Towards a Fully Automated Equipment Blind Spot Detection, Equipment Operator Visibility Monitoring, and Ground Personnel Proximity Warning and Alert System

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Abstract

Over six hundred construction worker deaths occurred in the United States during the inclusive years of 2004 to 2006 that were related to construction equipment and contact collisions. On average, about 25% of all construction work-related fatalities are due to the involvement of equipment. The goal of the presented research is to reduce these numbers to zero. This paper first presents findings about safety statistics as they relate to heavy construction equipment and vision-related construction fatalities. A framework follows to integrate a fully-automated approach to detect blind spots of construction vehicles as they are used in the field; an equipment operator visibility monitoring system; and real-time pro-active technology to warn or alert ground workers of nearby equipment. The paper will present details to the developed safety technology and results to field trials.

Key words: Construction equipment, blind spots, operator visibility, proximity warning and alert technology, real-time pro-active safety, RFID, SmartHat.

1. Introduction

In the past fifteen years nearly 1,200 construction workers have died each year (BLS 2009, CFOI 2007). That equates to approximately five construction worker deaths every working day in the US. Of these fatalities, 25% 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, further improvements can be gained in construction safety through the use of technology.

Advances in technology have made it possible to integrate and leverage their potential in construction industry applications. The ability to improve safety performance in construction has been proven; 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 the 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: A real-time pro-active safety technology framework that forms an additional barrier to protect from equipment-ground worker-related hazards.

As illustrated in Figure 1, this study presents preliminary findings about applying technology as an additional layer of protection 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 construction personnel of the presence of hazards in real-time and to monitor the location and movement of resources will help construction firms to 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. Secondary objectives were to measure equipment blind spots and 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 of the research was to select and evaluate a few promising and existing technologies through experimental field studies. These field tests could reveal how well the technology can be applied to construction operations. Field trials would include an assessment of the receptiveness of workers to the use of the technology.

**Research Methodology:** Past construction safety research has provided a solid base for making improvements in construction safety. A review of the literature revealed that most safety efforts have been focused on safety management issues. There has been a minimal emphasis on construction equipment operations. The research team reviewed existing research publications, occupational safety and health databases, and professional journals to evaluate the significance of worker/equipment interactions related to safety. The review focused on (OSHA 2002 and 2009):

1. The role played by construction equipment in 289 construction worker fatality cases between the years 1990 to 2007 where visibility was an issue.
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. Relevant technology applicability 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 application 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 few to many construction workers (15 to 2,000) and varying numbers of pieces of equipment (5 to 250). The type and number of construction sites that were selected for field trials involved small to large building construction (5), small commercial construction (7), large industrial construction (2), and one union ironworker indoor training facility (1).

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 warning distances of several pieces of equipment to construction workers. Surveys were conducted to record the opinions of workers and equipment operators who had used the 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 close to several pieces of equipment. Proximity data of construction resources were processed and visualized to inform equipment operators of the presence of obstructions in the vicinity of their machines.

2. How Technology Can Impact Construction Safety

Construction sites are completed by coordinating multiple resources, including personnel, equipment, and materials. These resources are often in motion and can come in close proximity to each other. If not coordinated and organized properly through optimized work planning (schedule and resource leveling), spatial interference can lead to incidents between two or more objects (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 attributed to:
1. Lack of knowledge of existing specific risk factors,
2. A myriad of distracters on the construction site,
3. Lack of real-time data concerning 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, while the construction industry has been slow in considering these technologies. If these were tested successfully in a construction environment, these emerging technologies could be adapted for application in construction. 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 there has been little improvement in preventing workers from being killed through contact collisions with vehicles and/or equipment.

(a) Visibility of a 1.5 meter tall object in front (green: up to 83% visible), rear (red: 100% invisible), and side view (red: up to 65% invisible) (Teizer et al. 2010a, Hinze and Teizer 2011).
Tracking the visibility of equipment operator’s utilizing a 3D range camera (left: test bed; middle: automated head pose estimation; operator’s range of field-of-view).

Figure 2: Visibility of heavy construction equipment operator and ground worker.

All 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%), followed by large construction equipment (30%). 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%), 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%) 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 (Fosbroke 2004, Larue and Giguère 1992). This research conducted measurements of blind spots with a laser scanner (see Figure 2a) and estimated the equipment operator’s head pose (see Figure 2b).

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% to 88% 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.

