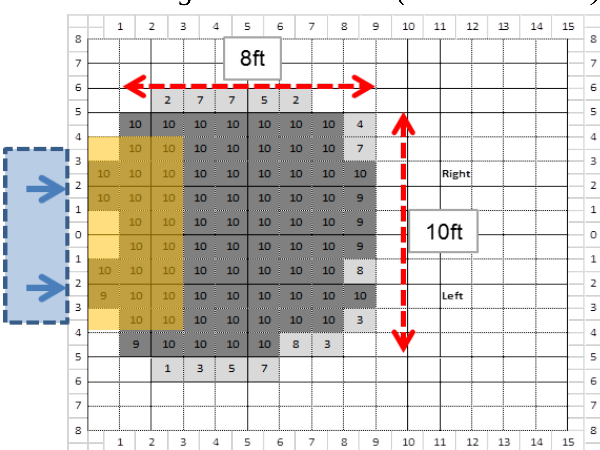


Figure 5.13E Test 5 (H: 36'' W: 40'')

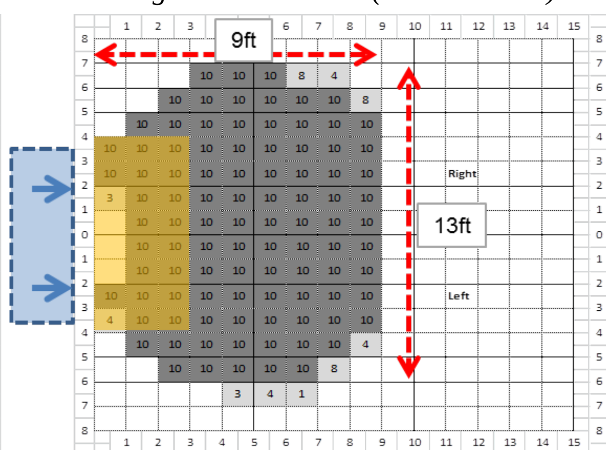


Figure 5.13F Test 6 (H: 36'' W: 64'')

Figure 5.13 HCS-700: Detection Zone Diagram at Six Installation Positions

When two ultrasonic sensors were installed at 12 inches height, the ground was detected frequently by sensors, so Test 1 could not be continued. Except for Test 1, there were no false alarms through the rest of tests. Because HCS-700 has two sensors, more than 70% of the cells were detected within close proximity. In addition, a sensor could not detect an object consistently when the object was located right behind the sensor, possibly due factory-calibrated sensitivity, weather impacts, or power source variances. Table 5.8 summarizes the HCS-700 static test results.

Table 5.8 HCS-700: Static Test Results

Test No.	Sensor Type	Height (inch)	Width (inch)	Total Coverage	Reliable Detection		Sporadic Detection		Close Proximity Detection	
1	HCS-700	12	52	Detect the ground frequently						
2		24	52	99	80	80.8%	19	19.2%	19	79.2%
3		36	52	88	67	76.1%	21	23.9%	20	83.3%
4		48	52	92	77	83.7%	15	16.3%	20	83.3%
5		36	40	81	67	82.7%	14	17.3%	17	70.8%
6		36	64	106	96	90.6%	10	9.4%	19	79.2%

5.5.4.2 System 2: Work Zone

The WorkZone system, which has a single radar-based sensor, was tested with three different heights in the middle of the frame; results are shown in Figure 5.14.

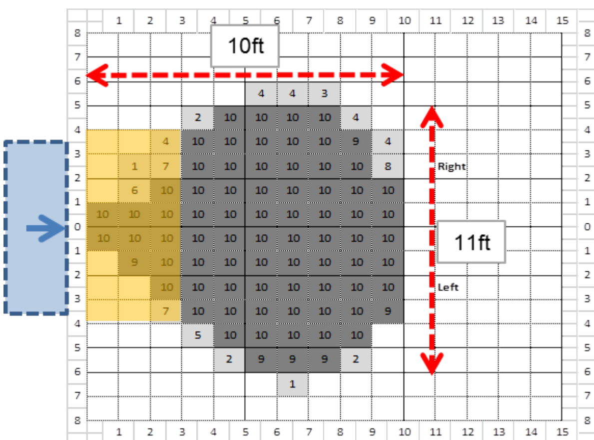


Figure 5.14A Test 7 (H: 24'' W: Center)

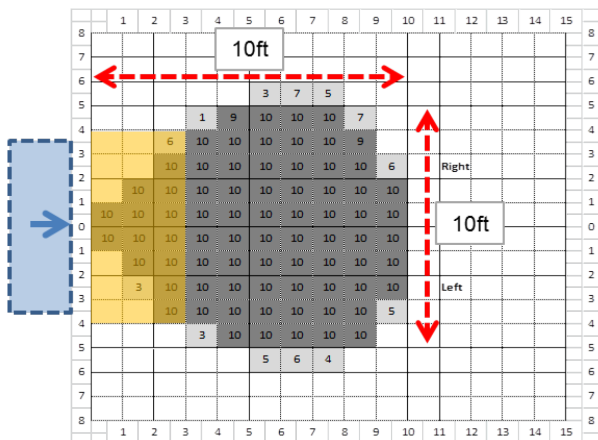


Figure 5.14B Test 8 (H: 36'' W: Center)

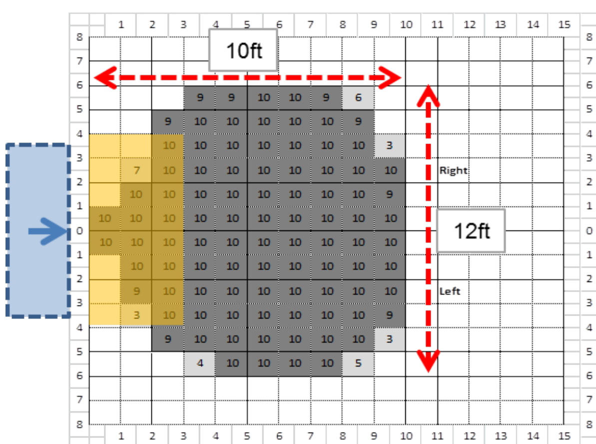


Figure 5.14C Test 9 (H: 48'' W: Center)

Figure 5.14 WorkZone: Detection Zone Diagram at Three Installation Positions

During the tests, there were no false alarms and WorkZone system showed worse capability to detect close proximity areas than HCS-700 system due to the nature of single sensor systems. Table 5.9 summarizes the static test results of WorkZone system.

Table 5.9 WorkZone: Static Test Results

Test No.	Sensor Type	Height (inch)	Width (inch)	Total Coverage	Reliable Detection		Sporadic Detection		Close Proximity Detection	
7	WorkZone	24	Center	88	75	85.3%	13	14.8%	13	54.2%
8		36	Center	92	98	76.5%	16	17.4%	10	41.7%
9		48	Center	100	108	83.7%	8	8.0%	15	62.5%

5.5.4.3 System 3: HighResolution

The HighResolution system, which has a single radar-based sensor and 20-feet detection range, was tested with three different heights; results are shown in Figure 5.15.

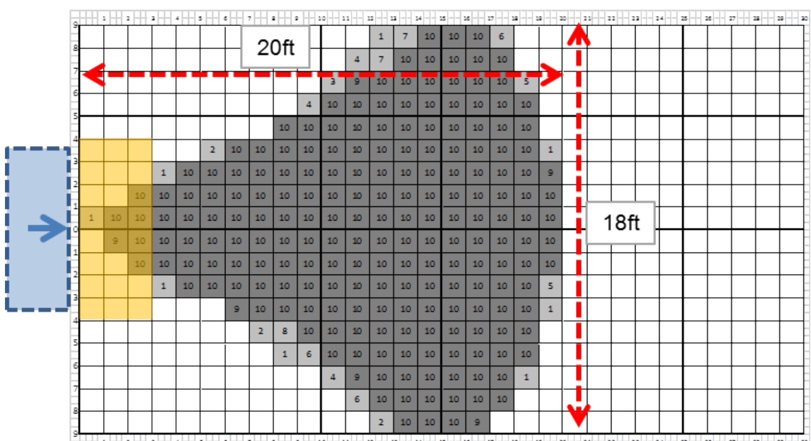


Figure 5.15A Test 10 (H: 24'' W: Center)

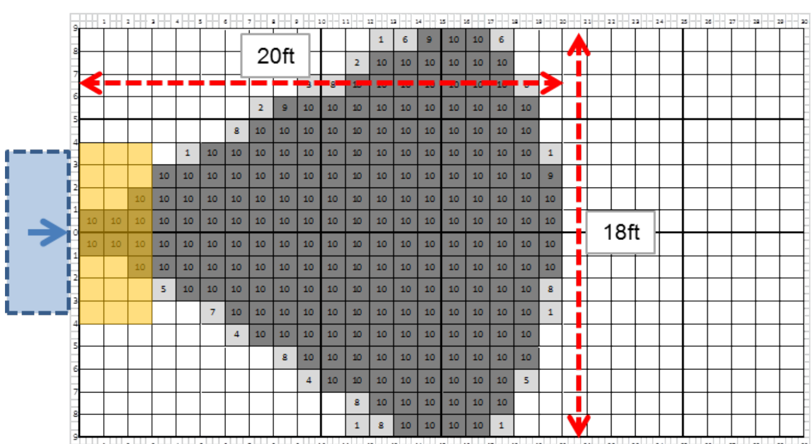


Figure 5.15B Test 11 (H: 36'' W: Center)

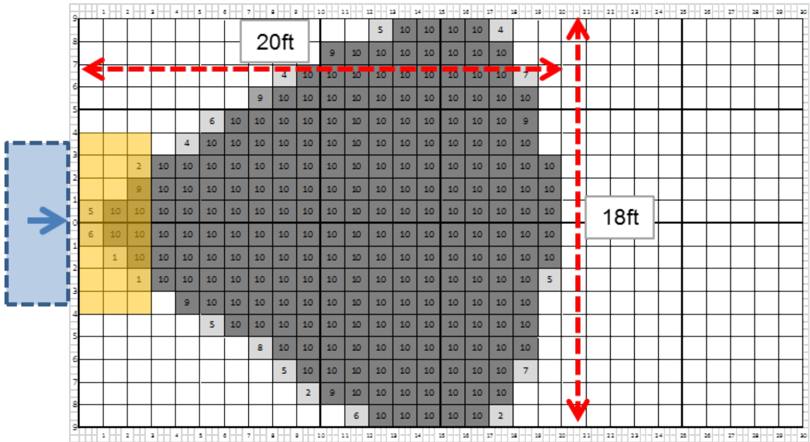


Figure 5.15C Test 12 (H: 48'' W: Center)

Figure 5.15 HighResolution: Detection Zone Diagram at Three Installation Positions

As Table 5.10 and Figure 5.15 indicate, this system showed very limited capabilities to detect at close proximity—at most 33.3%. Also, the cells behind the sensor were not detected consistently, which led very limited close-proximity area detection.

Table 5.10 HighResolution: Static Test Results

Test No.	Sensor Type	Height (inch)	Width (inch)	Total Coverage	Reliable Detection		Sporadic Detection		Close Proximity Detection	
10	HighResolution	24	Center	225	202	89.8%	23	10.2%	6	25.0%
11		36	Center	237	214	90.3%	23	9.7%	8	33.3%
12		48	Center	247	228	93.3%	19	7.7%	6	25.0%

5.5.4.4 System 4: WorkSight

WorkSight system has hybrid detection ranges of WorkZone and HighResolution systems, to increase maximum detection distance as well as to cover close proximity areas. Figure 5.16 illustrates three cumulative results of WorkSight system.

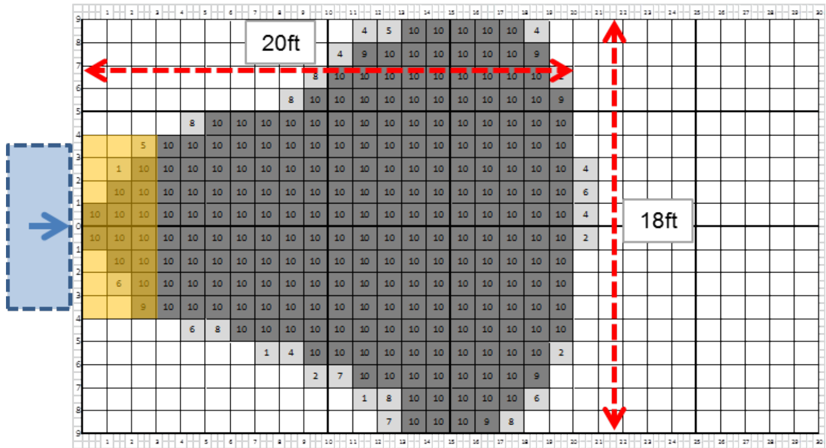


Figure 5.16A Test 13 (H: 24'' W: Center)

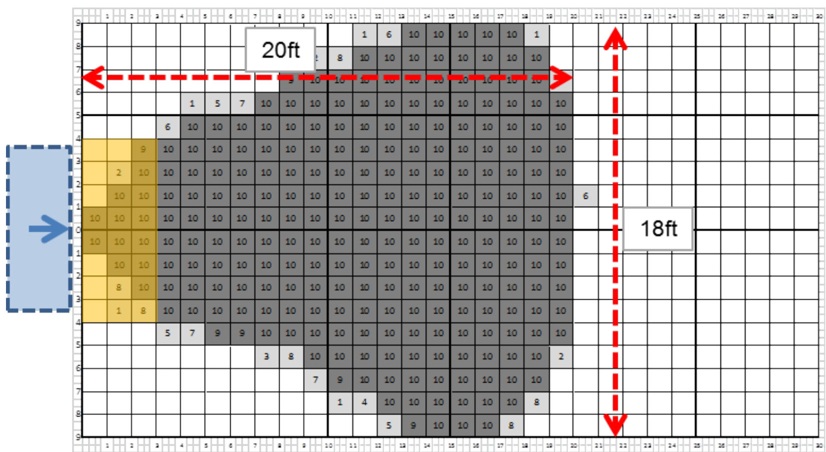


Figure 5.16B Test 14 (H: 36'' W: Center)

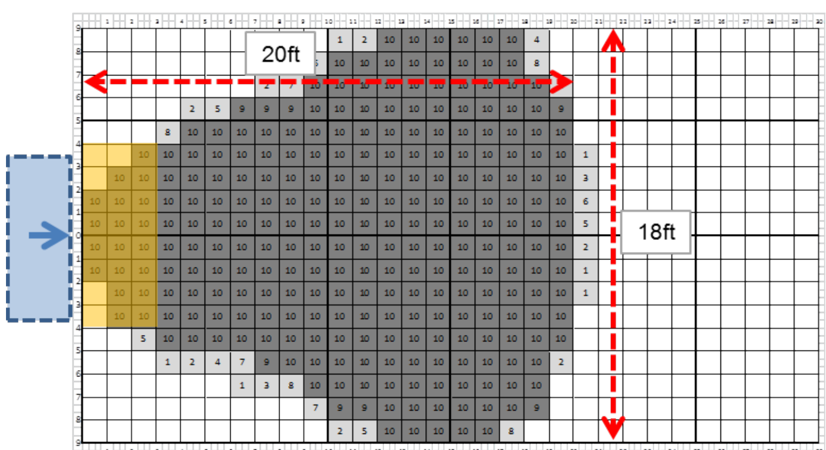


Figure 5.16C Test 15 (H: 48'' W: Center)

Figure 5.16 WorkSight: Detection Zone Diagram at Three Installation Positions

As can be seen in Table 5.11 and Figure 5.16, the capabilities to detect within 3 feet long areas were improved significantly compared to HighResolution system while maintaining maximum detection ranges, 20 feet.

Table 5.11 WorkSight: Static Test Results

Test No.	Sensor Type	Height (inch)	Width (inch)	Total Coverage	Reliable Detection		Sporadic Detection		Close Proximity Detection	
13	WorkSight	24	Center	264	238	90.2%	26	9.8%	13	54.2%
14		36	Center	272	246	90.4%	26	9.6%	13	54.2%
15		48	Center	294	262	89.1%	32	10.9%	19	79.2%

Overall, WorkSight system has the largest detection coverage with 20 feet maximum detection range. In terms of capability to detect close proximity areas, HCS-700 system showed the best performance since this system consists of two sensors, followed by WorkZone and WorkSight systems, which showed similar performance. However, HighResolution system has very limited detection capabilities within 3 feet long areas. Table 5.12 summarizes static test results of four sensor systems.

Table 5.12 Summary of Static Test Results

Test No.	Sensor Type	Height (inch)	Width (inch)	Total Coverage	Reliable Detection		Sporadic Detection		Close Proximity Detection	
1	HCS-700	12	52	Detect the ground frequently						
2		24	52	99	80	80.8%	19	19.2%	19	79.2%
3		36	52	88	67	76.1%	21	23.9%	20	83.3%
4		48	52	92	77	83.7%	15	16.3%	20	83.3%
5		36	40	81	67	82.7%	14	17.3%	17	70.8%
6		36	64	106	96	90.6%	10	9.4%	19	79.2%
7	WorkZone	24	Center	88	75	85.3%	13	14.8%	13	54.2%
8		36	Center	92	98	76.5%	16	17.4%	10	41.7%
9		48	Center	100	108	83.7%	8	8.0%	15	62.5%
10	HighResolution	24	Center	225	202	89.8%	23	10.2%	6	25.0%
11		36	Center	237	214	90.3%	23	9.7%	8	33.3%
12		48	Center	247	228	93.3%	19	7.7%	6	25.0%
13	WorkSight	24	Center	264	238	90.2%	26	9.8%	13	54.2%
14		36	Center	272	246	90.4%	26	9.6%	13	54.2%
15		48	Center	294	262	89.1%	32	10.9%	19	79.2%

5.5.5 Summary of Findings

- The detection performance of four sensor systems was influenced by different sensor installation locations. Generally, higher installations resulted in better detection performance to detect a human male. For HCS-700 system which has two ultrasonic sensors, wider installation resulted in better detection performance.

Therefore, to detect human male workers, higher and wider installations within the tests performed are recommended for the better sensor detection performance within limited spaces.

- Installing sensors at 12 inches high detected the ground frequently and generated false alarms. Therefore, sensors should not be installed below 12 inches height or should be tilted upward to avoid the detection of ground.
- Due to the nature of number of sensors, double sensor system (HCS-700) showed better capability to detect close proximity area than other three single sensor systems. Within single sensor systems, two systems (WorkZone and WorkSight) which have 'U' shaped detection showed better close proximity detection capability than the HighResolution system, which has 'V' shaped detection.

5.6 Dynamic Test

5.6.1 Test Overview

The dynamic test was performed to evaluate maximum detection range changes due to dynamic conditions of the vehicles. The basic scenario of dynamic test is that a vehicle is dynamic and an object is stationary. A dynamic test design was developed based on the theoretical detection range models in static and dynamic conditions (Figure 5.17).

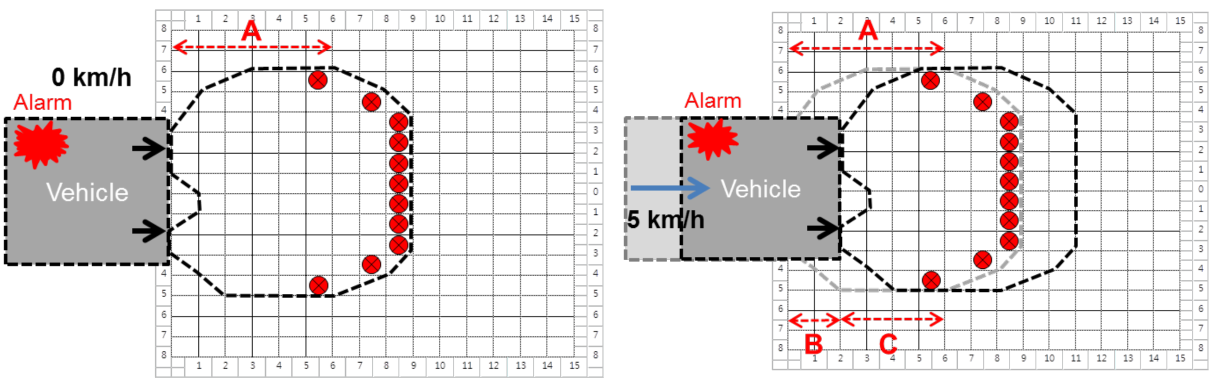


Figure 5.17A Static Test Model *Figure 5.17B Dynamic Test Model*

Note: Distance A: Maximum detection range of the sensor in static condition
Distance B: Reduced distance due to the dynamic condition

Figure 5.17 Detection Range Models of Static and Dynamic Tests

As illustrated in Figure 5.17A, the static test model reflects a scenario that both a vehicle and an object are stationary. In this scenario, researchers were able to obtain a maximum detection range; 'A' of a system regardless of sensor's response time and vehicle's backing speed. In the dynamic test, a vehicle is moving and a detectable object is stationary, and the dynamic test model reflects simple physics: D = V x T, where 'D' is distance, 'V' is velocity, and 'T' is time. As can be seen Figure 5.17B, maximum detection ranges reductions were expected because there is a lapse until a signal is reflected from the object and triggers an alarm. The reduced distance ('D') will be dependent on sensor's response time ('T') and vehicle's backing speed ('V').

The dynamic tests were conducted in the TxDOT Austin Maintenance Office. Dimensioned floor girds composed of one-foot squares was painted on a level and asphalted parking lot to place a test object on the same distance, ‘A’, as tested in the static test and to measure the reduced distance, ‘B’, in dynamic conditions. The total size of the outdoor grid was 20 by 20 feet and additional area for the backing vehicle was provided to reach the 3mph backing speed. To ensure the safety of test participants, a 16 feet male mannequin was used as a test object, shown in Figure 5.18. In order to minimize the impact of different vehicle speeds, the driver participated in the test was asked to back both pickup and dump trucks at 3mph and a researcher measured changed distance ‘B’ when an audible alarm was triggered from the cab.

Figure 5.18 Dynamic Test Overview

A total of six tests were performed and Table 5.13 summarizes the series of tests. Based on sensor selection criteria developed in Chapter 4, four sensor systems (more than 10 feet detection ranges) were tested with the pickup truck and two sensor systems, which have 20 feet detection ranges, were tested with the dump truck. Weather conditions such as temperature and humidity were recorded for each test.

Table 5.13 Summary of Dynamic Test Plan

Test No.	Vehicle Type	System Type	Height (inch)	Width (inch)	Temperature (°F)	Humidity (%)	Trials
1	Pickup Truck	HCS-700	24	52	94	44	5
2		WorkZone	24	Center	94	44	5
3		HighResolution	24	Center	95	43	5
4		WorkSight	24	Center	96	41	5
5	Dump Truck	HighResolution	36	Center	94	44	5
6		WorkSight	36	Center	96	39	5

5.6.2 Test Procedure

Based on the dynamic detection range model in Figure 5.17B, the dynamic test was designed to measure reduced detection range in dynamic conditions of vehicles. After installing a sensor system on a vehicle where researchers surveyed during the vehicle measurement, a piece of equipment moves at 3 mph toward the stationary obstacle, a mannequin which is positioned at the far edge of the detection range defined in the static test. When an alarm is triggered, a researcher records reduced distance ‘B’ as illustrated in Figure 5.19. Each test was performed five times during the dynamic test.

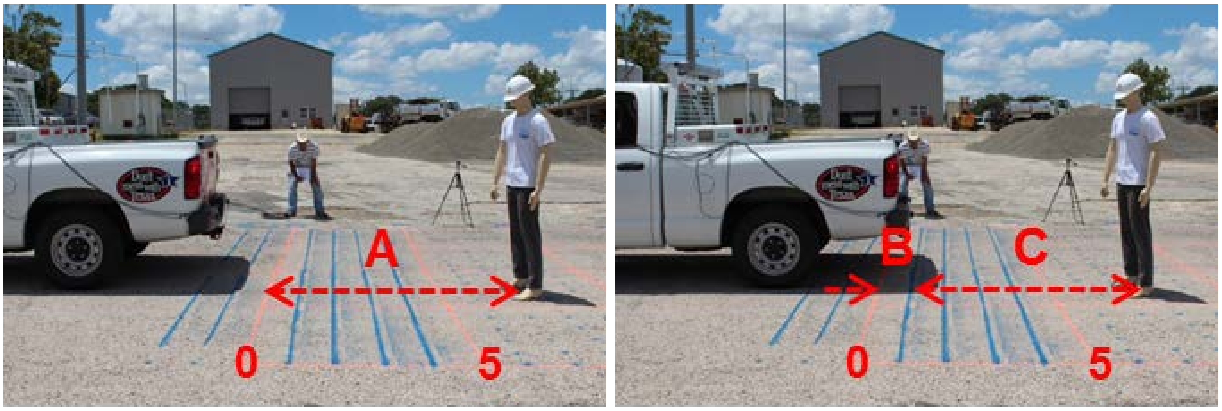


Figure 5.19 Basic Procedure of the Dynamic Test

5.6.3 Data Collection

During the field test, reduced detection distance ‘B’ (see Figure 5.19) was recorded on the data collection sheet, and then effective detection range ‘C’ was calculated from ‘A’ and ‘B’ in the cumulative results (Figure 5.20a). In Figure 5.20A, red colored cells indicate maximum detection range ‘A’ obtained from the static test and numbered cells in grey and red colored are effective detection range ‘C’ measured from the test. For example, boxed cells (3, 1, 1) indicate that ‘A’ is 6 feet in the static test and out of 5 trials ‘C’ is measured three times at 4 feet, one time at 5 feet, and another one time at 6 feet. Also, individual results (Figure 5.20B) were recorded.

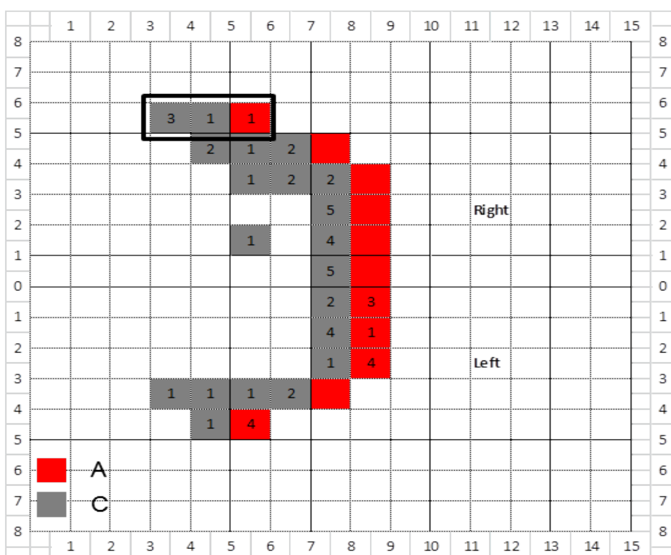


Figure 5.20A A Sample of Cumulative Record

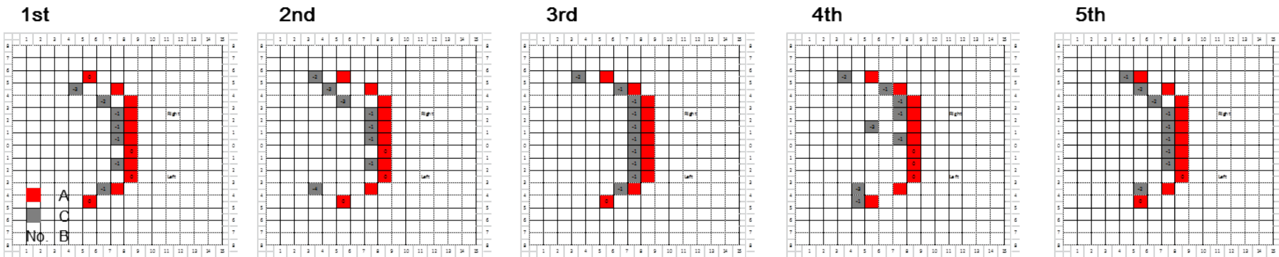


Figure 5.20B A Sample of Individual Record

Figure 5.20 A Sample of Data Collection

5.6.4 Result

During the dynamic test, the dynamic detection ranges of sensor systems were studied by placing sensor systems on moving equipment (i.e., a vehicle is backing and an obstacle is stationary). To access the performance of sensor systems in the dynamic conditions, following performance evaluation factors were checked:

1. Reduced maximum detection range (B): changed detection range due to the dynamic conditions of the vehicle. Individual result of each trial is presented in the detection zone diagram and averaged ‘B’ is recorded in the dynamic test results table. This changed detection ranges should be compared to maximum detection ranges in the static condition to see differences.
2. Non-detection: detection consistency for sensor systems comparing to the static test results and percentage indicates a ratio of the number of total trials and the number of no detection.
3. False alarm: alarms generated in the clear field because the sensor might detect the ground or parts of vehicle such as tires during the backing operation. Percentages of false alarms indicate a ratio of the number of total trials and the number of false alarms.

Following subsections will show dynamic test results of each sensor system with above three performance evaluation factors. Only cumulative results will be presented; individual results can be found in Appendix D.

5.6.4.1 System 1: HCS-700

HCS-700 system, which consists of two ultrasonic sensors, was tested with a 3mph backing pickup truck. Two sensors were installed on the bumper at 24 inches high and 52 inches wide as determined in the Section 5.4 Sensor Installation. Another possible installation position, which is under the dumper at 12 inches high, was not tested because the static test result showed that sensor installation at 12 inches high generate frequent false alarms due to the detection of the ground. Figure 5.21 illustrates a dynamic detection zone of HCS-700 system with the 3mph backing pickup truck. As described in the Section 5.6.3 Data Collection, red cells indicate maximum detection ranges measured in the static test and grey cells indicate reduced maximum detection ranges in the dynamic conditions.

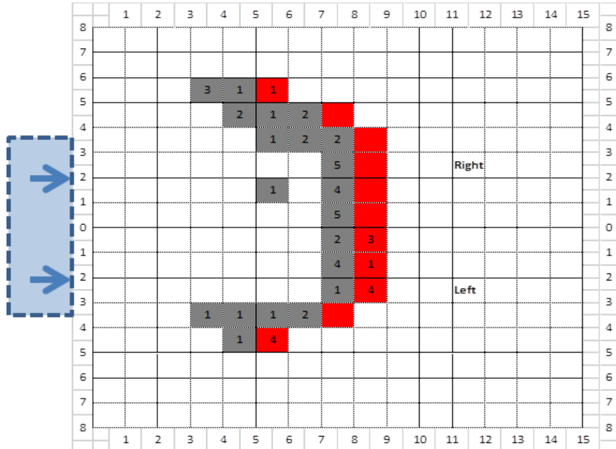


Figure 5.21 HCS-700: Detection Zone Diagram with Pickup Truck

Among 55 test trials, there were no non-detection area comparing to the static test results and 3 times false alarms. The average reduced distance 'B' was measured -1.13 feet. Table 5.14 summarizes the dynamic test results of HCS-700 system.

Table 5.14 HCS-700: Dynamic Test Results

Test No.	System Type	Vehicle Type	Height (inch)	Width (inch)	Average 'B' (feet)	Non-Detection		False Alarms		Trials
1	HCS-700	Pickup Truck	24	52	-1.13	0	0.0%	3	5.5%	55

5.6.4.2 System 2: WorkZone

The WorkZone system, which has a single radar-based sensor, was tested with the 3-mph backing pickup truck. The sensor was installed behind the license plate at 24 inches high in the middle. Figure 5.22 illustrates a dynamic detection zone of WorkZone system with the 3mph backing pickup truck.

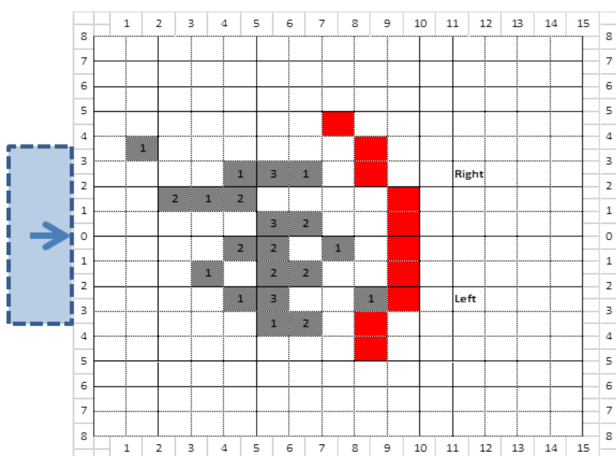


Figure 5.22 WorkZone: Detection Zone Diagram with Pickup Truck

In 55 test trials, 16 non-detections (32%) were measured and no false alarm was triggered. The average reduced distance ‘B’ was measured -3.97 feet (Table 5.15).

Table 5.15 WorkZone: Dynamic Test Results

Test No.	System Type	Vehicle Type	Height (inch)	Width (inch)	Average ‘B’ (feet)	Non-Detection		False Alarms		Trials
2	WorkZone	Pickup Truck	24	Center	-3.97	16	32.0%	0	0.0%	55

5.6.4.3 System 3: HighResolution

HighResolution system, which has a single radar-based sensor and 20 feet detection range, was tested with both a pickup and dump truck. The sensor was installed behind the license plate at 24 inches high in the middle for the test with the pickup truck while the sensor was attached to the bottom of the bed in the middle for the test with the dump truck. Figure 5.23 illustrates two dynamic detection zones of HighResolution system with the 3mph backing pickup and dump trucks.

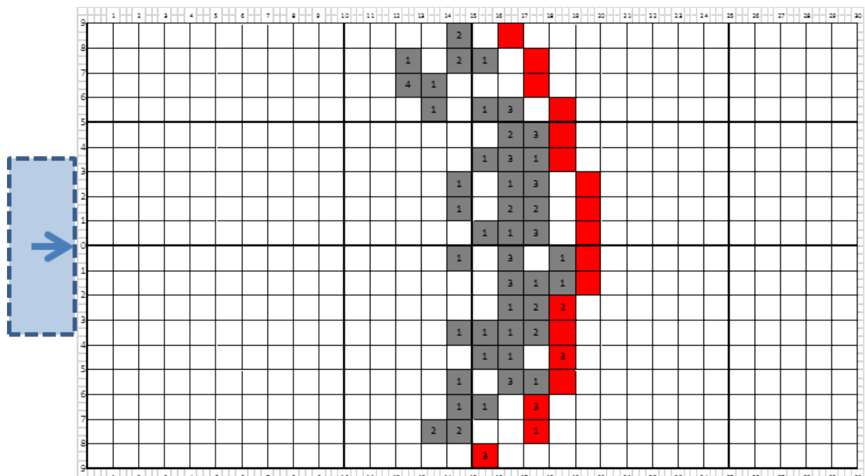


Figure 5.23A Dynamic Test 3 (H: 24’’ W: Center, Pickup truck)

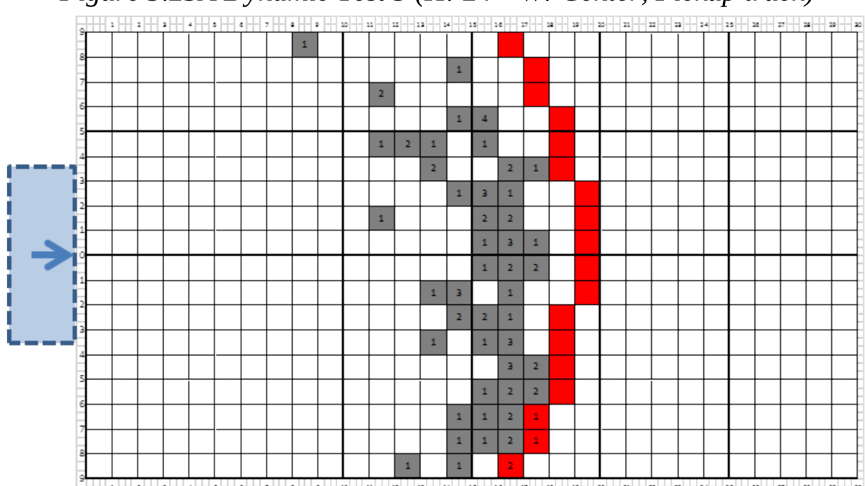


Figure 5.23B Dynamic Test 4 (H: 36’’ W: Center, Dump truck)

Figure 5.23 HighResolution: Detection Zone Diagram with Pickup and Dump Trucks

The test with the pickup truck yielded six non-detections (6.7%) and no false alarms. The average reduced distance 'B' was measured -2.27 feet. In the case of the test with the dump truck, 12 times non-detections (13.3%) were existed, and the average reduced distance 'B' was measured -3.01 feet. Table 5.16 summarizes the dynamic test results of HighResolution system.

