Construction Industry Institute®

Real-time Pro-active Safety in Construction

Research Summary 269-1
Version 1.1

Construction Industry Institute

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Real-time Pro-active Safety in Construction

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Executive Summary

Every year for the past 10 years, nearly 1200 construction workers have died on the job. That equates to approximately five construction worker deaths every working day in the U.S. Of these fatalities, 25 percent involved heavy equipment—most being categorized as struck-by incidents. As these statistics indicate, safety in construction remains a big problem. Despite the implementation of better safety practices in recent decades, further improvements can be gained in construction safety through the use of technology.

The primary objective of this research was to evaluate the performance of devices that warn construction personnel of the presence of potential hazards in real time. A secondary objective was to use remote sensing technology that records accurate location, proximity, and trajectory data of construction resources (workers, equipment, and materials) in real time. The intent was to evaluate existing technology through experimental field studies. These field tests were set up to provide insight into how well the technology can be applied to construction operations and were designed to include an assessment of workers' receptiveness to the use of the technology. The research scope was limited to equipment-pedestrian interactions on the kinds of construction sites that are typically controlled by behavioral management strategies and onsite traffic flow management.

Existing technology was explored that could help monitor worker location and/or warn of potential danger posed by equipment. The most promising technology was then field tested to determine whether it could be used effectively to enhance safety on construction projects. Field tests on small, medium, and large construction sites included real-time location tracking of workers and the use of sensing technology that would warn workers and operators of the close proximity of workers to equipment. The field tests demonstrated that existing safety technology can be implemented on construction jobsites, yielding various benefits (e.g., providing real-time pro-active alerts to workers/operators and monitoring the locations of workers, equipment, and materials.)

This research developed an implementation strategy of how technology can be incorporated into existing safety management programs. This included a cost-benefit analysis to validate the cost-effectiveness of the use of real-time pro-active alert technology. Benefits and barriers to the use of technology were explored through on-site worker surveys.

In summary, this research project has evaluated the impact that emerging safety technology can have on construction safety engineering. The results of the analysis of past construction fatalities provided the motivation and justification for the use of technology. Field trials demonstrated how technology can be used and implemented to enhance construction safety.

1

Introduction

Recent advances in technology have made it possible to integrate and leverage its potential in construction industry applications. The ability to improve safety performance in construction has been proven over the last few decades; however, these efforts have focused primarily on behavioral safety management and policy changes. Despite improvements in construction safety, the safety record in the construction industry continues to lag behind other industries. For example, for the inclusive years of 2004 to 2006, an investigation of construction worker deaths revealed that one-fourth of all construction deaths were related to construction equipment and contact collisions. Clearly, additional efforts are required to make further improvements in construction safety.

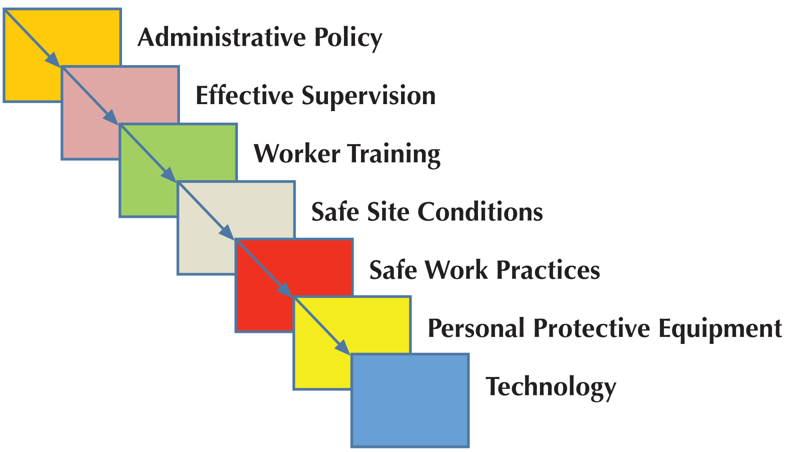

Figure 1. Technology as an additional barrier to protect from hazards.

As illustrated in Figure 1, this study presents findings on the application of technology as an additional layer of protection—a layer beyond the policy, practices, training, and physical measures already in use—to enhance safety performance on construction projects.

Problem Statement

It is assumed that significant improvements can be gained in construction safety if technology is applied in addition to implementing safety management practices. Understanding how existing technology can be used to warn onsite personnel of the presence of hazards in real time and to monitor the location and movement of resources will help construction firms integrate emerging technologies with work site safety.

Research Objectives

The primary objective of this research was to examine devices that warn construction personnel of the presence of potential hazards in real time. A secondary objective was to use remote sensing technology that records accurate location, proximity, and trajectory data of construction resources (i.e., workers, equipment, and materials) in real time. The intent of the research was to select and evaluate a few promising existing technologies through experimental field studies. These field tests were set up to reveal how well the technology can be applied to construction operations. Field trials were to include an assessment of workers' receptiveness to the use of the technology.

Research Methodology

Past construction safety research has provided a solid basis for making improvements in construction safety. The research team's literature review revealed that most safety efforts have been focused on safety management issues and that there has been a minimal emphasis on construction equipment operations. The team reviewed existing CII publications, occupational safety and health databases, and professional journals to evaluate the significance of worker/equipment interactions related to safety. The review focused on the following construction safety concerns:

1. The role played by construction equipment in 289 visibility-related construction worker fatality cases between the years 1990 to 2007.
2. The causes of fatalities related to more than 13,000 construction-related accidents.