<table>
<thead>
<tr>
<th>Equipment Type</th>
<th>(A): Overall fatality number</th>
<th>(B): Fatality number related to *</th>
<th>(B)/(A) [in %]</th>
<th>Top 3 leading causes including *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forklifts (incl. ware-houses)</td>
<td>1,021</td>
<td>368</td>
<td>36%</td>
<td>Rollover (22%), Crushed-by 20%, Struck-by (16%)</td>
</tr>
<tr>
<td>Skid steer loaders</td>
<td>83</td>
<td>31</td>
<td>37%</td>
<td>Crushed (24%), Struck-by (11%), Pinned-by (2%)</td>
</tr>
<tr>
<td>Scrapers</td>
<td>60</td>
<td>37</td>
<td>62%</td>
<td>Run over (49%), Rollover (23%), Crushed-by (6%)</td>
</tr>
<tr>
<td>Backhoe loaders</td>
<td>198</td>
<td>175</td>
<td>88%</td>
<td>Crushed-by 34%), Pinned-by (28%)</td>
</tr>
</tbody>
</table>
**Existing Safety Best Practices and the Role of Technology:** OSHA regulations help in establishing construction site safety, but 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 to be conducted to increase worker/operator ability to recognize and avoid construction hazards. The behavior of individuals on the work-site; however, 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.

Past research studies of the Construction Industry Institute (CII), e.g. RR101-11 and RR160-11, reported that better safety performances occurred when the behavior of the individuals on a job site was altered or site-specific safety programs were prepared early in the life of a project (CII 2010 and 2011). 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 common analogy used to depict the relationship of serious injuries to all incidents. Many close calls occur for every minor injury and that many minor injuries occur for every serious injury. The actual numbers are usually estimates and they often vary from one study to the next, but 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 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 avoid close calls and accidents. Such information could also be easily stored and automatically retrieved.

**Pro-active real-time safety:** 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 avoid 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 avoided.

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 project safety objectives, technology-driven safety can assist (but not replace) existing safety best practices.

In summary, the above reasons support a modified human error causation model. 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 the dangers occurring at that moment. Example: Almost all technologies have to work reliably in the harsh construction environment, and at the same time, solve constraints that equipment operators and workers-on-foot face during their 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 limitations for each technology exist. Criteria for selecting proximity warning and alert technology is 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 where 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”.

**3. Technology for 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 (workers and equipment) were in too close proximity (EV-Alert 2008, Motorola and 3D-P 2009, OrbitComs 2010, Protran1 2008, Pratt et al 2001, Ruff 2007 and 2010, Schiffbauer 2001, Schiffbauer and Mowrey 2008, Teizer et al. 2010b). Sensing technology can assist workers-on-foot and equipment operators in detecting the relative proximity to each other. When their proximity to each other is too close, visual, audio, and vibration alerts activate and warn both personnel on the ground and those operating the equipment. The devices, known as equipment and personal protection units (EPU and PPU, respectively) were deployed on workers and equipment and field tested on small, medium, and large jobsites.

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 a single antenna, reader, and alarm; called the Equipment Protection Unit (EPU). The personal device consisted of a chip, battery, and alarm; called the Personal Protection Unit (PPU). The term “personal” was used because subsequent interviews revealed that workers like to identify themselves with the safety devices (they like to “own it”).

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. Setting the signal strength is carefully performed 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. Figure 3 displays the EPU/PPU technology in field trial mode.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Technology</th>
<th>Objective</th>
<th>Range [m]</th>
<th>Accuracy of data</th>
<th>Signal bounce</th>
<th>Data processing effort</th>
<th>Secure signal</th>
<th>Day vs. Night</th>
<th>Signal update rate</th>
<th>Size and weight</th>
<th>Installation/Maintenance</th>
<th>Purchase Cost</th>
<th>Main barriers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ultrasound</td>
<td>Distance</td>
<td>0-10</td>
<td>Low</td>
<td>High</td>
<td>Small</td>
<td>Noise</td>
<td>Very Good</td>
<td>High</td>
<td>Small</td>
<td>Small/Medium</td>
<td>Small</td>
<td>Short range, noise</td>
</tr>
<tr>
<td></td>
<td>Radio Frequency</td>
<td>Proximity</td>
<td>0-40</td>
<td>Medium</td>
<td>Small</td>
<td>Small</td>
<td>Yes</td>
<td>Very Good</td>
<td>High</td>
<td>Small</td>
<td>Small/Medium</td>
<td>Small</td>
<td>Proximity</td>
</tr>
<tr>
<td></td>
<td>Ultra-High Frequency (UHF)</td>
<td>Proximity</td>
<td>0-500</td>
<td>Medium</td>
<td>Medium/High</td>
<td>Small</td>
<td>Yes</td>
<td>Very Good</td>
<td>High</td>
<td>Small</td>
<td>Small/Medium</td>
<td>Small</td>
<td>Omni dir., proximity</td>
</tr>
<tr>
<td></td>
<td>Very-High Frequency (VHF)</td>
<td>Proximity</td>
<td>0-500</td>
<td>Medium</td>
<td>Medium/High</td>
<td>Small</td>
<td>Yes</td>
<td>Fair/Good</td>
<td>High</td>
<td>Small</td>
<td>Small/Medium</td>
<td>Small</td>
<td>Line-of-sight, segmentation</td>
</tr>
<tr>
<td></td>
<td>(Stereo) / Video</td>
<td>Proximity</td>
<td>0-50</td>
<td>Low</td>
<td>Small</td>
<td>Small</td>
<td>No</td>
<td>Very Good</td>
<td>High</td>
<td>Medium</td>
<td>Small/Medium</td>
<td>Small</td>
<td>Line-of-sight, noise</td>
</tr>
<tr>
<td></td>
<td>Optical Eye-safe Laser (1D/2D/3D)</td>
<td>Location</td>
<td>0-30</td>
<td>Medium</td>
<td>Medium</td>
<td>Small</td>
<td>No</td>
<td>Fair/Good</td>
<td>High</td>
<td>Small</td>
<td>Small/Medium</td>
<td>Small</td>
<td>Line-of-sight, segmentation</td>
</tr>
<tr>
<td></td>
<td>Infrared</td>
<td>Proximity</td>
<td>0-30</td>
<td>Medium</td>
<td>Medium</td>
<td>Small</td>
<td>No</td>
<td>Fair/Good</td>
<td>High</td>
<td>Small</td>
<td>Small/Medium</td>
<td>Small</td>
<td>Line-of-sight, noise</td>
</tr>
</tbody>
</table>
### Table: Main benefits