Table 5.16 HighResolution: Dynamic Test Results

Test No.	System Type	Vehicle Type	Height (inch)	Width (inch)	Average 'B' (feet)	Non-Detection		False Alarms		Trials
3	High Resolution	Pickup Truck	24	Center	-2.27	6	6.7%	0	0.0%	90
4		Dump Truck	36	Center	-3.01	12	13.3%	0	0.0%	90

5.6.4.4 System 4: WorkSight

WorkSight system, which has hybrid detection ranges of WorkZone and HighResolution systems, was also tested with both pickup and dump trucks. The sensor was installed as the same location as HighResolution system and Figure 5.24 illustrates two dynamic detection zones of HighResolution system with the 3mph backing pickup and dump trucks.

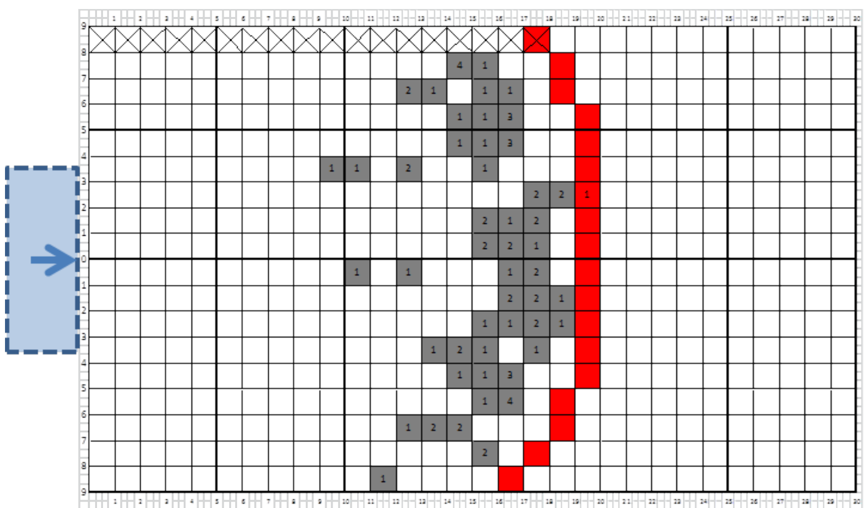


Figure 5.24A Dynamic Test 5 (H: 24'' W: Center, Pickup truck)

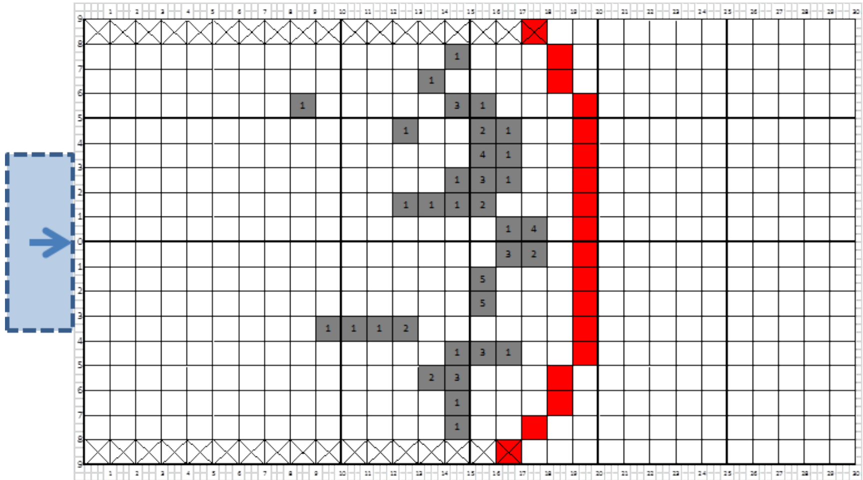


Figure 5.24B Dynamic Test 6 (H: 36'' W: Center, Dump truck)

Figure 5.24 WorkSight: Detection Zone Diagram with Pickup and Dump Trucks

During the test with the pickup truck, there were 12 times non-detections (13.3%) and no false alarms. The average reduced distance 'B' was measured -3.65 feet. In the case of the test with the dump truck, 27 times non-detections (30.0%) were existed, and the average reduced distance 'B' was measured -4.38 feet. Table 5.17 summarizes the dynamic test results of WorkSight system.

Table 5.17 WorkSight: Dynamic Test Results

Test No.	System Type	Vehicle Type	Height (inch)	Width (inch)	Average 'B' (feet)	No Detection		False Alarms		Trials
5	WorkSight	Pickup Truck	24	Center	-3.65	12	13.3%	0	0.0%	5
6		Dump Truck	36	Center	-4.38	27	30.0%	0	0.0%	5

Overall, HCS-700 system showed the shortest average reduced distance, around 1foot reduction while the WorkSight system test with dump truck presented average 4.38 detection distance reduction comparing to the static test results. Also, the WorkSight system test with dump truck showed 27 times non-detections, which is 30% of total test trials. In terms of false alarms, three radar systems presented no false alarms during the dynamic tests and HCS-700 system presented 3 times false alarms out of 55 trials. Table 5.18 summarizes static test results of four sensor systems.

Table 5.18 Summary of Dynamic Test Results

Test No.	System Type	Vehicle Type	Height (inch)	Width (inch)	Average 'B' (feet)	No Detection		False Alarms		Trials
1	HCS-700	Pickup Truck	24	52	-1.13	0	0.0%	3	5.5%	55
2	WorkZone	Pickup Truck	24	Center	-3.97	16	32.0%	0	0.0%	55
3	High Resolution	Pickup Truck	24	Center	-2.27	6	6.7%	0	0.0%	90
4		Dump Truck	36	Center	-3.01	12	13.3%	0	0.0%	90
5	WorkSight	Pickup Truck	24	Center	-3.65	12	13.3%	0	0.0%	90
6		Dump Truck	36	Center	-4.38	27	30.0%	0	0.0%	90

5.6.5 Summary of Findings

- Sensor's dynamic detection ranges are shorter than detection ranges in static conditions. Results show that maximum detection range of HCS-700 system in the dynamic test reduced average 1.13 feet compared to maximum detection range 'A', 9 feet, measured in the static condition. In other words, 9 feet detection zone of HCS-700 system will have approximately 7.67 feet detection range when a vehicle is reversing 3mph. In case of WorkZone system, which has 10 feet maximum detection 'A' in the static test, showed the average -3.97 feet distance reduction in the dynamic test, which means that this system is only able to detect 6.03 feet distance from the sensor in a 3mph backing operating condition. Reduced detection distance 'B' might be affected by sensor's response time and vehicle backing speed; longer sensor's response time and higher vehicle's backing speed, longer reduced distance 'B'.
- Comparing to the results from the static tests, non-detection cells were measured up to 32.0% (16 times no detection out of 55 trials for WorkZone system). Most non-detection cells were measured from the both sides (two feet, from right and left ends) of a detection zone obtained from the static tests. It is considered that most non-detection cells came from the measurement error of vehicle direction at zero distance point, which is illustrated in Figure 5.25.

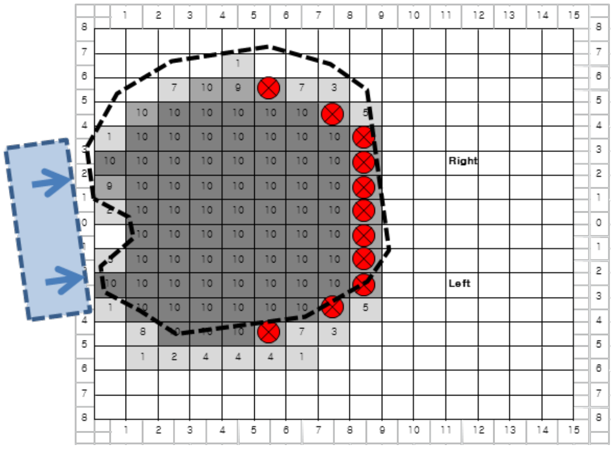


Figure 5.25A Vehicle angle

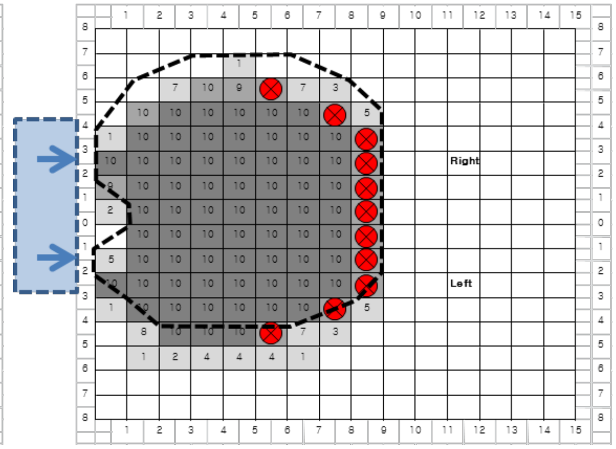


Figure 5.25B Vehicle location

Figure 5.25 Measurement Error of Vehicle Direction at Zero Distance Point

- The reduced detection distances ‘B’s were different when the same sensor systems (HighResolution and WorkSight) were tested with two different vehicle types, pickup and dump trucks. During the static test, higher sensor installation showed better detection coverage. However, during the dynamic test, when the sensor system was installed on the dump truck, 36 inches high, the detection performance was decreased than when the same sensor system was installed on the pickup truck, 24 inches high. It is possible the dump truck had more dynamic operating conditions, such as vibration when the vehicle was backing, which affected the sensor’s detection performance.

5.7 Dirty Sensor Test

In response to recommendations from a previous PMC meeting in September 2012, an additional experiment was conducted, which is the static test with dirty sensors. For the dirty sensor test, two sensor systems (HCS-700 and WorkSight) were tested to evaluate the change of detection performance with cleaned sensors. During the dirty sensor test, following factors were checked:

- Average Total Coverage: This coverage indicates the average number of cells detected by clean sensors from the static test.
- Coverage (first intervention): This coverage indicates number of cells detected by dirty sensors. To measure this coverage, sensors were got coated with soils (Figure 5.23 and 5.24). This number was calculated from the average of five trials.
- Coverage (second intervention): This coverage indicates number of cells detected by less or more soil covered sensors. This number was calculated from the average of five trials.
- Coverage (third intervention): This coverage indicates number of cells detected by partially cleaned sensor. This coverage was only measured with HCS-700 system.

5.7.1 HSC-700

As Figure 5.26 indicates, two ultrasonic sensors were coated with soil, and the same test was performed as the static test.

Figure 5.26 HCS-700 System: Before and After Soil Coverage

When the first five test trials were conducted with the first intervention dirty sensors, the detection capability of the sensors dropped dramatically from 82 cells to 16 cells detected, approximately 80% decline. The second five trials were performed with sensors with less soil coverage; researchers removed soil partially from the two sensors. After the second intervention, the detection performance almost doubled as compared to the first intervention. From the comparisons among coverage of the clean sensor and after the first and second interventions, researchers concluded that the detection performance of two ultrasonic sensors were significantly impacted by soil coverage. The third intervention was cleaning the red circled area. The test result after the third intervention showed that the detection performance returned to the performance of clean sensors. Table 5.19 summarizes the dirty sensor test result of HCS-700 system.

Table 5.19 HCS-700: Dirty Sensor Test Results

System Type	Height (inch)	Width (inch)	Average Total Coverage	First Intervention	Second Intervention	Third Intervention
HCS-700	36	52	82	16	34	82

5.7.2 Work Sight

As can be seen Figure 5.27, a pulsed radar sensor was coated with soil, and the same test was performed as the static test.

Figure 5.27 WorkSight System: Before and After Soil Coverage

When first five test trials were conducted with the first intervention (first layer of soil), there was no detection performance difference from the previous test with clean sensor. The second five trials were performed with the second intervention (second layer of soil) and there was also no detection performance difference. From the comparisons among coverage of cleaned sensor and after the first and second interventions, researchers concluded that the detection performance of the sensor was not affected a lot by soil coverage. Therefore, the test with third intervention was not performed and Table 5.20 summarizes the dirty sensor test result of WorkSight system.

Table 5.20 HCS-700: Dirty Sensor Test Results

System Type	Height (inch)	Width (inch)	Average Total Coverage	First Intervention	Second Intervention	Third Intervention
WorkSight	36	Center	258	260	262	NA

5.7.3 Summary of Findings

- HCS-700 system, which utilizes ultrasonic signals and has small emitting area, was significantly affected by soil coverage while WorkSight system, which utilizes pulsed radar signals and has large emitting area was not affected by soil coverage.

5.8 Conclusions

In this chapter, four sensor systems were compared based on four types of tests, which are sensor installation, static test, dynamic test, and dirty sensor test. The following Table 5.21 summarizes the features of four sensor systems tested.

Table 5.21 Summary of Four Sensor Systems

<table>
<tr><th colspan="2">Feature</th><th>HCS-700</th><th>WorkZone</th><th colspan="2">HighResolution</th><th colspan="2">WorkSight</th></tr>
<tr><td colspan="2">Technology</td><td>Ultrasonic</td><td>Pulsed Radar</td><td colspan="2">Pulsed Radar</td><td colspan="2">Pulsed Radar</td></tr>
<tr><td colspan="2">Cost
(cost with camera system)</td><td>$409
($806)</td><td>$659
($1,985)</td><td colspan="2">$766
($2,093)</td><td colspan="2">$1,770
($2,680)</td></tr>
<tr><td rowspan="2">Sensor Installation</td><td>Pickup</td><td>Yes</td><td>No</td><td colspan="2">No</td><td colspan="2">No</td></tr>
<tr><td>Dump</td><td></td><td></td><td colspan="2">Yes</td><td colspan="2">Yes</td></tr>
<tr><td rowspan="2">Static Test</td><td>Max. Detection Range (feet)</td><td>9</td><td>10</td><td colspan="2">20</td><td colspan="2">20</td></tr>
<tr><td>Close Proximity Detection (out of 24 cells (%))</td><td>20 (83.3%)</td><td>10 (41.7%)</td><td colspan="2">8 (33.3%)</td><td colspan="2">13 (54.2%)</td></tr>
<tr><td rowspan="5">Dynamic Test</td><td rowspan="2">Reduced Detection Distance ‘B’ (feet)</td><td rowspan="2">-1.13</td><td rowspan="2">-3.97</td><td>Pickup</td><td>-2.27</td><td>Pickup</td><td>-3.65</td></tr>
<tr><td>Dump</td><td>-3.65</td><td>Dump</td><td>-4.38</td></tr>
<tr><td rowspan="2">Non-Detection</td><td rowspan="2">0</td><td rowspan="2">16</td><td>Pickup</td><td>6</td><td>Pickup</td><td>12</td></tr>
<tr><td>Dump</td><td>12</td><td>Dump</td><td>27</td></tr>
<tr><td>False Alarms</td><td>3</td><td>0</td><td colspan="2">0</td><td colspan="2">0</td></tr>
<tr><td>Dirty Sensor Test</td><td>Impact of soil coverage</td><td>Yes</td><td>No</td><td colspan="2">No</td><td colspan="2">No</td></tr>
</table>

- HCS-700: This system is the cheapest sensor system and only system which had possible installation area for the pickup truck since this system consists of two ultrasonic sensors. Also, this system showed the best performance in close proximity detection capability (83.3%), reduced detection distance with the 3mph backing vehicle (-1.13 feet), and non-detection (0). However, HCS-700 system generated false alarms infrequently during the dynamic test and was significantly affected by soil coverage on the sensors.
- WorkZone: This system did not generate false alarm and was not affected by soil coverage on the sensor. However, researchers could not find proper installation area for the pickup truck. Also, WorkZone system showed the worst performance during the dynamic test in terms of reduced detection distance (-3.97 feet) and non-detection (16 times out of 55 trials).
- HighResolution: This system has 20 feet detection range and did not generate false alarm. Also, the dirty sensor test showed that this system was not affected by the soil coverage on the sensor. However, HighResolution system had very limited capability to detect close proximity area (33.3%).
- WorkSight: This system also showed good performance in terms of maximum detection range, false alarms, and impact of soil coverage. However, WorkSight system showed bad performance during the dynamic test when this system was tested with dump truck; reduced detection distance was -4.38 feet and there were 27 times non-detection out of 90 trials.

In sum, the HCS-700 system is recommended for pickup trucks; it should be cleaned frequently to maintain the detection performance. For dump trucks, two sensor systems (HighResolution and WorkSight) have their own pros and cons; the HighResolution system has better performance during the dynamic test, but poor performance in terms of close proximity detection as compared to the WorkSight system.

5.9 Summary

Four sensor systems selected from the Chapter 4 were tested using these four testing approaches: 1) sensor installation; 2) static test; 3) dynamic test; and 4) dirty sensor test.

From the sensor installation reviews in Section 5.4, proper sensor systems mounting positions surveyed for typical TxDOT construction vehicles, such as pickup, dump, and service trucks. In the static test, detection performances of four selected sensor systems were evaluated at different sensor installation locations. With the static test results, the dynamic test with a pickup and dump truck was performed to measure detection performance changes in dynamic vehicle operation conditions. Finally, two sensor systems were coated with soil and the detection performance was checked.

Chapter 6. Recommendation for TxDOT Traffic Control Practices

The purpose of this chapter is to develop a set of recommendations for TxDOT traffic control practices, incorporating commercially available systems for the prevention of backing fatalities. Recommendations are based on a detailed review of internal traffic control plans as identified in Chapter 2 (Literature Review) and Chapter 3 (Identifications and Analysis of Appropriate Responses) and tested technologies for the prevention of backing fatalities as identified in Chapter 5.

The information in this chapter is organized into the following sections. Section 6.1 discusses the engineering and technology controls, including modified Internal Traffic Control plans, detailed traffic control notes, and integrating the use of technology with engineering controls. Section 6.2 covers administrative controls such as selecting safety officers, how to better conduct safety meetings, and the training of everyone that will be on the job site.

6.1 Engineering and Technology Controls

Internal Traffic Control Plans (ITCP) shall be designed to include buffer zones to keep public and workers away from trucks/equipment within the work zone as well as to keep the length of the work zone appropriate to the work in progress. The ITCP should direct the movement of workers and equipment in a work zone reducing the need for backing. The ITCP should include designated worker-only and pedestrian-free zones. The ITCP can be changed throughout project progression by the safety officer or competent person, with the changes being communicated to all other personnel on the work site. Up to date safety concerns should be discussed with workers at least once per shift, keeping a hierarchical approach to prevention of worker injuries.

The Integrated Internal Traffic Control Plans (IITCP) incorporates ITCP with sensing technology implementation to improve vehicle-related safety practices in the work zone. Based on ITCP, IITCP shall be designed including important guidelines and recommendations when sensing technology is applied on jobsites. An IITCP should contain a traffic control diagram, a legend explaining this diagram, and notes explaining the details of the diagram, work zone, and technology implementation. The creation of the IITCP should involve:

1. Reviewing the contracts and model plan for the project, deciding the sequence of events in the project, and then creating a basic design for the work zone designating storage utility, and staging areas.
2. Designing vehicle and pedestrian paths throughout the work zone, and then creating the IITCP notes containing all information to give an accurate representation of the flow within the IITCP.
3. Explaining technology guidelines for effective implementation of new technology.

Similarly to guidelines of ITCP, the guideline of IITCP shall be designed to reflect jobsite and technology-specific because the characteristics of work zones and technologies are dynamic. The following are general guidelines and recommendations for IITCP development.

- *Sensing systems should be installed above 12 inches high, measured from the ground.*

  Findings from the Chapter 5 show that installing sensors at or below 12 inches high detected the ground frequently and generated false alarms. If it is inevitable mounting sensors at or below 12 inches high on the vehicle, it is recommended that sensors should be tilted upward to avoid the detection of ground.

- *The width of sensor detection zone should not exceed 10 feet for work zones on the shoulder or one lane closures.*

  In terms of sensor's detection coverage, characteristics of jobsites should be considered before selecting sensor systems. A trade-off exists between detection range and false alarms. A sensor system with longer detection range generally has a wider detection range. As a result, a wider clear field is required to implement this system without false and nuisance alarms in the work zone. If sensor systems with wider detection coverage (more than 10 feet) are used in a relatively narrow jobsite such as one lane closures, the sensors will detect traffic cones or other fixed objects (personal vehicles parked or materials) and generate unnecessary false alarms. These kinds of false alarms will make operators distrust the sensor systems and ignore alarms. For jobsites such as two lanes closures or new highway construction, longer and wider detection sensor systems might be more effective if enough clear backing area is secured.

- *When multiple vehicles are in a wait area idling close to one another, only the ready-to-back-up vehicle should set its gear in reverse.*

  In the idling zone, if multiple vehicles activate sensor system by setting their gears in reverse, sensors will detect the other vehicles behind them and generate false alarms. This kind of false alarm will make operators indifferent to the alarm system and create other accident possibilities such as backing on a worker who is between two vehicles. Also, the second vehicle should back up only after the first vehicle leaves the work zone.

- *Equipment only area (backing path) in the work zone should be clear field.*

  As well as minimizing false alarms by detecting fixed objects while backing up, backing path should be clear enough to secure clear line-of-sight between an operator and a spotter. If the line-of-sight between an operator and a spotter is too long or blocked by fixed objects such as personal vehicles or materials, positioning of multiple spotters is recommended.

- *Spotters and idle workers should stay on the opposite side of roadway traffic.*

  Workers should make it a point to stay clear of construction vehicles for their own safety. They should not rely on the operators of the vehicles to yield for them and should always be on the lookout for trucks and machinery.

- *While a vehicle is loading or dumping, it is recommended to change its gear into neutral to avoid unnecessary alarms between the vehicle and other equipment.*

Except for general guidelines described above, jobsite-specific guidelines should be developed and workers should be educated before they enter the jobsite.

6.1.1 Integrated Internal Traffic Control Plan Diagram

The IITCP diagram should contain detailed schematic diagrams with illustrations for all paving trenching, and dirt spread operations depicting the movement of construction workers and vehicles within the work space, allowing workers and vehicles to enter and leave the work zone safely. The diagrams should be modified to assure compatibility with the overall ITCP and to address site-specific conditions.

Figure 6.1 is an example of IITCP developed based on a TxDOT Traffic Control Plan Standard. The left side diagram is the original TxDOT Traffic Control Plan Standard (TPC 1-4b) and the right diagram is the IITCP diagram developed from the TPC 1-4b with the integration of HCS-700 system which has 9 by 10 feet detection coverage. For better illustration, specific dimensions described in TPC 1-4b are omitted in the IITCP diagram. As can be seen, the IITCP contains a diagram, general and technology notes, and legend explaining the diagram. In the diagram, all necessary signs shall meet designated specifications and be used in the appointed locations to better conduct movement and actions throughout the plan. Also, the diagram includes vehicle entering and leaving area, positioning of flaggers and spotters, sensor detection size, equipment only area, and pedestrian only area. The general notes provide an understanding of the principles of the traffic control zone and direct movements. The notes shall include a description of designated worker, pedestrian areas, and a spotter to direct backing movements. The technology notes explain general guidelines for effective technology implementation.

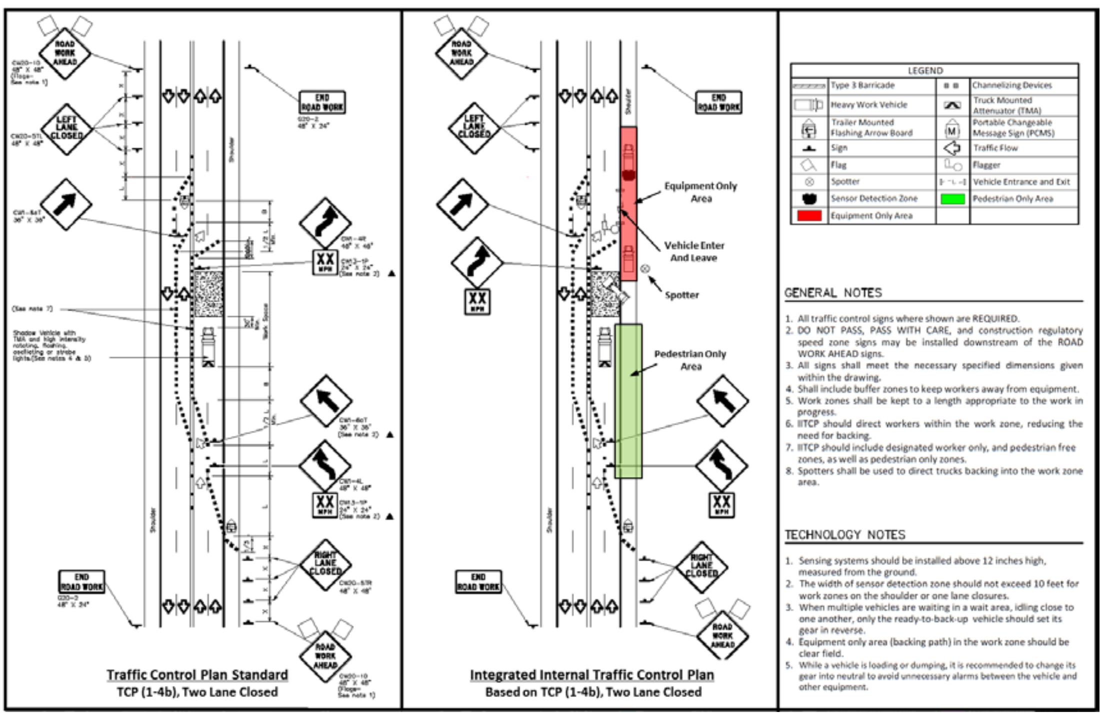


Figure 6.1 A Sample of Integrated and Internal Traffic Control Plan Based on TCP Standard (1-4b)

In order to provide a better understanding of IITCP in the work zone, detailed diagrams are provided, which represent five equipment related jobsite scenarios: Vehicle Entering, Vehicle Idling, Vehicle Backing, Vehicle Loading or Dumping, and Vehicle Exiting.

Figure 6.2 shows where a vehicle enters at the pre-determined area. The entering area of the work zone should be noted before the vehicle arrives at the work zone. Also, a flagger is needed to maintain smooth traffic flow and a spotter should be ready to guide the vehicle.

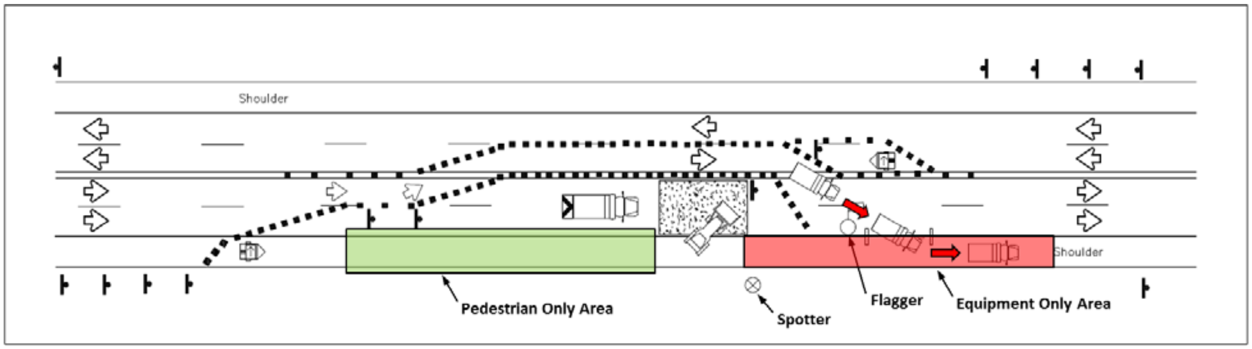


Figure 6.2 Detailed IITCP Diagram 1: Vehicle Entering

Figures 6.3 and 6.4 illustrate when vehicles are waiting in the idle zone. Figure 6.3 shows when HCS-700 system (9 by 10 feet detection coverage) is used on the vehicle and Figure 6.4 shows when WorkSight system (20 by 18 feet detection coverage) is used on the vehicle. As shown in Figure 6.4, the WorkSight system is not effective in this work zone because its wider detection coverage will detect traffic cones or other fixed objects around the work zone and will trigger false alarms. All vehicles should stay in the equipment only area and make sure line-of-sight between a spotter and a driver is secured. When multiple vehicles are waiting in the idle zone, Dump Truck 1 should set reverse gear and Dump Truck 2 should be set to neutral gear to avoid false alarms by detecting a vehicle behind it.

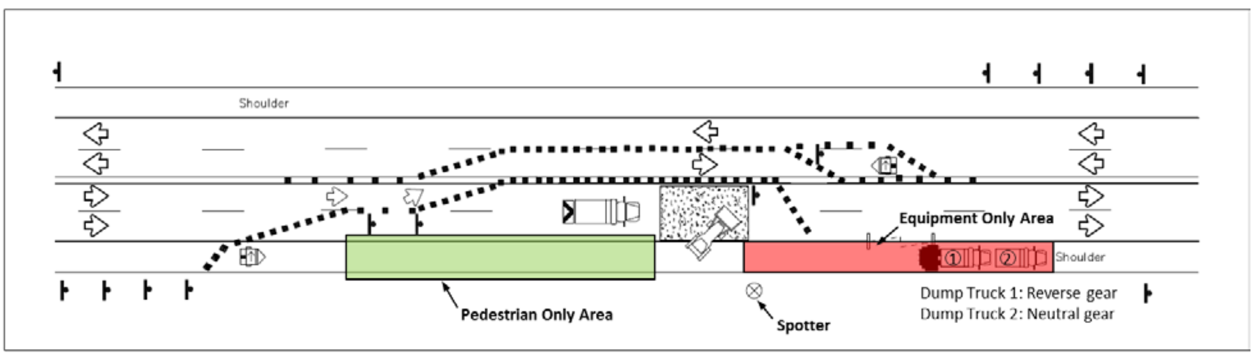


Figure 6.3 Detailed IITCP Diagram II: Vehicle Idling with HCS-700 System

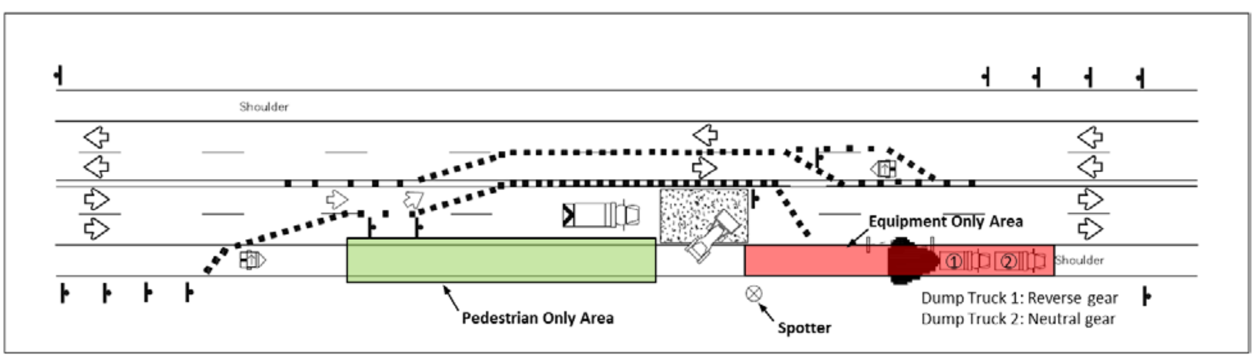


Figure 6.4 Detailed IITCP Diagram II: Vehicle Idling with WorkSight System

Figure 6.5 shows when a vehicle is backing up. Before the vehicle backs up, two things should be double checked: clear backing path and clear line-of-sight between a spotter and a driver. If the line-of-sight between an operator and a spotter is too long or blocked by fixed objects such as personal vehicles or materials, positioning of multiple spotters and special monitoring are recommended. Figure 6.6 illustrates the scenario where a parked personal vehicle is blocking communication between a spotter and a driver. In this scenario, there can be a potential accident between a backing vehicle and a worker walking into the dangerous area from behind the fixed object, which is a vehicle parked. To avoid this accident scenario, an additional spotter and special care of dangerous area are recommended.

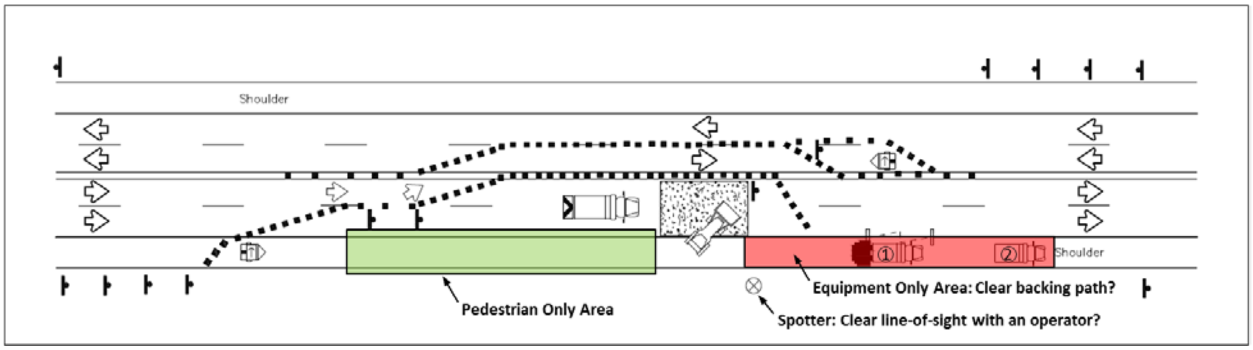


Figure 6.5 Detailed IITCP Diagram III: Vehicle Backing

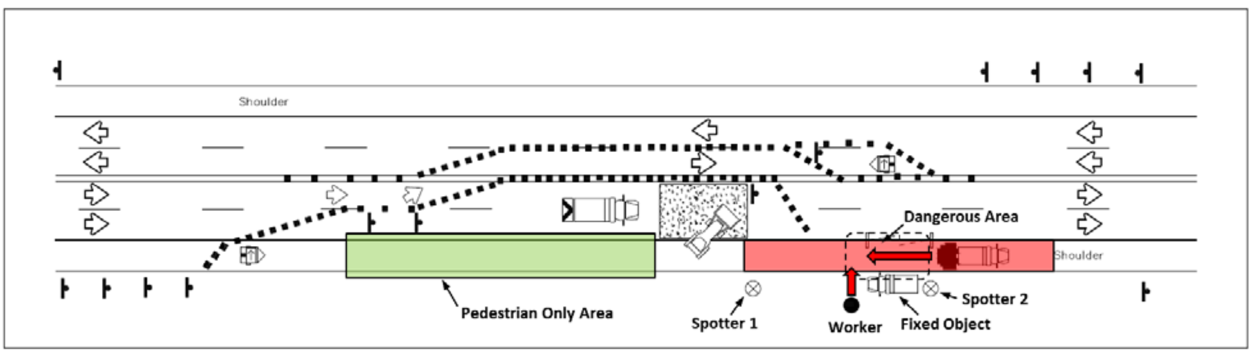


Figure 6.6 Detailed IITCP Diagram III: Vehicle Backing with Fixed Object

Figure 6.7 describes when a vehicle is loading or dumping. To avoid unnecessary alarms between the vehicle and other equipment, it is recommended to change Dump Truck 1's gear into neutral while the vehicle is loading or dumping.

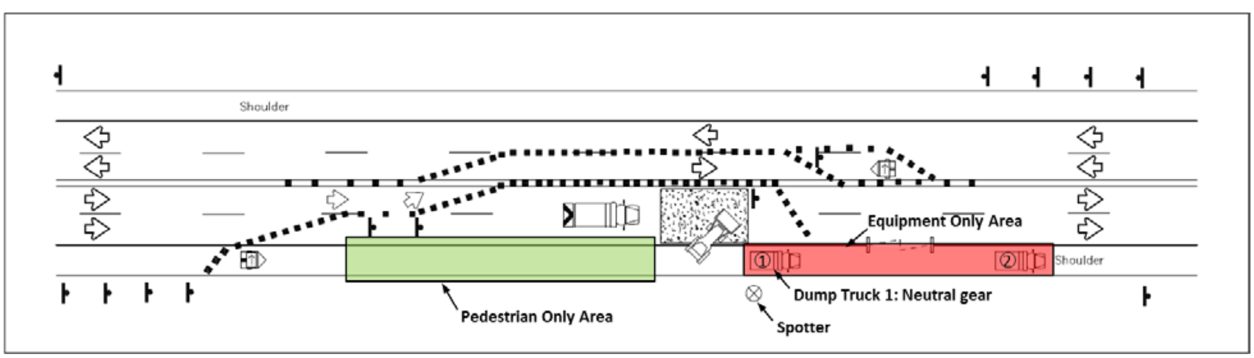


Figure 6.7 Detailed IITCP Diagram IV: Vehicle Loading or Dumping

Figure 6.8 shows the scenario of leaving a vehicle at the pre-determined area. Similarly to a vehicle entering scenario (Figure 6.2), a flagger is needed to maintain smooth traffic and safe vehicle exit from the work zone. To avoid a possible accident between Dump Truck 1 leaving and Dump Truck 2 reversing, Dump Truck 2 should reverse after Dump Truck 1 has completely left the work zone.