3. The applicability of existing safety management and best practices in real-time construction site safety.
4. The applicability of relevant technology to daily construction operations involving construction equipment.

The research team also employed opinion-based surveys to develop a real-time pro-active safety framework. The main focus of the real-time pro-active safety framework was to understand how and where technology is applied in an existing safety management system and which stakeholder of a construction project (owner, contractor) benefits from applying the technology.

To validate the developed real-time pro-active safety framework, the research team conducted field trials using warning and tracking devices. The research team developed a field trial methodology to cover a broad spectrum of job site applications of technology. The research team selected 15 candidate sites in the southeastern United States, ranging from small to large capital investments ($2 million to $1 billion). The construction sites ranged from having a few to having many construction workers (i.e., 15 to 2,000) and they had varying numbers of pieces of equipment (i.e., five to 250). The final sample of selected construction sites consisted of five small to large building construction sites, seven small commercial construction sites, two large industrial construction sites, and one union ironworker indoor training facility.

The field trials focused on the use of radio frequency-based real-time proximity warning technology that warns workers and equipment operators when the worker/equipment proximity is too close. Tests in controlled construction environments were performed to measure the warning distances between several pieces of equipment and nearby construction workers. Surveys were conducted to record the opinions of workers and equipment operators who had used these devices.

Field trials also included the testing of real-time resource location tracking technology. Data were retrieved on the real-time location of up to 50 workers who were close to several pieces of equipment. Proximity data of construction resources were automatically processed and visualized to inform equipment operators of the presence of obstructions in the vicinity of their machines.

The following sections include details on the field trials and other technologies. An implementation strategy is presented that was developed through the use of opinion-based surveys, input from safety professionals, and a review of best safety practices. A cost-benefit analysis is performed and some legal implications on the use of emerging monitoring and warning technology are also discussed.

2

How Technology Affects Construction Safety

Construction sites are organized by coordinating multiple resources, including personnel, equipment, and materials. These resources are often in motion and can come into close proximity to each other. If not coordinated and organized properly through optimized work planning (i.e., schedule and resource leveling), spatial interference can lead to incidents between two or more objects (e.g., members of the workforce, equipment, material). These incidents can be characterized as contact collisions that threaten the safety and health of construction personnel. It is further noted in the literature that information on the causation of construction accidents has yet to be thoroughly examined and recorded.

Contact collisions between construction workers on the ground and construction equipment are attributable to the following factors:

- a lack of knowledge of specific existing risk factors
- a myriad of distracters on the construction site
- the lack of real-time information concerning potential incidents.

Construction companies are slow in adapting automated technologies that have proven to work in other industries. Railroad operations, freight transportation, and the mining industry, for example, have been testing various prototype safety technologies for some time now, while the construction industry has been slow in considering these technologies. If these emerging technologies were to be tested successfully in a construction environment, they could be adapted for application in the industry. However, there has been a lack of scientific evaluation for new and existing automated safety technology for use in construction. Emerging safety technology needs to be thoroughly evaluated through research using current or newly developed methods, along with case studies and data analysis.

Injury Statistics Related to Workers and Construction Equipment

Findings by the Center for Disease Control (CDC) show that, in spite of the ongoing efforts to improve safety, there has been little improvement in preventing workers from being killed through contact collisions with vehicles and/or equipment. (All CDC information was based on after-the-fact data and was recorded after incidents had occurred.) Fatality statistics from 1992 through 1998 show that, out of the 465 vehicle-related construction fatalities, 318 of the victims were workers-on-foot. Vehicles involved in these struck-by incidents were most commonly a type of truck (60 percent), followed by large construction equipment (30 percent). The study reported that 110 of the 465 fatalities involved operators. Of these 110 operator-related fatalities, more than half were construction equipment operators (53 percent), followed by operators who were driving trucks. The remaining 37 fatality victims were supervisors and other personnel. Of the 465 fatality incidents, the majority of the fatalities (51 percent) occurred when a vehicle was operated in reverse—an operation that is exacerbated by blind spots that are prevalent on the backside of construction vehicles.

Table 1 presents data extracted from OSHA's (Occupational Safety and Health Administration) construction worker fatality database from 1990-2007. These statistics show that for forklifts, skid steer loaders, scrapers and backhoe loaders, 36 percent to 88 percent of the fatalities involved workers-on-foot. The most frequently noted causes are crushed-by, struck-by, pinned-by, run-over, and rollovers.

Table 1. Construction worker fatality data from OSHA (1990-2007). Fatality numbers by equipment type and specific incident cause*: run over, rollover, collisions with another, caught-in/between vehicle, crushed-by, pinned-by, hit-by, and struck-by.

Equipment Type	(A) Overall number of fatalities	(B) Number of fatalities related to *	(B)/A) in Percent	Top 3 leading causes including *
Forklifts (incl. warehouses)	1,021	368	36%	Rollover (22%), Crushed-by (20%), Struck-by (16%)
Skid steer loaders	83	31	37%	Crushed (24%), Struck-by (11%), Pinned-by (2%)
Scrapers	60	37	62%	Run over (49%), Rollover (23%), Crushed-by (6%)
Backhoe loaders	198	175	88%	Crushed-by (34%), Pinned-by (28%), Struck-by (26%)

Existing Safety Best Practices and the Role of Technology

While OSHA regulations help establish construction site safety policies and procedures, they are not sufficient to prevent the occurrence of contact collisions. For example, for applicable conditions, OSHA mandates the use of personal protective equipment (PPE), such as hard hats, safety shoes, goggles, face shields, reflective clothing such as safety vests, heavy or thin (leather) gloves, hearing protection, wet weather gear, and respirators or filter masks. These types of PPE are ***passive safety devices***, because they do not pro-actively warn or provide feedback to the wearer.

