8-2017

Perceptions of Key Stakeholders Regarding the Utilization of Locatable Sound for the Prevention of Occupational Pedestrian Injuries and Fatalities

Richard S. Kilpatrick

PERCEPTIONS OF KEY STAKEHOLDERS REGARDING THE UTILIZATION OF LOCATABLE SOUND FOR THE PREVENTION OF OCCUPATIONAL PEDESTRIAN INJURIES AND FATALITIES

A Dissertation

Submitted to the School of Graduate Studies and Research

in Partial Fulfillment of the

Requirements for the Degree

Doctor of Philosophy

Richard S. Kilpatrick

Indiana University of Pennsylvania

August 2017

Indiana University of Pennsylvania
School of Graduate Studies and Research
Department of Safety Sciences

We hereby approve the dissertation of

Richard S. Kilpatrick

Candidate for the degree of Doctor of Philosophy

June 17, 2017 | Signature on file
Tracey Cekada, D.Sc., CSP, CHSP
Associate Professor of Safety Sciences, Chair

June 17, 2017 | Signature on file
Christopher A. Janicak, Ph.D., CSP, CEA, ARM
Professor of Safety Sciences

June 17, 2017 | Signature on file
Wanda Minnick, Ph.D., CSP
Associate Professor of Safety Sciences

ACCEPTED

Signature on file
Randy L. Martin, Ph.D.
Dean
School of Graduate Studies and Research

Title: Perceptions of Key Stakeholders Regarding the Utilization of Locatable Sound for the Prevention of Occupational Pedestrian Injuries and Fatalities

Author: Richard S. Kilpatrick

Dissertation Chair: Dr. Tracey Cekada

Dissertation Committee Members: Dr. Christopher A. Janicak
Dr. Wanda Minnick

The purpose of this quantitative study was to analyze the perspectives of key stakeholders to determine if the use of broadband sound emitting reversing alarms is perceived to improve safety in the workplace more so than traditional tonal sound emitting reversing alarms. The survey population consisted of steel industry occupational pedestrians, forklift operators, leadership and maintenance employees working at fifty-five locations of one North American steel company that is currently using broadband sound emitting reversing alarms and has been doing so for a period exceeding two years.

Results indicated that persons with increased familiarity of reversing alarms (obtained via awareness, experience, insight, knowledge, and understanding) were more likely to have greater perceptions of the benefits of reversing alarms. In addition, individuals with no forklift near miss/injury event experiences (59.9% of all respondents) also had increased perceptions of the benefits of reversing alarm. When respondents were presented with eight individual traits that are beneficial of reversing alarms, broadband reversing alarms were selected by respondents as matching the eight traits on average of 61% whereas only 33% (on average) of respondents selected tonal reversing alarms (6% selected neither or both).

This study is significant as it 1) validates the need to ensure those exposed to reversing alarms are trained on their benefits; greater familiarly of an alarm yields greater perceived alarm benefits, 2) determined the perceptions of a large study population (n=698), with over two years'

experience with broadband reversing alarms, and 3) identifies broadband reversing alarms are perceived by survey respondents to have more beneficial characteristics than tonal alarms specific to the protection of occupational pedestrians. This study provides the unique perspective of key stakeholders in an uncontrolled study group and will serve as a reference point for reversing alarm analysis and provides empirical data on which future research may expand.

ACKNOWLEDGEMENTS

First and foremost, I thank God for providing me the strength and guidance required during this process. Without Him, I would not have had the wisdom or abilities to see this through to fruition.

I especially want to thank my wife Annette and son Spencer for their unyielding support and patience throughout this journey as many events were missed due to the hours of coursework and the dissertation process. Without the total support of my entire family, I would never have completed this program.

A special thank you to Dr. David W. Wilbanks; a mentor and a best friend for many years. We started this degree adventure together and he often served as my confidant and counselor as we had numerous consults throughout the process. Though our paths may now go separate ways, the friendship will remain.

Thank you to my Committee Chair Dr. Tracey Cekada. I am grateful for her insight and guidance as well as her persistence with the things out of my control. I would also like to thank my committee members: Dr. Chris Janicak for his guidance to improve my study and for his assistance in validating my statistical analysis, and Dr. Wanda Minnick for her insightful perspectives and critical reviews.

A special acknowledgement is in order for the faculty and staff of IUP's Safety Sciences Program. Specifically, Dr. Chris Janicak for having the vision and tenacity to spearhead the development of IUP's PhD in Safety Sciences program and providing this opportunity for Cohort #1 and for all those who will come after.

A key component of this dissertation was the study population. I am very grateful to the leadership of Gerdau for providing access to hundreds of employees who were willing to participate and provide the needed data for this study. Without access to this population, this study would have never materialized. Special thanks to the Gerdau Safety Professionals for promoting the study and encouraging their leaders and employees to participate. I anticipate the results within will be beneficial to your cause and might encourage additional implementations throughout your organization.

I dedicate this dissertation to my parents, Richard and Lorraine, who provided the foundation for my being, who worked hard so I could go to college and get a "good education," parents who have always wanted only the best for their sons. I Thank You!

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figures Page

CHAPTER 1

THE PROBLEM

Injuries and fatalities within industry and construction are often preventable, none more so than those involving occupational pedestrians. Whenever an individual and moving mobile equipment interact in an unplanned manner, it is the pedestrian who suffers the wrath. The Bureau of Labor Statistics (BLS) (2016) reported 62 pedestrians were fatally injured by backing equipment during the year 2015. The Occupational Safety and Health Administration (OSHA) (2012) also identified 358 backover fatalities occurred from 2005 to 2010. Withington (2004) identified one category of backover accidents as those involving slow reversing equipment such as forklifts and other lift truck equipment and notes there are 68,000 forklift-related accidents that result in injuries within the United States (U.S.) annually.

In the construction industry, over 425 fatalities during 1992 – 2002 were related to construction vehicles. Of these, 41% were occupational pedestrians within the work area and 52% were fatally injured by reversing dump trucks (Washington State Department of Labor & Industries, 2009). The American Road & Transportation Builders Association (ARTBA) described backover events as being one of the leading causes of fatalities of occupational pedestrians in construction areas with over 50% resulting from pedestrians being struck by mobile equipment in work zones (Zeyher, 2007).

OSHA (n.d.) defined a backover incident as an occurrence of a backing vehicle that strikes an occupational pedestrian that is kneeling, standing or walking behind mobile equipment. In 2014, studies conducted by Choe, Leite, Seedah, and Caldas (2014) and Flannagan, Kiefer, Bao, LeBlanc, and Geisler (2014), focused on backover crashes in an attempt to identify developing technologies that could potentially minimize backing fatalities. OSHA

(2012) conducted meetings in Washington, D.C. and Arlington, VA in 2013 to bring together stakeholders to solicit comments regarding the prevention of occupational pedestrian fatalities resulting from backover related events. The purpose of OSHA's meetings was to seek information from stakeholders and to evaluate backover risks within industries. The meetings also focused on the impact new technologies or other methods may have, and the potential effectiveness of these new technologies, in the prevention of backover fatalities.