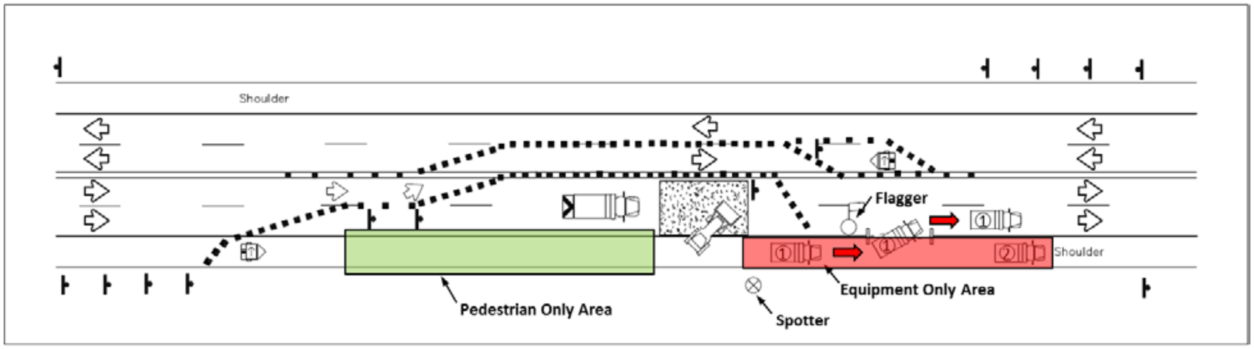


Figure 6.8 Detailed IITCP Diagram V: Vehicle Exiting the Work Zone

6.1.2 Integrated Internal Traffic Control Plan Legend

The legend should clearly label all parts of a traffic control plan diagram including heavy equipment paths, pedestrian free and backing free zones. Some of the movements and objects that are represented by symbols include the following:

- Lights and channelizing devices
- Barriers
- Direction of highway traffic, and traffic within the work zone
- Sign locations
- Worker locations, with a different symbol for each worker
- Different equipment within the work zones
- Sensor system detection coverage

Figure 6.9 shows the legend used in the IITCP we developed. From Type 3 Barricade to Flagger are existing legend in the TPC 1-4b and we added five symbols, which are Spotter, Vehicle Entrance and Exit, Sensor Detection Zone, Pedestrian Only Area, and Equipment Only Area, to develop IITCP.

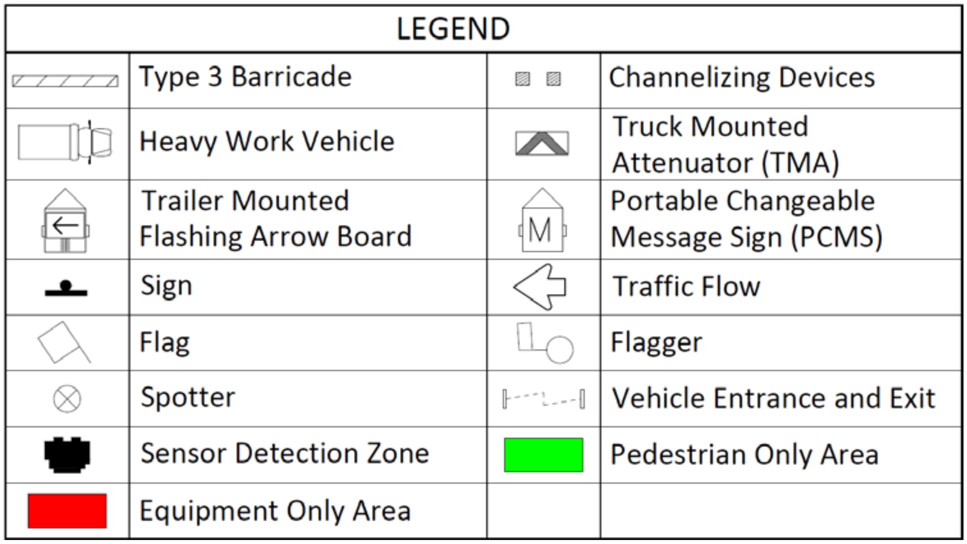


Figure 6.9 A Sample of Legend Based on TPC 1-4B

6.1.3 Integrated Internal Traffic Control Plan Notes

The IITCP notes consist of general notes and technology notes. General notes should contain site-specific safety measures, and contractor duties in reference to safety. Safety points should be clearly depicted such as pedestrian free zones, buffer zones, safety meeting frequencies, truck arrival times, and internal speed limits for the work zone. Technology notes should contain general guidelines and recommendations for effective technology implementation. Notes should be frequently updated to reflect changes in working conditions throughout the project. The following are general as well as technology notes used in the IITCP we developed.

6.1.3.1 General Notes

- All traffic control signs where shown are REQUIRED.
- DO NOT PASS, PASS WITH CARE, and construction regulatory speed zone signs may be installed downstream of the ROAD WORK AHEAD signs.
- All signs shall meet the necessary specified dimensions given within the drawing.
- Shall include buffer zones to keep workers away from equipment.
- Work zones shall be kept to a length appropriate to the work in progress.
- IITCP should direct workers within the work zone, reducing the need for backing.
- IITCP should include designated worker only, and pedestrian free zones, as well as pedestrian only zones.
- Spotters shall be used to direct trucks backing into the work zone area.

6.1.3.2 Technology Notes

- Sensing systems should be installed above 12 inches high, measured from the ground.

- The width of sensor detection zone should not exceed 10 feet for work zones on the shoulder or one lane closures.
- When multiple vehicles are waiting in a wait area, idling close to one another, only the ready-to-back-up vehicle should set its gear in reverse.
- Equipment only area (backing path) in the work zone should be clear field.
- While a vehicle is loading or dumping, it is recommended to change its gear into neutral to avoid unnecessary alarms between the vehicle and other equipment.

6.2 Administrative Controls

This section discusses the recommendations based on Administrative Controls. These include safety meetings, the use of safety officers, the implementation of regulations and guidelines, and the proper training of employees.

6.2.1 Safety Meetings

Preconstruction safety meetings should take place every day in order to remind workers of changing conditions in the work zone which can affect their safety. All key players over a work site should be present during the meetings, to insure the cohesion to the IITCP notes, ensuring all workers, including contract workers, understand the job taking place and are in consensus on how the work zone will be set up.

6.2.2 Safety Officers

Every work zone should be assigned a traffic control supervisor who is knowledgeable on the type of project at hand. The supervisor should possess the ability to halt work in the instance of unsafe conditions and should carry out tasks such as coordination at the work site, determining traffic routes within the work zone, documenting hazards and how they were mitigated, and maintaining multiple lines of communication. The safety officer and work-zone supervisors should review the Traffic Control Plan and decide on how to demarcate traffic routes within the work zone and include a plan for communicating between vehicle operators and workers-on-foot.

6.2.3 Regulations & Guidelines for Workers

Guidelines and expectations should be presented to workers during safety meetings to inform them of what is expected and provide notifications that violations will be treated as violations of standard company policy.

6.2.4 Training

Training should be considered the first step to keeping the job site safe, and makes it much more likely that employees follow company policy and standard safety policies since it is expected that they will have a complete understanding of the rules and guidelines presented. Supervisors should understand all of the following protocols so that they may instruct and enforce them to employees.

6.2.4.1 Workers on Foot

- Workers must be trained with the IITCP, and to recognize and avoid the hazards of working in dynamic work zones on foot around equipment. Examples of precautionary measures include not crossing directly in front of, or behind dump trucks or other equipment without direct contact and instruction from the operator.
- Workers should wear high visibility clothing, and make eye contact with heavy equipment and large truck operators before entering an area near the equipment or truck, as well as when standing in front or on the operator side of the vehicle if they must work in an area.
- Workers should be knowledgeable and properly trained in the tasks that they are required to do and should report to an officer if they do not feel their skills are sufficient to perform their tasks safely.

6.2.4.2 Spotters

- Should be assigned whenever backing maneuvers are regularly expected, and know how to understand and use hand signals to communicate with equipment operators and other workers in the work zone.
- Should be placed in a location where they are visible to equipment and vehicle operators, only directing one backing vehicle at a time.

6.2.4.3 Flaggers

- Must have the skills and knowledge to understand the traffic flow, the work zone setup, and proper placement of channelizing devices
- Shall be assigned an area to be responsible for monitoring operations, and should direct only traffic moving in one direction,
- Should be present when work is being performed on the sides of roadways normally open to the public, and in the event of multiple flaggers, should be trained to communicate effectively with one another by sight, or with two-way radios.
- Should be authorized to recommend to traffic control supervisors that operations be halted in his or her immediate work area.

6.2.4.4 Equipment Operators

- Must always use provided safety equipment such as safety belts when operating their equipment, and know how to react in work zone events such as a rollover.
- Must understand the IITCP as well as the workplaces current conditions to better reflect the movements that are safe for them to make.
- Operators must understand hand signals for use when communicating with workers on the ground, especially when in backing maneuvers, and while being directed by a spotter, operators should keep constant view of the spotter and if direct view is interrupted, the operator should stop to regain contact with the spotter.

- Equipment operators should be trained to check work areas for pedestrians, and if an equipment operator believes there is a possibility of pedestrian workers being in the area where they are making maneuvers, they must keep positive visual contact with these workers during the maneuver. If no spotter or visual backing aid is in use, equipment operators must exit their vehicle and walk around the back to ensure no pedestrian workers or obstructions are present.
- Horseplay should never be tolerated, and operators should never allow passengers on their vehicle without proper safety constraints in use e.g. safety belt.
- Operators should never move equipment without making positive visual contact with any workers on foot or near the equipment, and then blowing their horn twice to warn workers on site of their intention to back.
- Employers should perform pre-inspection checks to ensure that backup alarms, horns, and other safety equipment on construction machinery are functional and tested daily. Equipment that has nonfunctioning backup alarms, horns, or other safety equipment should be reported to the designated competent person, and should be removed from service until it is repaired.

6.3 Summary

After developing and reviewing guidelines, the recommendations were developed in this chapter. These recommendations included changes, and new policies in Engineering Controls, Administrative controls, and Technology controls as well as if the controls are integrated. These policies and changes are expected to greatly aid in the prevention of backing fatalities in construction work zones if executed properly.

Chapter 7. Development of Guidelines for Backing Fatalities Prevention System

7.1 Introduction

The purpose of the task in this chapter is to develop a set of guidelines for a backing fatalities prevention system from system selection to implementation. Each guideline is based on findings of previous tasks and feedback from TxDOT personnel. This chapter consists of guidelines for system selection and guidelines for system implementation.

7.2 Guidelines for System Selection

Chapter 4 described the system selection process. This section presents a finalized system selection process based on lessons learned through the project. Following is the recommended system selection process and each process will be explained in subsections. The project scope (enclosed in red dashed area in Figure 7.1) is limited to the activities from 'Identify Work Zone' to 'Controlled Test' and pilot test in the real work zones are recommended in the future.

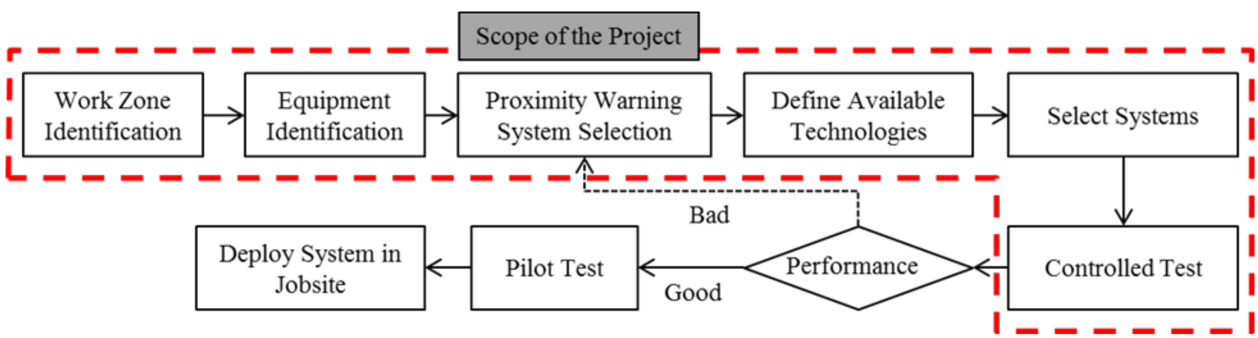


Figure 7.1 Process of System Selection

7.2.1 Work Zone Identification

Construction work zones are diverse and dynamic, and usually have different hazardous environments due to work types. For example, new highway construction, road repair, and building construction work zones require different types of equipment and pedestrian workers. According to the characteristics of jobsite, anticipated hazard zones will vary and different types of technologies should be applied to reflect specific jobsite conditions. In this project, we focused on typical road construction/repair work zones which might be useful for TxDOT.

7.2.2 Equipment Identification

Due to the various construction equipment characteristics, there is no panacea in terms of technology that will work for all types of construction equipment. For example, dump trucks and dozers have significantly different blind areas that require different criteria for a proximity warning system selection. Therefore, it is important to identify equipment types which systems will be installed. In this project, from accident analysis and blind area data analysis, pickup and dump trucks were selected, which are dominant in causing backing accidents and have the largest blind areas. Details of accidents and blind area analysis are described in section 4.4.1 Equipment Selection, Chapter 4.

7.2.3 Proximity Warning System Selection

Due to the rapidly changing sensing technology market, developing generic sensor selection criteria is important because the same process can be consistently used to select new sensing systems in the future when new technologies are developed. Our system selection process consists of two parts: identifying evaluation factors and defining thresholds for each factor. From section 4.4.2 Proximity Warning System Selection, Chapter 4, eight evaluation factors were identified, but these factors are partially modified based on lessons learned from the tests conducted. The following table shows the finalized evaluation factors, which should be considered in the future and justifications are provided in each subsection.

Table 7.1 Finalized Evaluation Factors

Evaluation Factors (Previous)	Evaluation Factors (Finalized)
Technology	Technology
For use in all weather	For use in dirty/rainy environment
Max. range of rear detection zone	Static detection zone
Response time	Response time (Dynamic detection range)
False-alarm rate in clear field	False-alarm rate in clear field
Cost	Cost
Level of effort in mounting	Installation Location
Camera as supplemental method	Camera as supplemental method

- *Technology*
  The term of technology seems to be general concept as an evaluation factor, but this evaluation factor determines many factors such as system operation principle, required components, and possibility of data collection. For example, RFID and GPS based systems required workers equipped with tags or other devices to be detected while radar, ultrasonic, and camera-based systems are able to directly detect objects (see section 4.2 Technology Review, Chapter 4). Because of implementation simplicity, radar and ultrasonic technologies are selected for both pickup and dump trucks.

- *For use in dirty/raining environment*
  Since 'For use in all weather' is too broad concept to test, this factor is modified to 'For use in dirty/rainy environment'. In response to recommendations from the previous a project management committee (PMC) meeting, two tests in realistic environments were considered, which are the dirty sensor test and the test with raining environments. From the dirty sensor test, we found that the detection performance of ultrasonic-based sensor system was significantly affected by soil covered on sensors while radar-based systems were not affected by dirt (see section 5.7 Dirty Sensor Test, Chapter 5). Therefore, it is highly recommended to consider for use in dirty environment before selecting the system. In case of the test with raining environment, the test failed to continue because of the possibility of electronic short with designed testbed. However, this factor should be tested and considered in future system selection.

- *Static detection zone*
  Static detection zone can be defined as the size of detection area when both a vehicle and an object are stationary. Static detection zone should be a diagram and three performance factors (maximum detection range, reliable/sporadic detection area, and capability to detect close proximity areas) must be identified. Also, because our static test results showed static detection zones are different at system installation heights, it is recommended to identify detection zone diagrams at specific heights where the system will be installed (see section 5.5 Static Test, Chapter 5). In terms of maximum detection range selection, we found that a trade-off exists between detection range and false/nuisance alarms. A sensor system with longer detection range generally has a wider detection range. As a result, a wider clear field is required to implement this system without false and nuisance alarms in the work zone (see section 6.1 Engineering and Technology Control, Chapter 6). From the Chapter 4, required maximum detection ranges were defined as 10 feet for pickup trucks and 20 feet for dump trucks based on literatures, but we found that both vehicles stopped within 10 feet when vehicles were backing at 3mph. Also, there were little stopping distance differences between two types of vehicles. Stopping distance can be defined as the combination of reaction distance and braking distance. In low speed reversing, operator's reaction time is critical factor than vehicle speed to determine stopping distance. Therefore, more investigation is recommended to determine system maximum detection range for both vehicle types.

- *Response time (Dynamic detection range)*
  Dynamic detection range can be defined as the maximum detection range of a sensor system when a vehicle is backing and an object is stationary or when both a vehicle and an object are moving. Dynamic detection range is shorter than maximum detection distance in static conditions because of system response time and vehicle speed. Since users cannot control the system response time, understanding this factor is critical to simulate dynamic detection range of the system with different vehicle's backing speeds. Since system response times provided from vendors are mostly tested in controlled indoor conditions, it is also recommended to measure systems response times in realistic conditions. According to the dynamic test, HCS-700 system (0.2 second response time, 9 feet maximum detection range in the static test) showed 1-foot detection range reduction while WorkZone system (0.5 second response time, 10 feet maximum detection range in the static test) resulted in 4 feet detection range reduction. Therefore, shorter system response time is recommended although ISO defined maximum system response time as 0.5 second within detection zone (see section 5.6 Dynamic Test, Chapter 5).

- *False-alarm rate in clear field*
  False alarm rate is an important factor because frequent false alarms might eventually make the operators ignore warnings from the systems. During the field test, only ultrasonic-based sensor system, HCS-700, generated a few false alarms and the other three radar-based systems did not generate false alarms.

- *Cost*
  In the economic perspective, cost criterion is a critical factor for the successful system implementation. Costs of selected sensor systems range from $409 to $1,769.50 without a camera system. Details of cost information can be found in section 5.3 Tested Proximity Warning Systems, Chapter 5.

- *Installation Location*
  'Level of effort in mounting' is somehow subjective factor and changed to 'Installation Location' based on findings from sensor installation review in Chapter 5. It is common practice that every construction equipment type has limited possible sensor installation locations and sensor installation height and angle are influential factors in detection performance of sensor systems. Also, in order to hang on sensors at the bottom of the dump bed, additional devices such as 'L' shaped bracket might be necessary. Therefore, it is important to identify proper sensor mounting positions and limitations with end users and vendors to evaluate practical mounting positions.

- *Camera as supplemental method*
  A camera enables to display the rear-view area of vehicles to operators via a cab-mounted monitor. The advantage of video camera is that this system is able to monitor the cause and exact location of obstacles, not just detecting the presence of obstacles. However, this system does not generate an alarm, so it is recommended as a supplemental method with other sensing technologies (Ruff 2000, Ruff 2001a). Most sensing systems we reviewed are able to be compatible with more than one camera systems. The use of video camera is highly recommended for dump trucks because an operator cannot see objects through the back mirror due to the dump bed.

7.2.4 Define Available Technologies

Sensing technologies are developing rapidly. In this project, we focus on commercially available systems designed for low speed backing maneuvering aids. Ten available systems identified in Section 4.4.2 of Chapter 4, with specific information based on eight evaluation factors.

7.2.5 Select Systems

Based on system selection process (PWS selection matrix) developed and available technologies (PWS list) collected, three systems were chosen as appropriate sensors for the pickup truck. Figure 7.2 describes how three sensors were selected and the others were discarded.

Systems	Preview		Guardian Alert	Sensor Vision	Hindsight 20-20			Buddy	AMT	Becker CAS
Model	Workzone	HighResolution		Ogden radar	HS-30 + CS-561	HS-100F + CS-561	HCS-700 (HS-345NL)		CAS-CAM /RF	CAS-430
Technology	Pulsed radar		Doppler radar	FMCW Radar	Pulsed Ultrasonic			Tag-based	Tag-based	Tag-based
Maximum length of rear detection zone	3m (10ft)	1.8 - 6m (6 – 20ft)	2.7 - 3.6m (9 – 12ft)	1.5 - 24m (5 – 78ft)	2.4m (8ft)	2.4m (8ft)	2.7m (9ft)	18m (60ft)	0 - 80m (0 – 260ft)	0 - 100m (0 – 328ft)
False-alarm rate in clear field	None		Frequent	None	None			None	None	None
Cost (*)	$659 ($1,985)	$766 ($2,093)	Below $2,000	Below $2,000	$266 ($586)	$130 ($489)	$409 ($806)	Between $2,000 and $10,000	Over $10,000	[illegible] ($60,000)
For use in all weather	Yes		Yes	Yes	Yes			Yes	Yes	Yes
Response time	0.50sec		NA	0.48sec	0.20sec			NA	0.30sec	0.25sec
Level of effort in mounting	4-6hours		Low	Specialist required	1hour			Medium	Medium	Specialist required (One day)
Camera as supplemental method	Optional		No	No	Optional			Optional	Yes	Optional
Note	Direct contact		[5]	[5] Not approved by FCC	Direct contact			[5]	[7] Not approved by FCC	Direct contact
			False Alarm Rates	FCC	Detection Zone			Tech. Cost	FCC	Cost

NOTE: (*) = cost including a camera system, NA = not available
FCC = Federal Communication Commissions

Figure 7.2 PWS Selection for Pickup Trucks

Sensor Vision and AMT systems were discarded because they have not been approved by the US federal Communication Commissions (FCC). Due to the technology and cost criteria, two tag-based systems, Buddy and Becker CAS, were discarded and HS-30 and HS-100F models were discarded due to the short rear detection zone. Also, Guardian Alert system was discarded because of frequent false alarm rates. As a result, WorkZone, HighResolution, and HCS-700 sensor systems were selected for the pickup truck.

Similarly for dump trucks, Sensor Vision and AMT systems were discarded because they have not been approved by the US federal Communication Commissions (FCC). Two tag-based systems, Buddy and Becker CAS, were discarded due to technology criteria. Because of rear detection zone criteria, 6 meters (19.7 feet) for dump truck, five models were discarded. As a result, only HighResolution was selected for dump trucks.

Based on PWS selection matrix and PWS list, three sensor models, WorkZone, HighResolution, and HCS-700, were selected for pickup trucks while only HighResolution sensor system was selected for dump trucks (see Figure 7.3). Details of each sensor system are found in section 5.3 Tested Proximity Warning Systems, Chapter 5.

Systems	Preview		Guardian Alert	Sensor Vision	Hindsight 20-20			Buddy	AMT	Becker CAS
Model	Workzone	HighResolution		Ogden radar	HS-30 + CS-561	HS-100F + CS-561	HCS-700 (HS-345NL)		CAS-CAM /RF	CAS-430
Technology	Pulsed radar		Doppler radar	FMCW Radar	Pulsed Ultrasonic			Tag-based	Tag-based	Tag-based
Maximum length of rear detection zone	3m (10ft)	1.8 - 6m (6 – 20ft)	2.7 - 3.6m (9 – 12ft)	1.5 - 24m (5 – 78ft)	2.4m (8ft)	2.4m (8ft)	2.7m (9ft)	18m (60ft)	0 - 80m (0 – 260ft)	0 - 100m (0 – 328ft)
False-alarm rate in clear field		None	[illegible]	None	None			None	None	None
Cost (*)	[illegible] **Detection Zone**	$766 ($2,093)	Below $2,000 **Detection Zone, False Alarm Rates**	Below $2,000 **FCC**	[illegible] ($585) **Detection Zone**	[illegible] ($489)	[illegible] ($806)	Between $5,000 and $10,000 **Tech.**	Over $10,000 **FCC**	Avg $45,000 [illegible] **Tech. Cost**
For use in all weather	Yes		Yes	Yes	Yes			Yes	Yes	Yes
Response time	0.50sec		NA	0.48sec	0.20sec			NA	0.30sec	0.25sec
Level of effort in mounting	4-6hours		Low	Specialist required	1hour			Medium	Medium	Specialist required (One day)
Camera as supplemental method	Optional		No	No	Optional			Optional	Yes	Optional
Note	Direct contact		[5]	[5] Not approved by FCC	Direct contact			[5]	[7] Not approved by FCC	Direct contact

NOTE: (*) = cost including a camera system, NA = not available
FCC = Federal Communication Commissions

Figure 7.3 PWS Selection for Dump Trucks

7.2.6 Controlled Test

In order to evaluate performance of sensor systems, testing systems in different conditions is an essential process in terms of the reliability of sensor systems. In this study, one experiment was conducted to evaluate proper sensor installation positions on the vehicles and three experiments (Static test, Dynamic test, and Dirty sensor test) were performed to assess the performance of sensor systems in different scenarios, which can commonly occur in construction work zones.

7.2.6.1 Sensor Installation Review

Sensor installation review is to consider proper sensor installation positions. Because each equipment type has different models with their own limited space for sensor installation, it is recommended to survey each of them. In order to consider both technical and practical issues, it is also recommended that sensor installation positions reviews be conducted with system vendors and practitioners who are closely related to construction vehicles.

7.2.6.2 Static Test

Static test reflects the vehicle operation condition which is before the vehicle is backing (i.e., both a vehicle and an obstacle are stationary). In this scenario, a sensor system can generate a maximum size of detection performance regardless of sensor response time and vehicle operation conditions. The detection area measured in the best condition serves as a benchmark for the dynamic test and dirty sensor test. Also, sensor detection performance at different installation locations measured from the sensor installation review tested. To assess the performance of sensor systems in the static conditions, the following factors were observed in the static test:

- *Reliable Detection Area:* This area indicates the detection coverage with more than 90% accuracy. This area will be used to determine overall detection capacity of the system.
- *Sporadic Detection Area:* This area indicates the detection coverage with less than 90% accuracy.
- *Close Proximity Detection*: This factor will evaluate sensor system's close proximity detection capability within 3 feet of vehicle and along the vehicle width.

Figure 7.4 illustrates an example of performance evaluation factors.

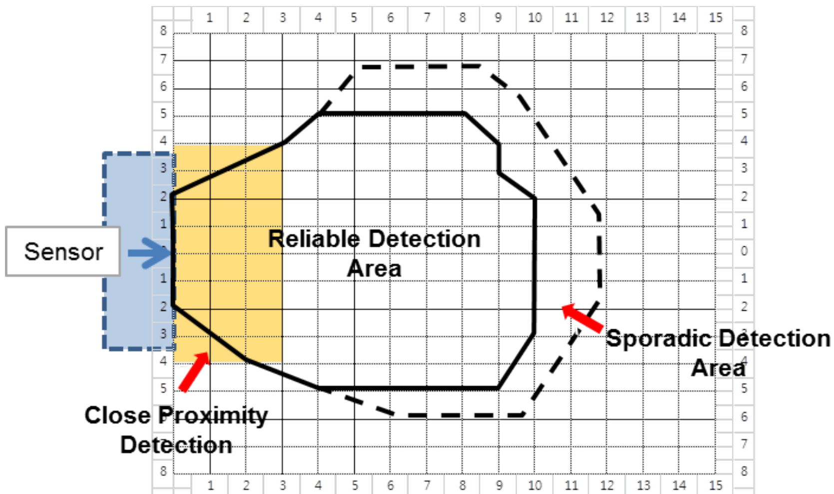


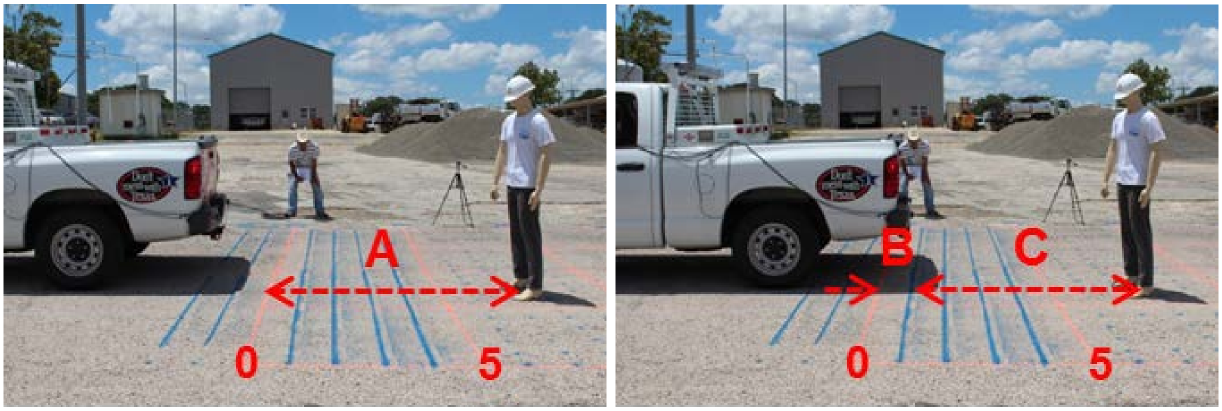
Figure 7.4 Example of Performance Evaluation Factors in the Static Test

7.2.6.3 Dynamic Test

During the dynamic test (see Figure 7.5), the dynamic detection ranges of sensor systems studied by placing sensor systems on moving equipment (i.e., a vehicle is backing and an obstacle is stationary). The impact of dynamic operation condition examined with possible environmental factors such as vehicle speed or sensor response time. Also, for safety reasons, a mannequin was used as a test object as opposed to a human. To access the performance of sensor systems in the dynamic conditions, the following performance evaluation factors were checked:

- *Dynamic detection range:* changed detection range due to the dynamic conditions of the vehicle. This changed detection ranges should be compared to maximum detection ranges in the static condition to see differences.

- *False alarm:* alarms generated in the clear field because the sensor might detect the ground or parts of vehicle such as tires during the backing operation.



Note: Distance A: Maximum detection range of the sensor in the static condition
Distance B: Reduced distance due to the dynamic condition
Distance C: Dynamic detection range of the sensor in the dynamic condition

Figure 7.5 Basic Procedure of the Dynamic Test

7.2.6.4 Dirty Sensor Test

Due to the nature of construction work zones, sensor systems are likely to be covered in dirt, mud, or other materials at some point in the construction process. Since ultrasonic and radar-based sensor systems use signals to detect objects, any materials covering sensors might impact the detection performance of the sensor systems by interrupting the process of emitting and receiving signals. The dirty sensor test was designed to evaluate the impact of dirt on sensor systems related to their detection performance.

7.2.7 Pilot Test

For the final verification of system implementation feasibility, a pilot test in an active work zone should be conducted prior to deployment of the system in the large scale. Even though a pilot test was not conducted in this research project, it is highly recommended because more practical implementation challenges might be identified during a pilot test. Any findings from a pilot test need to be reported to update system selection process and controlled test. It is recommended that a Pilot Test be developed as part of a follow-on Implementation Project with TxDOT.

7.2.8 Deploy System in Jobsite

Based on the results of controlled and pilot tests, the sensing system can be deployed in the jobsite in the large scale. Prior to actual implementation of the system, all users should be properly educated about the systems and specific guidelines should be provided.

7.3 Guidelines for System Implementation

Development of system implementation guidelines should be developed from lessons learned of controlled and pilot tests. Also, close cooperation with vendors and end users is recommended. Since pilot test was not conducted in this project, this guideline is developed mostly based on findings from controlled test conducted and communications with vendors. However, further modification of this guideline is highly recommended after pilot test to present more practical guideline. The guidelines for system implementation are divided into general guidelines and guidelines for development of integrated internal traffic control plans.

7.3.1 General Implementation Guidelines

The following guidelines are based on the findings from the controlled tests. To complete general implementation guidelines, lessons learned from pilot test and opinions from vendors are highly recommended. General implementation guidelines consist of installation, education/training, and daily check list.

7.3.1.1 Installation

Installation guidelines should be developed to aid in maintenance personnel who will install systems on TxDOT vehicles. Since each equipment type has its own limited space for sensor installation and installation heights will affect system detection performance, careful efforts are required. In order to consider both technical and practical issues, it is also recommended that sensor installation positions should be determined with system vendors and practitioners who are closely related to construction vehicles. Following are the key findings:

- *Sensing systems should be installed above 12 inches high, measured from the ground.*

  Installing sensors at or below 12 inches high detected the ground frequently and generated unnecessary alarms. If mounting at or below 12 inches high on the vehicle is required, we recommend that sensors be tilted upward to avoid detecting the ground.

- *For pickup trucks, systems composed of double sensors are recommended.*

  Our findings indicate that single sensor systems have limitations when installing on the rear of the pickup trucks because of the tailgate, license plate, and trailer hitch. Any other installations off the middle will generate asymmetric detection zone in the perspective of operators and might result in confusion of actual detection zone.

7.3.1.2 Education/Training

Guidelines and expectations should be presented to workers during safety meetings to inform them of what is expected and provide general understandings of systems implemented. Even though most sensing systems will generate alarms to operators in the cab except for active RFID systems, other workers including workers on foot, spotters, and flaggers should be trained for successful implementation. During the education/training session, at least the following should be presented.

- *Benefits of sensing system implementation*

  Effective understandings of benefits of system implementation will increase end users' reliability toward systems. Real world cases and any statistic results which describe the benefits of the sensing systems will be effective for this purpose.

- *General information of the system*

  General information of the system should at least include system operational principle and when the system is activated to provide better understandings of the system implementation.

- *Detection diagram of the system*

  Understanding of system detection zone is one of the key points all workers should be aware of. All users related to system implementation have to carefully understand where will be detected and where won't be detected by the systems. Our static test results show that sensor systems tested have different limitations to detect close proximity areas. Excessive belief on the technology will result in unexpected accidents.

- *Expected detection range difference between static and dynamic conditions*

  Common misunderstanding about the sensor system detection zone is that the static maximum detection range of the system will be maintained when a vehicle is moving because people believe that the signals are too fast to effect on detection range changes. However, the dynamic test results showed that dynamic detection ranges were reduced up to 4 feet comparing static test results when vehicles were backing 3mph. Therefore, thorough education/training are required to make users understand the realistic detection zones in static and dynamic conditions.

7.3.1.3 Daily Checklist

Most sensor systems provide self-test capabilities and failure indication (ISO, 2010). Typical self-tests include electronic circuit and wiring test, which check the function of the electronic components, and sensor components test which check whether there is any damage to the sensor elements. In addition, some manual checks are required by end users, such as cleanness of the system, availability of power source, and stability of sensors installed.

7.3.2 Guidelines for Development of Integrated Internal Traffic Control Plans (Chapter 6)

The guideline for Integrated Internal Traffic Control Plan (IITCP) shall be designed to reflect jobsite and technology-specific because the characteristics of work zones and technologies are dynamic. The following are general guidelines and recommendations for IITCP development.

- *The width of sensor detection zone should not exceed 10 feet for work zones on the shoulder or one lane closures.*

  In terms of sensor's detection coverage, characteristics of jobsites should be considered before selecting sensor systems. A trade-off exists between detection range and false alarms. A sensor system with longer detection range generally has a wider detection range. As a result, a wider clear field is required to implement this system without false and nuisance alarms in the work zone. If the sensor systems with wider detection coverage (more than 10 feet) are used in a relatively narrow jobsite such as one lane closures, the sensors will detect traffic cones or other fixed objects (personal vehicles parked or materials) and generate unnecessary false alarms. These kinds of false alarms will make operators distrust the sensor systems and ignore alarms. For jobsites in areas such as two-lane closures or new highway construction, longer and wider detection sensor systems might be more effective if enough clear backing area is secured.

- *When multiple vehicles are in a wait area, idling close to one another, only the ready-to-back-up vehicle should set its gear in reverse.*

  In the idling zone, if multiple vehicles activate sensor system by setting their gears in reverse, sensors will detect the other vehicles behind them and generate false alarms. This kind of false alarm makes operators ignore alarms and create other accident possibilities such as backing on a worker who is between two vehicles. Also, the second vehicle should back up only after the first vehicle leaves the work zone.

- *Equipment only area (backing path) in the work zone should be clear field.*

  As well as minimizing false alarms by detecting fixed objects while backing up, backing path should be clear enough to secure clear line-of-sight between an operator and a spotter. If the line-of-sight between an operator and a spotter is too long or blocked by fixed objects such as personal vehicles or materials, positioning of multiple spotters is recommended.

- *Spotters and idle workers should stay on the opposite side of roadway traffic.*
- *While a vehicle is loading or dumping, it is recommended to change its gear into neutral to avoid unnecessary alarms between the vehicle and other equipment.*

7.4 Summary

The development of guidelines to follow in construction work zones can be of great benefit in preventing backing fatalities. In selecting a system that would be the best fit for a particular scenario, it was found the steps to follow were to identify the characteristics of the work zone, identify equipment that could be of use, select the proximity warning system, define available technologies, select suitable systems, use controlled testing, review the sensor installation requirements, conduct static and dynamic testing, conduct pilot testing and finally deploy the system in the jobsite. Once the proper systems have been selected for use it is important to understand the most efficient manner for implementing the systems in the field. Installation guidelines should be developed to ensure the systems are installed at the ideal locations on each vehicle to ensure they work in the proper order. For pickup trucks, systems composed of double sensors are recommended. Education and training should be conducted on the systems at use to give workers a better understanding of how the systems can benefit and how they are most efficiently used. Daily checklists should be conducted to ensure proper functionality of the detection systems. Guidelines for integrated internal traffic control plans should be developed, and how to best set up work zones to make the most out of the technology at use, giving workers the best protection.