Safety training and education are conducted to increase the worker/operator ability to recognize and avoid construction hazards. However, the behavior of individuals on a construction site may change or may be affected by other factors, including fatigue and other distractions. Safety training and education is another (important) form of ***pro-active safety***. Nonetheless, it is up to the worker to also follow the rules, guidelines, and best safety practices. CII Research Report 101-11 and Research Report 160-11 found that better safety performance occurred when the behavior of the individuals on a job site was altered or when site-specific safety programs were prepared early in the life of a project. These studies involved work sampling techniques that require manual analysis and feedback and, thus, are quite limited in providing real-time feedback during the monitoring period.

The injury pyramid is a commonly used analogy, depicting the relationship of serious injuries to all incidents. Figure 2 shows that many close calls occur for every minor injury and that many minor injuries occur for every serious injury.

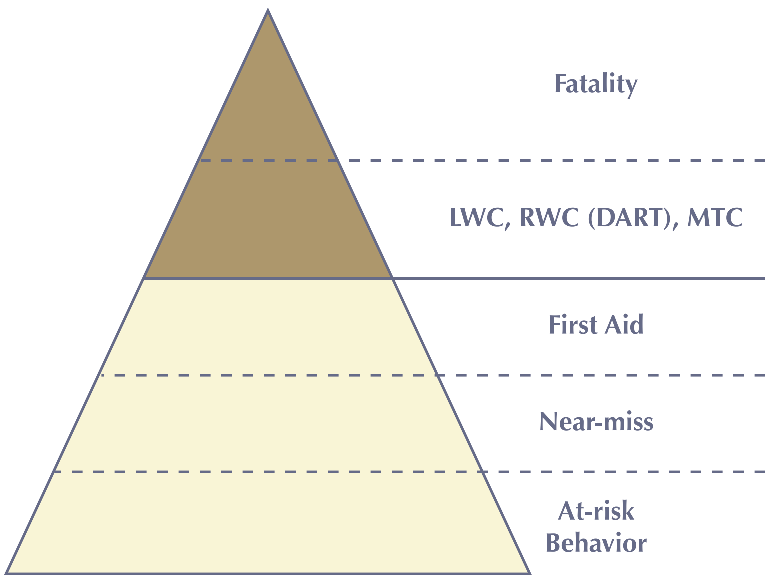

Figure 2. Safety Pyramid

The actual numbers of these injuries and accidents are usually estimates and they often vary from one study to the next. Yet, they show why the focus should be on the causes of the less serious incidents. Most safety research has been focused on the upper part of the injury pyramid, but there is merit in focusing on the lower part of the pyramid, representing as it does the more numerous minor incidents. Currently, very few firms record statistical data on incidents that do not result in an injury and only a few will record first aid injuries. For example, collecting data on close calls is a challenge because it requires workers to voluntarily acknowledge that a negative event occurred.

Automation may help to solve or simplify some of the aspects of identifying the potential for close calls. Technological devices that could provide real-time pro-active proximity alerts to warn workers-on-foot when they are too close to construction equipment could help to prevent close calls and accidents. Such information could also be easily stored and automatically retrieved.

Pro-active real-time safety is necessary when organizational commitment, supervisory influence, and PPE fail. Providing workers-on-foot and equipment operators with real-time proximity alert devices can help prevent collision events through an early warning mechanism. Different accident causation theories help to explain accident occurrence. One theory is the "domino" theory or the "chain of events" theory that states that accidents are the result of a series of occurrence or actions. Every one of the actions must take place in order for an accident to occur. If one action is changed, the accident is prevented.

A related theory is the "human error causation" model that states that accidents occur when weaknesses in a series of levels take place. A number of safeguards may be in place to prevent accidents, but if each fails, an accident may still occur. Technology may be added as an additional safeguard to help ensure worker safety. Since zero incidents and zero collateral damage are the overall project safety objectives, technology-driven safety can assist (but not replace) existing safety best practices.