The United States Department of Labor (USDOL) (n.d.) states injuries cost organizations more than most individuals realize with the average cost of a fatality being $910,000. The obvious costs are direct. Workers compensation claims cover expenses association with medical treatment plus any indemnity payments paid to the injured employee. The indirect costs are the ones that are less obvious and can include examples such as the costs incurred for the replacement employee and associated trainings so the new employee can perform the tasks, expenses associated with property damage repairs, the costs of all individuals involved in the incident investigation and corrective action implementation. A significant indirect cost could be increased workers' compensation premiums. Other expenses which are less apparent are related to delays in the schedule or work output, increased administrative costs, employee morale, counseling, and the potential for negative impact to customer service. It is the combination of these indirect and direct costs that comprise the average cost of each workplace fatality in the United States (USDOL, n.d.). Considering this average, the estimated cost of the 360 backover fatalities occurring from 2005 to 2010, using the USDOL's metric calculates to $327,600,000. Assuming a typical 5% profit margin for the companies involved, the total income required to break even would exceed 6.55 billion dollars. Though staggering at this level, it is an exorbitant cost for a company with only one fatality; using the 5% profit margin, the total income to offset the cost of the fatality is approximately $20,000,000.

Even with existing controls, occupational pedestrians remain at significant risk to backing mobile equipment that requires additional strategies to ensure the risk is mitigated. This study will focus on broadband reversing alarms, a relatively new technology intended to prevent occupational fatalities and enhance worker safety (Brigade Electronics, 2009; Vaillancourt, Nélisse, Laroche, Giguère, Boutin, & Laferrière, 2013). This chapter will include the following key sections: (a) background, (b) statement of the problem, (c) purpose of the study, (d) research questions, (e) definitions of key terms, (f) assumptions, (g) scope and delimitations, (h) limitations, and (i) significance. The chapter ends with a summary of the key components and arguments that are central to the research study.

Background

The primary control strategy for protecting occupational pedestrians from reversing vehicles is the ubiquitous "beep – beep sounding" tonal backup alarm. According to Swanson (2004), tonal alarms were first implemented in 1971 as a requirement of the Army Corps of Engineers. Occupational pedestrians were deemed at significant risk of being struck and fatally injured by construction vehicles and multiple fatalities had occurred as a result. Also in 1971, job-site vehicles became covered within OSHA's construction standard 29 (CFR) 1926.601 entitled *Motor Vehicles.* 1926.601(b)(4) states that either a reverse signal alarm audible above the surrounding noise level is required or the vehicle must be backed with the assistance of an observer. The standard also applies to earthmoving and compacting equipment, in addition to other job site vehicles, such as materials handling equipment (1926.602(a)(9)(ii). Backup alarm requirements are only remotely addressed within the General Industry regulations. Within

1910.269; entitled *Electric Power Generation, Transmission, and Distribution*, section 269(p)(1)(ii) states "No motor vehicle or earthmoving or compacting equipment having an obstructed view to the rear may be operated on off-highway jobsites where any employee is exposed to the hazards created by the moving vehicle, unless" 269(p)(1)(ii)(A) "the vehicle has a reverse signal alarm audible above the surrounding noise level…" Absent additional standards related to other mobile equipment such as forklifts; OSHA has stated within letters of interpretation that equipment supplied with backup alarms cannot have the alarms made inoperable. If a serious injury or fatality exposure exists from backing forklifts within an industrial environment, OSHA has stated their ability to issue citations under the general duty clause via letters of interpretation.

Even with adequate regulations, the numbers of injuries and fatalities involving reversing mobile equipment remains constant year after year (Murray, Mills, & Moore, 1998; NIOSH, 2004). Purswell & Purswell, (2001), determined that tonal alarms installed by the original equipment manufacturers failed to prevent over 66% of the backover accidents they investigated. As presented by Redel, (2012), mandating tonal sound emitting reversing alarms on all forklifts could potentially prevent twenty fatalities resulting from forklift pedestrian interaction, and may eliminate or reduce up to 7,000 injuries resulting from these same interactions each year. The primary strength of the tonal alarm is the sound recognition by most, as wells as their accepted presence. Most people know the sound of a tonal alarm and that it represents a vehicle in reverse motion. When heard, it is expected one knows to move away. Tonal alarms are also ubiquitous; most new equipment is typically provided with the alarm so no additional expenditure is required of the customer. Tonal alarms are passive systems that require no interaction by the operator as they activate whenever the equipment is shifted into reverse.

Though mandated over 45 years ago, and considered the norm, pedestrians are still fatally injured by vehicles equipped with tonal reversing alarms. The reason for many of these occurrences can be associated with the tonal alarm's identified weaknesses (Brammer & Laroche, 2012, Army Corps of Engineers, 2009; Vaillancourt, Nelisse, Laroche, Giguere, Boutin, & Laferriere, 2014). One potential tonal alarm weakness exists when the exposed individual is wearing hearing protection, common personal protective equipment of most occupational pedestrians. If hearing protection is used effectively, the tonal alarm sound may not penetrate well and could possibly be unheard. Also related are the effects of hearing loss. If high frequency hearing loss has occurred, the pedestrian may not hear the tonal alarm, or may not hear it loud enough to know to react. The sudden exposure to high frequency noise can also be an issue. If a pedestrian is in the immediate area of an alarm that suddenly activates, a fright reaction can be caused by the high sound level which may actually prevent immediate movement away from the hazard. Brigade Electronics (2009), as published within ISO-7731 entitled *Ergonomics -- Danger signals for public and work areas -- Auditory danger signals*, notes this startle reaction can occur from 30 dB sound increases in 0.5 seconds. This excessively high sound pressure level increase can delay a pedestrian's reactions thus delaying exit from the hazard area. Other weaknesses of tonal alarms include ignoring (tuning out) the alarm (Brammer & Laroche, 2012). Over time, tonal alarms can become annoying to pedestrians and can eventually be unconsciously blocked thereby reducing their effectiveness. When multiple alarms are operating in the same area, confusion can be created for the pedestrian as they may be uncertain of the location and path of travel for the mobile equipment. In addition, tonal alarms are also perceived as distracting beyond the facility or job site as the sound travels beyond the facility perimeter and affects neighboring homes and businesses (Brammer & Laroche, 2012).

If the alarms are too loud and annoying, those exposed may intentionally defeat or deactivate them. Withington (2004) notes this can occur with any highly repetitive audible alarm including reversing alarms on mobile equipment.

One newer technology that can possibly address the weaknesses of tonal alarms is broadband sound emitting reversing alarms (Brigade Electronics, 2009). Broadband alarms are relatively new to the United States though they were introduced in Europe in 1976 after development in Japan in the mid 1970's. Broadband, as the name implies, emits a 'broadband' sound at three parts of the sound frequency spectrum, which are heard by the occupational pedestrian as a single sound. See frequency comparison below in Figure 1.