Chapter 8. Summary and Conclusions

8.1 Introduction

According to Zeyher (2007), between 70 and 80 pedestrian construction workers are struck and killed each year by construction vehicles within a work zone. The American Road & Transportation Builders association named run-overs and back-overs as the leading cause of death for roadway construction workers. While already possessing the risk of highway traffic errantly entering into the work zone and striking workers, factoring in the risks of being struck by construction equipment within the work zone, make construction work an extremely dangerous job.

The primary function of this report is to review current practices and procedures for preventing backing fatalities, identify and analyze appropriate responses, and test commercially available systems that can aid in the prevention of backing fatalities. The report works to present TxDOT with guidelines that were developed from the research conducted in hopes of creating a safer work zone.

The rest of this chapter is organized as follows. Section 8.2 provides a brief review of the conclusions made throughout the research and notes how safety zones can be improved. Section 8.3 details the directions that should be taken in future research in order to continue to improve safety work zones and prevent backing fatalities.

8.2 Summary and Conclusions

After a comprehensive literature review and synthesis of current and historic research, the sections were developed. It was found that among the methods of preventing backing fatalities, three specific methods could greatly reduce the likelihood of a backing fatality. These methods include modified Engineering Controls, Administrative Controls, and Technology controls, as well as the integration of the three controls. An in-depth look at each control and their components was conducted, and how they can affect safety within a work zone.

Technology controls were reviewed in great detail using developed criteria based on the primary factors of 'For use in all weather', 'Response time', 'Technology', Camera as supplemental method', 'Cost', 'Level of effort in mounting', 'Maximum range of rear detection zone', and 'False-alarm rate in clear field'. Using this criterion, suitable systems for pickup trucks, and dump trucks were selected, and compared using tables, and validation for reassurance purposes. Once suitable systems were found, different testing for these systems was conducted such as tests of 1) Sensor installation; 2) Static test; 3) Dynamic test; and 4) Dirty sensor test. Based on the test results, suggestions for TxDOT Traffic Control Practices were developed, incorporating commercially available systems with engineering and administrative controls.

It was found that for pickups, a dual sensor system is the most suitable system being that it can have a sensor located on each side of the bumper where a single sensor system does not have an ideal mounting location due to the working tailgate, and license plate. An example of this system was the HCS-700, which is an ultrasonic-based sensor system using low frequency sound waves with a 9-feet detection range. For dump trucks a single sensor system is effective being the system can be mounted in the middle of the bed at the bottom. The WorkSight system was found to be a good example which is a radar-based system using high frequency pulsed radar signals to detect objects within a detection zone with a 20-feet maximum range. Being that no single control is completely effective, it is important to consider grouping the different types of controls for the most effective method of preventing backing fatalities. Developing internal traffic control plans considering the technology at hand & its capabilities allows for the most efficient work zone to be developed incorporating the use of the sensors to best detect workers around the equipment. Integrating technology controls along with site planning (i.e., internal traffic control plans), and training can greatly reduce the risk of fatal construction accidents especially caused by backing.

After reviewing appropriate responses based off of prior research, the recommendations section of this report was composed. Changes in engineering controls such as the improvement of traffic control plans as well as using more specific notes and procedures have been noted. Changes in administrative controls such as enforcing a safety officer to conduct safety meetings, and more stringent training policies for all workers have been made. After developing and reviewing recommendations that were presented, the guidelines section was developed. These policies and changes are believed to greatly aid in the prevention of backing fatalities in construction work zones if executed properly. It has been found that no single control is completely effective but that coupling multiple controls together is the most efficient with the best results.

8.3 Directions for Future Research

As technology is improved, there should be a continuous effort made to find the most suitable technologies for construction work zones to provide workers with the safest place to work possible. As the guidelines presented in this report are given to TxDOT, future implementation into the field should be reviewed to find the most effective way of applying these to the work zone. Efforts to improve training and communication can also be made being that more experienced workers with a better understanding of the work zone will make for a much safer work zone environment.

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Appendix A: Development of Guidelines for Backing Fatalities Prevention System

A.1 Introduction

The purpose of the task in this appendix is to develop a set of guidelines for a backing fatalities prevention system from Engineering, Technology, and Administrative controls to system selection and implementation. Each guideline is based on findings of previous tasks and feedback from TxDOT personnel. This chapter consists of guidelines for Engineering controls, Technology controls, Administrative controls, system selection and guidelines for system implementation.

A.2 Guidelines for Engineering and Technology Controls

Internal Traffic Control Plans (ITCP) shall be designed to include buffer zones to keep public and workers away from trucks/equipment within the work zone as well as to keep the length of the work zone appropriate to the work in progress. The ITCP should direct the movement of workers and equipment in a work zone reducing the need for backing. The ITCP should include designated worker-only and pedestrian-free zones. The ITCP can be changed throughout project progression by the safety officer or competent person, with the changes being communicated to all other personnel on the work site. Up to date safety concerns should be discussed with workers at least once per shift, keeping a hierarchical approach to prevention of worker injuries.

The Integrated Internal Traffic Control Plans (IITCP) incorporates ITCP with sensing technology implementation to improve vehicle-related safety practices in the work zone. Based on ITCP, IITCP shall be designed including important guidelines and recommendations when sensing technology is applied on jobsites. An IITCP should contain a traffic control diagram, a legend explaining this diagram, and notes explaining the details of the diagram, work zone, and technology implementation. The creation of the IITCP should involve:

1. Reviewing the contracts and model plan for the project, deciding the sequence of events in the project, and then creating a basic design for the work zone designating storage utility, and staging areas.
2. Designing vehicle and pedestrian paths throughout the work zone, and then creating the IITCP notes containing all information to give an accurate representation of the flow within the IITCP.
3. Explaining technology guidelines for effective implementation of new technology.

Similarly to guidelines of ITCP, the guideline of IITCP shall be designed to reflect jobsite and technology-specific because the characteristics of work zones and technologies are dynamic. The following are general guidelines and recommendations for IITCP development.

- *Sensing systems should be installed above 12 inches high, measured from the ground.*

  Findings from the Chapter 5 show that installing sensors at or below 12 inches high detected the ground frequently and generated false alarms. If it is inevitable mounting sensors at or below 12 inches high on the vehicle, it is recommended that sensors should be tilted upward to avoid the detection of ground.

- *The width of sensor detection zone should not exceed 10 feet for work zones on the shoulder or one lane closures.*

  In terms of sensor's detection coverage, characteristics of jobsites should be considered before selecting sensor systems. A trade-off exists between detection range and false alarms. A sensor system with longer detection range generally has a wider detection range. As a result, a wider clear field is required to implement this system without false and nuisance alarms in the work zone. If sensor systems with wider detection coverage (more than 10 feet) are used in a relatively narrow jobsite such as one lane closures, the sensors will detect traffic cones or other fixed objects (personal vehicles parked or materials) and generate unnecessary false alarms. These kinds of false alarms will make operators distrust the sensor systems and ignore alarms. For jobsites such as two lanes closures or new highway construction, longer and wider detection sensor systems might be more effective if enough clear backing area is secured.

- *When multiple vehicles are in a wait area idling close to one another, only the ready-to-back-up vehicle should set its gear in reverse.*

  In the idling zone, if multiple vehicles activate sensor system by setting their gears in reverse, sensors will detect the other vehicles behind them and generate false alarms. This kind of false alarm will make operators indifferent to the alarm system and create other accident possibilities such as backing on a worker who is between two vehicles. Also, the second vehicle should back up only after the first vehicle leaves the work zone.

- *Equipment only area (backing path) in the work zone should be clear field.*

  As well as minimizing false alarms by detecting fixed objects while backing up, backing path should be clear enough to secure clear line-of-sight between an operator and a spotter. If the line-of-sight between an operator and a spotter is too long or blocked by fixed objects such as personal vehicles or materials, positioning of multiple spotters is recommended.

- *Spotters and idle workers should stay on the opposite side of roadway traffic.*

  Workers should make it a point to stay clear of construction vehicles for their own safety. They should not rely on the operators of the vehicles to yield for them and should always be on the lookout for trucks and machinery.

- *While a vehicle is loading or dumping, it is recommended to change its gear into neutral to avoid unnecessary alarms between the vehicle and other equipment.*

Except for general guidelines described above, jobsite-specific guidelines should be developed and workers should be educated before they enter the jobsite.

A.2.1 Integrated Internal Traffic Control Plan Diagram

The IITCP diagram should contain detailed schematic diagrams with illustrations for all paving trenching, and dirt spread operations depicting the movement of construction workers and vehicles within the work space, allowing workers and vehicles to enter and leave the work zone safely. The diagrams should be modified to assure compatibility with the overall ITCP and to address site-specific conditions.

Figure A.1 is an example of IITCP developed based on a TxDOT Traffic Control Plan Standard. The left side diagram is the original TxDOT Traffic Control Plan Standard (TPC 1-4b) and the right diagram is the IITCP diagram developed from the TPC 1-4b with the integration of HCS-700 system which has 9 by 10 feet detection coverage. For better illustration, specific dimensions described in TPC 1-4b are omitted in the IITCP diagram. As can be seen, the IITCP contains a diagram, general and technology notes, and legend explaining the diagram. In the diagram, all necessary signs shall meet designated specifications and be used in the appointed locations to better conduct movement and actions throughout the plan. Also, the diagram includes vehicle entering and leaving area, positioning of flaggers and spotters, sensor detection size, equipment only area, and pedestrian only area. The general notes provide an understanding of the principles of the traffic control zone and direct movements. The notes shall include a description of designated worker, pedestrian areas, and a spotter to direct backing movements. The technology notes explain general guidelines for effective technology implementation.

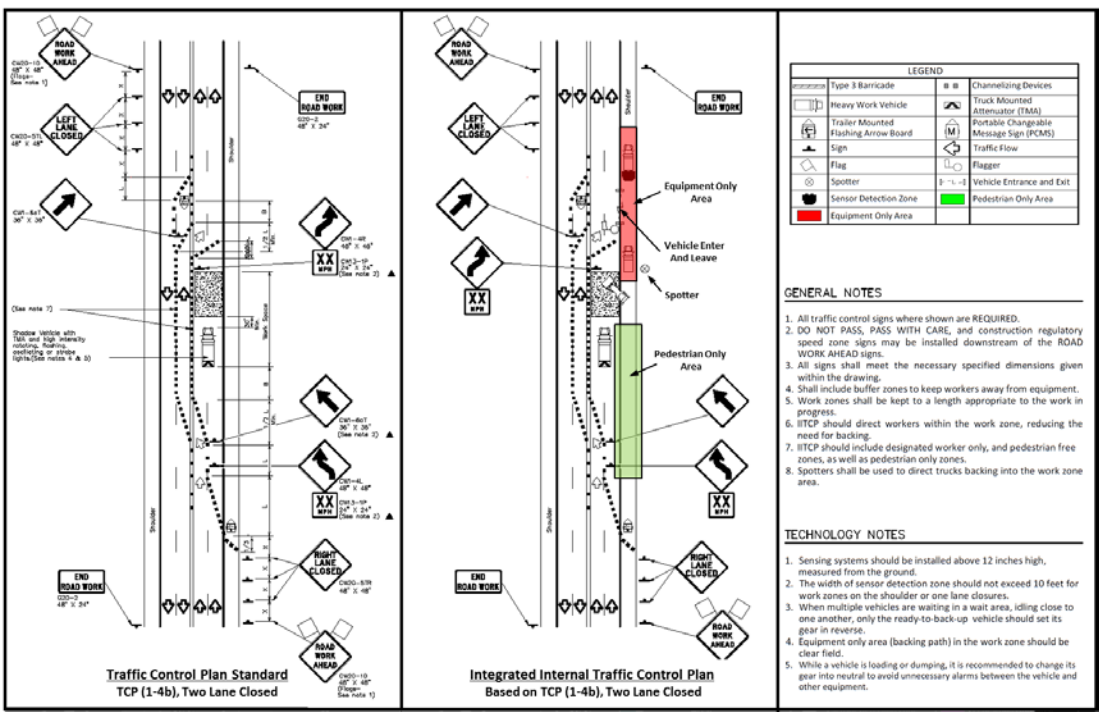


Figure A.1 A Sample of Integrated and Internal Traffic Control Plan Based on TCP Standard (1-4b)

In order to provide a better understanding of IITCP in the work zone, detailed diagrams are provided, which represent five equipment related jobsite scenarios: Vehicle Entering, Vehicle Idling, Vehicle Backing, Vehicle Loading or Dumping, and Vehicle Exiting.

Figure A.2 shows where a vehicle enters at the pre-determined area. The entering area of the work zone should be noted before the vehicle arrives at the work zone. Also, a flagger is needed to maintain smooth traffic flow and a spotter should be ready to guide the vehicle.

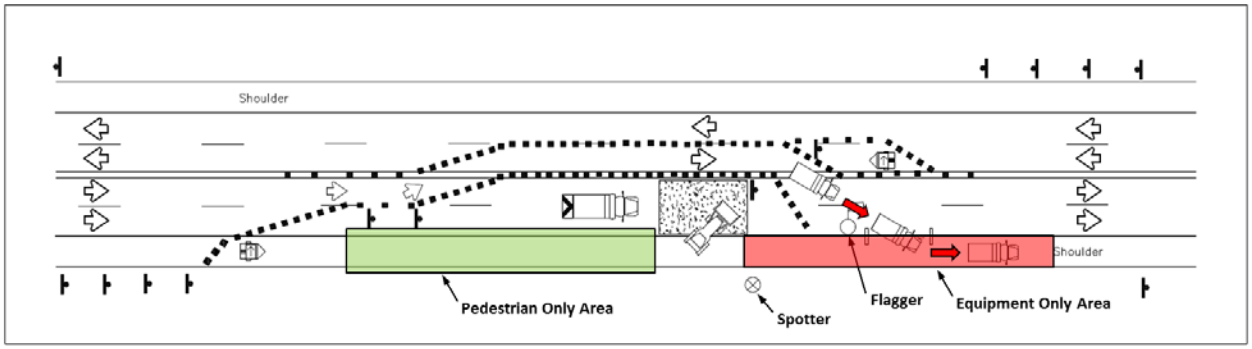


Figure A.2 Detailed IITCP Diagram 1: Vehicle Entering

Figures A.3 and A.4 illustrate when vehicles are waiting in the idle zone. Figure A.3 shows when HCS-700 system (9 by 10 feet detection coverage) is used on the vehicle and Figure A.4 shows when WorkSight system (20 by 18 feet detection coverage) is used on the vehicle. As shown in Figure A.4, the WorkSight system is not effective in this work zone because its wider detection coverage will detect traffic cones or other fixed objects around the work zone and will trigger false alarms. All vehicles should stay in the equipment only area and make sure line-of-sight between a spotter and a driver is secured. When multiple vehicles are waiting in the idle zone, Dump Truck 1 should set reverse gear and Dump Truck 2 should be set to neutral gear to avoid false alarms by detecting a vehicle behind it.

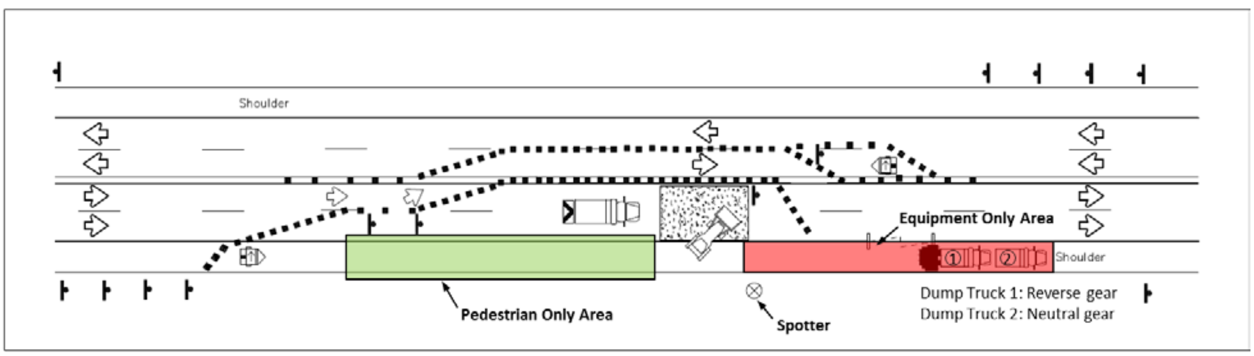


Figure A.3 Detailed IITCP Diagram II: Vehicle Idling with HCS-700 System

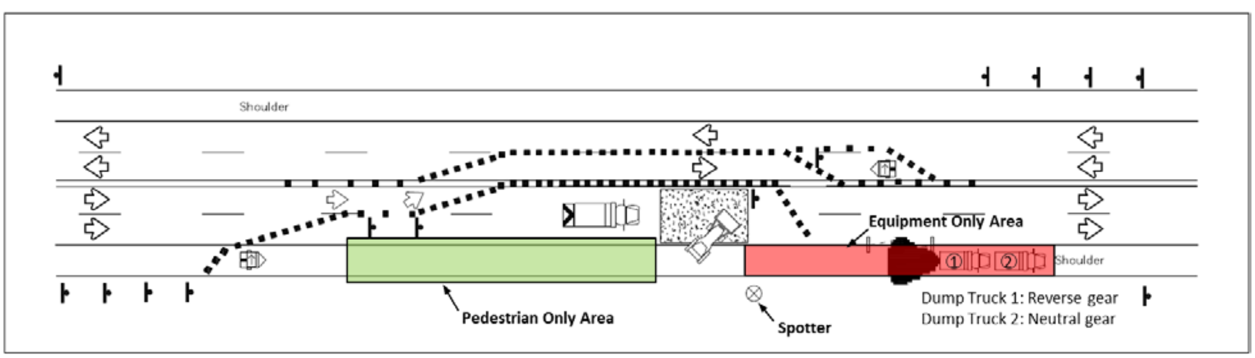


Figure A.4 Detailed IITCP Diagram II: Vehicle Idling with WorkSight System

Figure A.5 shows when a vehicle is backing up. Before the vehicle backs up, two things should be double checked: clear backing path and clear line-of-sight between a spotter and a driver. If the line-of-sight between an operator and a spotter is too long or blocked by fixed objects such as personal vehicles or materials, positioning of multiple spotters and special monitoring are recommended. Figure A.6 illustrates the scenario where a parked personal vehicle is blocking communication between a spotter and a driver. In this scenario, there can be a potential accident between a backing vehicle and a worker walking into the dangerous area from behind the fixed object, which is a vehicle parked. To avoid this accident scenario, an additional spotter and special care of dangerous area are recommended.

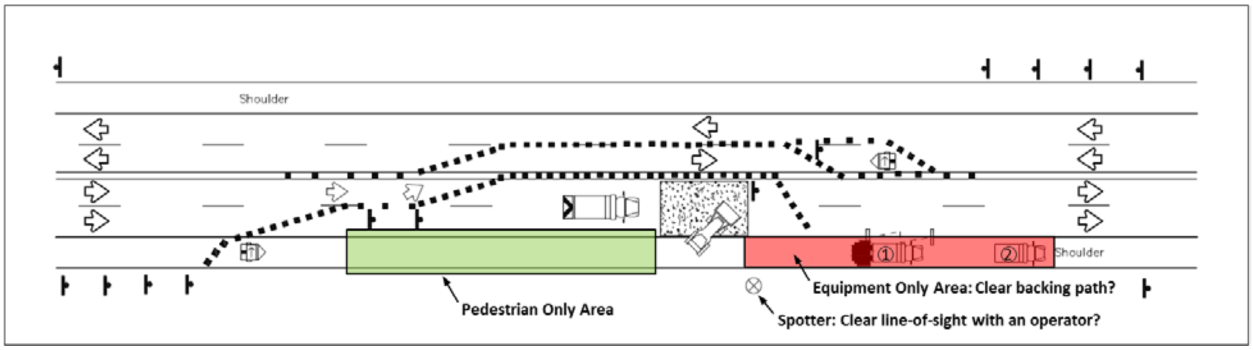


Figure A.5 Detailed IITCP Diagram III: Vehicle Backing

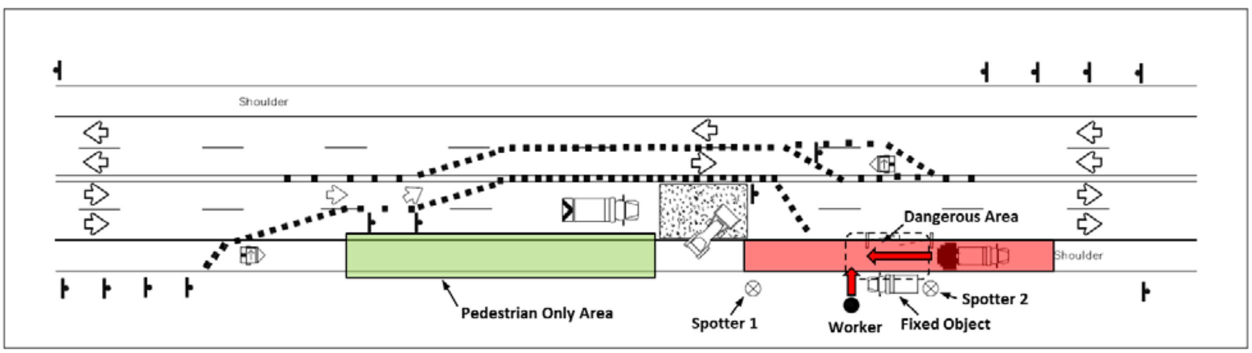


Figure A.6 Detailed IITCP Diagram III: Vehicle Backing with Fixed Object

Figure A.7 describes when a vehicle is loading or dumping. To avoid unnecessary alarms between the vehicle and other equipment, it is recommended to change Dump Truck 1's gear into neutral while the vehicle is loading or dumping.

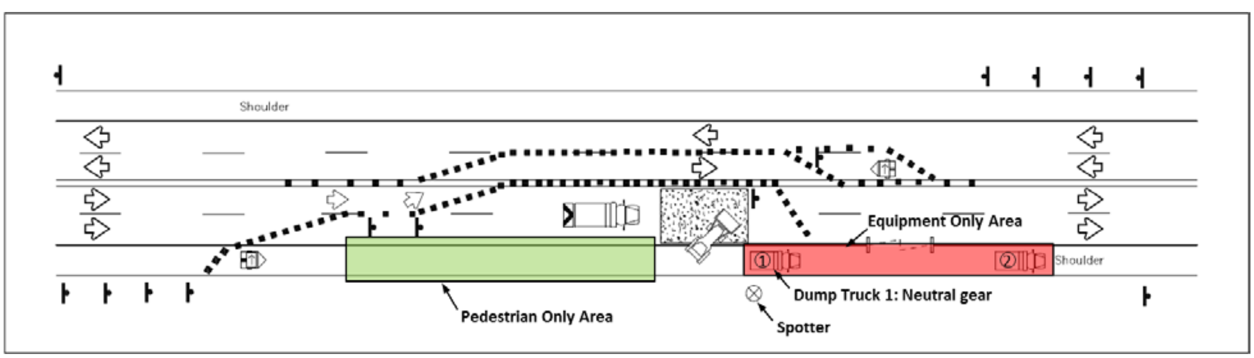


Figure A.7 Detailed IITCP Diagram IV: Vehicle Loading or Dumping

Figure A.8 shows the scenario of leaving a vehicle at the pre-determined area. Similarly to a vehicle entering scenario (Figure A.2), a flagger is needed to maintain smooth traffic and safe vehicle exit from the work zone. To avoid a possible accident between Dump Truck 1 leaving and Dump Truck 2 reversing, Dump Truck 2 should reverse after Dump Truck 1 has completely left the work zone.

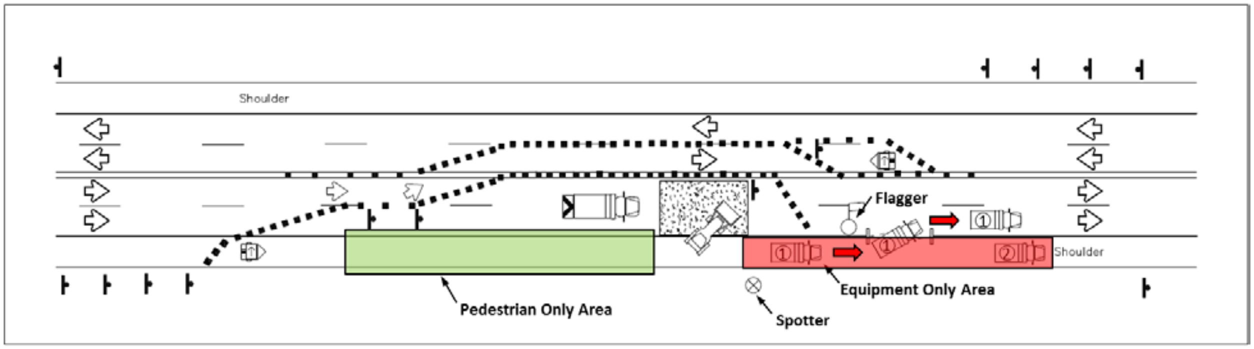


Figure A.8 Detailed IITCP Diagram V: Vehicle Exiting the Work Zone

A.2.2 Integrated Internal Traffic Control Plan Legend

The legend should clearly label all parts of a traffic control plan diagram including heavy equipment paths, pedestrian free and backing free zones. Some of the movements and objects that are represented by symbols include the following:

- Lights, and Channelizing devices
- Barriers
- Direction of Highway Traffic, and Traffic within the work zone
- Sign Locations
- Worker Locations, with a different symbol for each worker
- Different Equipment within the work zones
- Sensor system detection coverage

Figure A.9 shows the legend used in the IITCP we developed. From Type 3 Barricade to Flagger are existing legend in the TPC 1-4b and we added five symbols, which are Spotter, Vehicle Entrance and Exit, Sensor Detection Zone, Pedestrian Only Area, and Equipment Only Area, to develop IITCP.

LEGEND			
	Type 3 Barricade		Channelizing Devices
	Heavy Work Vehicle		Truck Mounted Attenuator (TMA)
	Trailer Mounted Flashing Arrow Board		Portable Changeable Message Sign (PCMS)
	Sign		Traffic Flow
	Flag		Flagger
	Spotter		Vehicle Entrance and Exit
	Sensor Detection Zone		Pedestrian Only Area
	Equipment Only Area		

Figure A.9 A Sample of Legend Based on TPC 1-4B

A.2.3 Integrated Internal Traffic Control Plan Notes

The IITCP notes consist of general notes and technology notes. General notes should contain site-specific safety measures, and contractor duties in reference to safety. Safety points should be clearly depicted such as pedestrian free zones, buffer zones, safety meeting frequencies, truck arrival times, and internal speed limits for the work zone. Technology notes should contain general guidelines and recommendations for effective technology implementation. Notes should be frequently updated to reflect changes in working conditions throughout the project. The following are general as well as technology notes used in the IITCP we developed.

General Notes

- All traffic control signs where shown are REQUIRED.
- DO NOT PASS, PASS WITH CARE, and construction regulatory speed zone signs may be installed downstream of the ROAD WORK AHEAD signs.
- All signs shall meet the necessary specified dimensions given within the drawing.
- Shall include buffer zones to keep workers away from equipment.
- Work zones shall be kept to a length appropriate to the work in progress.
- IITCP should direct workers within the work zone, reducing the need for backing.
- IITCP should include designated worker only, and pedestrian free zones, as well as pedestrian only zones.
- Spotters shall be used to direct trucks backing into the work zone area.

Technology Notes

- Sensing systems should be installed above 12 inches high, measured from the ground.
- The width of sensor detection zone should not exceed 10 feet for work zones on the shoulder or one lane closures.
- When multiple vehicles are waiting in a wait area, idling close to one another, only the ready-to-back-up vehicle should set its gear in reverse.
- Equipment only area (backing path) in the work zone should be clear field.
- While a vehicle is loading or dumping, it is recommended to change its gear into neutral to avoid unnecessary alarms between the vehicle and other equipment.

A.3 Guidelines for Administrative Controls

This section discusses the recommendations based on Administrative Controls. These include safety meetings, the use of safety officers, the implementation of regulations and guidelines, and the proper training of employees.

A.3.1 Safety Meetings

Preconstruction safety meetings should take place every day in order to remind workers of changing conditions in the work zone which can affect their safety. All key players over a work site should be present during the meetings, to insure the cohesion to the IITCP notes, ensuring all workers, including contract workers, understand the job taking place and are in consensus on how the work zone will be set up.

A.3.2 Safety Officers

Every work zone should be assigned a traffic control supervisor who is knowledgeable on the type of project at hand. The supervisor should possess the ability to halt work in the instance of unsafe conditions and should carry out tasks such as coordination at the work site, determining traffic routes within the work zone, documenting hazards and how they were mitigated, and maintaining multiple lines of communication. The safety officer and work-zone supervisors should review the Traffic Control Plan and decide on how to demarcate traffic routes within the work zone and include a plan for communicating between vehicle operators and workers-on-foot.

A.3.3 Regulations & Guidelines for Workers

Guidelines and expectations should be presented to workers during safety meetings to inform them of what is expected and provide notifications that violations will be treated as violations of standard company policy.

A.3.4 Training

Training should be considered the first step to keeping the job site safe, as training makes it much more likely that employees follow company policy and standard safety policies, as the workers should then have a complete understanding of the rules and guidelines presented. Supervisors should understand all of the following protocols so that they may instruct and enforce them to employees.

A.3.4.1 Workers on Foot

- Workers must be trained with the IITCP, and to recognize and avoid the hazards of working in dynamic work zones on foot around equipment. Examples of precautionary measures include not crossing directly in front of, or behind dump trucks or other equipment without direct contact and instruction from the operator.
- Workers should wear high visibility clothing, and make eye contact with heavy equipment and large truck operators before entering an area near the equipment or truck, as well as when standing in front or on the operator side of the vehicle if they must work in an area.
- Workers should be knowledgeable and properly trained in the tasks that they are required to do and should report to an officer if they do not feel their skills are sufficient to perform their tasks safely.

A.3.4.2 Spotters

- Should be assigned whenever backing maneuvers are regularly expected, and know how to understand and use hand signals to communicate with equipment operators and other workers in the work zone.
- Should be placed in a location where they are visible to equipment and vehicle operators, only directing one backing vehicle at a time.

A.3.4.3 Flaggers

- Must have the skills and knowledge to understand the traffic flow, the work zone setup, and proper placement of channelizing devices
- Shall be assigned an area to be responsible for monitoring operations, and should direct only traffic moving in one direction,
- Should be present when work is being performed on the sides of roadways normally open to the public, and in the event of multiple flaggers, should be trained to communicate effectively with one another by sight, or with two-way radios.
- Should be authorized to recommend to traffic control supervisors that operations be halted in his or her immediate work area.

A.3.4.4 Equipment Operators

- Must always use provided safety equipment such as safety belts when operating their equipment and know how to react in work zone events such as a rollover.

- Must understand the IITCP as well as the workplaces current conditions to better reflect the movements that are safe for them to make.
- Operators must understand hand signals for use when communicating with workers on the ground, especially when in backing maneuvers, and while being directed by a spotter, operators should keep constant view of the spotter and if direct view is interrupted, the operator should stop to regain contact with the spotter.
- Equipment operators should be trained to check work areas for pedestrians, and if an equipment operator believes there is a possibility of pedestrian workers being in the area where they are making maneuvers, they must keep positive visual contact with these workers during the maneuver. If no spotter or visual backing aid is in use, equipment operators must exit their vehicle and walk around the back to ensure no pedestrian workers or obstructions are present.
- Horseplay should never be tolerated, and operators should never allow passengers on their vehicle without proper safety constraints in use e.g. safety belt.
- Operators should never move equipment without making positive visual contact with any workers on foot or near the equipment, and then blowing their horn twice to warn workers on site of their intention to back.
- Employers should perform pre-inspection checks to ensure that backup alarms, horns, and other safety equipment on construction machinery are functional and tested daily. Equipment that has nonfunctioning backup alarms, horns, or other safety equipment should be reported to the designated competent person, and be removed from service until it is repaired.

A.4 Guidelines for System Selection

Chapter 4 described the initial system selection process. This section presents a finalized system selection process based on lessons learned through the project. Following is the recommended system selection process and each process will be explained in subsections. The project scope (enclosed in red dashed area in Figure A.10) is limited to the activities from 'Identify Work Zone' to 'Controlled Test' and pilot test in the real work zones are recommended in the future.

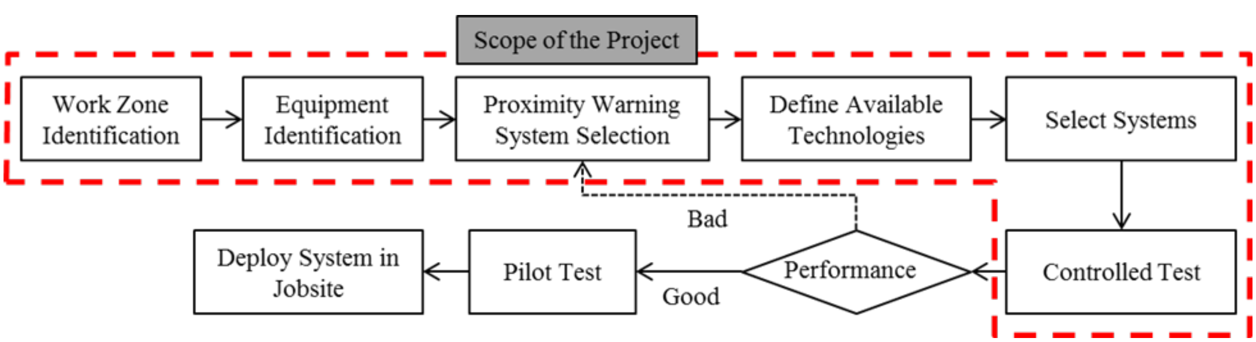


Figure A.10 Process of System Selection

A.4.1 Work Zone Identification

Construction work zones are diverse and dynamic, and usually have different hazardous environments due to work types. For example, new highway construction, road repair, and building construction work zones require different types of equipment and pedestrian workers. According to the characteristics of the jobsite, anticipated hazard zones will vary and different types of technologies should be applied to reflect specific jobsite conditions. In this project, we focused on typical road construction/repair work zones which might be useful for TxDOT.

A.4.2 Equipment Identification

Due to the various construction equipment characteristics, there is no panacea in terms of technology that will work for all types of construction equipment. For example, dump trucks and dozers have significantly different blind areas that require different criteria for a proximity warning system selection. Therefore, it is important to identify equipment types which systems will be installed. In this project, from accident analysis and blind area data analysis, pickup and dump trucks were selected, which are dominant in causing backing accidents and have the largest blind areas. Details of accidents and blind area analysis are described in section 4.4.1 Equipment Selection, Chapter 4.

A.4.3 Proximity Warning System Selection

Due to the rapidly changing sensing technology market, developing generic sensor selection criteria is important because the same process can be consistently used to select new sensing systems in the future when new technologies are developed. Our system selection process consists of two parts: identifying evaluation factors and defining thresholds for each factor. From section 4.4.2 Proximity Warning System Selection, Chapter 4, eight evaluation factors were identified, but these factors are partially modified based on lessons learned from the tests conducted. The following table shows the finalized evaluation factors, which should be considered in the future and justifications are provided in each subsection.

Table A.1 Finalized Evaluation Factors

Evaluation Factors (Previous)	Evaluation Factors (Finalized)
Technology	Technology
For use in all weather	For use in dirty/rainy environment
Max. range of rear detection zone	Static detection zone
Response time	Response time (Dynamic detection range)
False-alarm rate in clear field	False-alarm rate in clear field
Cost	Cost
Level of effort in mounting	Installation Location
Camera as supplemental method	Camera as supplemental method

- *Technology*
  The term of technology seems to be general concept as an evaluation factor, but this evaluation factor determines many factors such as system operation principle, required components, and possibility of data collection. For example, RFID and GPS based systems required workers equipped with tags or other devices to be detected while radar, ultrasonic, and camera-based systems are able to directly detect objects (see section 4.2 Technology Review, Chapter 4). Because of implementation simplicity, radar and ultrasonic technologies are selected for both pickup and dump trucks.