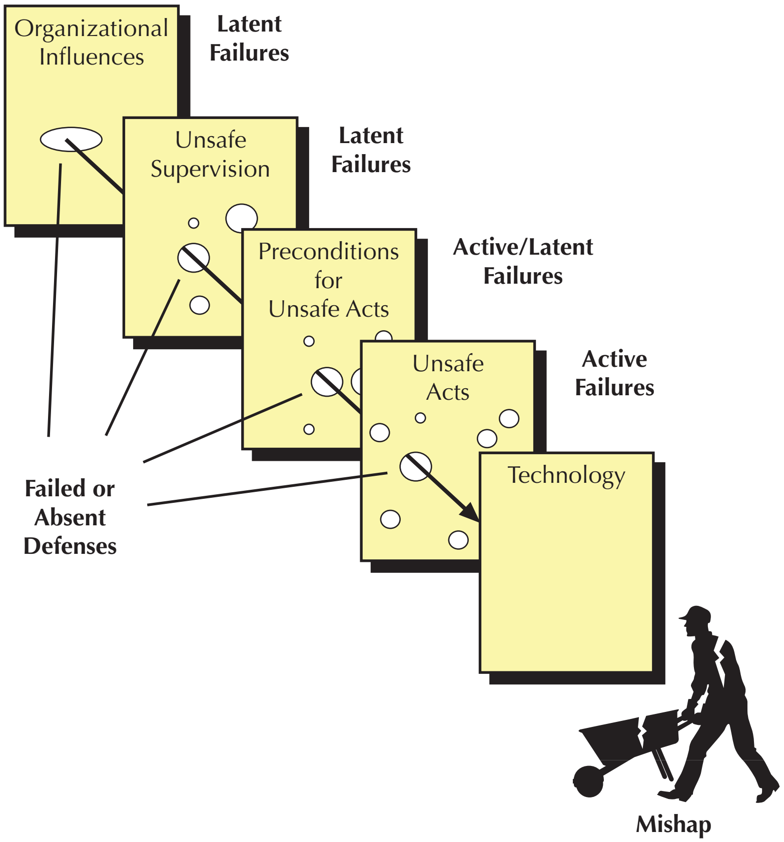

Figure 3. Human error causation model, with technology as last layer of defense

In summary, the above reasons support a modified human error causation model. (See Figure 3.) Emerging safety technology can be applied at two levels. First, it can serve as a final barrier by giving workers an opportunity to escape serious harm through the use of real-time proximity-warning devices. Second, the data retrieved from these devices can generate information from previously unrecorded events, such as close calls. This new information can lead to significant changes in existing organizational safety practices. Effective implementation of technology can help to close up the "holes" in the human error causation model and further decrease the number of incidents on worksites.

Potential for Pro-Active Safety Technologies in Construction Safety

There is a distinct difference between re-active and pro-active safety technology. Re-active technology collects data in real-time, but consists of a post data collection processing effort to convert the data into information. Pro-active technology works in real-time to warn and alert personnel of dangers occurring at that moment. Indeed, almost all of these technologies have to work reliably in the harsh construction environment and they have to handle the same constraints that equipment operators and workers-on-foot face during the work day.

Summary of Review

A report by the Center for Disease Control (1997) entitled "Recommendations for Evaluating and Implementing Proximity Warning Systems on Surface Mining Equipment" states that many proximity systems are available, but that there are limitations for each technology. Criteria for selecting proximity warning and alert technology are presented in Table 2, along with some key technologies considered for application in the construction industry. Based on the literature search, this research recommends that a proximity warning system evaluation must be conducted on the actual equipment onto which technology will be installed before any conclusions can be made about reliable detection areas, false alarm rates, or alarm effectiveness. Because every piece of equipment is different, the NIOSH report further notes that "a system that works well on haul trucks may not be suitable for excavators," and the "detection range would [need to] automatically adjust to equipment travel speed."

Table 2. Sample criteria for selecting proximity warning and alert technology

Technology / Criteria	Radio Frequency			Optical		
	Ultrasound	Ultra-High Frequency (UHF)	Very-High Frequency (VHF)	(Stereo) /Video	Eye-safe Laser (1D/2D/3D)	Infrared
Objective	Distance	Proximity	Proximity	Proximity/Distance	Location	Proximity
Range [m]	0-10	0-40	0-500	0-500	0-50	0-30
Accuracy of data	Low	Medium	Low/Medium	Medium	Medium/High	Low
Signal bounce	High	Small	Medium/High	Small	Small	Medium
Data processing effort	Small	Small	Small	Small/High	Small/High	Small
Secure signal	Noise	Yes	Yes	No	No	No
Day vs. Night	Very Good	Very Good	Very Good	Poor	Very Good	Fair/Good
Signal update rate	High	High	High	High	High	High
Size and weight	Small	Small	Small	Small	Medium	Small
Installation/ Maintenance	Small/Medium	Small/Medium	Small/Medium	Small/Medium	Small/Medium	Small/Med. ium
Purchase Cost	Small	Small	Small	Small	Medium	Small
Main barriers	Short range, noise	Proximity	Omni directional signal, proximity	Line-of-sight, segmentation	Line-of-sight, segmentation	Line-of-sight, noise
Main benefits	Inexpensive	Works in high metal areas	Long range	Location, range	Location	Inexpensive

3

Technology Field Trials

The primary objective of the field trials was to test ***pro-active real-time safety technology*** that increases situational awareness and safety in construction equipment operations. The technology consisted of devices that autonomously provided wireless pro-active real-time warnings and alerts when two or more construction resources (i.e., workers and equipment) were too close in proximity. Sensing technology can assist workers-on-foot and equipment operators in detecting their relative proximity to each other. When their proximity to each other is too close, visual, auditory, and vibrating alerts are activated and warn both personnel on the ground and those operating the equipment. The field-tested device—known as equipment and personal protection units or as EPU and PPU, respectively—were deployed on workers and equipment on small, medium, and large jobsites. Figure 4 shows the implementation of technology at one of the larger test sites.

Figure 4. Test site for field trials
(permission to use by Shaw Constructors Inc.)