<table>
<thead>
<tr>
<th></th>
<th>Inexpensive</th>
<th>Works in metal areas</th>
<th>Long range</th>
<th>Location, Range</th>
<th>Location</th>
<th>Inexpensive</th>
</tr>
</thead>
</table>

**Figure 3:** Alert types for workers-on-foot and equipment operators: a vehicle approaching a motor grader issues alerts inside both equipment cabins.

**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 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.

The PPU’s 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 different sound than 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 3 shows a warning and alert system during a field trial involving two pieces of equipment. When the vehicles got in close proximity to each other, the visual and audible alarms alerted both. 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. 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 excavator, Table 3). Cranes, for example, are static, and alerts may only be needed 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 activate alerts earlier and at further distances to ensure the safety of workers close by. All distance measurements included the operator’s reaction time and the distance required to stop the vehicle.

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

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

The results of a machine in static position are illustrated in Figure 9. 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.

4. **SmartHat: Self-Monitoring, Analysis, and Reporting Technology for Hazard Avoidance and Training**

Radio frequency identification (RFID) technology was initially conceived around the notion of transferring only a unique ID (UID) or a small amount of on-chip memory from a tag to a reader. In particular, low-cost passive UHF “smart label” transponders, including those based on EPC Global’s Generation 2 specification, need to derive all tag operating power from an incoming reader RF carrier. This results in a drive toward IC simplicity and low power CMOS design techniques. Minimizing tag IC complexity and on-chip clock frequencies results in lower tag operating power, which is crucial for maximizing read range in a power-limited passive UHF RFID system. At the same time, simplifying the tag design results in a smaller tag die, more tag die on a given wafer and improved yield, and thus lower overall tag cost.

As passive UHF RFID technology has matured, many new application scenarios have been proposed where a tag is expected to transmit ever-increasing amounts of data. These scenarios
include tags with expanded on-chip memory of 128KB or more, tags including complex cryptographic security protocols, or tags that transfer stored sensor data in a semi-passive mode.

As seen in Figure 4, a new prototype SmartHat warning/alert device was designed. Testing of multiple SmartHat devices in harsh construction environments have resulted in warning and alert distances of up to 16 m. Further tests are pending and results are expected that ultimately demonstrate that a SmartHat device has the potential to work under harsh conditions, at highest reliability factor, and at low economical cost. Although not part of this research project, the goal is to transfer this technology into the field and make it become a best practice in construction safety.

![Figure 4: SmartHat tag in field application.](image)

5. Conclusions and Recommendations

Various applications areas for real-time pro-active safety technology exist that have the potential to significantly reduce hazards in high risk construction or maintenance work. The purpose of this research was to develop a framework that accounts for static (from equipment frame) and dynamic (from limited operator visibility) blind spots during equipment operation by implementing real-time wireless proximity detection and alert devices.

Real-time pro-active warning and alert devices proved to be effective in bolstering the safety environment on construction sites. Current safety practices are not sufficient in prevent every worker fatally, especially when workers are in close proximity to heavy equipment. The devices can detect the presence of tagged resources (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 assist in the development of new safety concepts and training.
It is difficult to put a price tag on a person’s life. Medical and insurance costs, time lost due to accidents, and lawsuits must be taken into consideration to justify any investment in safety. 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 of importance for 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 advanced are 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 technology. Workers are generally open to adapt 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 may be carefully evaluated on benefits, limitations, and promises.
- Adequate testing of technology in site environments plays a critical role for successful site implementation. Advanced technology may require initial analysis to optimize its field implementation. Extensive pre-planning and discussions are essential to meet optimal performance.
- Pro-active real-time safety technology advances multiple 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 turned out to be successful, it is noted 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, etc. These and other barriers require further investigation.

6. Acknowledgements

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7. References