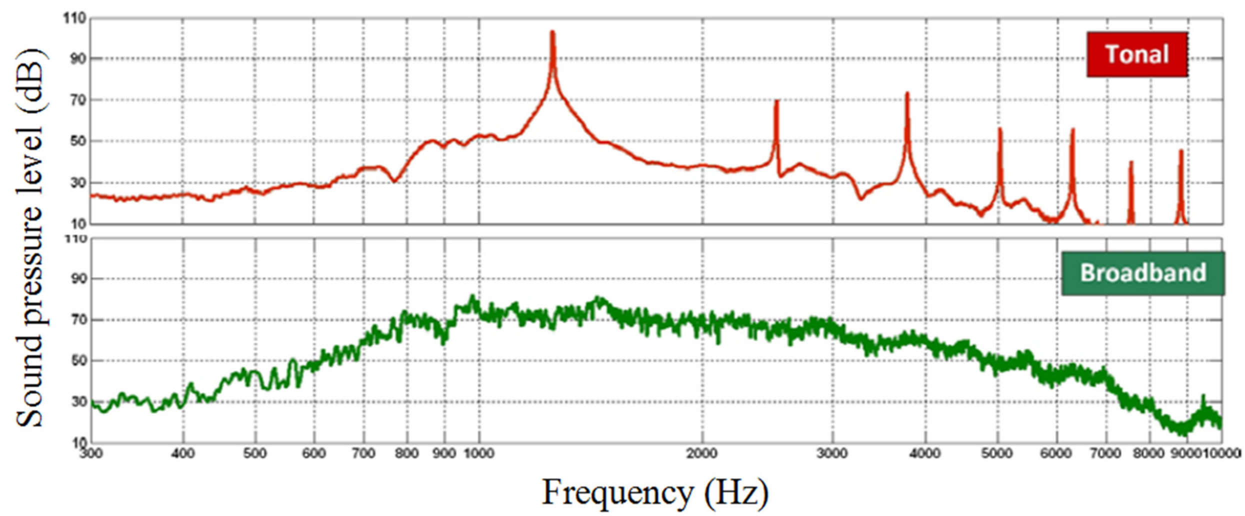


Figure 1. Frequency content of a tonal and broadband alarm.   Reprinted from "Comparison of different vehicle backup-alarm types with regards to worker safety" by Nelisse, Laroche, Giguere, Boutin, Vaillancourt, & Laferriere, 2011, p.280. Copyright 2011 by ICBEN.

According to Brigade Electronics (2009), the three parts of the sound spectrum are used for the following reasons:

- Low frequencies – the human brain is able to determine the differing sound arrival times at each ear.

- Mid frequencies – the human brain is able to determine the differences in sound intensity at each ear which is beneficial in determining which ear is closest to the sound source.
- Higher frequencies – allows the brain to determine the sound/source location; either the front of rear of the head.

The varying frequencies of broadband sound, best described as that of a duck's "quack," provide a directional audio output across many frequencies. This sound is distinguishable in both location and direction of travel, providing the occupational pedestrian the ability to sense the location and travel direction of the mobile equipment. Broadband alarms come in a variety of dB(A) levels and, based on the model selected, their output can be self-adjusting based on ambient background levels. The self-adjusting feature, and other characteristics of broadband alarms, allows them to operate at typically 5 dB(A) less than tonal alarms, as the wide frequency sound enables lower sound pressure levels for the same loudness, thus reducing noise pollution potential. Brigade Electronics (2009) notes the high frequencies from the broadband alarm are also more readily absorbed by air, and nuisance sounds are reduced more quickly as distance from the source increases, which are represented in Figure 2.

Based on Figure 2 below, the articulated rectangle (labeled truck/mobile plant) identifies the mobile equipment from which the sound is emitted. The outermost ring (labeled alarm zone of tonal alarm) represents the impact area of a typical tonal reversing alarm, an impact area that covers 360^0. In comparison, the second from the smallest circle (labeled equivalent broadband alarm zone with directivity characteristic) represents the impact zone of an equivalent (based on dB(A) level) broadband sound emitting reversing alarm. A significant difference in impact area for tonal alarms vs. broadband alarms is visually represented. Even more significant is the area within the smallest circle (labeled broadband alarm zone if 5dB(A) lower output alarm is used) which indicates when a comparable alarm with a lower output is used. As referenced previously, the sound characteristics of broadband allows the alarm to operate at typically,

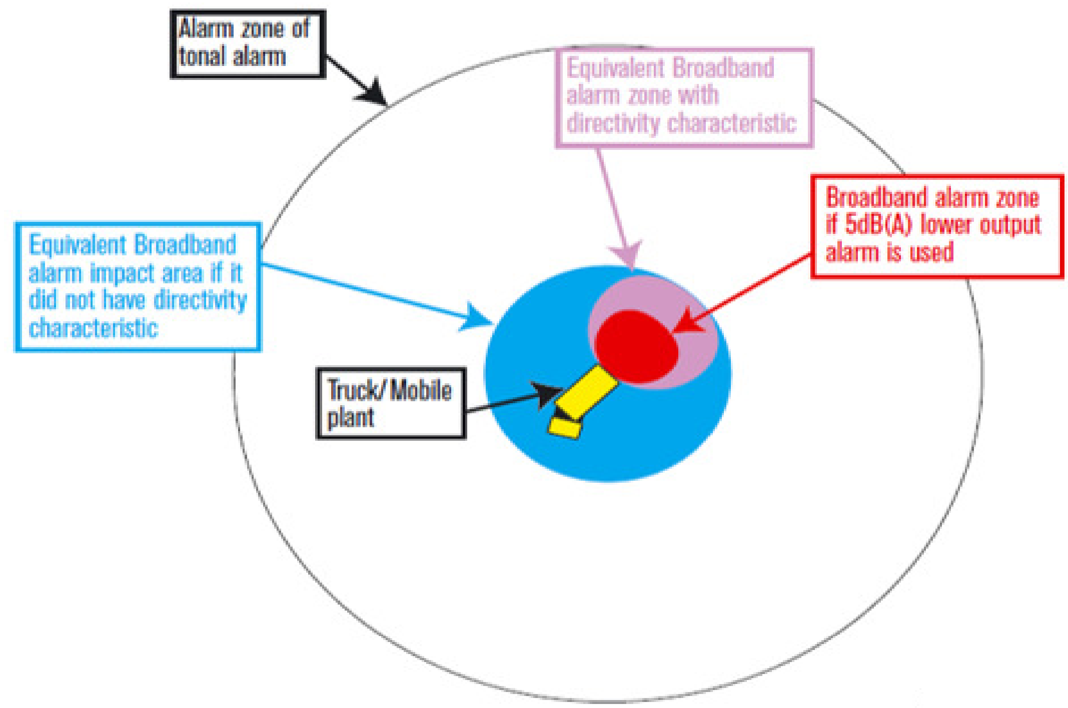


Figure 2. Broadband alarm net effect. Reprinted from "Broadband sound; The safer and noiseless* back-up alarm" by Brigade Electronics, 2009, p. 10. Copyright 2009 by Brigade Electronics**.**

5 dB(A) less than a tonal alarm. Figure 2 also visually represents the directional feature of a broadband alarm. If an equipped vehicle passes a pedestrian, the sound then dissipates once the pedestrian is passed, as the sound is only being projected toward the vehicle's path. The tonal alarm, identified above as a black ring, generates significant noise pollution that affects pedestrians in all directions.

Figure 3 (below) represents the observable difference in sound levels based on direction and distance. Sound dissipation in the hazard area (0^0 degree axis) reduces from 68.9 dB(A) at 10 meters to 55.7 dB(A) at 40 meters. At 90 degrees from the alarm's direction, the sound at the same distance is 8 dB(A) less. This decreases the nuisance noise typical of tonal alarms as the sound is focused in the direction of travel. Pedestrians not in harm's way, to the side and past where the equipment has traveled, have minimal exposure.