The system employed in this research used a special secure wireless communication line of Very High Frequency (VHF) active Radio Frequency (RF) technology near 700 MHz. This consisted of an in-cab device and a personal device. The in-cab device was equipped with an equipment protection unit (EPU) that consisted of a single antenna, a reader, and an alarm. The personal protection unit (PPU) consisted of a chip, a battery, and an alarm. The term "personal" was used because subsequent interviews revealed that workers like to identify themselves with the safety devices—they like to "own" them. Although the user can define the signal strength of the EPU unit for each piece of equipment, the signal is typically transmitted in a radial manner and loses strength with distance from the EPU. (The signal strength should be set for each EPU prior to its use.) The PPU then intercepts the signal at a user-adjustable distance and, once this occurs, the PPU automatically returns the signal such that both systems trigger their internal alarms. The operation of sending and receiving information is instantaneous; the whole process occurs in real-time. Figures 5 and 6 show the EPU/PPU technology in the field trial mode.

Methodology of Field Trials

The warning and alert technology was scientifically evaluated through an experimental plan. Testing was performed with the proximity warning devices on different pieces of construction equipment including personnel movers, wheel loaders, forklifts, graders, forklifts, dozers, excavators, articulated dump trucks, and mobile cranes. Each piece of equipment was then directed to travel towards a simulated work crew. The operator was then asked to stop the machine once the audible or visual alert was activated within the equipment cabin. The distance between work crew and equipment was measured, recorded, and analyzed. For each test, the worker-on-foot and equipment operator were interviewed. Testing was also performed over extended time periods and workers and operators were asked about the effectiveness of the devices over longer test periods.

Figure 5. Alert devices on personnel and equipment during field experiments

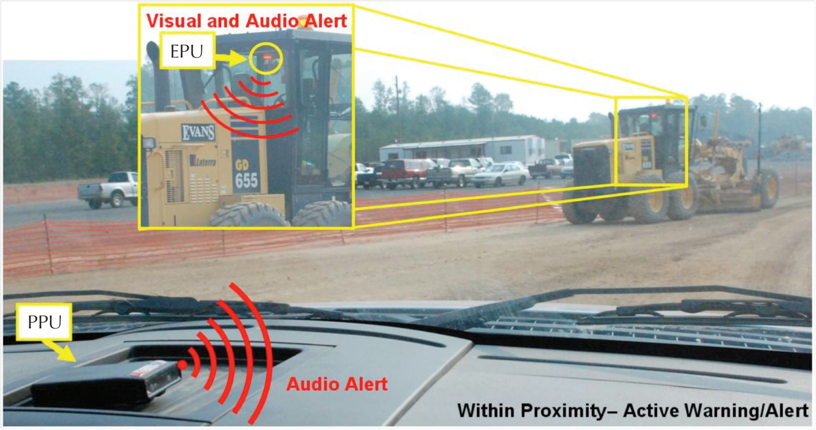

Figure 6. Alert types for workers-on-foot and equipment operators: a vehicle approaching a motor grader issues alerts inside both equipment cabins.

The PPUs are durable and wearable since they come in different sizes. For a typical PPU, the casing is sturdy and can stand up to the daily weathering that occurs on construction sites. The devices are powered with conventional AA batteries and last for at least two months, depending on the frequency of alerts. Light-emitting-diodes (LEDs) indicate when batteries are low on power and need to be recharged. The audible alarm that occurs on both the EPU and PPU is of sufficient strength to get the attention of workers and operators. The alarm emits a sound that is from any other sound that is common on construction sites. The PPU also has a vibrating alarm so that workers can be notified even if wearing hearing protection or when working in an area with loud construction noises. Vibration alerts have the drawback of not working well when workers wear heavy coats in cold weather.

Field Trials and Results to Proximity Warning and Alert Device

Figure 6 shows a warning and alert system during a field trial involving two pieces of equipment. When the vehicles moved into close proximity to each other, the visual and audible alarms alerted both operators. (See Figure 7.) The EPU is compact and can fit into an equipment cab without creating any visual or mechanical obstruction. The PPU can be worn on the belt of the worker or around the arm with an arm band.

Figure 7. Audio and visual alerts for worker-on-foot and equipment operator in open cabins of a scraper (rear view, at left), and on a sheep-foot-roller (forward view, at right)

Five PPUs of the same configuration were tested in the preliminary field trials. Since each equipment type may require its own unique signal strength, setting the warning and alert distances at a lower level reduces the number of nuisance alerts. The shortest empirical warning and alert distance from EPU to PPU was 2.80 m. (See the excavator data in Table 3.) Cranes, for example, are static, and alerts may only be needed for them when a lift is performed. The operator would be able to activate the EPU/PPU alert system only during lifts. In contrast, scrapers can travel with significant speeds (up to 60 km/h) and thus may require activated alerts earlier and at further distances to ensure the safety of nearby workers close. All distance measurements included the operator's reaction time and the distance required to stop the vehicle.

Table 3. Distance measurements for pro-active real-time proximity alert device with static (*) and dynamic construction equipment in realistic construction environments (with obstructions present)

Equipment Type	Number of Trials	Average Recorded Alert Distance [m]	Minimum Recorded Alert Distance [m]	Maximum Recorded Alert Distance [m]	σ [m]
Personnel Mover	4	11.9	10.6	13.6	1.4
Loader/Forklift	11	17.8	12.7	29.9	6.1
Grader and Scraper	10	31.5	25.5	50.2	7.6
Dozer*	8	24.5	7.8	43.0	8.5
Excavator*	8	23.4	2.8	38.0	10.6
Art. Dump Truck*	72	35.6	19.0	50.0	7.4
Mobile Crane*	80	34.0	8.9	62.5	16.0

The results of a machine in static position are illustrated in Figure 8. The jagged circular shape illustrates the alert zone around an articulated dump truck. The average alert distance was 35.6 meters. Table 3 lists the results to a total of 193 tests of other pieces of equipment at 15 different construction locations.