- *For use in dirty/raining environment*
  Since 'For use in all weather' is too broad concept to test, this factor is modified to 'For use in dirty/rainy environment'. In response to recommendations from the previous a project management committee (PMC) meeting, two tests in realistic environments were considered, which are the dirty sensor test and the test with raining environments. From the dirty sensor test, we found that the detection performance of ultrasonic-based sensor system was significantly affected by soil covered on sensors while radar-based systems are not affected by dirt (see section 5.7 Dirty Sensor Test, Chapter 5). Therefore, it is highly recommended to consider for use in dirty environment before selecting the system. In case of the test with raining environment, the test failed to continue because of the possibility of electronic short with designed testbed. However, this factor should be tested and considered in future system selection.

- *Static detection zone*
  Static detection zone can be defined as the size of detection area when both a vehicle and an object are stationary. Static detection zone should be a diagram and three performance factors (maximum detection range, reliable/sporadic detection area, and capability to detect close proximity areas) must be identified. Also, because our static test results showed static detection zones are different at system installation heights, it is recommended to identify detection zone diagrams at specific heights where the system will be installed (see section 5.5 Static Test, Chapter 5). In terms of maximum detection range selection, we found that a trade-off exists between detection range and false/nuisance alarms. A sensor system with longer detection range generally has a wider detection range. As a result, a wider clear field is required to implement this system without false and nuisance alarms in the work zone (see section 6.1 Engineering and Technology Control, Chapter 6). From the Chapter 4, required maximum detection

ranges were defined as 10 feet for pickup trucks and 20 feet for dump trucks based on literatures, but we found that both vehicles stopped within 10 feet when vehicles were backing at 3mph. Also, there were little stopping distance differences between two types of vehicles. Stopping distance can be defined as the combination of reaction distance and braking distance. In low speed reversing, operator's reaction time is critical factor than vehicle speed to determine stopping distance. Therefore, more investigation is recommended to determine system maximum detection range for both vehicle types.

- *Response time (Dynamic detection range)*
  Dynamic detection range can be defined as the maximum detection range of a sensor system when a vehicle is backing and an object is stationary or when both a vehicle and an object are moving. Dynamic detection range is shorter than maximum detection distance in static conditions because of system response time and vehicle speed. Since users cannot control the system response time, understanding this factor is critical to simulate dynamic detection range of the system with different vehicle's backing speeds. Since system response times provided from vendors are mostly tested in controlled indoor conditions, it is also recommended to measure systems response times in realistic conditions. According to the dynamic test, HCS-700 system (0.2 second response time, 9 feet maximum detection range in the static test) showed 1-foot detection range reduction while WorkZone system (0.5 second response time, 10 feet maximum detection range in the static test) resulted in 4 feet detection range reduction. Therefore, shorter system response time is recommended although ISO defined maximum system response time as 0.5 second within detection zone (see section 5.6 Dynamic Test, Chapter 5).

- *False-alarm rate in clear field*
  False alarm rate is an important factor because frequent false alarms might eventually make the operators ignore warnings from the systems. During the field test, only ultrasonic-based sensor system, HCS-700, generated a few false alarms and the other three radar-based systems did not generate false alarms.

- *Cost*
  In the economic perspective, cost criterion is a critical factor for the successful system implementation. Costs of selected sensor systems range from \$409 to \$1,769.50 without a camera system. Details of cost information can be found in section 5.3 Tested Proximity Warning Systems, Chapter 5.

- *Installation Location*
  'Level of effort in mounting' is somehow subjective factor and changed to 'Installation Location' based on findings from sensor installation review in Chapter 5. It is common practice that every construction equipment type has limited possible sensor installation locations and sensor installation height and angle are influential factors in detection performance of sensor systems. Also, in order to hang on sensors at the bottom of the dump bed, additional devices such as 'L' shaped bracket might be necessary. Therefore, it is important to identify proper sensor mounting positions and limitations with end users and vendors to evaluate practical mounting positions.

- *Camera as supplemental method*
  A camera enables to display the rear-view area of vehicles to operators via a cab-mounted monitor. The advantage of video camera is that this system is able to monitor the cause and exact location of obstacles, not just detecting the presence of obstacles. However, this system does not generate an alarm, so it is recommended as a supplemental method with other sensing technologies (Ruff 2000; Ruff 2001a). Most sensing systems we reviewed are able to be compatible with more than one camera systems. The use of video camera is highly recommended for dump trucks because an operator cannot see objects through the back mirror due to the dump bed.

A.4.4 Define Available Technologies

Sensing technologies are developing rapidly. In this project, we focus on commercially available systems designed for low speed backing maneuvering aids. Ten available systems identified in section 4.4.2 Proximity Warning System List, Chapter 4 with specific information based on eight evaluation factors.

A.4.5 Select Systems

Based on system selection process (PWS selection matrix) developed and available technologies (PWS list) collected, three systems were chosen as appropriate sensors for the pickup truck. Figure A.11 describes how three sensors were selected and the others were discarded.

Systems	Preview		Guardian Alert	Sensor Vision	Hindsight 20-20			Buddy	AMT	Becker CAS
Model	Workzone	HighResolution		Ogden radar	HS-30 + CS-561	HS-100F + CS-561	HCS-700 (HS-345NL)		CAS-CAM /RF	CAS-430
Technology	Pulsed radar		Doppler radar	FMCW Radar	Pulsed Ultrasonic			Tag-based	Tag-based	Tag-based
Maximum length of rear detection zone	3m (10ft)	1.8 - 6m (6 – 20ft)	2.7 - 3.6m (9 – 12ft)	1.5 - 24m (5 – 78ft)	2.4m (8ft)	2.4m (8ft)	2.7m (9ft)	18m (60ft)	0 - 80m (0 – 260ft)	0 - 100m (0 – 328ft)
False-alarm rate in clear field	None		Frequent	None	None			None	None	None
Cost (*)	$659 ($1,985)	$766 ($2,093)	Below $2,000	Below $2,000	$266 ($58[illegible])	$130 ([illegible]89)	$409 ($806)	Between $[illegible] and $10,000	Over $10,000	A[illegible]0 ($60,000)
For use in all weather	Yes		Yes	Yes	Yes			Yes	Yes	Yes
Response time	0.50sec		NA	0.48sec	0.20sec			NA	0.30sec	0.25sec
Level of effort in mounting	4-6hours		Low	Specialist required	1hour			Medium	Medium	Specialist required (One day)
Camera as supplemental method	Optional		No	No	Optional			Optional	Yes	Optional
Note	Direct contact		[5]	[5] Not approved by FCC	Direct contact			[5]	[7] Not approved by FCC	Direct contact

False Alarm Rates
FCC
Detection Zone
Tech. Cost
FCC
Cost

NOTE: (*) = cost including a camera system, NA = not available
FCC = Federal Communication Commissions
Figure A.11 PWS Selection for Pickup Trucks

Sensor Vision and AMT systems were discarded because they have not been approved by the US federal Communication Commissions (FCC). Due to the technology and cost criteria, two tag-based systems, Buddy and Becker CAS, were discarded and HS-30 and HS-100F models were discarded due to the short rear detection zone. Also, Guardian Alert system was discarded because of frequent false alarm rates. As a result, WorkZone, HighResolution, and HCS-700 sensor systems were selected for the pickup truck.

Similarly for dump trucks, Sensor Vision and AMT systems were discarded because they have not been approved by the US federal Communication Commissions (FCC). Two tag-based systems, Buddy and Becker CAS, were discarded due to technology criteria. Because of rear detection zone criteria, 6 meters (19.7 feet) for dump truck, five models were discarded. As a result, only HighResolution was selected for dump trucks.

Based on PWS selection matrix and PWS list, three sensor models, WorkZone, HighResolution, and HCS-700, were selected for pickup trucks while only HighResolution sensor system was selected for dump trucks (see Figure A.12). Details of each sensor system are found in section 5.3 Tested Proximity Warning Systems, Chapter 5.

Systems	Preview		Guardian Alert	Sensor Vision	Hindsight 20-20			Buddy	AMT	Becker CAS
Model	Workzone	HighResolution		Ogden radar	HS-30 + CS-561	HS-100F + CS-561	HCS-700 (HS-345NL)		CAS-CAM /RF	CAS-430
Technology	Pulsed radar		Doppler radar	FMCW Radar	Pulsed Ultrasonic			Tag-based	Tag-based	Tag-based
Maximum length of rear detection zone	3m (10ft)	1.8 - 6m (6 – 20ft)	2.7 - 3.6m (9 – 12ft)	1.5 - 24m (5 – 78ft)	2.4m (8ft)	2.4m (8ft)	2.7m (9ft)	18m (60ft)	0 - 80m (0 – 260ft)	0 - 100m (0 – 328ft)
False-alarm rate in clear field	Detection Zone	None	Frequent Detection Zone, False Alarm Rates	None	None			None	None	None
Cost (*)	$[illegible] ($[illegible])	$766 ($2,093)	Below $2,000	Below $2,000 FCC	[illegible] ($585) Detection Zone	[illegible] ($489)	[illegible] ($806)	Between $5,000 and $10,000 Tech.	Over $10,000 FCC	Avg $45,000 ([illegible]) Tech. Cost
For use in all weather	Yes		Yes	Yes	Yes			Yes	Yes	Yes
Response time	0.50sec		NA	0.48sec	0.20sec			NA	0.30sec	0.25sec
Level of effort in mounting	4-6hours		Low	Specialist required	1hour			Medium	Medium	Specialist required (One day)
Camera as supplemental method	Optional		No	No	Optional			Optional	Yes	Optional
Note	Direct contact		[5]	[5] Not approved by FCC	Direct contact			[5]	[7] Not approved by FCC	Direct contact

NOTE: (*) = cost including a camera system, NA = not available
FCC = Federal Communication Commissions

Figure A.12 PWS Selection for Dump Trucks

A.4.6 Controlled Test

In order to evaluate performance of sensor systems, testing systems in different conditions is an essential process in terms of the reliability of sensor systems. In this study, one experiment was conducted to evaluate proper sensor installation positions on the vehicles and three experiments (Static test, Dynamic test, and Dirty sensor test) were performed to assess the performance of sensor systems in different scenarios, which can commonly occur in construction work zones.

A.4.6.1 Sensor Installation Review

Sensor installation review is to consider proper sensor installation positions. Because each equipment type has different models with their own limited space for sensor installation, it is recommended to survey each of them. In order to consider both technical and practical issues, it is also recommended that sensor installation positions reviews be conducted with system vendors and practitioners who are closely related to construction vehicles.

A.4.6.2 Static Test

Static test reflects the vehicle operation condition which is before the vehicle is backing (i.e., both a vehicle and an obstacle are stationary). In this scenario, a sensor system can generate a maximum size of detection performance regardless of sensor response time and vehicle operation conditions. The detection area measured in the best condition serves as a benchmark for the dynamic test and dirty sensor test. Also, sensor detection performance at different installation locations measured from the sensor installation review tested. To assess the performance of sensor systems in the static conditions, the following factors were observed in the static test:

- *Reliable Detection Area:* This area indicates the detection coverage with more than 90% accuracy. This area will be used to determine overall detection capacity of the system.
- *Sporadic Detection Area:* This area indicates the detection coverage with less than 90% accuracy.
- *Close Proximity Detection*: This factor will evaluate sensor system's close proximity detection capability within 3 feet of vehicle and along the vehicle width.

Figure A.13 illustrates an example of performance evaluation factors.

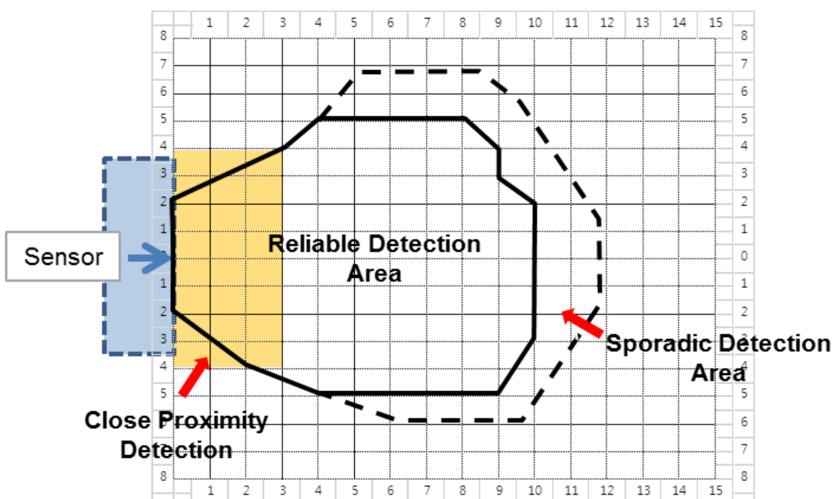
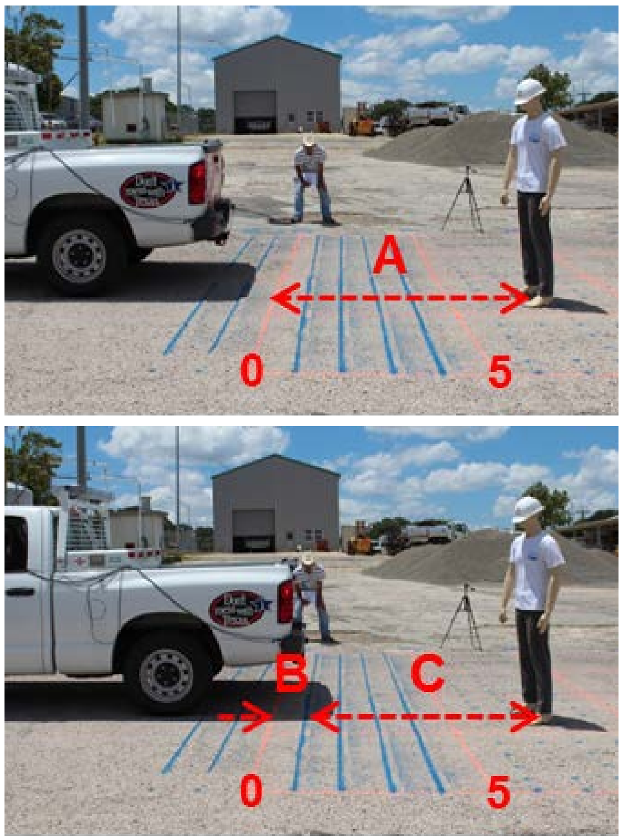


Figure A.13 Example of Performance Evaluation factors in the Static Test

A.4.6.3 Dynamic Test

During the dynamic test (see Figure A.14), the dynamic detection ranges of sensor systems studied by placing sensor systems on moving equipment (i.e., a vehicle is backing and an obstacle is stationary). The impact of dynamic operation condition examined with possible environmental factors such as vehicle speed or sensor response time. Also, for safety reasons, a mannequin was used as a test object as opposed to a human. To access the performance of sensor systems in the dynamic conditions, the following performance evaluation factors were checked:

- *Dynamic detection range:* changed detection range due to the dynamic conditions of the vehicle. This changed detection ranges should be compared to maximum detection ranges in the static condition to see differences.
- *False alarm:* alarms generated in the clear field because the sensor might detect the ground or parts of vehicle such as tires during the backing operation.



Note: Distance A: Maximum detection range of the sensor in the static condition
Distance B: Reduced distance due to the dynamic condition
Distance C: Dynamic detection range of the sensor in the dynamic condition

Figure A.14 Basic Procedure of the Dynamic Test

A.4.6.4 Dirty Sensor Test

Due to the nature of construction work zones, sensor systems are likely to be covered in dirt, mud, or other materials at some point in the construction process. Since ultrasonic and radar-based sensor systems use signals to detect objects, any materials covering sensors might impact the detection performance of the sensor systems by interrupting the process of emitting and receiving signals. The dirty sensor test was designed to evaluate the impact of dirt on sensor systems related to their detection performance.

A.4.7 Pilot Test

For the final verification of system implementation feasibility, a pilot test in an active work zone should be conducted prior to deployment of the system in the large scale. Even though a pilot test was not conducted in this research project, it is highly recommended because more practical implementation challenges might be identified during a pilot test. Any findings from a pilot test need to be reported to update system selection process and controlled test. It is recommended that a Pilot Test be developed as part of a follow-on Implementation Project with TxDOT.

A.4.8 Deploy System in Jobsite

Based on the results of controlled and pilot tests, the sensing system can be deployed in the jobsite in the large scale. Prior to actual implementation of the system, all users should be properly educated about the systems and specific guidelines should be provided.

A.5 Guidelines for System Implementation

Development of system implementation guidelines should be developed from lessons learned of controlled and pilot tests. Also, close cooperation with vendors and end users is recommended. Since pilot test was not conducted in this project, this guideline is developed mostly based on findings from controlled test conducted and communications with vendors. However, further modification of this guideline is highly recommended after pilot test to present more practical guideline. The guidelines for system implementation are divided into general guidelines and guidelines for development of integrated internal traffic control plans.

A.5.1 General Implementation Guidelines

Guidelines presented this section is based on findings of controlled tests conducted. To complete general implementation guidelines, lessons learned from pilot test and opinions from vendors are highly recommended. General implementation guidelines consist of installation, education/training, and daily check list.

A.5.1.1 Installation

Installation guidelines should be developed to aid in maintenance personnel who will install systems on TxDOT vehicles. Since each equipment type has its own limited space for sensor installation and installation heights will affect system detection performance, careful efforts are required. In order to consider both technical and practical issues, it is also recommended that sensor installation positions should be determined with system vendors and practitioners who are closely related to construction vehicles. Some findings from our sensor installation reviews are:

- *Sensing systems should be installed above 12 inches high, measured from the ground.* Findings from the Chapter 5 show that installing sensors at or below 12 inches high detected the ground frequently and generated unnecessary alarms. If it is inevitable mounting sensors at or below 12 inches high on the vehicle, it is recommended that sensors should be tilted upward to avoid detecting the ground.

- *For pickup trucks, systems composed of double sensors are recommended.*
  Findings from the sensor installation review showed that single sensor systems have limitations to be installed middle of the pickup trucks' rears because of a tailgate, license plate, and trailer connecting device. Any other installations off the middle will generate asymmetric detection zone in the perspective of operators and might result in confusion of actual detection zone.

A.5.1.2 Education/Training

Guidelines and expectations should be presented to workers during safety meetings to inform them of what is expected and provide general understandings of systems implemented. Even though most sensing systems will generate alarms to operators in the cab except for active RFID systems, other workers including workers on foot, spotters, and flaggers should be trained for successful implementation. During the education/training session, at least the following should be presented.

- *Benefits of sensing system implementation*
  Effective understandings of benefits of system implementation will increase end users' reliability toward systems. Real world cases and any statistic results which describe the benefits of the sensing systems will be effective for this purpose.

- *General information of the system*
  General information of the system should at least include system operational principle and when the system is activated to provide better understandings of the system implementation.

- *Detection diagram of the system*
  Understanding of system detection zone is one of the key points all workers should be aware of. All users related to system implementation have to carefully understand where will be detected and where won't be detected by the systems. Our static test results show that sensor systems tested have different limitations to detect close proximity areas. Excessive belief on the technology will result in unexpected accidents.

- *Expected detection range difference between static and dynamic conditions*
  Common misunderstanding about the sensor system detection zone is that the static maximum detection range of the system will be maintained when a vehicle is moving because people believe that the signals are too fast to effect on detection range changes. However, the dynamic test results showed that dynamic detection ranges were reduced up to 4 feet comparing static test results when vehicles were backing 3mph. Therefore, thorough education/training are required to make users understand the realistic detection zones in static and dynamic conditions.

A.5.1.3 Daily Checklist

Most sensor systems provide self-test capabilities and failure indication (ISO, 2010). Typical self-tests include electronic circuit and wiring test, which check the function of the electronic components, and sensor components test which check whether there is any damage to the sensor elements. In addition, some manual checks are required by end users, such as cleanness of the system, availability of power source, and stability of sensors installed.

A.5.2 Guidelines for Development of Integrated Internal Traffic Control Plans (Chapter 6)

The guideline for Integrated Internal Traffic Control Plan (IITCP) shall be designed to reflect jobsite and technology-specific because the characteristics of work zones and technologies are dynamic. The following are general guidelines and recommendations for IITCP development.

- *The width of sensor detection zone should not exceed 10 feet for work zones on the shoulder or one lane closures.*
  In terms of sensor's detection coverage, characteristics of jobsites should be considered before selecting sensor systems. A trade-off exists between detection range and false alarms. A sensor system with longer detection range generally has a wider detection range. As a result, a wider clear field is required to implement this system without false and nuisance alarms in the work zone. If the sensor systems with wider detection coverage (more than 10 feet) are used in a relatively narrow jobsite such as one lane closures, the sensors will detect traffic cones or other fixed objects (personal vehicles parked or materials) and generate unnecessary false alarms. These kinds of false alarms will make operators distrust the sensor systems and ignore alarms. For jobsites in areas such as two-lane closures or new highway construction, longer and wider detection sensor systems might be more effective if enough clear backing area is secured.

- *When multiple vehicles are in a wait area, idling close to one another, only the ready-to-back-up vehicle should set its gear in reverse.*
  In the idling zone, if multiple vehicles activate sensor system by setting their gears in reverse, sensors will detect the other vehicles behind them and generate false alarms. This kind of false alarm makes operators ignore alarms and create other accident possibilities such as backing on a worker who is between two vehicles. Also, the second vehicle should back up only after the first vehicle leaves the work zone.

- *Equipment only area (backing path) in the work zone should be clear field.*
  As well as minimizing false alarms by detecting fixed objects while backing up, backing path should be clear enough to secure clear line-of-sight between an operator and a spotter. If the line-of-sight between an operator and a spotter is too long or blocked by fixed objects such as personal vehicles or materials, positioning of multiple spotters is recommended.

- *Spotters and idle workers should stay on the opposite side of roadway traffic.*

- *While a vehicle is loading or dumping, it is recommended to change its gear into neutral to avoid unnecessary alarms between the vehicle and other equipment.*

A.6 Summary

The development of guidelines to follow in construction work zones can be of great benefit in preventing backing fatalities. In selecting a system that would be the best fit for a particular scenario, it was found the steps to follow were to identify the characteristics of the work zone, identify equipment that could be of use, select the proximity warning system, define available technologies, select suitable systems, use controlled testing, review the sensor installation requirements, conduct static and dynamic testing, conduct pilot testing and finally deploy the system in the jobsite. Once the proper systems have been selected for use it is important to understand the most efficient manner for implementing the systems in the field. Installation guidelines should be developed to ensure the systems are installed at the ideal locations on each vehicle to ensure they work in the proper order. For pickup trucks, systems composed of double sensors are recommended. Education and training should be conducted on the systems at use to give workers a better understanding of how the systems can benefit and how they are most efficiently used. Daily checklists should be conducted to ensure proper functionality of the detection systems. Guidelines for Integrated internal traffic control plans should be developed, and how to best set up work zones to make the most out of the technology at use, giving workers the best protection.

Appendix B: Manual of Sensor Systems

- Manual_HCS-700
  http://hindsight20-20.com/pdf/HCS-700/techinfo/installation-manual.pdf

- Manual_WorkZone
  http://www.previewradar.com/sites/default/files/WorkZoneSensorManual_3700135C.pdf

- Manual_HighResolution
  http://www.previewradar.com/sites/default/files/HighResolution_PreViewManual_3700112B.pdf

- Manual_WorkSight
  http://www.previewradar.com/sites/default/files/WorkSightManual_3700062D.pdf

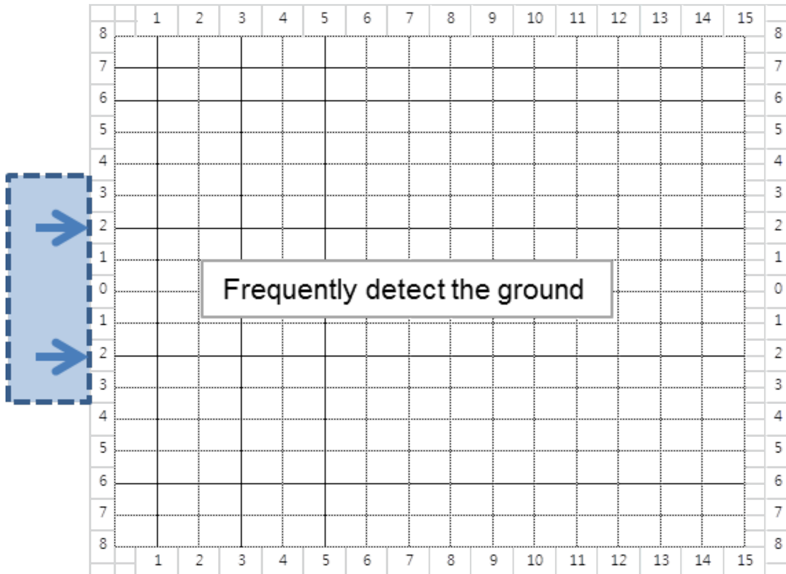
Appendix C: Static Test Results (Details)

Table C.1 Summary of Static Test Plan

Test No.	System Type	Height (inch)	Width (inch)	Temperature (°F)	Humidity (%)	Trials
1	HCS-700	12	52	82	57	NA
2		24	52	85	57	10
3		36	52	84	58	10
4		48	52	91	45	10
5		36	40	89	50	10
6		36	64	79	74	10
7	WorkZone	24	Center	85	55	10
8		36	Center	86	57	10
9		48	Center	80	66	10
10	HighResolution	24	Center	83	39	10
11		36	Center	90	34	10
12		48	Center	93	41	10
13	WorkSight	24	Center	85	65	10
14		36	Center	95	43	10
15		48	Center	86	59	10

TEST 1

- **Cumulative Result**

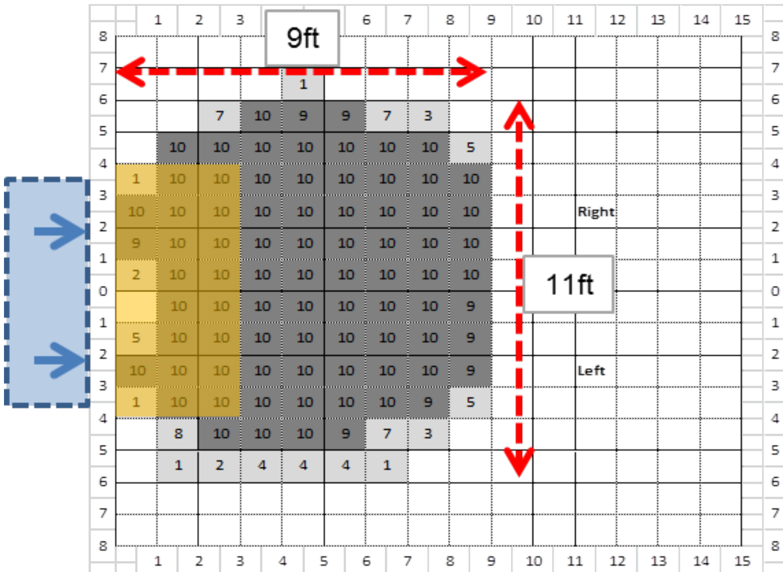


- **Individual Results**

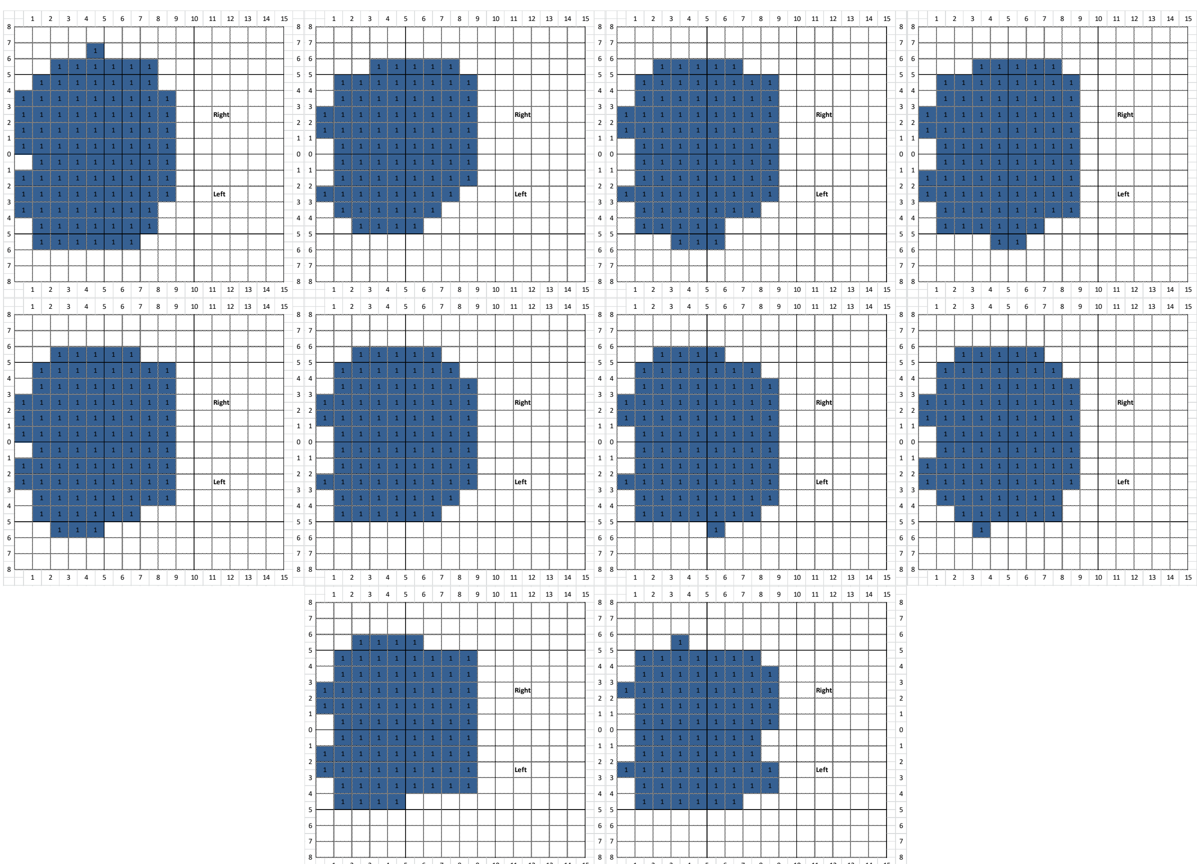
None.