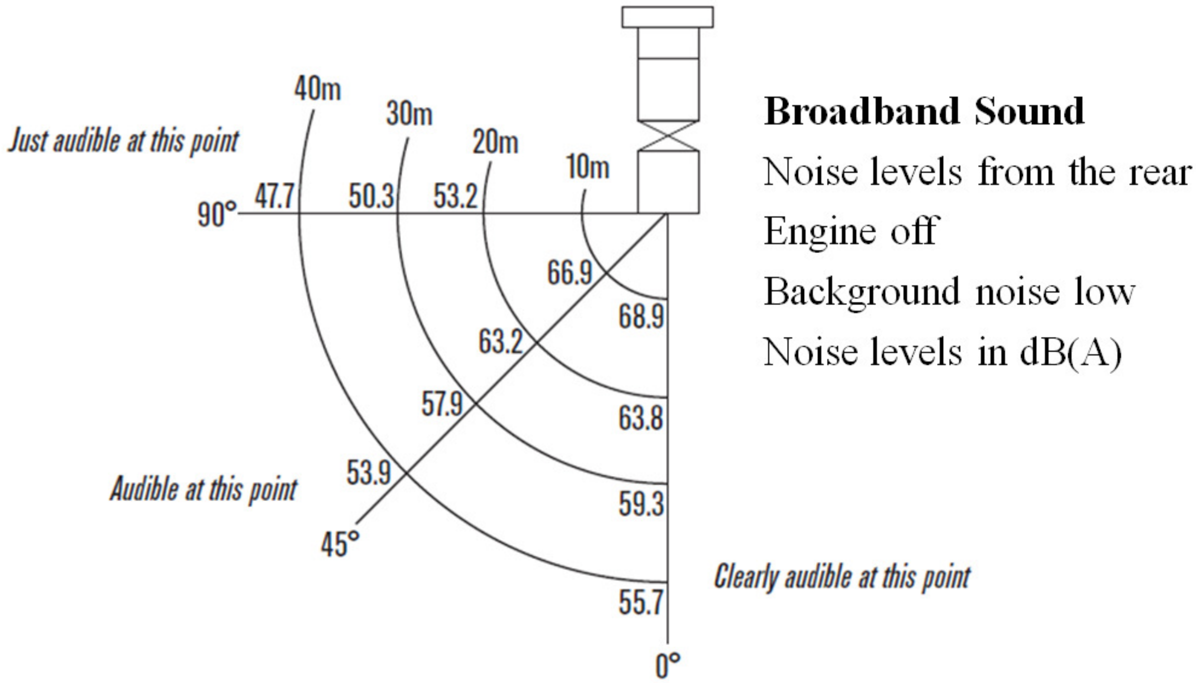


Figure 3. Dissipation off-axis. Reprinted from "Broadband sound; The safer and noiseless* back-up alarm" by Brigade Electronics, 2009, p. 8. Copyright 2009 by Brigade Electronics.

Another benefit of certain broadband alarms is their ability to self-regulate output based on ambient noise levels. If the mobile equipment enters a production building with loud machinery operating, the sound level will increase. The inverse occurs when the equipment returns to an area of low ambient noise. This adjustability assists in eliminating noise pollution and ensures the emitted sound levels rise only to the levels needed for pedestrian warning.

The weaknesses associated with broadband alarms include: (a) improper selection, (b) duty cycle, (c) reflectivity, (d) improper mounting, and (e) improper operation. A pilot study is beneficial to determine the proper model of alarm needed based on mobile equipment type and ambient background sound levels. If an improper type of alarm is selected, the emitted sound levels could be too low or too high for the ambient noise levels of the work site. Though the units are self-adjusting, their adjustability is within a range, so the proper range must be selected at the time of purchase.

Duty cycle is also a consideration. Though most units have a lifetime warranty, if a light duty unit is installed on a forklift that operates in reverse 50% of the time and operates 16-24 hours per day, it is possibly operating beyond its designed duty cycle.

Reflectivity is an issue in certain environments. As the emitted sound is directional, it has the ability to ‘reflect’ back toward the equipment in operation if it is within 30 meters of a wall or other fixed object. This reflected sound is audible to the machine operator but is also detected by the alarm. When the alarm ‘hears’ itself, it will self-adjust to compensate in a cyclical manner until it has reached its peak output which can create excessive and unintended noise levels. Once the equipment moves away from the fixed object and the sound reflection ceases, the alarm will reset to its lowest output.

Improperly mounting the alarm can also cause significant performance issues and decreased sound localization (Heckman, Kim, Khan, Bare, & Yamaguchi, 2011; Laroche & Lefebvre, 1998). A broadband alarm needs to be mounted at the rear of the vehicle, facing the rear only - not down, to the side, up, etc. - in order for the sound to travel properly. The alarm should be visible and preferably mounted on a rear bumper, overhead guard, top of the cab, etc., with no obstruction in the path of the sound output. This requirement precludes a broadband alarm from being mounted where typical tonal alarms are mounted by the original equipment manufacturer. If a vendor simply replaces a tonal alarm with a broadband alarm and does not locate and orient it correctly, the sound will not be directional. In addition, the self-adjusting feature will not function properly due to the reflectivity issue previously mentioned, negating some of the expected benefit from the broadband alarm.

Another weakness of the broadband reversing alarms pertains to improper operation. For proper operation, broadband alarms should only operate when the mobile equipment is shifted into reverse. If the technician installs the alarm as 'always on,' the device will sound at all times, which creates confusion for pedestrians in the immediate area and nuisance sound for others. In addition to impacting those outside of the hazard area, this unwanted noise, as described by Stanton & Edworthy (1999), can increase stress in an already stressful work environment, potentially distracting others in the immediate area and potentially masking other important alarms.

Statement of the Problem

The main problem addressed is the perspectives of stakeholders have not been analyzed to determine if the use of broadband sound emitting reversing alarms is perceived to improve safety in the workplace more so than traditional tonal sound emitting reversing alarms. For the purpose of this study, "Stakeholders" refers to steel industry occupational pedestrians, forklift operators, maintenance employees and location leaders. This study addresses the gap in the literature by conducting an in-depth exploration of the perspectives of the stakeholders in the use of broadband reversing alarms to have a deeper understanding of the technology's benefits and implementation challenges.

Backup reversing alarms have the technological features to potentially prevent occupational injuries and fatalities, but the planning, training, and management of individuals remains critical in the technology's success (Fan, Choe, & Leite, 2014). Their effectiveness remains dependent on the people who are directly involved in the implementation of the technology in the workplace (Gallagher, 2003).

Purpose of the Study

The purpose of this quantitative study was to analyze the perspectives of key stakeholders to determine if the use of broadband sound emitting reversing alarms is perceived to improve safety in the workplace more so than traditional tonal sound emitting reversing alarms. The setting of the study included multiple workplaces of one North American steel company, which currently uses broadband sound emitting reversing alarms and has been doing so for a period exceeding two years. The survey population consisted of steel industry occupational pedestrians, forklift operators, maintenance employees, and location leaders working at varying locations throughout the United States.

Research Questions

Based on the problem identified from the literature, the research questions of the study are the following:

1. Are there significant differences in the perceptions of the benefits of broadband sound emitting (quack quack) reversing alarms when comparing forklift operators, occupational pedestrians, maintenance employees and leadership?