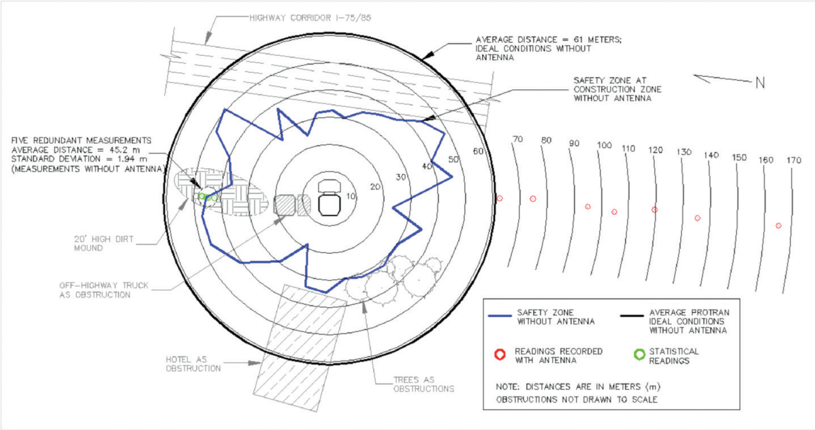

Figure 8. Protected work zone (within blue line) of an articulated dump truck

The largest case studies of the pro-active real-time proximity warning devices were performed on two large clean-coal power plant construction projects being constructed by CII members. One of the studies involved large earth-moving equipment and lasted for several months. (See Figures 6 and 7.) About 20 workers were given PPUs and the 30 pieces of equipment were equipped with EPUs. Close to the end of the research observation period, this project had performed 100,000 accident-free work hours.

Results and Outlook to Other Real-time Technologies: Resource Location Tracking and Data Visualization

This research project also included preliminary tests of real-time location tracking and visualization technologies to study the location of construction resources (i.e., workers, equipment, materials) in an immersive 3D virtual environment.

A virtual environment can be used to enhance safety training and education. The helmets of construction workers were tagged with ultra-wideband technology, a real-time location tracking technology. Field trials were conducted that recorded the location of tagged resources and visualized the information to safety decision makers in remote locations. Following are the steps that are involved in real-time resource location tracking:

1. Install a location tracking tag on each resource. (See Figure 9.)
2. Monitor activities. (See Figure 10.)
3. Visualize the activities in a virtual 3D environment. (See Figure 11.)

Figure 9. Real-time location tracking of the movements of a crane, tractor and trailer, and workers-on-foot

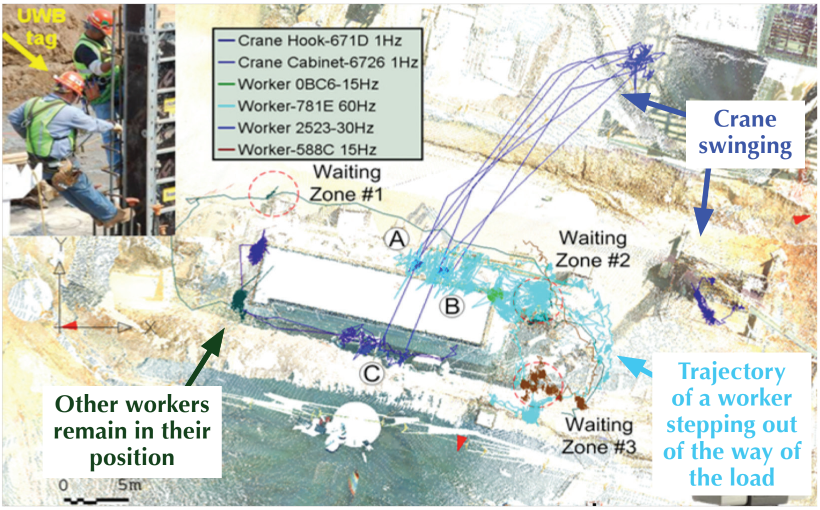

Figure 10. Results of real-time location tracking in plan view. The worker temporarily stepped out of the way while the crane was swinging; other workers continued to work in their positions.

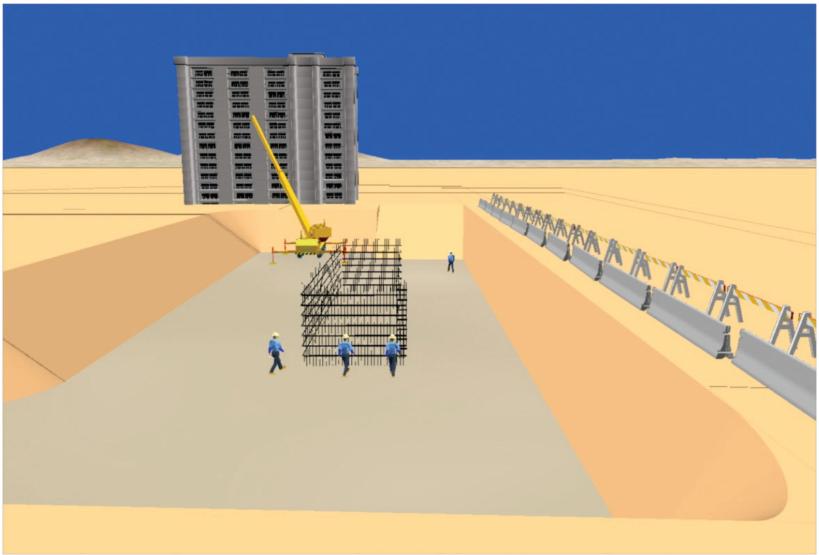

Figure 11. Example of a three-dimensional immersive visualization interface in which visually obscured workers are made visible to a crane operator; such visualizations can be provided in real-time in the equipment cabin or at any other location of an on-site decision maker.