TEST 2

- **Cumulative Result**

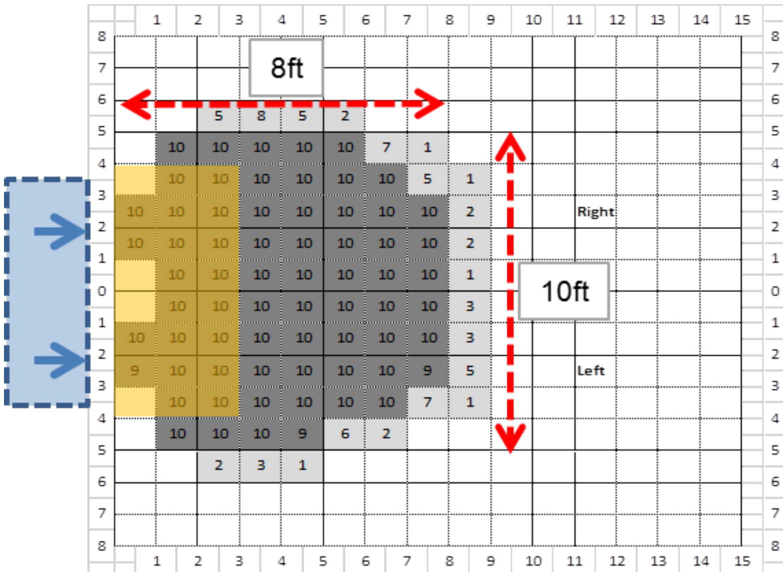


- **Individual Results**

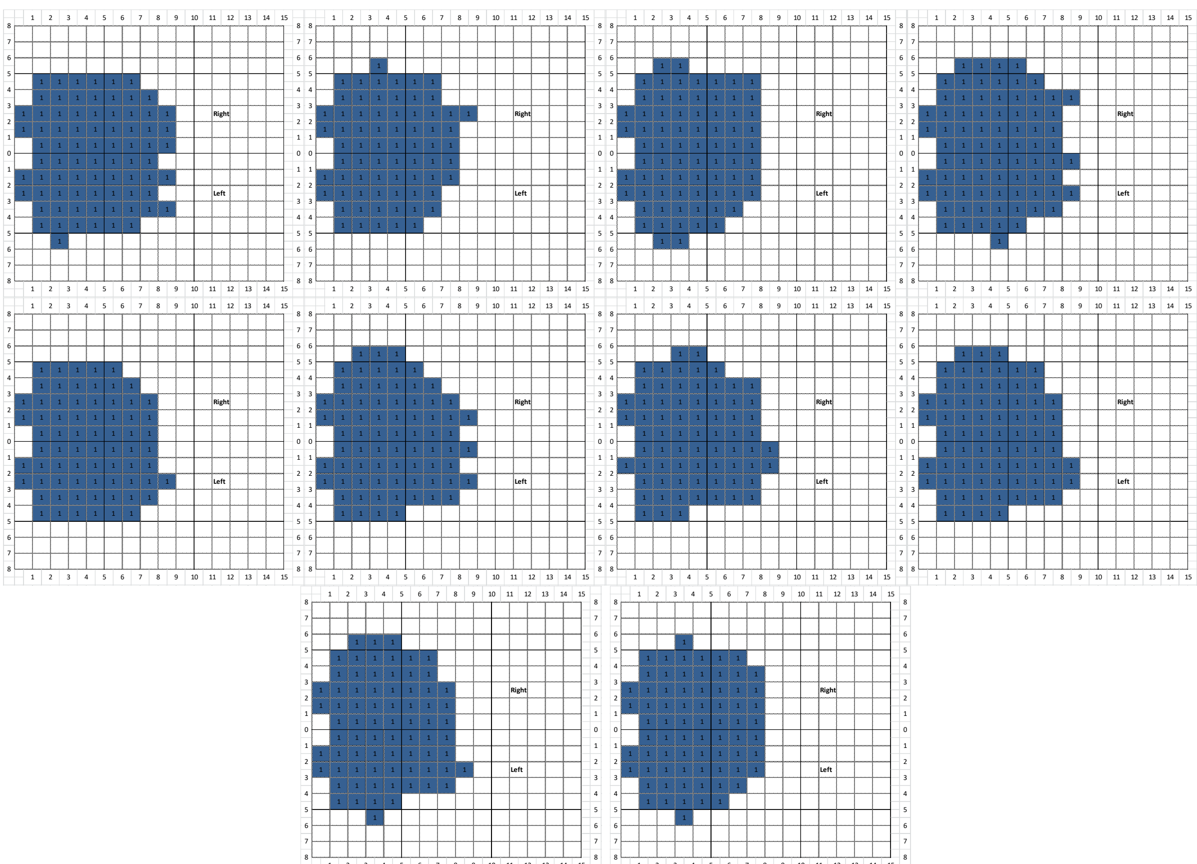


TEST 3

- **Cumulative Result**

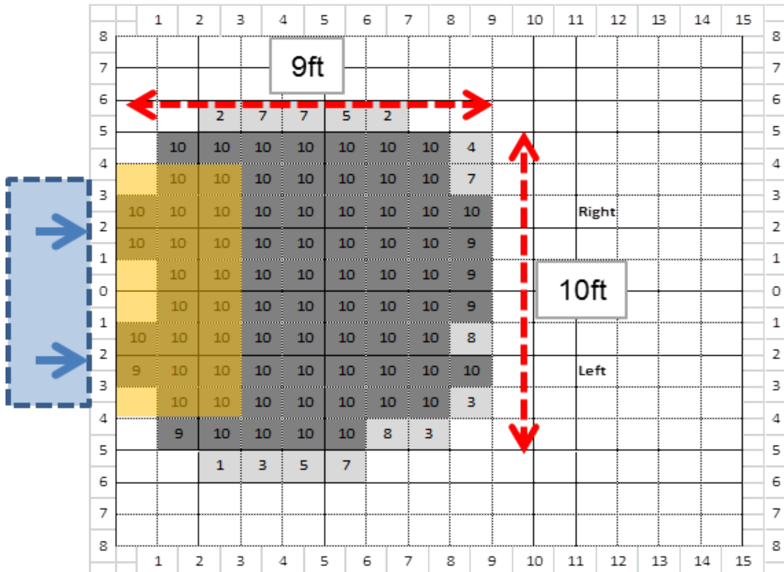


- **Individual Results**

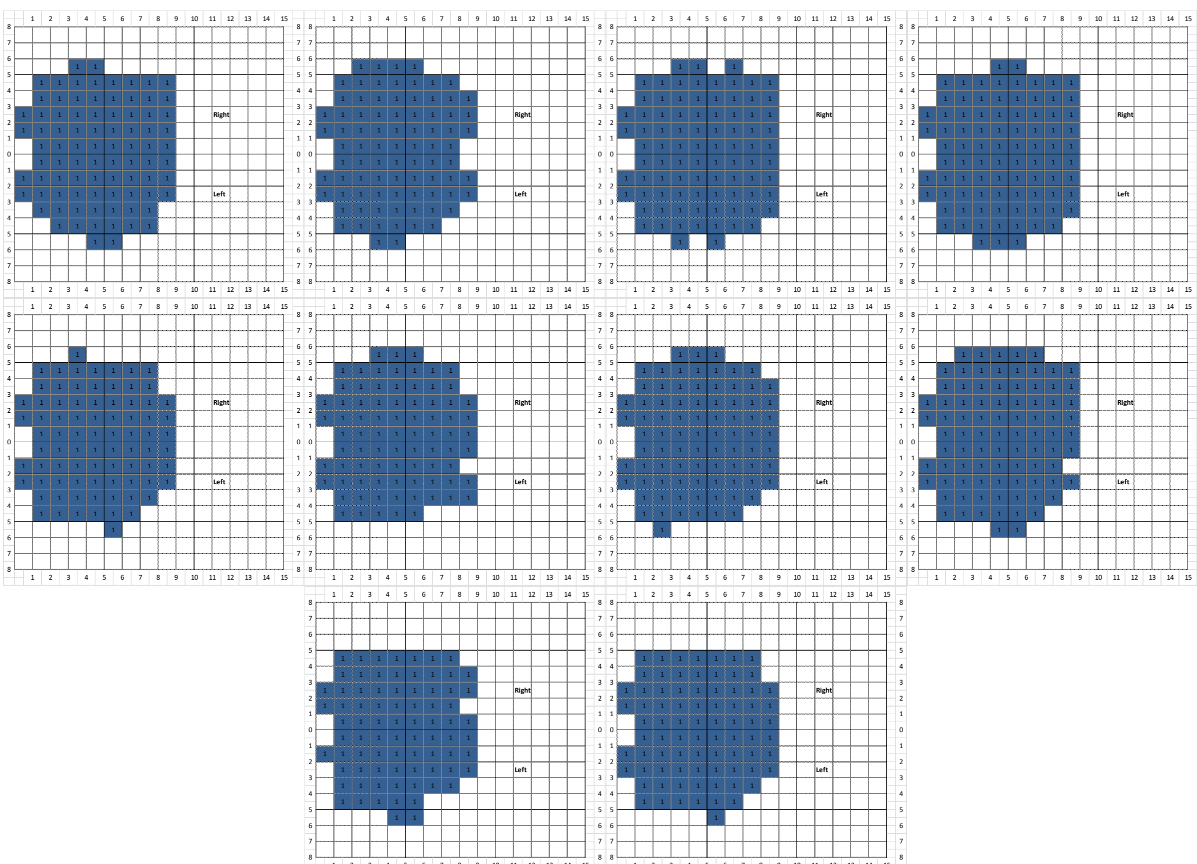


TEST 4

- **Cumulative Result**

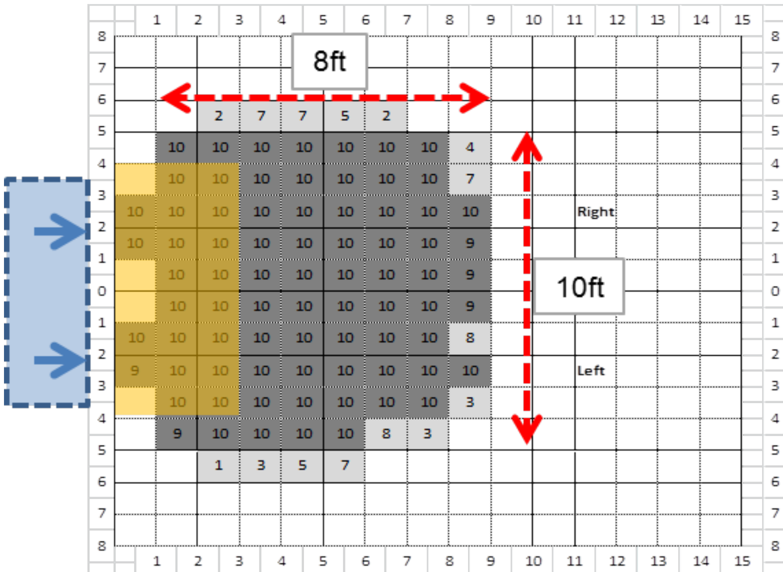


- **Individual Results**

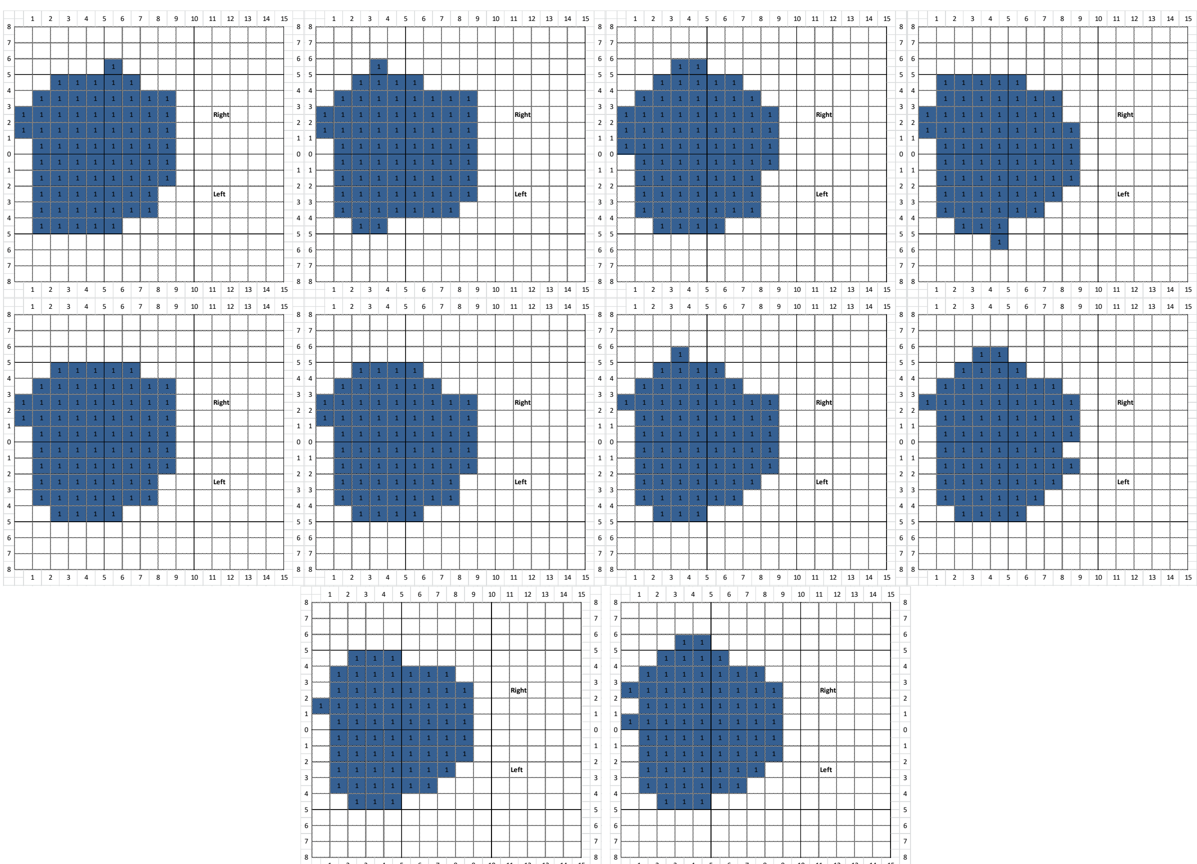


TEST 5

- **Cumulative Result**

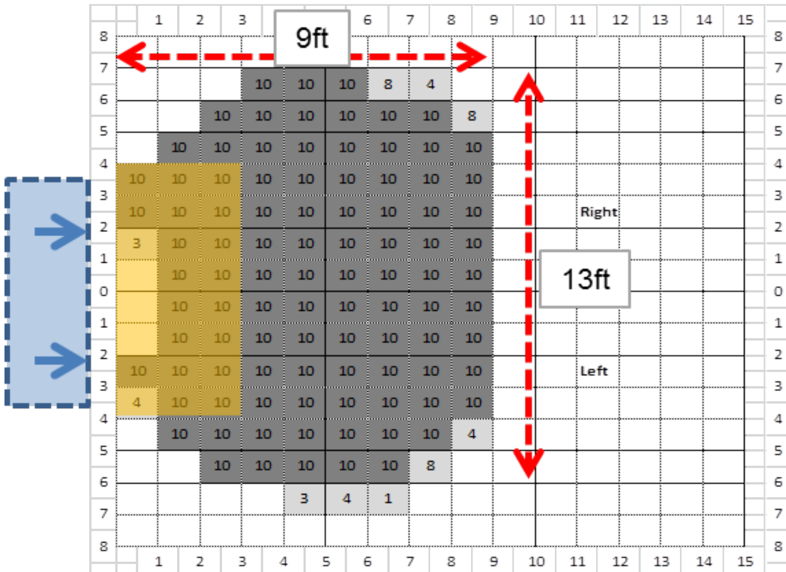


- **Individual Results**

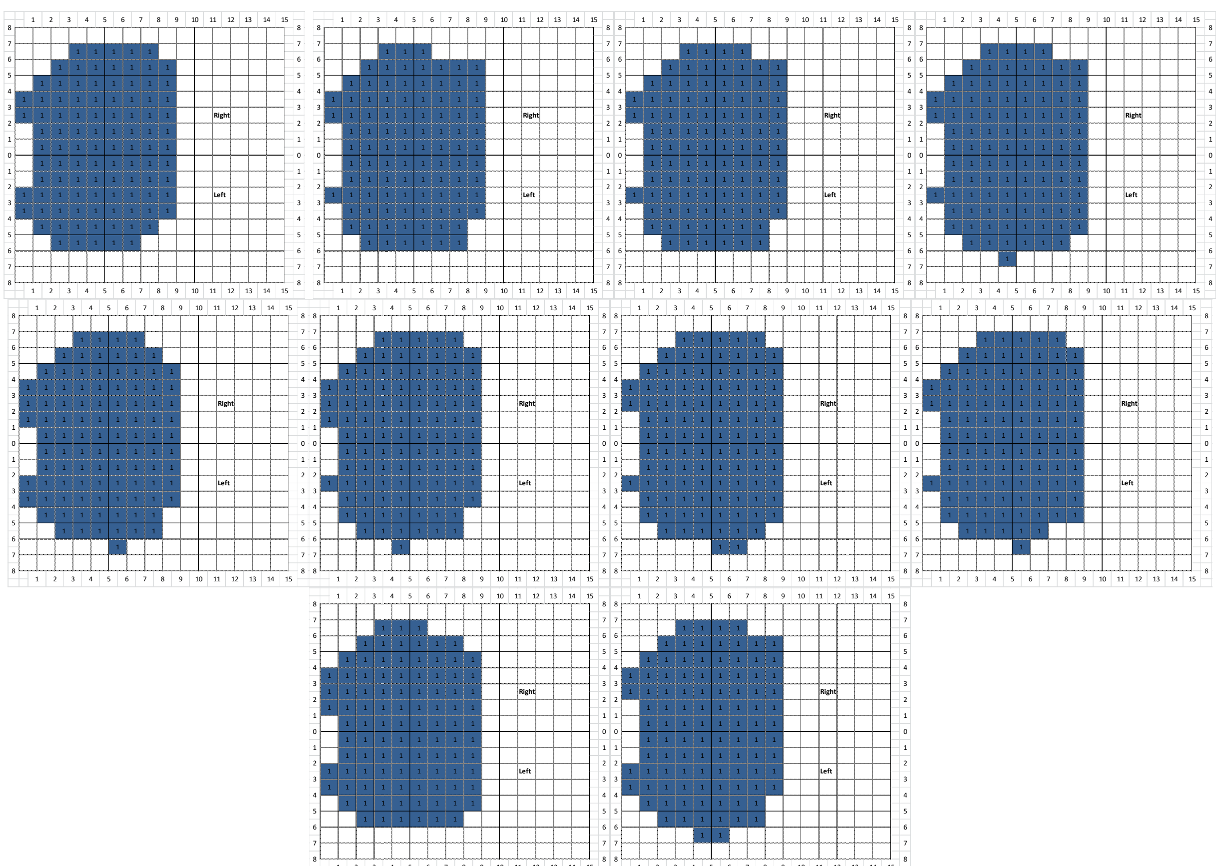


TEST 6

- **Cumulative Result**

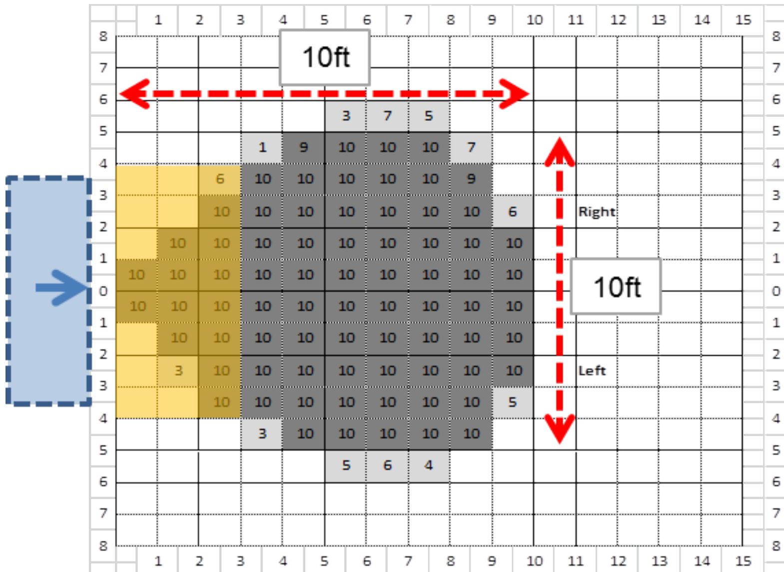


- **Individual Results**

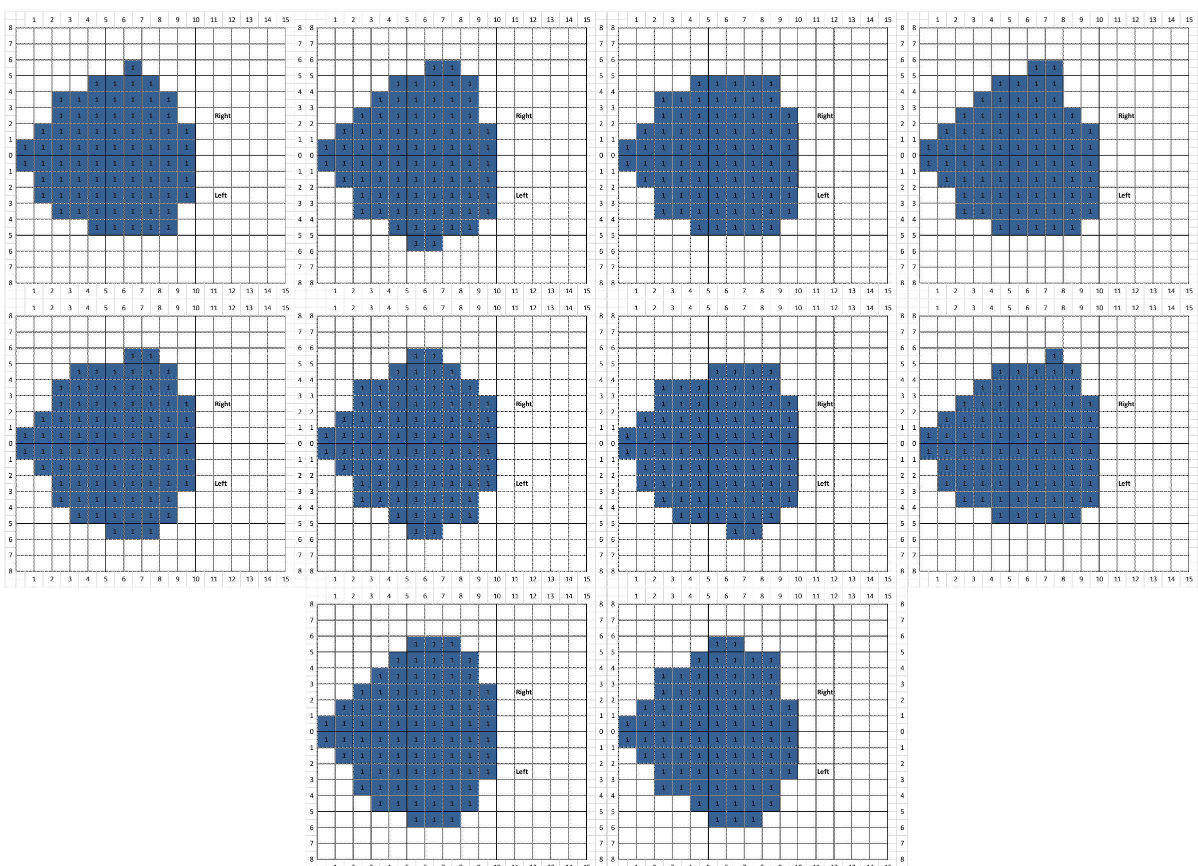


TEST 7

- **Cumulative Result**

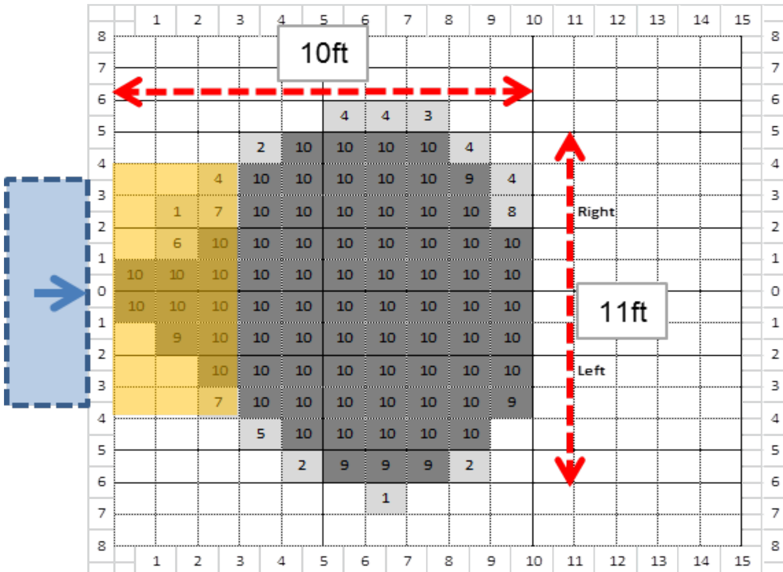


- **Individual Results**

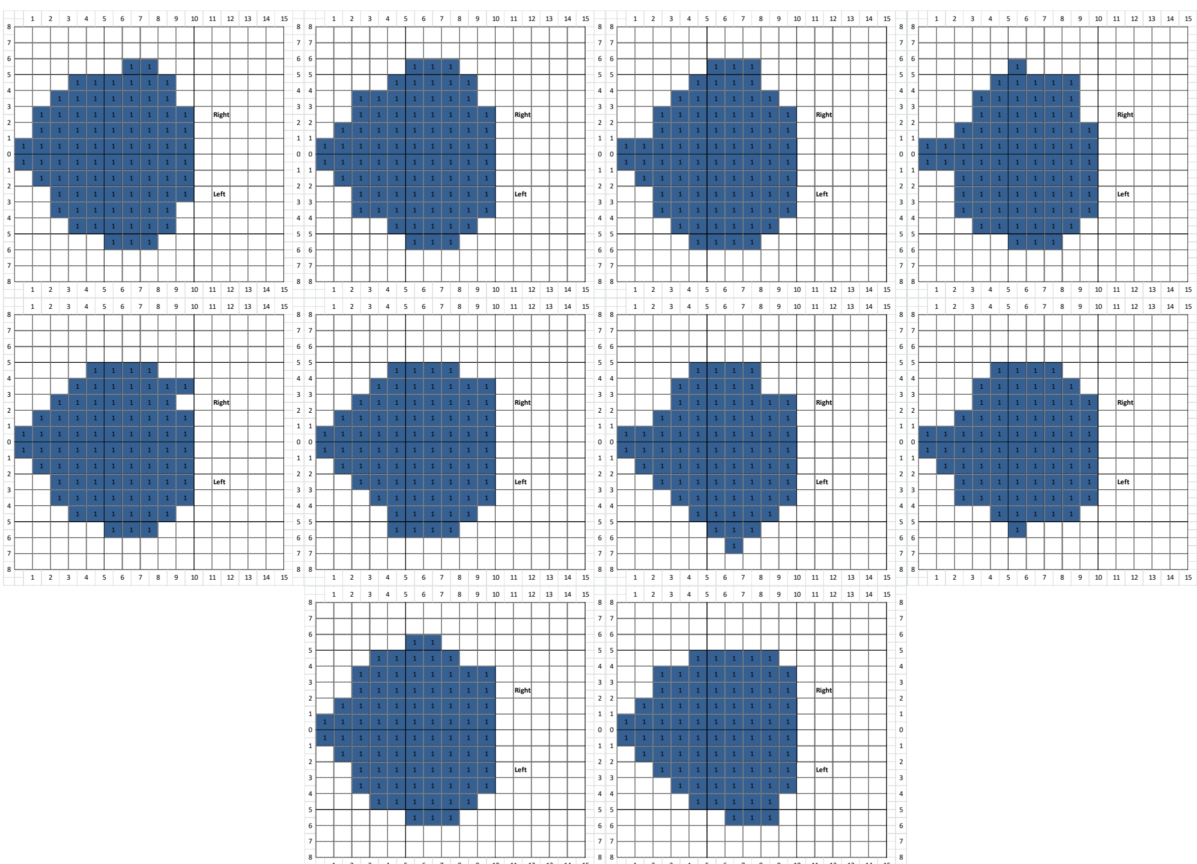


TEST 8

- **Cumulative Result**

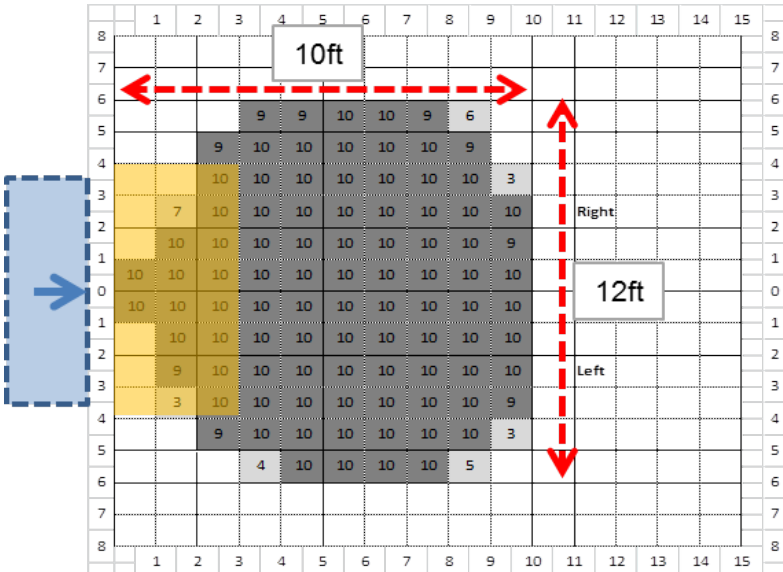


- **Individual Results**

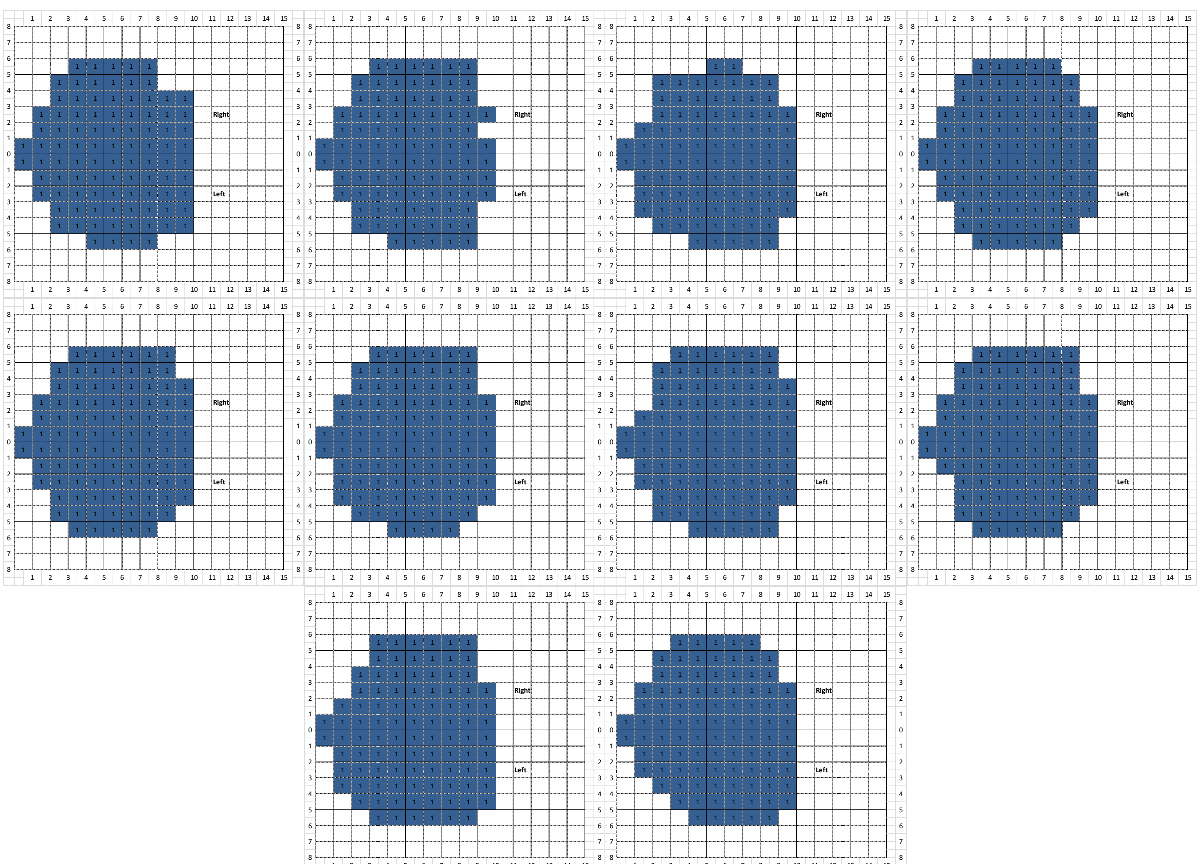


TEST 9

- **Cumulative Result**

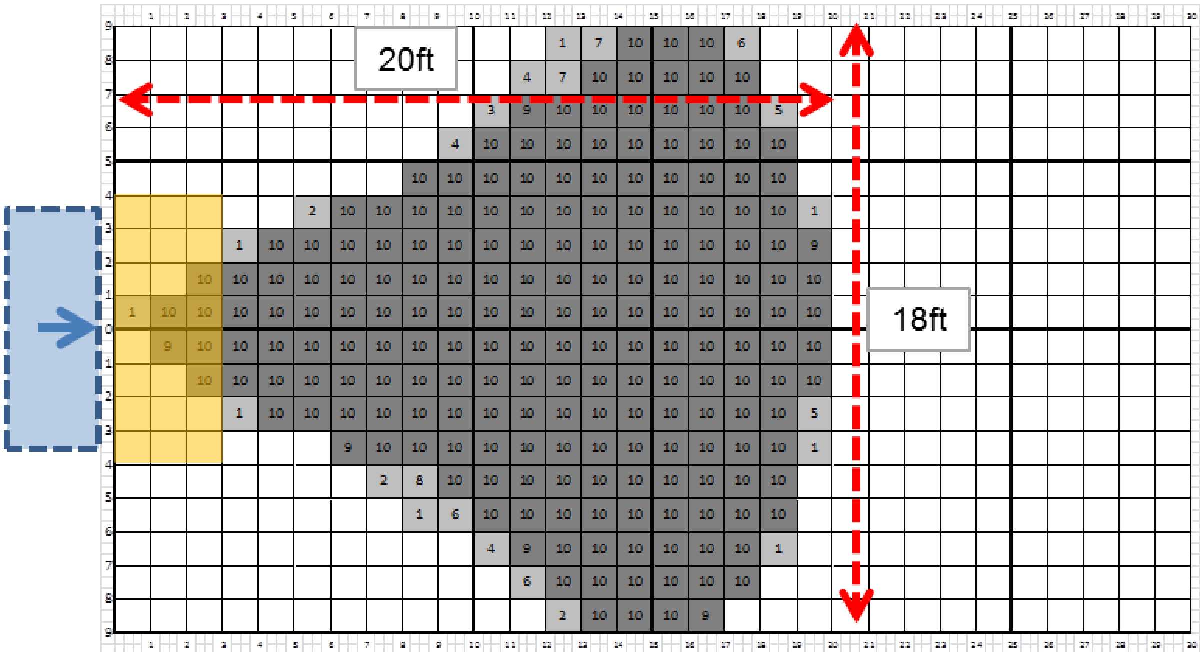


- **Individual Results**

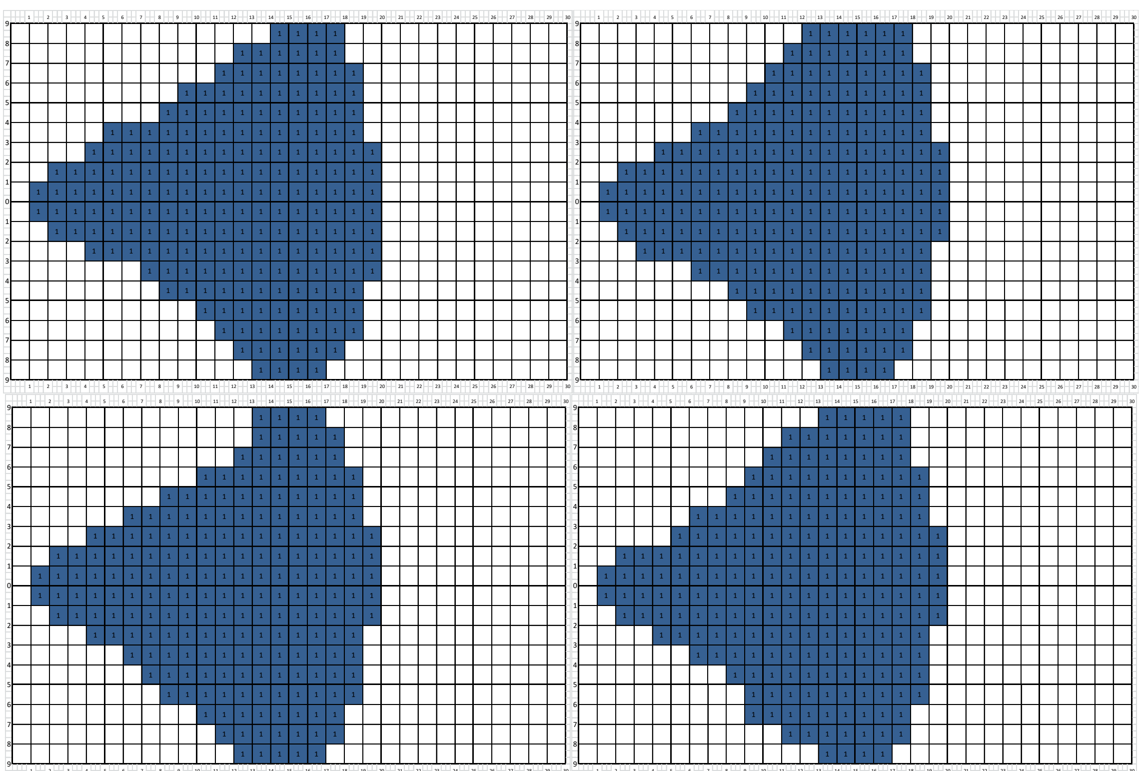


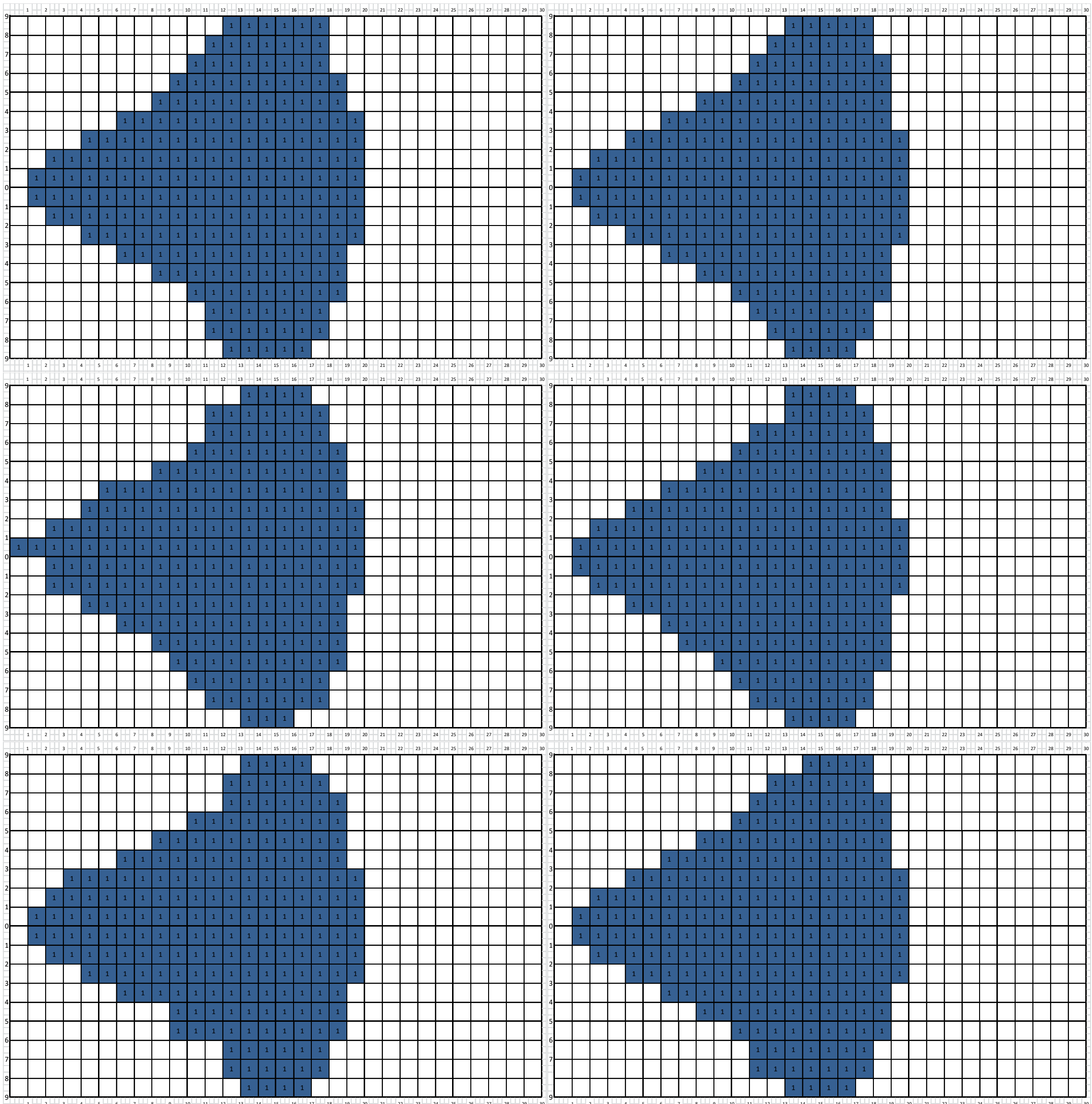
TEST 10

- **Cumulative Result**



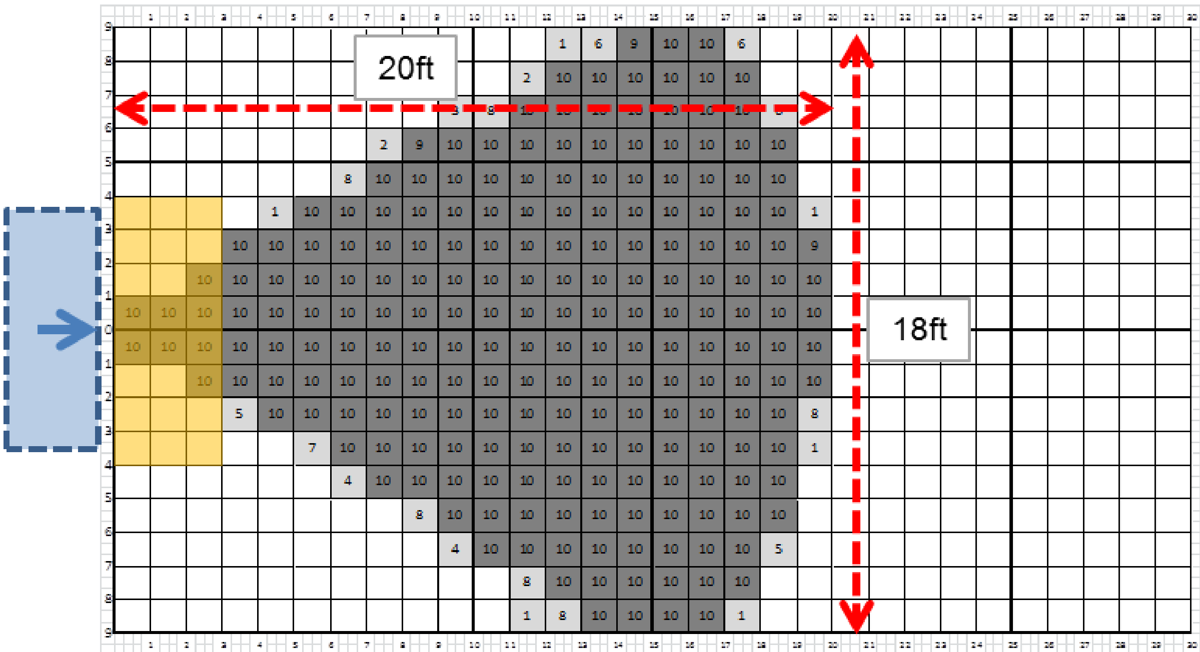
- **Individual Results**



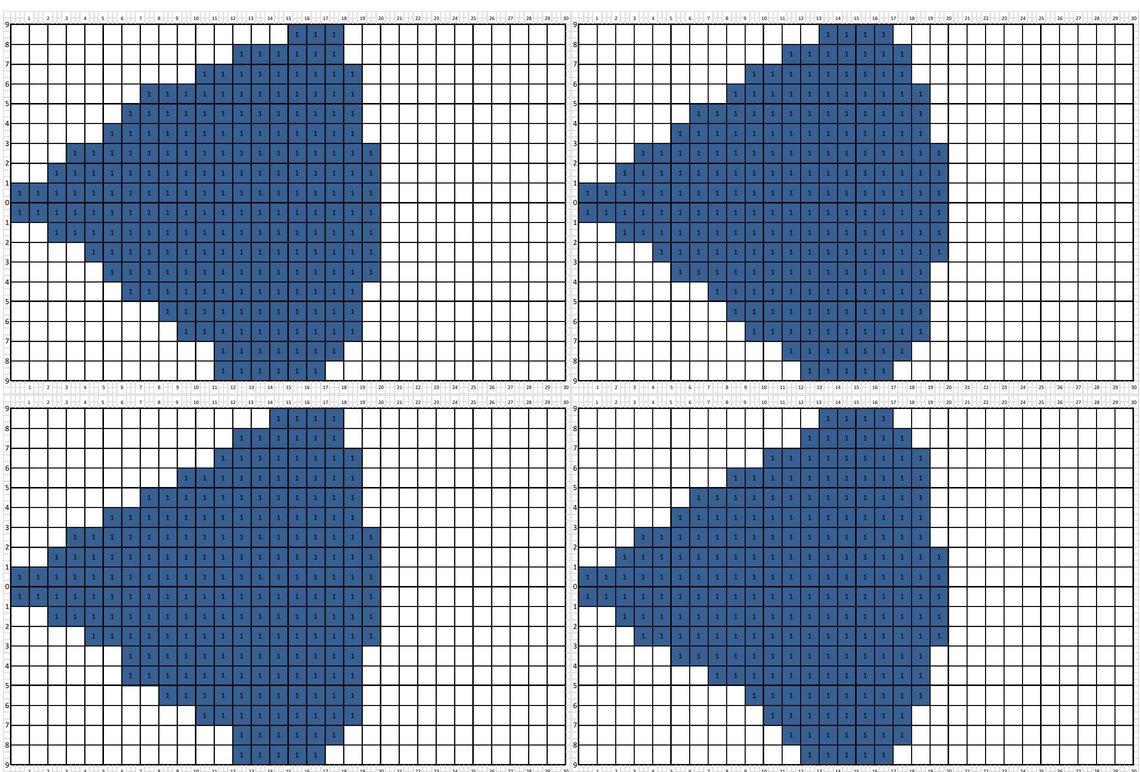


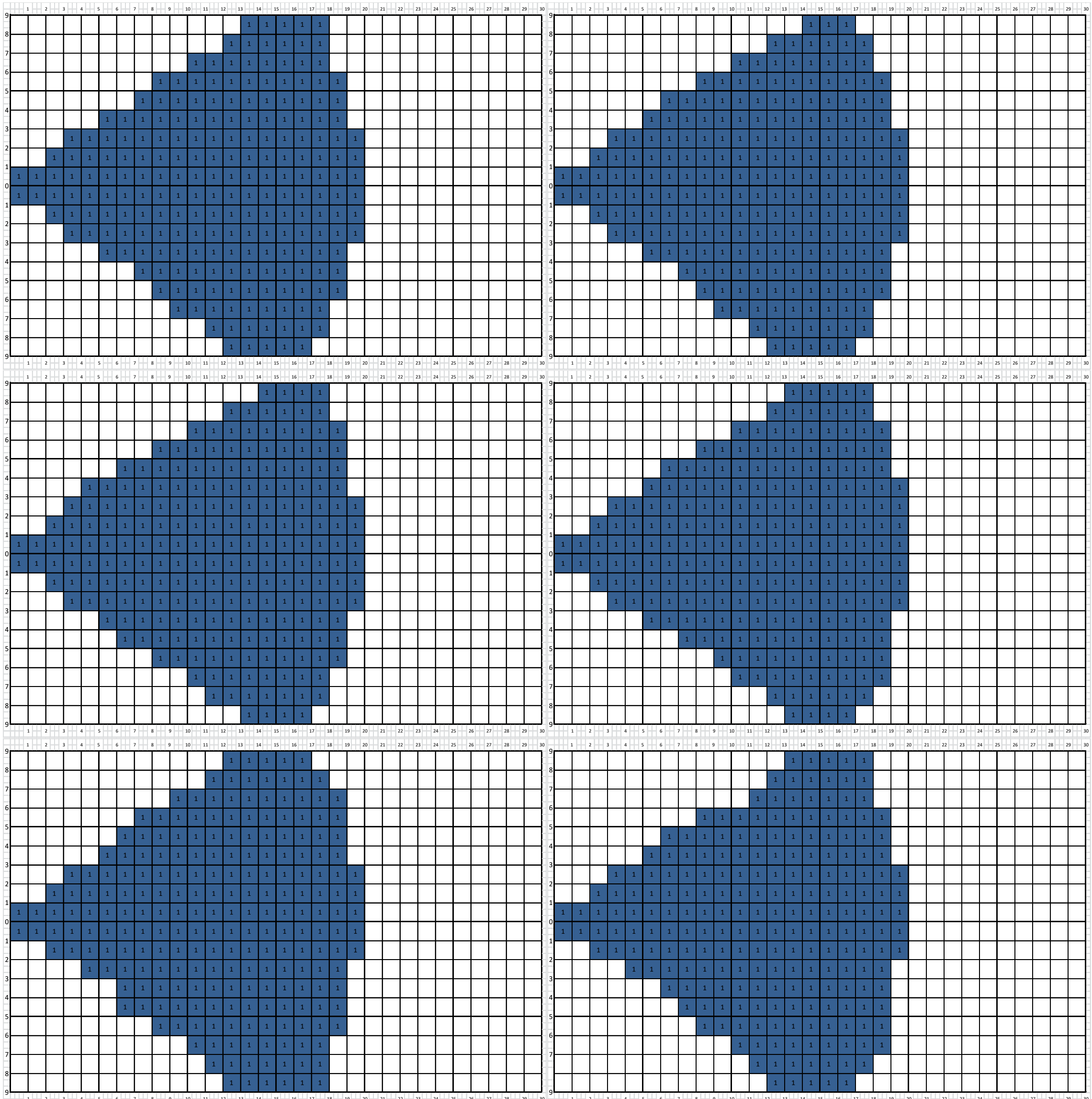
TEST 11

- **Cumulative Result**



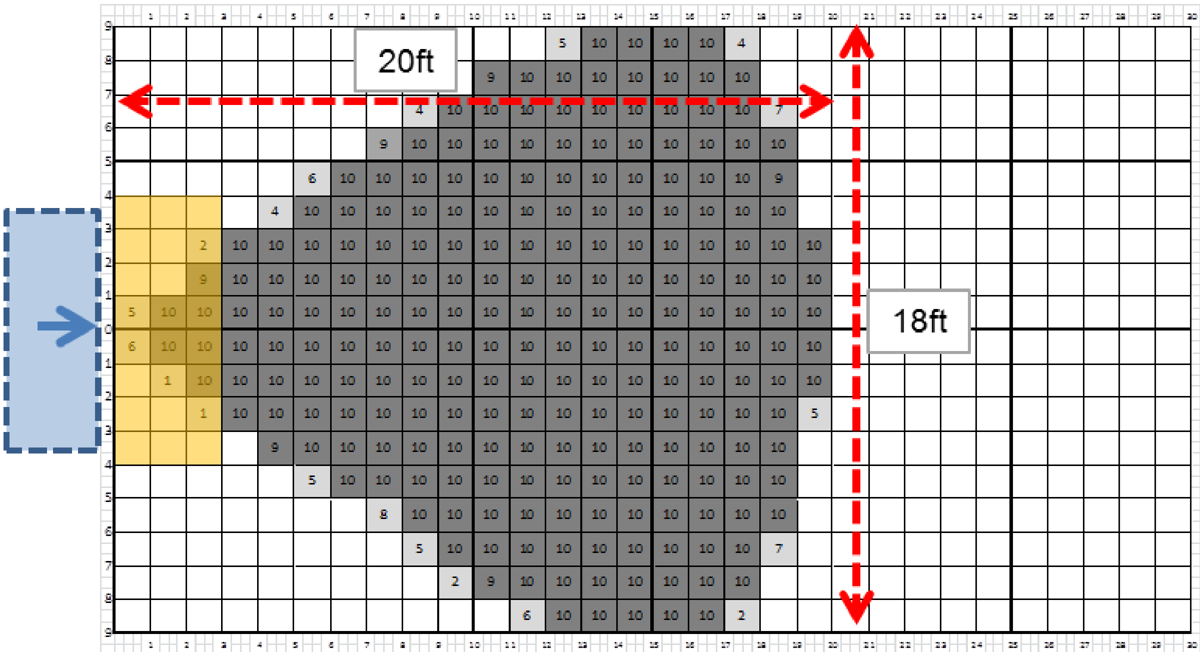
- **Individual Results**



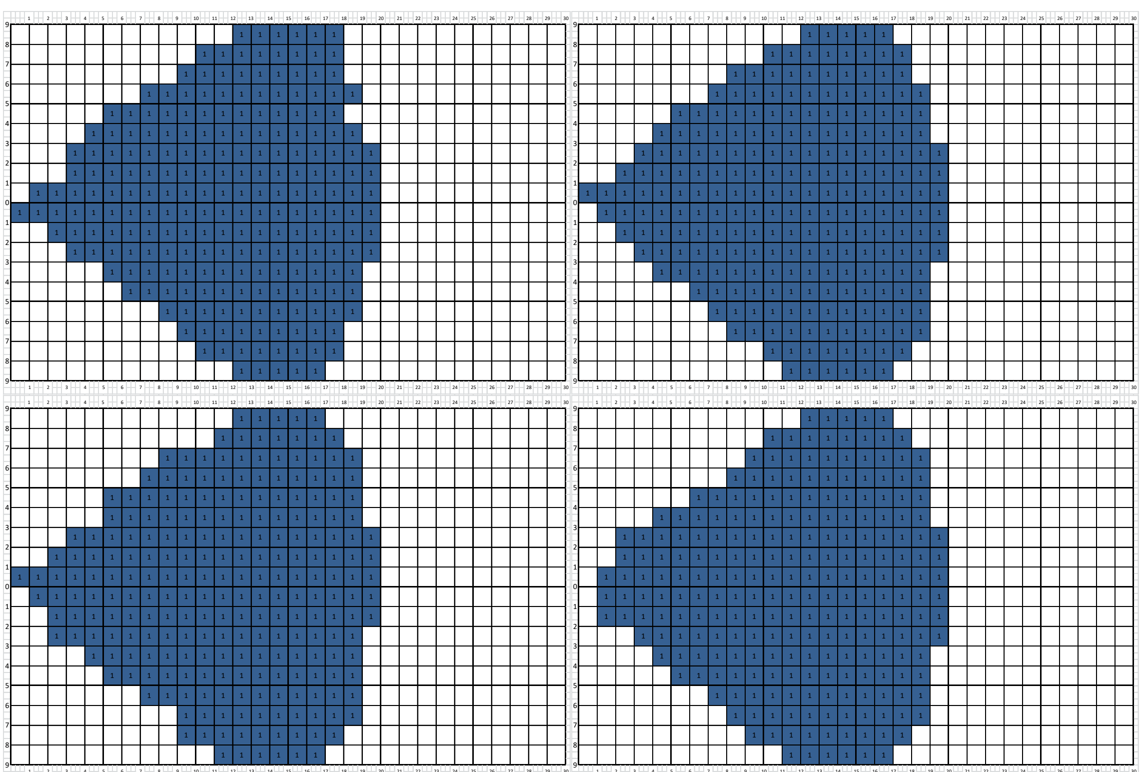


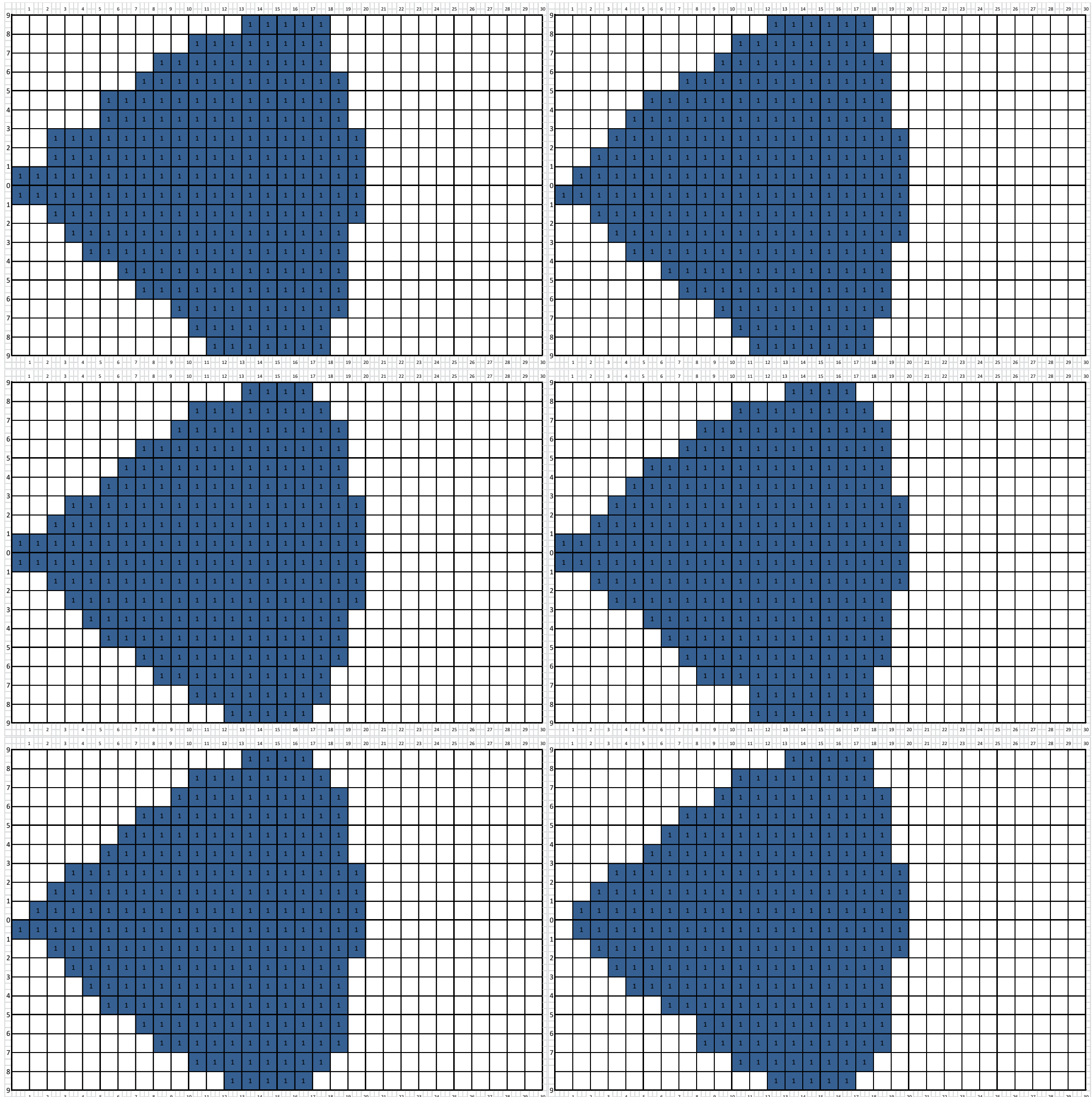
TEST 12

- **Cumulative Result**



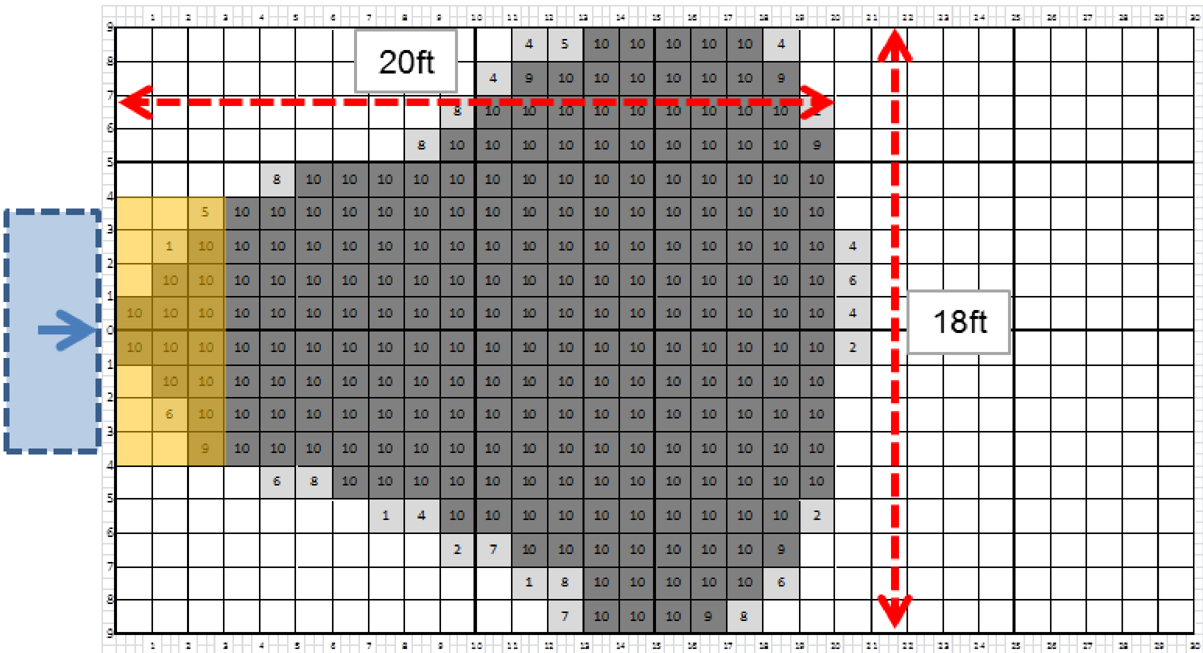
- **Individual Results**



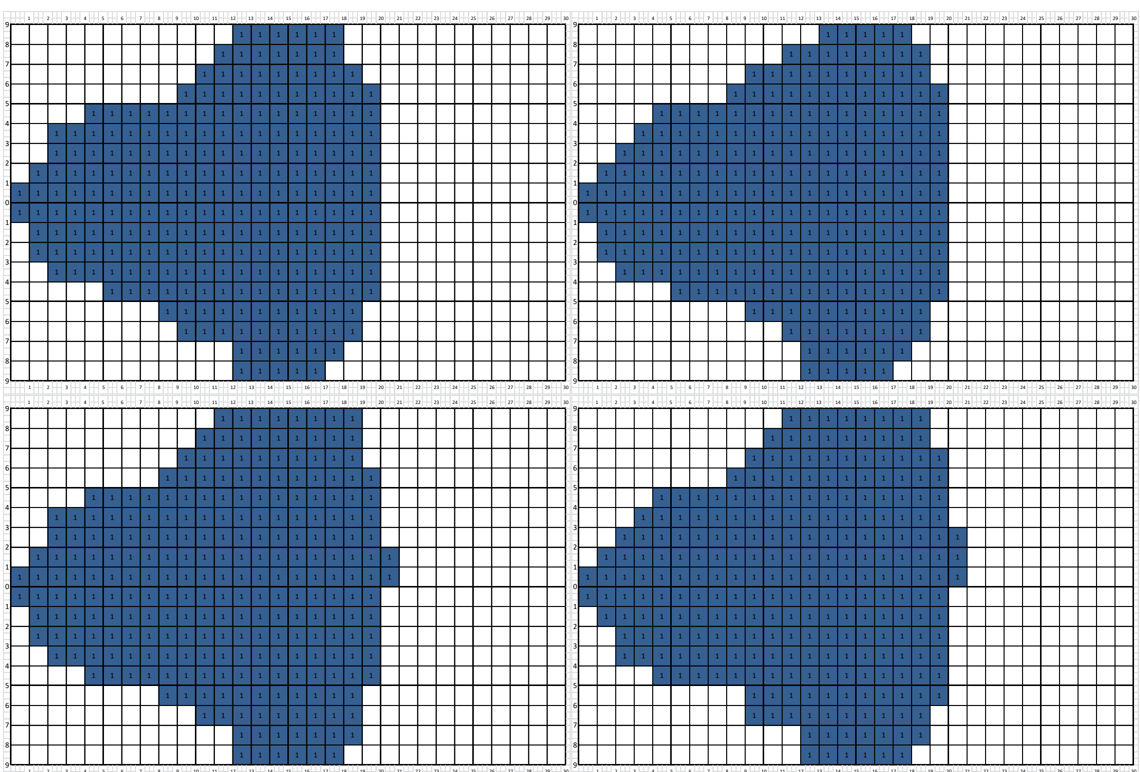


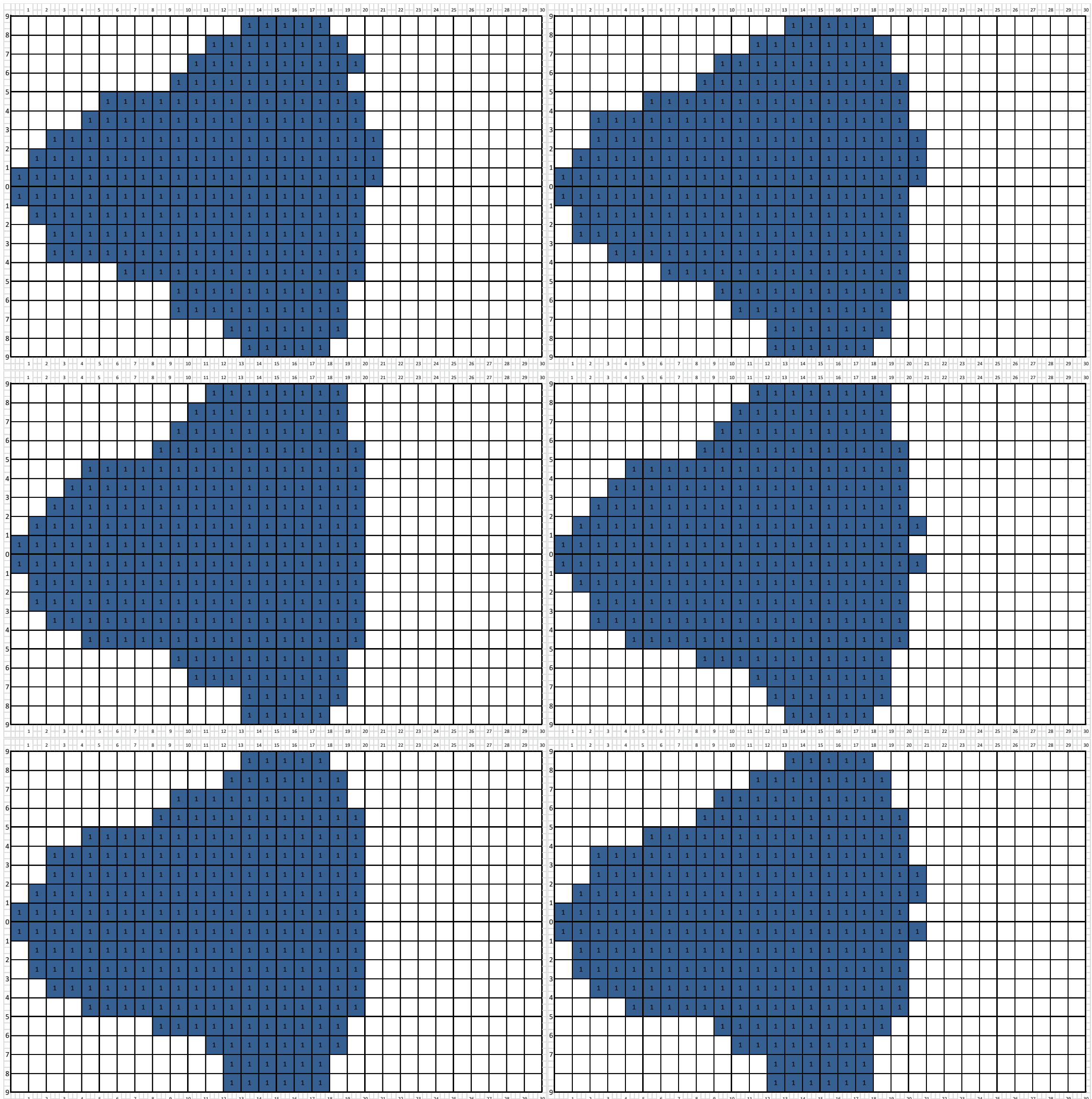
TEST 13

- **Cumulative Result**



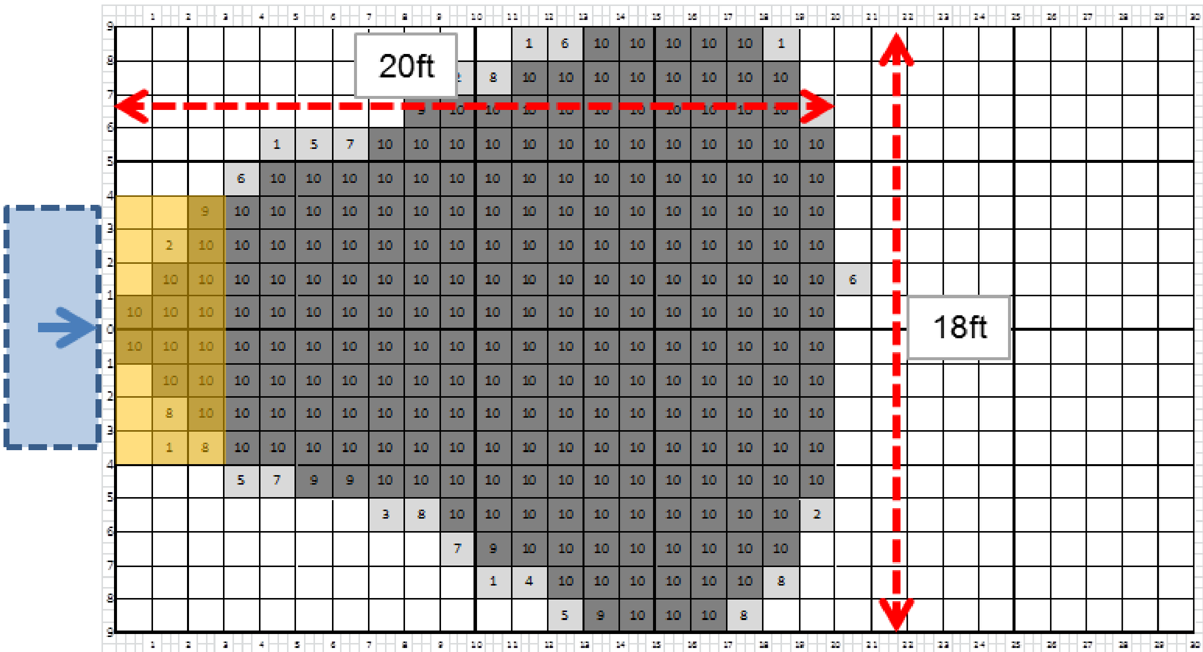
- **Individual Results**



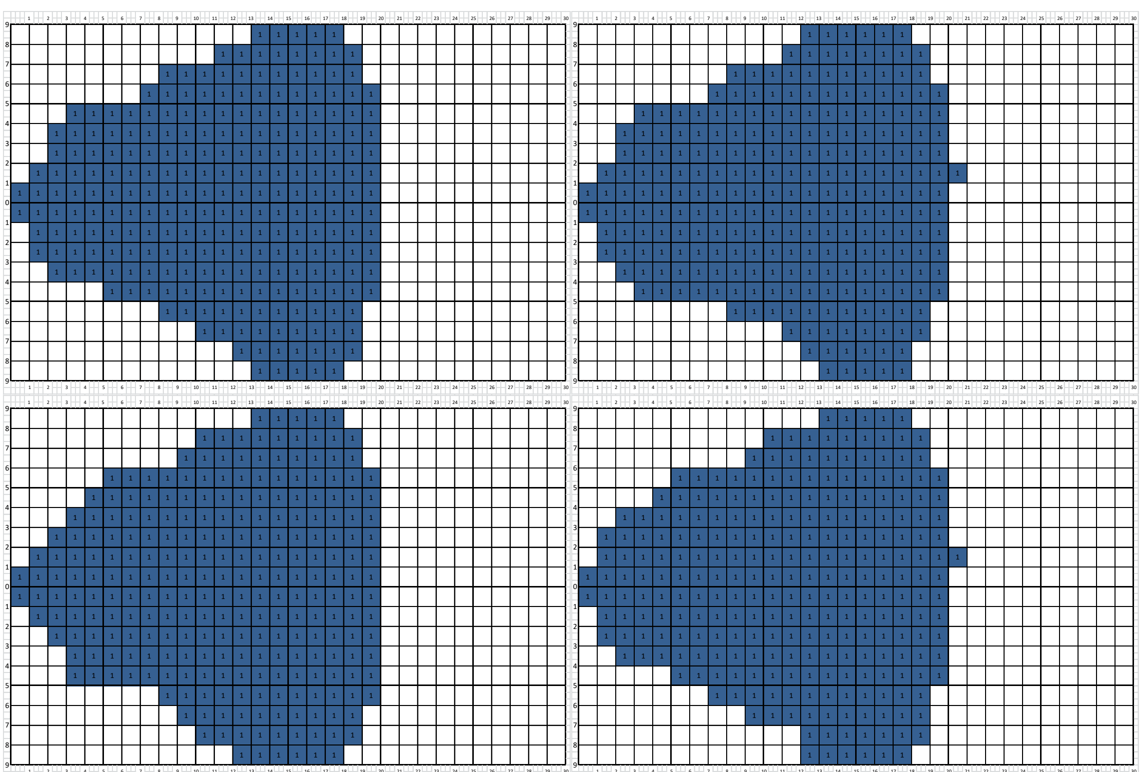


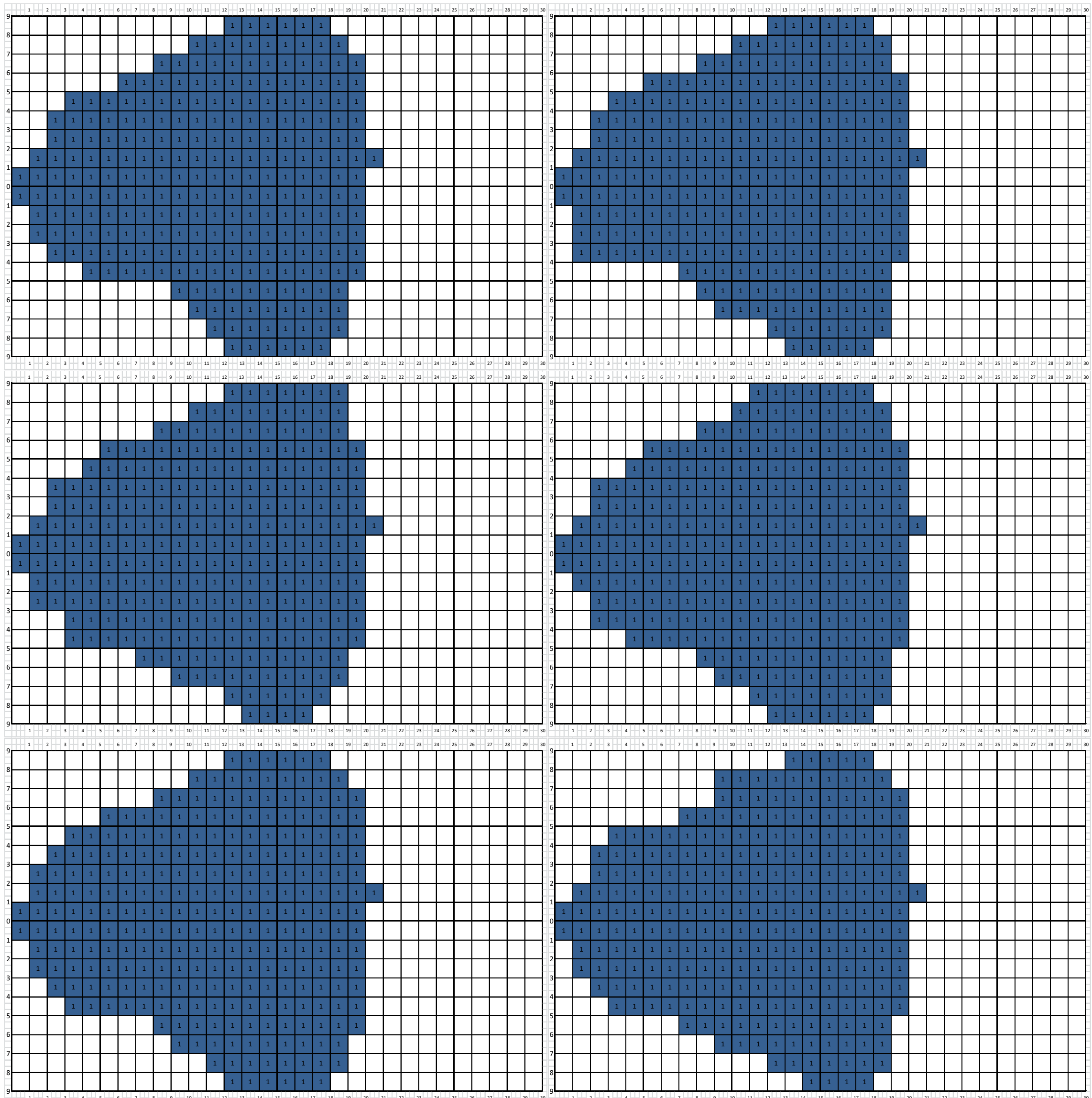
TEST 14

- **Cumulative Result**



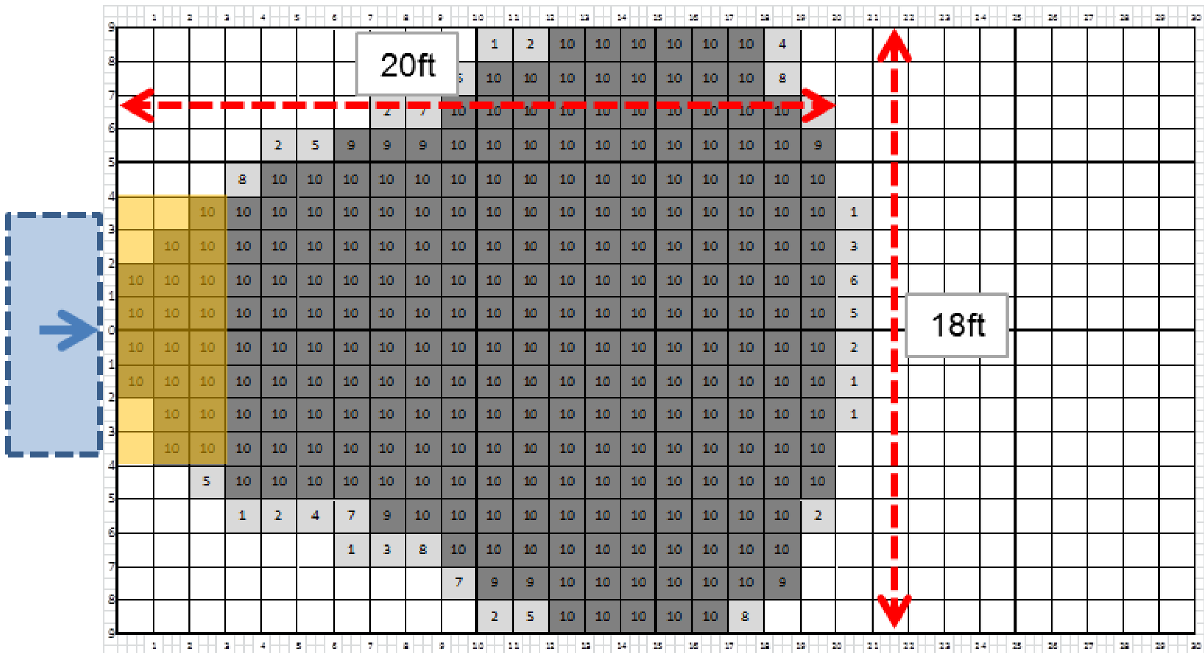
- **Individual Results**



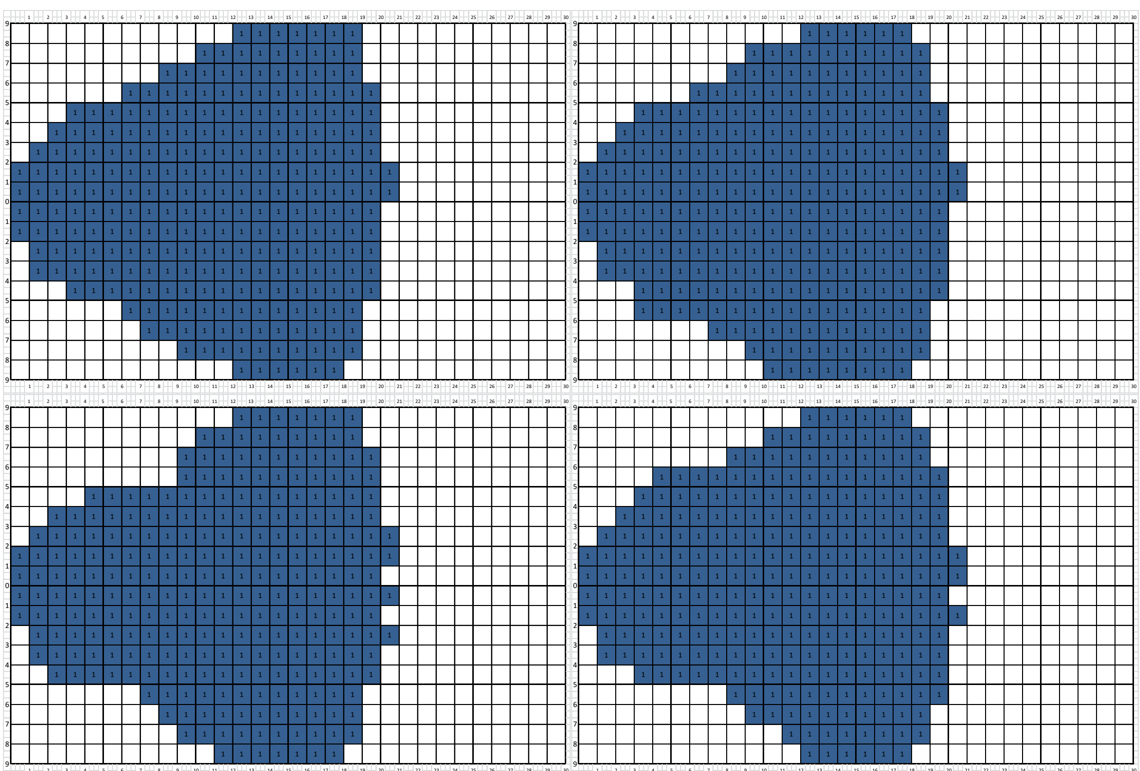


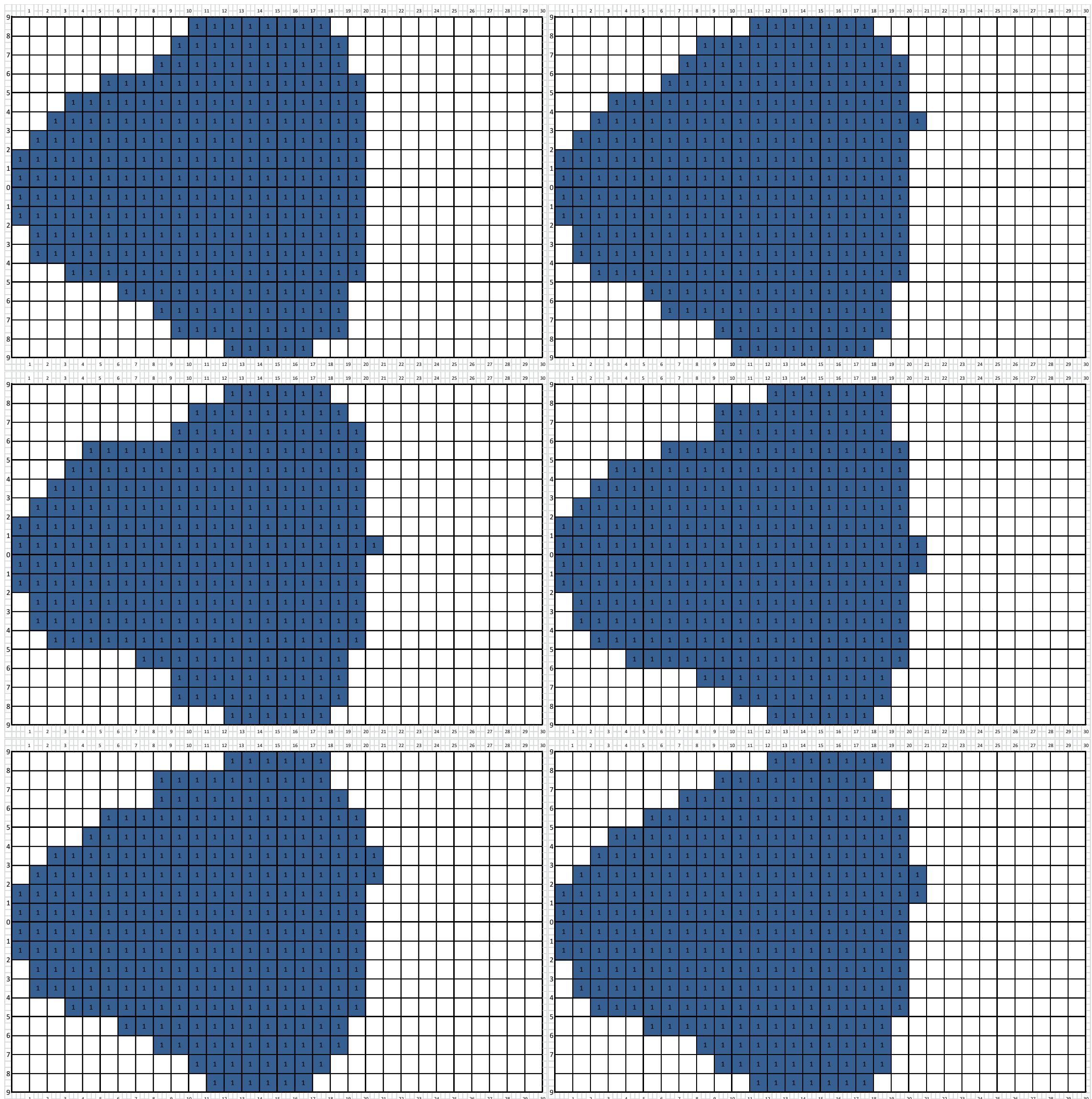
TEST 15

- **Cumulative Result**



- **Individual Results**





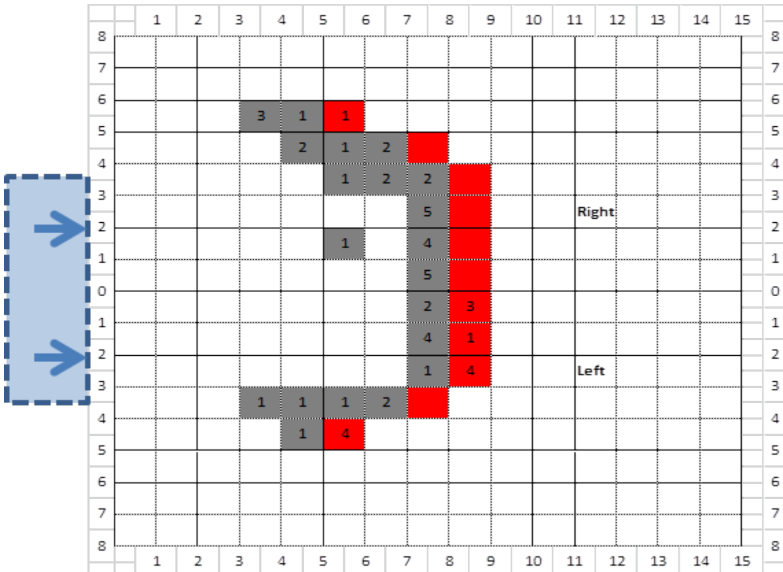
Appendix D: Dynamic Test Results (Details)

Table D.1 Summary of Dynamic Test Plan

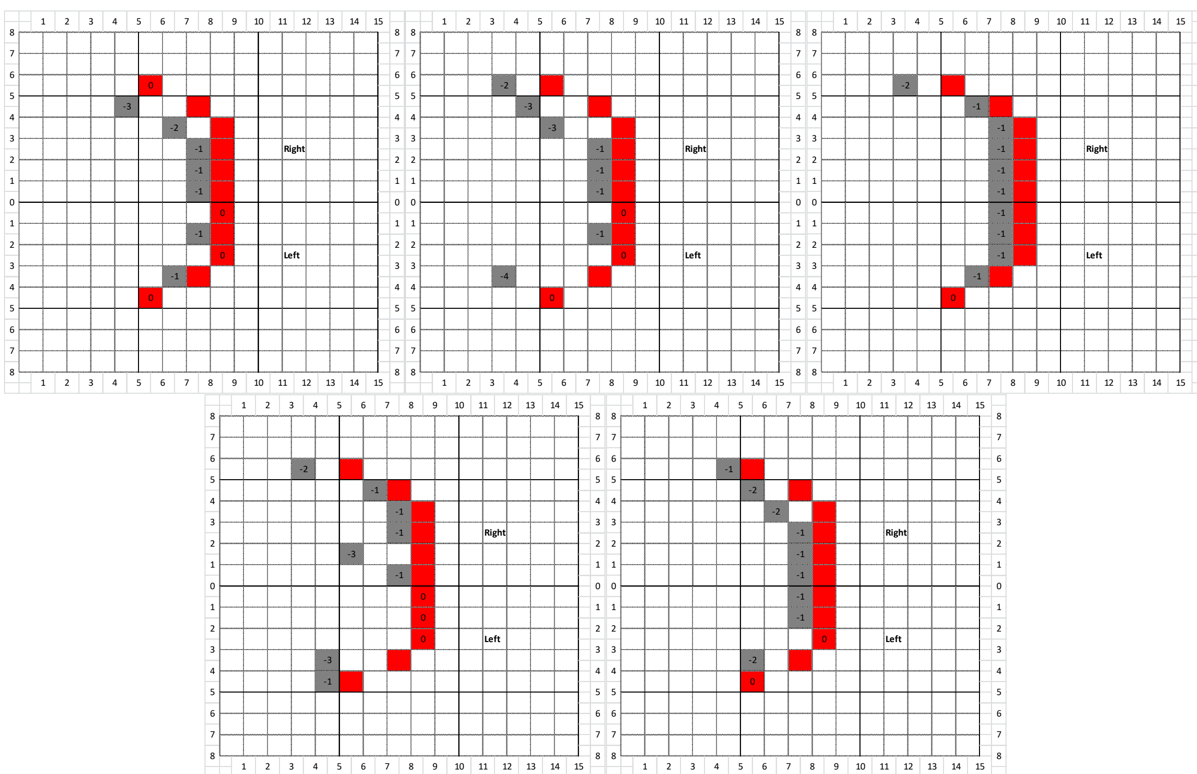