2. Are there significant differences in the perceptions of the benefits of tonal sound emitting (beep beep) reversing alarms when comparing forklift operators, occupational pedestrians, maintenance, and leadership?

3. Is there a significant relationship between the value respondents place on the benefits of broadband sound emitting (quack quack) reversing alarms and their previous experiences with injury/near miss events resulting from forklift-pedestrian interactions?

4. Is there a significant relationship between the value respondents place on the benefits of tonal sound emitting (beep beep) reversing alarms and their previous experiences with injury/near miss events resulting from forklift-pedestrian interactions?

5. Is there a significant relationship between the respondents' years of work experience and their perceived benefits of broadband sound emitting (quack quack) reversing alarms?

6. Is there a significant relationship between the respondents' years of work experience and their perceived benefits of tonal sound emitting (beep beep) reversing alarms?

7. Is there a significant relationship between the respondents' familiarity with reversing alarms and their perceived benefits of reversing alarms?

8. Are there relationships between the respondents' perceptions of the key benefits of reversing alarms and the type of reversing alarms?

Definition of Terms

Broadband sound emitting reversing alarms: Broadband reversing alarms are multi-frequency technology intended to prevent deaths or injuries in the workplace involving vehicular accidents (Brigade Electronics, 2009).

Interaural Intensity Differences (IID): The difference in loudness or intensity of higher frequency sounds (greater than 3000Hz) as processed by the brain at each ear (Hartman, 1999, Withington, 2004; Vaillancourt et al., 2013).

Interaural Time Differences (ITD): The different sound arrival times as processed by the brain at each ear for lower frequency sound (below 1500 Hz) (Hartman, 1999; Withington, 2004; Vaillancourt et al., 2013).

Occupational fatalities: Occupational fatalities are deaths that occur during a person's job (Das, 2015).

Occupational pedestrians: Occupational pedestrians are employees who are exposed to reversing mobile equipment during the course of their job (Wood, Marszalek, Lacherez, & Tyrrell, 2014).

Sound to Noise Ratio (SNR): The ratio of desired sound to the existing background noise (represented in decibels). A ratio greater than 1:1 (> 0 dB) indicates more desired sound than background noise (Homer, 2008).

Tonal Sound Emitting Reversing Alarms: Tonal reversing alarms emit a pulsed sound of one or two alternating higher pitched frequency tones, which are intended to be louder than the background noise in the area (Burgess & McCarty, 2009a).

Assumptions

Assumptions are defined as aspects of the study that cannot be verified, but are assumed to be true (Simon, 2011). The main assumption of the researcher was that the perceptions of steel industry occupational pedestrians, forklift operators, maintenance employees, and location leaders would be sufficient in understanding the benefits of using broadband reversing alarms in preventing serious injuries and fatalities. There was also an assumption that all respondents would understand the difference between broadband and tonal reversing alarms, and could therefore be honest and candid with regard to their answers to the survey questions, and would respond independently and without sharing responses among each other.

Scope and Delimitations

The scope and delimitations pertain to the methodological choices made by the researcher that bound the study, both in terms of the phenomenon and context (Simon, 2011; Yin, 2013). This study was based on the perceptions of steel industry occupational pedestrians, forklift operators, maintenance employees, and location leaders of one company, which has locations throughout the United States, in which broadband sound emitting reversing alarms are currently being used as a safety measure to protect occupational pedestrians. The scope of the study was confined to the perspectives of these select steel industry employees regarding the perceived benefits of broadband sound emitting reversing alarms. The scope of the data collection was confined to the occupational pedestrians, forklift operators, maintenance employees and location leaders of one steel manufacturer with multiple locations throughout the United States.

Limitations

Limitations pertain to the methodological weaknesses of the study that can affect the transferability and dependability of the results (Simon, 2011). One limitation of the study was that the effectiveness of broadband reversing alarms could not be supported by a cause and effect relationship. No specific experiments were conducted, which means the effects of using broadband reversing alarms for the prevention of occupational injuries and fatalities was not determined.

Significance

The potential contribution of the study is enhanced understanding of the perceived benefits of using broadband sound emitting reversing alarm technology in a manufacturing environment as there have been very few independent and scientific studies to validate improved occupational pedestrian safety with the broadband reversing alarm. Most studies conducted on the effectiveness of broadband reversing alarms focused on quantitative methods in a controlled environment, which means that the findings tend to be based on conclusions about relationships of cause and effects without in-depth explanation (Vaillancourt et al., 2013). This study addresses a gap in the literature by focusing on the perceptions of key stakeholders, including steel industry occupational pedestrians, forklift operators, maintenance employees, and location leaders.

The potential contribution of the study that advances practice is a safer working environment for pedestrians in manufacturing sites as a result of broadband reversing alarm technology. The potential implications for positive social change that are consistent with and bounded by the scope of the study is the possible decrease in preventable occupational fatalities, safer working environments in industrial and construction settings, and decreased operational costs as a result of fewer accidents (Gallagher, 2003). Even though adopting broadband reversing alarms can be costly for organizations, the benefits that can be accrued as a result of adopting the technology can outweigh these costs.

Considering various business units of the steel manufacturer surveyed, and the large survey population (n=698), the results of the study are able to be generalized to other manufacturing companies. The results and may support the benefits of broadband reversing alarms in the prevention of serious injuries and fatalities in many industrial and manufacturing environments.

Summary

According to OSHA (2012), employees in general industry and construction are both at risk to reversing mobile equipment. 358 back over fatalities occurred during the years 2005 – 2010; 142 were construction related and 216 occurred in general industry. One technology gaining support in preventing occupational fatalities is broadband reversing alarms. The unit of analysis for the study was one steel manufacturer with multiple U.S. locations which has been using broadband reversing alarm technology for at least two years. The survey population was occupational pedestrians, forklift operators, maintenance employees, and location leaders at these facilities. The effectiveness of broadband reversing alarms still remains dependent on the planning, training, and management of individuals who are directly involved in the implementation and use of the technology in the workplace (Fan et al., 2014). The specific problem is that the perceptions of steel industry occupational pedestrians, forklift operators, maintenance employees, and location leaders had not been explored in previous studies. The purpose of this quantitative study was to explore the perceptions of key stakeholders regarding the benefits of broadband sound emitting reversing alarms in preventing occupational pedestrian fatalities. The next chapter will present the literature review regarding broadband reversing alarms.

CHAPTER 2

REVIEW OF THE LITERATURE

Introduction

The broadband reversing alarm is a relatively new technology that is installed on mobile equipment, including fork trucks, as a means of preventing occupational injuries and fatalities and enhancing workplace safety (Brigade Electronics, 2009; Vaillancourt et al., 2013). The effectiveness of these alarms in preventing pedestrian injuries depends on the people who are directly involved in the implementation of the technology in the workplace (Gallagher, 2003). Broadband reversing alarms may help to prevent occupational injuries and fatalities, but the planning, training, and management of the individuals that the technology affects remains critical to the technology's success (Fan et al., 2014). Past researchers who have studied broadband reversing alarms have employed various methods to explore the relationships of hearing protection and the user's ability to detect the broadband sound emitted from the alarm (Alali, 2011; Withington, 2000), or investigated the sound propagation of various types of reversing alarms, including broadband (Nelisse, Laroche, Giguere, Boutin, Vaillancourt, & Laferriere, 2011; Vaillancourt et al., 2013). The previous research has reported findings that omit the perception of the benefits of broadband alarms based on stakeholders' experiences with the technology (Vaillancourt et al., 2013). This quantitative study explored the perceptions of key stakeholders - occupational pedestrians, forklift operators, maintenance employees and facility leadership - regarding the utilization of broadband reversing alarms for the prevention of occupational pedestrian injuries and fatalities.