4

Worker Feedback and Investment in Safety

The analysis of the worker feedback data and the justification for investment in real-time pro-active safety technology are presented in the following sections.

Worker Feedback on Using Monitoring and Tracking Technology

At the beginning and end of each field trial, the participants were asked their opinions about using the proximity and tracking devices. A total of 143 equipment operators and workers responded to 23 questions. Results of 49 interviews involving the following six questions are presented and summarized in this research summary:

1. Did you volunteer to wear the warning device?
2. Do you understand how the device is supposed to keep you safe?
3. Do you have any concerns about the warning device?
4. Do you feel that this device has the potential to save lives?
5. Was there any discomfort in wearing the device?
6. Would you wear the device again voluntarily in the future?

Nine surveys were completed by operators of cranes, utility vehicles, forklifts, front-end loaders, tractors, and yard-dogs. All equipment operators volunteered to use the warning devices while performing their tasks. Although the operators had never used them before, each of them perceived the potential of the devices to save lives on a construction site. Four equipment operators reported multiple instances when the alarms sounded when they were not aware of possible danger. Although one worker commented on the desirability of making the device smaller, no workers reported feeling any discomfort. Most comments were supportive of the use of the warning devices, since they helped uncover blind spots. One worker had a question about the purpose of tracking employees. Overall, the equipment operators agreed that they would use the warning devices again if they were made available by the company.

There were 36 field workers (men and women) consisting of welders, carpenters, rod busters, and other trades who were questioned about their first experiences with wearing a warning device. Similar to the responses from the equipment operators, the responses of all of the field workers related to their perception of the ability of the devices to save lives. Nearly all of them reported feeling safer on the site during the trial. Workers stated that there were numerous situations in which the alarms sounded due to materials or equipment passing overhead. Three workers reported discomfort due to the size of the device and its placement on the side of their hardhats. Eighty percent of the field workers were comfortable with the device, but a few workers voiced concerns about placing the device on the side of a hardhat. Two workers expressed concern at the idea of being tracked on the construction site. With the exception to these two individuals, the field workers agreed that they would wear the devices again. Comments from workers were mostly positive regarding the warning devices, since they understood the safety benefits associated with the devices. One worker stated that increasing the volume of the alarm would be more effective. Several workers commented that equipment operators would greatly benefit from the devices. Answers to the questions that were addressed to equipment operators and workers are summarized in Figure 12.

In addition, the team interviewed four site managers supervising work involving several pieces of large equipment for excavation and formwork. Each foreman encouraged worker participation by simply asking for volunteers and expressing the importance of improving safety on the worksite. Three site managers noted that workers received the devices positively, while one manager noted that some workers were hesitant to participant. One manager said that six workers refused to participate in the experiment. Nonetheless, all four site managers agreed to voluntarily wear the warning devices in the future as each recognized the potential of the equipment to improve safety and, ultimately, to save lives. Most comments were positive, and none of the workers who participated expressed any concerns. The managers reported that workers generally responded positively to the devices. One foreman suggested that it would be better to embed the warning device inside the helmet.

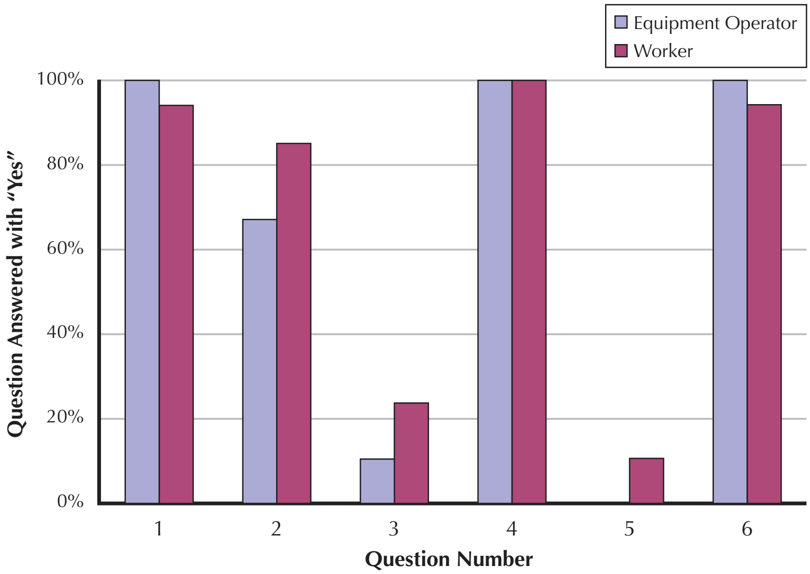

Figure 12. Worker and equipment operator opinions on technology

In summary, most of the workers who volunteered in the field trial felt comfortable wearing the devices. They offered constructive feedback on how the technology could be improved to increase overall participation.