Test No.	Vehicle Type	System Type	Height (inch)	Width (inch)	Temperature (°F)	Humidity (%)	Trials
1	Pickup Truck	HCS-700	24	52	94	44	5
2		WorkZone	24	Center	94	44	5
3		HighResolution	24	Center	95	43	5
4		WorkSight	24	Center	96	41	5
5	Dump Truck	HighResolution	36	Center	94	44	5
6		WorkSight	36	Center	96	39	5

TEST 1

- **Cumulative Result**

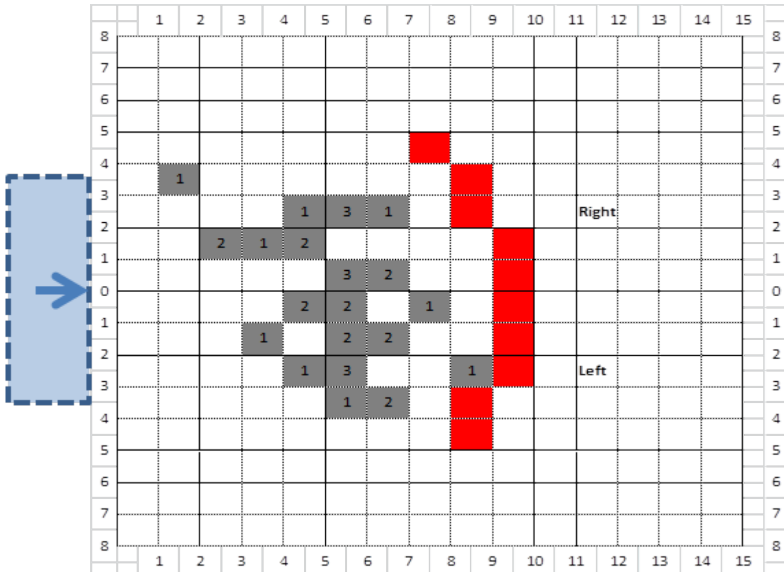


- **Individual Results**



TEST 2

- **Cumulative Result**



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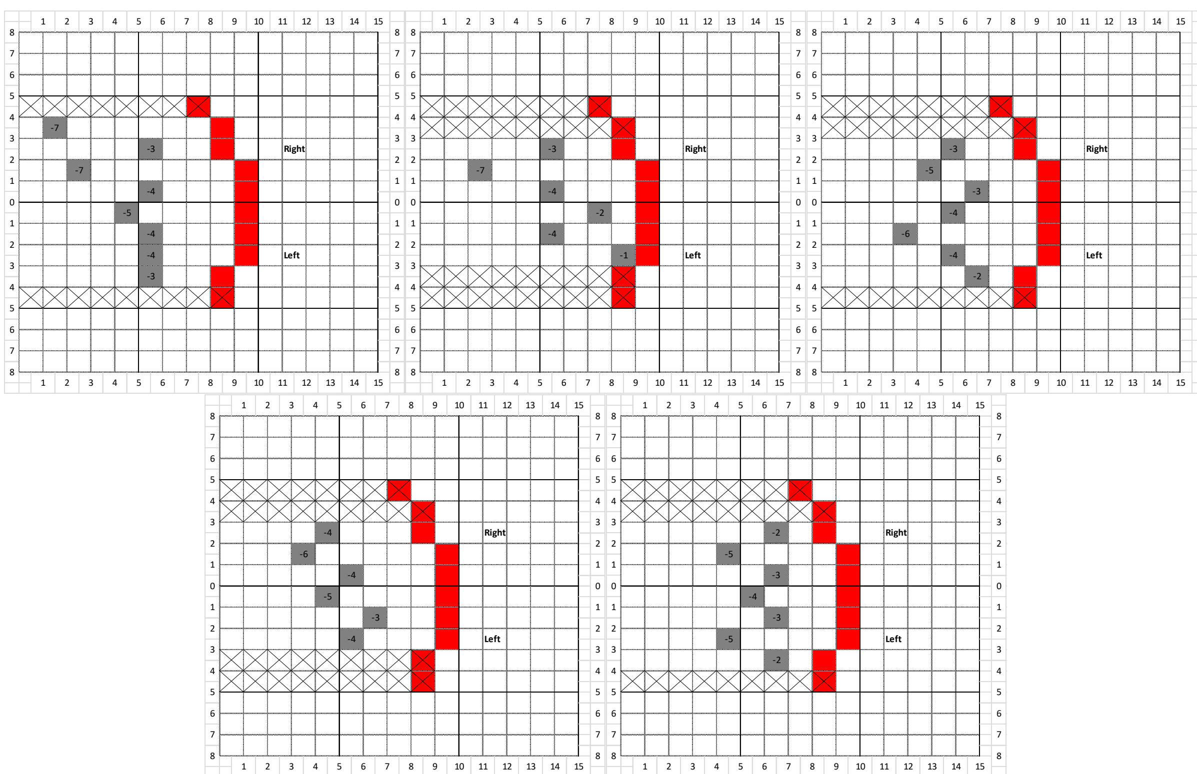

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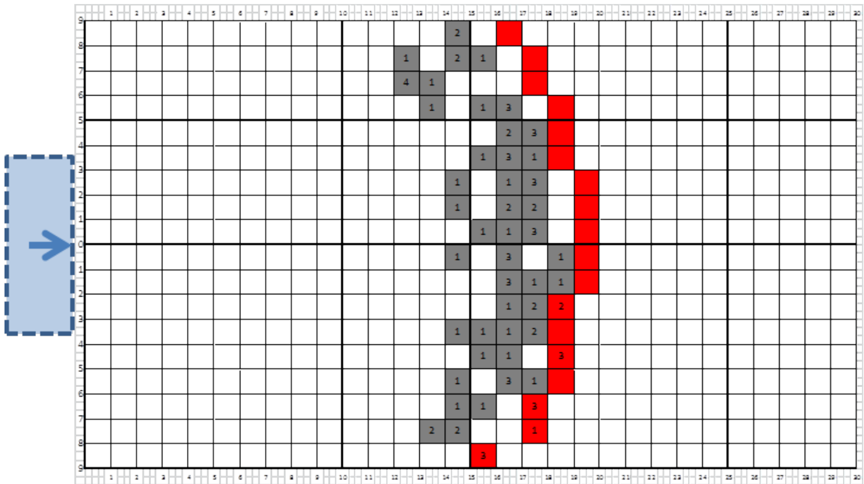

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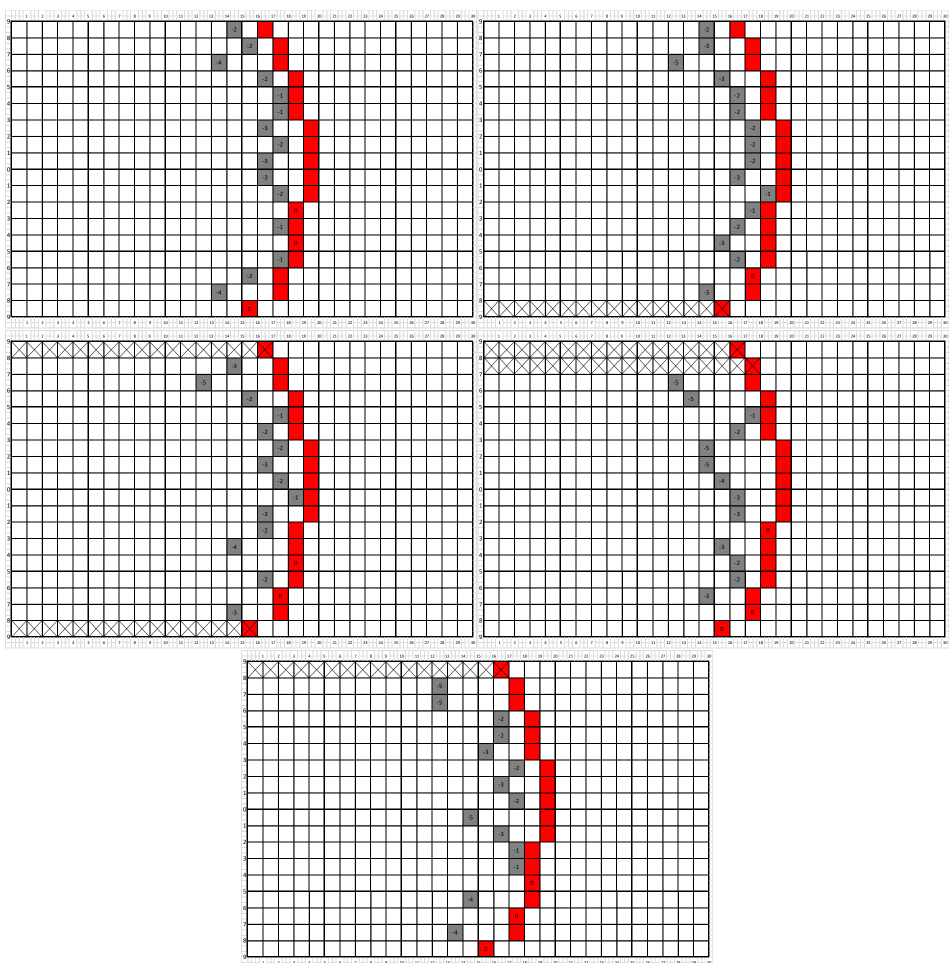

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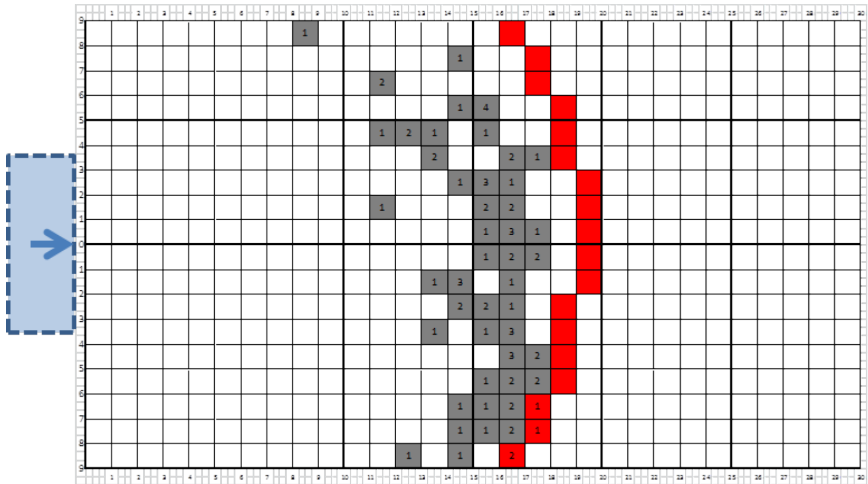

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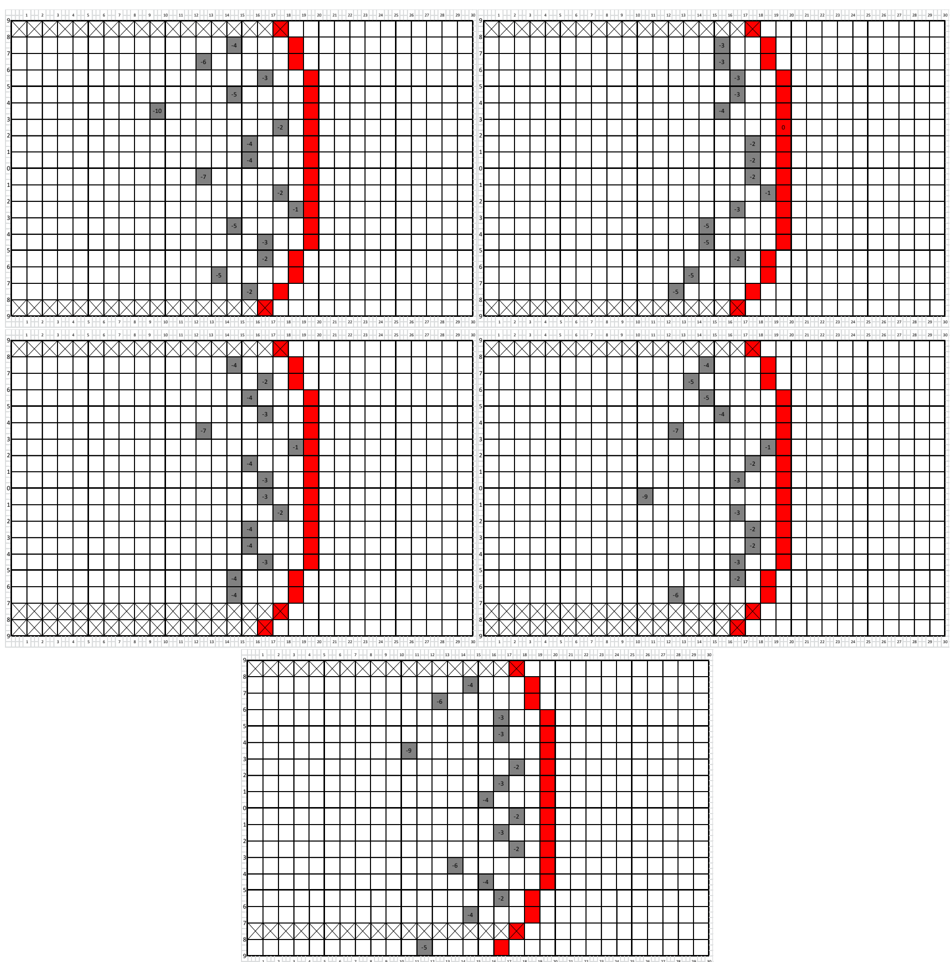

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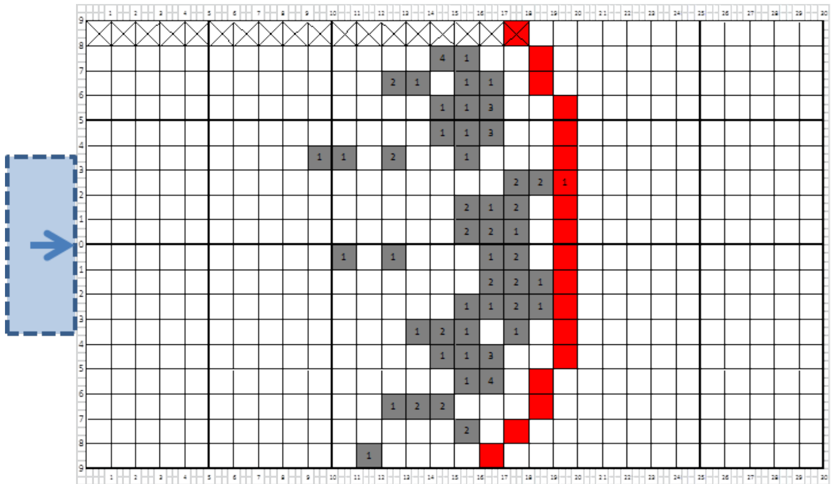

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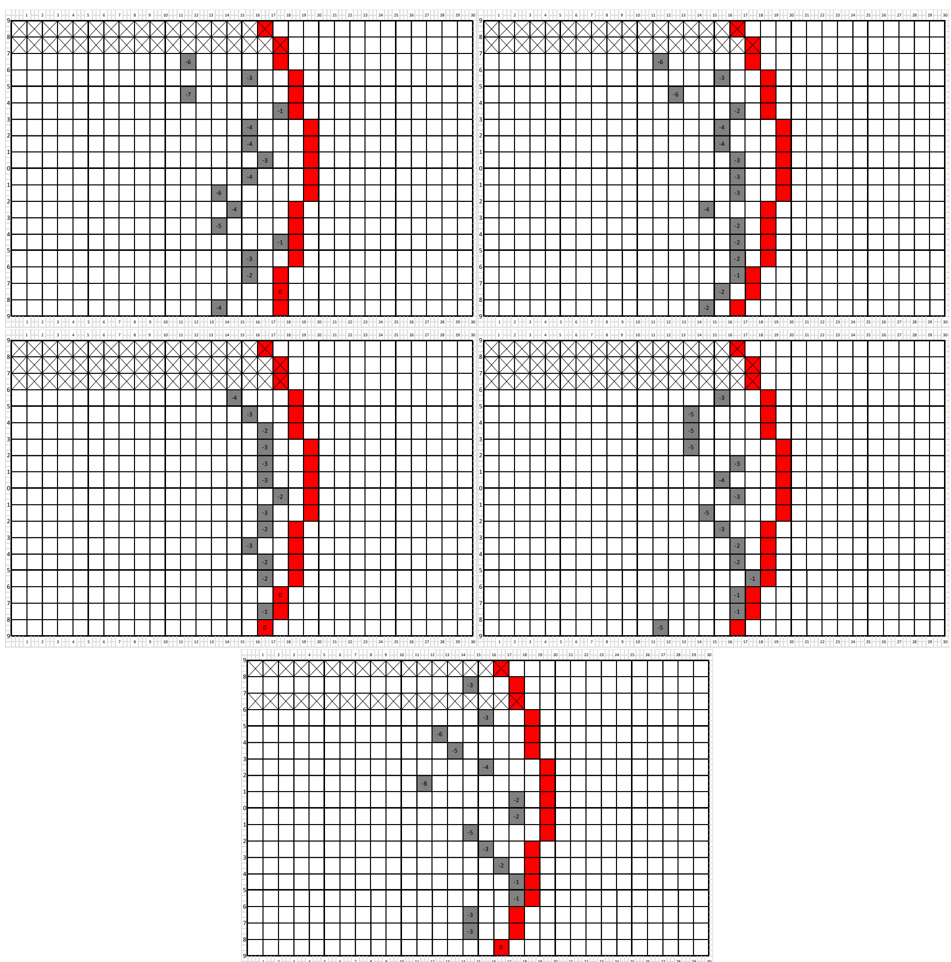

TEST 6

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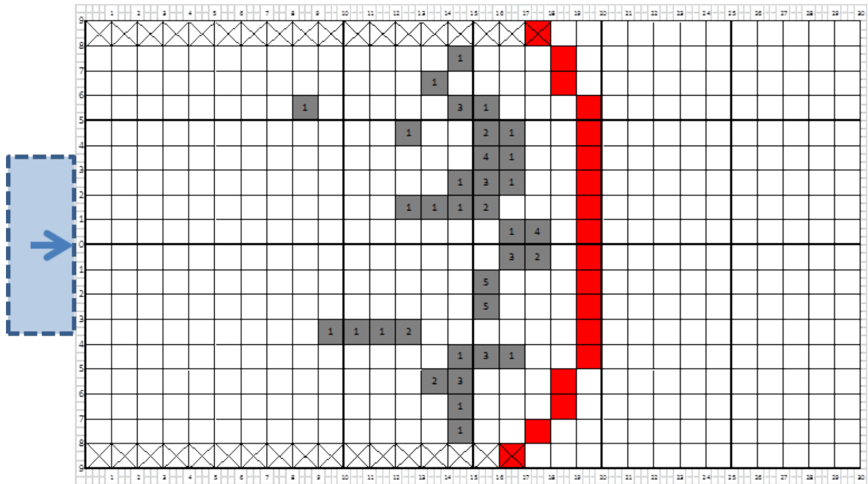

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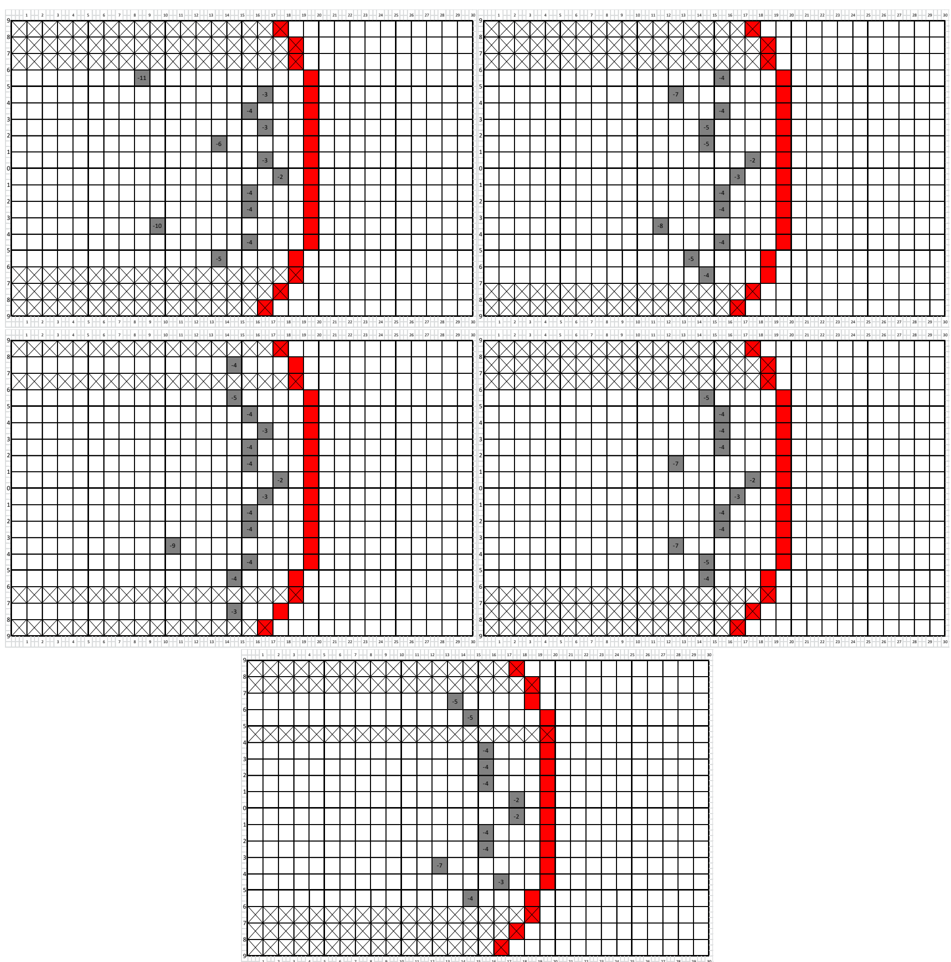

Appendix E: Prevention of Backing Fatalities in Construction Work Zones: A Comprehensive Survey of Current Practices and Procedures

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Word Count: 5855 words + 3 figures + 3 tables = 7355 word-equivalents

ABSTRACT: The purpose of this paper is to conduct a comprehensive survey of current practices and procedures on the prevention of backing fatalities in construction work zones. A review of fatal backing incidents has been done and indicates that backing fatalities are a real and immediate hazard to most construction work zones. Procedures and policies are reviewed and discussed in detail. First, general work zone safety hazards are reviewed, particularly blind areas are identified. Second, engineering controls currently in use are examined and explained to help understand what steps can be taken to prevent future backing fatalities. The internal traffic control plan (ITCP) is described as one of the most promising engineering solutions to this issue. An ITCP designates