The search strategy for this literature review began with a specific focus on backup alarms, both tonal sound emitting reversing alarms and broadband sound emitting reversing alarms. Iterative searches were conducted within *Google Scholar*, *EBSCOhost*, *ProQuest*, and *Sciencedirect* to retrieve articles containing key search terms and combinations of key terms. These key terms included: *broadband alarms, broadband sound, backup alarms, back up alarms, reverse alarms, non-tonal alarms, beeper alarms, vehicle alarms, tonal backup alarms, tonal back up alarms, tonal reversing alarms, construction safety, back over prevention, auditory detection, auditory warning, localization and occupational pedestrian.* The keywords and combinations of keywords listed above were entered in each of the listed databases and search engines and included all relevant disciplines. Reference pages for relevant articles were searched for additional relevant sources, which were then located by searching in the aforementioned databases and search engines. For this review, 11 books and 99 journal articles were reviewed and a total of eight books, 59 journal articles, and 22 internet references (technical papers, dissertations, thesis', OSHA documents, etc) were included.

The United States Occupational Safety and Health Administration (2012) reported that approximately 360 industrial workers were killed in "backover" accidents in the U.S. between 2005 and 2010. Backover events involving construction vehicles are a leading cause of death among roadway construction workers (Choe, et al., 2014; Flannagan, et al., 2014), and a majority of fatalities involving heavy construction equipment result from the vehicle backing up (Kazan, 2013; Lingard, Cooke, & Gharaie, 2013). The most common means of averting pedestrian fatalities and injuries caused by backover incidents is the industry standard tonal backup alarm (Redel, 2012); however, the tone made by these alarms produces noise pollution, may not penetrate the hearing protection worn by construction workers, may provoke a fright response, and may be ignored by pedestrians who have grown accustomed to it (Brammer & Laroche, 2012). Broadband reversing alarms, by emitting a "broadband" sound at three different pitches simultaneously, allow the ear to distinguish the distance and direction of the reversing vehicle (Brigade Electronics, 2009). The alarm's sound, which Brigade Electronics (2009) compared to a duck's quack, is less likely than a tonal alarm's high-pitched chime to provoke a fright response. The alarm's limited audibility to pedestrians outside of the hazard area reduces noise pollution, and increases the awareness for pedestrians who hear it and are most likely in the path of the reversing vehicle, which means they are less likely to ignore the signal, even if they are accustomed to it (Brigade Electronics, 2009). The broadband sound emitting reversing alarm is believed to enhance safety at worksites by addressing several weaknesses of the currently prevalent tonal alarm (Brigade Electronics, 2009). This study of key stakeholder's perceptions regarding broadband alarms may contribute to a reduction in workplace injuries and fatalities.

Tonal Sound Emitting Reversing Alarms

Tonal reversing alarms were invented by Matsusaburo Yamaguchi in April 1963, (Triton Signal, 2016). Mr. Yamaguchi's invention, the single tone BA1 (Back-Up Alarm No. 1) sparked the backup alarm industry, which is committed to the safety of reversing vehicles. Tonal reversing alarms were introduced in the United States in 1971 when, according to Swanson (2004), the Army Corps of Engineers began to require reversing alarms on their projects as multiple occupational pedestrians had been fatally injured and many more pedestrians were deemed at significant risk of being struck by reversing construction vehicles. Job-site construction vehicles are addressed within 29 (CFR) 1926.601entitled, *Motor Vehicles.* 1926.601(b)(4) states a reverse signal alarm audible above the surrounding noise level is required, or the vehicle can be backed with the assistance of an observer. The standard also applies to earthmoving and compacting equipment in addition to other job site vehicles. As previously referenced, backup alarm requirements are only remotely addressed within the

General Industry regulations. Within 1910.269, entitled *Electric Power Generation, Transmission, and Distribution*, section 269(p)(1)(ii) it states "No motor vehicle or earthmoving or compacting equipment having an obstructed view to the rear may be operated on off-highway jobsites where any employee is exposed to the hazards created by the moving vehicle, unless" 269(p)(1)(ii)(A) "the vehicle has a reverse signal alarm audible above the surrounding noise level…" (OSHA, 2015). Though forklifts are not specifically addressed, OSHA has stated within letters of interpretation that equipment supplied with backup alarms cannot have the alarms made inoperable. If a serious injury exposure exists from backing forklifts within an industrial environment, OSHA has stated their ability to cite under the general duty clause via letters of interpretation (OSHA n.d.; OSHA, 2012).

The United States Patent Office (1975) identifies Carl Peterson as the first US inventor of an improved electronic tonal alarm, which could operate if installed with the direct current (DC) polarity reversed, ensuring operation even if incorrectly installed. Eight additional patents for reversing alarms were granted through April 2005 when Christopher Hanson-Abbott and Masato Yamashita, representing Brigade Electronics and Yamaguchi Electric Ind. Co. Ltd. respectively, were granted patent # 6,885,295. Their reversing alarm would emit pulses of broad band sound which the inventors stated would allow occupational pedestrians the ability to locate the location of the vehicle traveling in reverse motion (United States Patent Office, 2005).

Even though the use of backup alarms has been largely mandated since 1971, Purswell & Purswell (2001) identified 150 backing accidents that were investigated by OSHA between 1972 and 2001. Of these 150 accidents, the backup alarm was only found operational in 65 of the cases. With a 43% operational rate, one has to question the overall effectiveness of tonal alarms in protecting occupational pedestrians within the occupational environment. In addition, there are many other challenges associated with tonal reversing alarms. Traumatic events can still occur when the reversing alarm does not attract the attention of the pedestrian because it is not heard, or is ignored in some cases because of the habitual existence of continuous tonal alarm sounds when there is no real danger. In other situations, as reported by Vaillancourt et al. (2013), the tonal alarms are so loud and annoying to the mobile equipment operator or the pedestrian, they are purposefully disconnected. Additionally, other factors that can lead to the tonal alarm not being heard include hearing loss, use of hearing protection, the alarm not being loud enough to overcome the ambient background noise, or improper installation on mobile equipment (Laroche & Lefebvre, 1998; Noble & Russell, 1972). However, previous studies showed that a tonal alarm could remain audible with relatively low signal to noise ratios in areas with ambient sound levels greater than 85 dB and with the use of passive earmuffs (Casali, Robinson, Dabney, & Gauger, 2004; Robinson & Casali, 1995). Granted, these studies tend to contradict each other, but they raise concerns about the effectiveness of tonal reversing alarms in ensuring they are able to convey to all population groups the required sense of urgency in the critical area directly behind reversing mobile equipment. In two similar studies (Casali & Wright, 1995; Lovejoy, 2008), amplitude sensitive hearing protection was evaluated to determine if it increased the wearer's ability to detect a backup alarm. Amplitude sensitive ear muffs are designed to improve hearing in lower noise environments through amplification or attenuation and are ideal for areas with periods of high and low ambient background noise such as a shooting range or airport. The researchers determined there was no statistically significant advantage to the electronic muff in comparison to a traditional, passive ear muff (Casali & Wright, 1995; Lovejoy, 2008).