Investment in Safety

An example of the return on investment (ROI) in pro-active real-time safety technology best illustrates its value. The contractor on a two-year construction project worth $120 million and employing 175 workers and 50 pieces of construction equipment decided to take an aggressive stance on safety. While safety practices such as toolbox meetings, regular safety inspections, worker orientation, accident investigations, and drug testing are commonplace on large projects, this contractor also implemented the following initiatives:

- pre-task planning
- worker observations
- 100% tie-off for fall protection

- mandatory PPE (i.e., hard hats, safety glasses, and hearing protection)
- worker safety perception surveys
- a site-specific safety program
- safety committees
- recognition program for safe behavior
- investigation of near misses
- integration of subcontractors into the site safety program
- a fully-staffed nurse's station on site
- a full-time safety professional for every 50 field employees.

The total cost of the safety investment was 2.2 million or 1.83% of the total project value.

The contractor decided to purchase and utilize warning devices for all workers on site. Initially the contractor only wanted to place warning devices on those workers who were involved in tasks that were deemed high-risk, but ultimately decided that every worker should have a warning device. Each PPU device cost $400 and each EPU device cost $1,000. The total cost of the warning devices was $120,000, an addition of 0.1 percent to the investment in safety.

The contractor became aware of two potentially serious accidents that were prevented through the use of the warning devices. While both of the incidents might have resulted in fatalities, it was assumed that one of the injuries would have cost $50,000 and the other would have cost $500,000. The total costs of these injuries (namely $550,000) clearly justify the $120,000 investment in the warning devices. This would represent a greater than fourfold return of the $120,000 investment.

It is important to note that, had only one injury been prevented, the warning devices would still have been worth the investment going forward. Given the assumed $50,000 cost of the one injury, one might conclude that the investment would not have been cost-effective;

however, it must be recognized that the warning devices can be reused. If the contractor were to have two similar-sized projects, use the warning devices, and prevent one injury valued at $50,000 on each project, the investment in warning devices would still be justified.

It is also critical to remember that the number of equipment-related construction worker fatalities is nearly 25 percent and that equipment-related injuries tend to be serious. (Relatively few first aid injuries are associated with equipment incidents.) Because equipment is widely used on virtually every construction project, there is a significant risk to worker safety on most construction sites. It is easy to understand that the warning devices can save lives. As the ROI example demonstrates, the relative cost of warning devices is small in comparison to the potential expenditures that are saved.

5

Conclusions and Recommendations

The purpose of this research was to determine whether proximity detection and alert devices are feasible for construction applications. Various applications areas for real-time pro-active technology exist and have the potential to significantly reduce hazards in high risk construction or maintenance work. Real-time pro-active warning and alert devices have proven to be effective in bolstering the safety environment on construction sites. Current safety practices are not sufficient to prevent every worker fatality, especially when workers are in close proximity to heavy equipment. The devices can detect the presence of tagged resources (i.e., workers, equipment, materials).

The warning and alert devices were successfully tested in realistic construction environments on a wheel loader, forklift, scraper, dozer, excavator, motor grader, personnel mover, articulated dump truck, crane, and pick-up truck. When working in a construction environment, the personal protection unit (PPU) and equipment protection unit (EPU) were both effective at alerting personnel of the danger through auditory, visual, and vibrating alarms, even when surrounded by other construction noise. These devices have the capability of recording safety data, making currently unrecorded data on close calls (near misses) available. These data can then be analyzed and used to improve the positioning of workers and equipment and to assist in the development of new safety concepts and training. Medical and insurance costs, time lost due to accidents, and lawsuits must be taken into consideration to justify any investment in safety. It is impossible to put a price tag on a person's life.

The key research findings are listed and require each detailed investigation:

- **Project scope and complexity determine the level of technology use**. Early decision making and involvement of all project stakeholders is critical to successful implementation.
- **A spectrum of choices rather than a single or all-or-nothing alternative exists**. Proximity warning, alert, tracking and monitoring, remote real-time data visualization, and other advances are only a few of many useful technologies.
- **The selection and use of real-time pro-active technology requires involvement of technology-literate project participants**. Personnel with safety and advanced technology expertise can link form and degree of real-time pro-active safety early on in the project.
- **Worker involvement early in the process is a key factor in adopting technology**. Companies must evaluate and implement the input of personnel into decision making for technology. Emphasis must be on explaining the purpose of the technology to the workers. Workers are generally open to adapting technology.
- **Successful implementation depends on overcoming a lack of industry awareness and knowledge of benefits and opportunities offered by real-time pro-active technologies**. Demonstrations of providers to companies must be carefully evaluated on benefits, limitations, and promises.
- **Adequate testing of technology in site environments plays a critical role in successful site implementation**. Advanced technology may require initial analysis to optimize its field implementation. Extensive pre-planning and discussions are essential to achieve optimal performance.

- **Pro-active real-time safety technology adds value across project levels.** It primarily enhances existing safety management practices and other project goals. It provides warnings and alerts for workers/operators close to heavy equipment; it improves communication and recording of previously unreported incidents; it advances overall site safety and progress tracking methodologies; and/or it uses data visualization for advanced decision making and learning. Some technology that is used for safety can also be leveraged for multiple other project goals, such as productivity or site security control.

While field trials with the devices were successful, it was evident that several parameters can influence signal propagation in the construction environment. Some of these influencing factors include ambient temperature, relative humidity, mounting position and orientation of the devices on workers and equipment, obstacles (metal or wooden) in the construction field, multipath effects during signal transmission, reaction of workers, among others. These and other barriers require further investigation.

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Notes

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