the movement of people and equipment through the work zone in an effort to maximize safety by minimizing hazardous situations in the work zone. Third, administrative controls (including signalers, drivers, and workers-on-foot training) are also discussed. These in-house communication educational directives could help workers understand and use safe practices to prevent future backing fatalities. Fourth, existing technology controls are reviewed for use in aiding equipment operators in identifying when pedestrian personnel are in dangerous areas around their equipment (i.e., back-up camera, radar). Finally, a summary of the review is given, and future research directions are discussed.

Appendix F: Development of an Evaluation Criteria for Commercially Available Proximity Warning Systems to Prevent Backing Fatalities in Construction Work Zones

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ABSTRACT: Various sensing technologies, such as radars, video cameras, and tag based systems, have been developed and tested to provide hazard warnings to operators in order to prevent collisions within blind areas of construction equipment. However, due to the various construction equipment characteristics, there is no panacea in terms of technology that will work for all types of construction equipment. Therefore, it is necessary to develop criteria for selecting proximity warning systems for specific equipment types. The main objectives of this study were: (1) to select construction equipment types which most frequently cause backing accidents in construction work zones; (2) to establish a generic proximity warning systems selection criteria for selected equipment types; and (3) to select appropriate proximity warning systems for selected vehicle types. From accident to blind area data analysis, pickup and dump trucks were selected for our test. In addition, the sensor selection criteria for both pickup and dump trucks were developed based on eight evaluation factors and criteria which were collected from related publications and specifications from commercially available systems. The selection criteria were validated by 20 external experts in the field of construction safety and sensing. As a result, three sensor systems for pickup trucks and one sensor for dump trucks were selected based on the developed evaluation criteria.