Additional review of the literature identifies three primary negative characteristics of tonal sound emitting reversing alarms: the pedestrian's inability to locate the source of the sound, irregular sound spread patterns behind the reversing mobile equipment, and the noise pollution transmitted to areas where the sound is not intended to be heard.

To be effective, a number of factors contribute including the alarm's frequency range: the occupational pedestrians level of hearing, sound masking by ambient background noise, recognition of the hazard, reaction time, the perceived urgency once the sound is heard, the ability to locate the sound's source and the alarms sound pattern (Burt, Bartolome, Burdette, & Comstock, 1995; Guillaume, Pellieux, Chastres, & Drake, 2003; Morgan & Peppin, 2008). Catchpole, McKeown, & Withington (2004) identify three specific questions that a sounding alarm must address to be effective; what, where and when. What is the hazard? Where is the hazard? When is it a hazard?

The "beep-beep" sound of a tonal reversing alarm is ubiquitous and familiar to most everyone, but as documented by Vaillancourt et al. (2014), occupational pedestrians are often unable to immediately conclude from which direction the sound is emanating. Stanton & Edworthy (1999) identify the ability to locate sound as a prerequisite for human survival; at times when an alarm is heard, there is no time to pause and look around to determine from where the alarm originates. The inability to locate the source of the sound can lead to confusion, which can create a delayed response by the pedestrian at a moment in time when a quick reaction is required to avoid the danger of the reversing mobile equipment. Humans have the ability to hear sound frequencies from 20 to 20,000 Hz, but the key frequencies for locating the source of a sound are in range below 800 Hz and exceeding 1600 Hz (Holzman, 2011). The typical frequency of a tonal sound emitting reversing alarm is around 1000 Hz (Holzman, 2011). The

Society of Automotive Engineers (SAE), (2014) J994 standard entitled *Alarm—Backup—Electric laboratory performance testing* identifies the recommended frequency of backup alarms to be between 800 Hz and 1800 Hz, a frequency range that is just out of the key range for sound localization. Vaillancourt et al. (2013) notes the SAE J994 standards were developed initially for tonal reversing alarms and the existing parameters and testing requirements have not been updated to address the acoustical properties of broadband sound emitting reversing alarms.

There are three key negative characteristics of tonal sound emitting reversing alarms. The first key negative characteristic relates to the use of hearing protection devices, especially for pedestrians with existing hearing loss. The use of hearing protection and/or existing hearing loss is considered a potential detriment as these can possibly be hinder the listener's ability to locate the sounds source (Berger, 2003; Simpson, Bolia, McKinley, & Brungart, 2005; Stanton & Edworthy, 1999). Morgan, (2007), Morgan and Peppin (2008), Brigade Electronics (2009) all concluded the sound spectrum of the broadband alarm provides a greater opportunity for pedestrians with hearing loss, as well as those wearing some form of passive hearing protection, to more easily hear the alarm. In one human factors experiment conducted by Casali & Alali, (2011), research indicated the actual type of hearing protection selected by the pedestrian can affect their ability to localize the sound.

The second key negative characteristic of tonal sound emitting reversing alarms is the irregular sound spread patterns behind the reversing mobile equipment that causes detection challenges and confusion for the occupational pedestrian. This irregularity causes sound pressure level variation over very short distances directly behind the mobile equipment (Laroche, 2006). At distances of less than six feet from the rear of mobile equipment, significant variations can occur in noise levels with variations up to 15 decibels occurring (Nelisse, Laroche, Giguere, Boutin, Vaillancourt, & Laferriere, 2011). The resulting issue is the occupational pedestrian may underestimate or overestimate the direction and distance of the mobile equipment outside of their immediate area or field of vision. The sound pressure levels also do not decrease as the distance increases; this causes the noise to carry significantly past the intended warning area directly behind the reversing equipment. When the alarm is heard by an unintended pedestrian, this can lead to false alarms and disassociation. The listener no longer correlates the sound to a warning, thus affecting the tonal alarms effectiveness (Bliss, Gilson, & Deaton, 1995; Holzman, 2011; Morgan & Peppin, 2008). In Bliss et al. (1995), the researchers identified the occupational pedestrian's reaction closely aligns with the reliability of the alarm. If the occupational pedestrians associate the tonal reversing alarm with a high number of false alarms (i.e. 80%), then most individuals will only react to the sound of the alarm 20% of the time. The safety of the workplace can become jeopardized by the tonal reversing alarm, which is intended to protect pedestrians, but may fail to transmit a danger warning due to the excessive percentage of false alarms.

The third key negative characteristic of tonal sound emitting reversing alarms is noise pollution. Burgess & McCarty, (2009a), Holzman, (2011) note the sound from a tonal reversing alarm often carries beyond the intended hazard warning area and is often a distraction for the general public. For these individuals, tonal reversing alarms become an irritating and unavoidable nuisance that has led to aggravation, complaints and legal challenges. In fact, many large municipalities have mandated changes to reversing alarms levels due to outcry from the public. The National Academy of Engineering (2010) identified tonal reversing alarms as having the ability to cause emotional and behavioral issues. This is thought to be due to the unpredictability of the tonal alarm and the listener's lack of control over the sound source. Tonal reversing alarms are also known to be if significant nuisance at overnight construction projects (Federal Highway Administration, 2008). This noise pollution not only negatively affects the public but exposed workers are also impacted as they often disconnect the reversing alarm because they deem them too distracting and loud (Burgess & McCarty, 2009a; Burgess & McCarty, 2009b; Edworthy & Stanton, 1995).

An effective reversing alarm should convey to the pedestrian an adequate level of warning and urgency. As many factors of a reversing alarm can determine the intended urgency, it is the sound frequency and frequency range emitted and the sounds rhythm that is important (Hellier & Edworthy, 1989; Holzman, 2011). The SAE J994 standard specifies the following characteristics to be used for all reversing alarms: frequency, pulse rate and off/on duration interval (SAE, 2014). Edworthy, Loxley, & Dennis (1991) and Haas & Edworthy (1996) identified high frequencies, rapid sound recurrence rate and an expansive frequency range as characteristics of an alarm that invokes an urgent response.

Broadband Sound Emitting Reversing Alarms

Broadband sound emitting reversing alarms are touted by the manufacturer, as well as within several published documents, as being a superior product to tonal reversing alarms due to the alarms having the required characteristics that promote increased sound propagation at the rear of mobile equipment, which decreases noise pollution and improves the pedestrian's ability to locate the sound (Brigade Electronics, 2009; Holzman, 2011; Morgan, 2007; Morgan & Peppin, 2008).

The term broadband refers to the alarms broad frequency spectrum that is emitted by the alarm. Figure 4 below is a visual representation of the sound propagation characteristics of both tonal and broadband reversing alarms. The tonal alarm levels are very erratic, as levels of 107 dB(A) are present at the sound source and travel out 4 meters. Conversely, at distances of less than one meter the level was as low as 80 dB(A). The broadband alarms sound spread is significantly more level across the hazard area as the highest sound pressure levels are confined to the area just beyond the sound source, and the levels continually decrease as distance increases. This propagation ensures the highest sound levels are present in the immediate area of most significant warning.

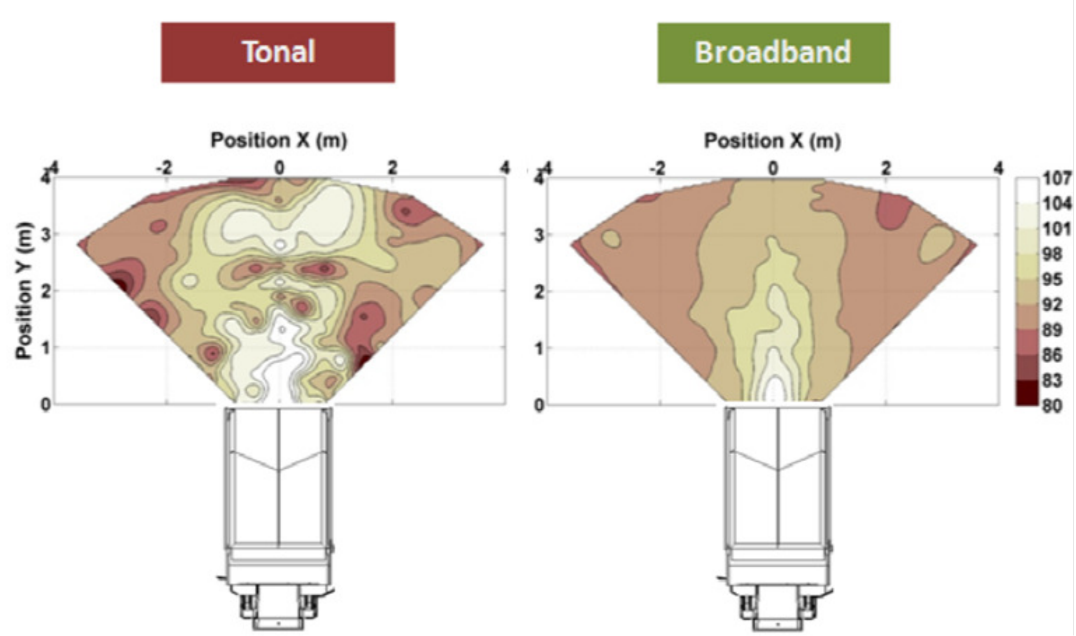


Figure 4. Sound pressure levels measured directly behind the vehicle, expressed in dB(A) for the alarms with ideal placement. Reprinted from “Comparison of different vehicle backup-alarm types with regards to worker safety” by Nelisse, Laroche, Giguere, Boutin, Vaillancourt, & Laferriere, 2011, p.283. Copyright 2011 by ICBEN.

The sound propagation and the broad spectrum of the warning signal emitted create localization cues which are believed to allow the occupational pedestrian to more easily identify from where the sound is generated. Vaillancourt et al. (2013) identified the localization benefits of broadband alarms as a characteristic that provides a greater number of position cues compared to tonal alarms, which have a single dominant frequency.

Hartman (1999), Vaillancourt et al. (2013), and Withington (2004) identifies these cues as interaural time differences (ITD) and interaural intensity differences (IID), as shown in Figure 5 below. At lower frequencies, the brain processes the different sound arrival times, ITD, at each ear which aids in the localization of sound below 1500 Hz. At higher frequencies (greater than 3000Hz), the brain processes the loudness/intensity differences (IID) at each ear. These two cues, known as the 'duplex' theory, were first proposed in 1877 by Lord Raleigh (Withington, 2004).

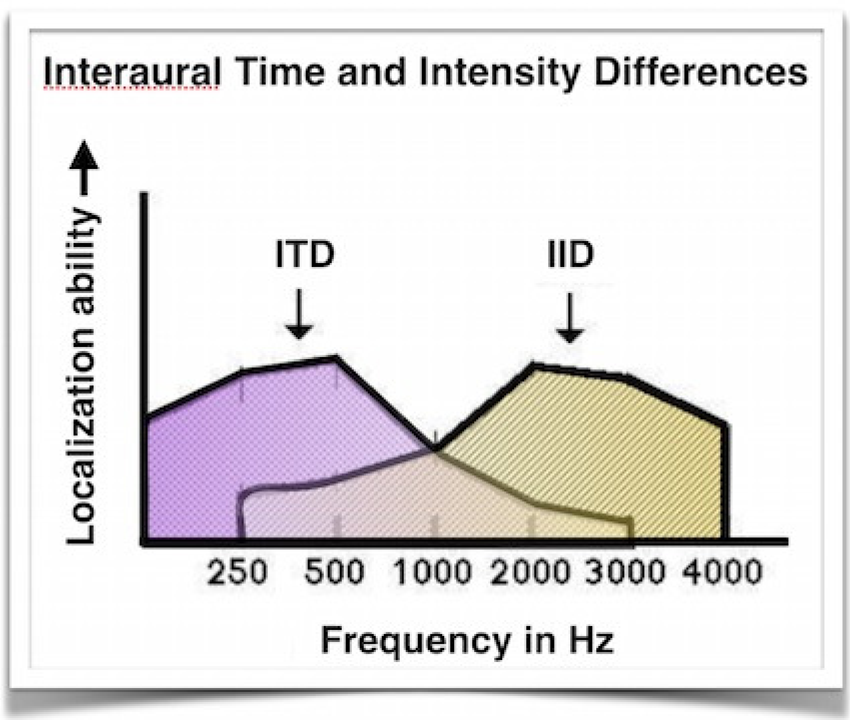


Figure 5. Interaural time and intensity differences. Reprinted from Hearing Health Matters. (2015). [Image]. Retrieved from http://hearinghealthmatters.org/waynesworld/files/2015/03/ITD-and-IID-a.jpg.

High frequency sounds (greater than 5000 Hz) provide the needed spectral cues that help to determine front or back alarm position and to identify the source in a vertical plane. The broad sound spectrum also creates less sound wave interference due to a more consistent sound spread and emits sound over more frequencies in the key hearing range of 2000 Hz and 4000 Hz. At the frequencies the sound is emitted, the broadband reversing alarm is much less likely to be masked by ambient background noise. Morgan (2007) and Vaillancourt et al., (2013) concluded that the localization cues and decreased sound masking eliminates confusion in judging the position of the mobile equipment, allowing the occupational pedestrian a decreased response time when it is critical to avoid an approaching hazard. Brigade Electronics (2009), Morgan (2007), and Morgan & Peppin (2008) state another benefit of the broadband alarm is that it is only heard where it is intended, and the source of the sound is much easier to identify. Because the broadband sound is being contained near the mobile equipment from which it is emanating, there are fewer propensities for false alarms as opposed to tonal alarms. Withington (2004) documented the results of a United Kingdom nonscientific comparative study that validated the sound localization benefit of broadband reversing alarms. The study included 313 vehicles - out of a population of 1477 - that were equipped with broadband reversing alarms. A questionnaire was provided to site employees and site managers at a range of companies to assess their views on both conventional (tonal) and broadband reversing alarms. Six questions were posed to the respondents and the data collected was analyzed as descriptive statistics. 80% of the respondents claimed they always correctly identified the location of the mobile equipment equipped with broadband whereas only 10% stated they could locate the mobile equipment sounding a tonal alarm. 100% of respondents identified the broadband reversing alarm was less irritating than the tonal reversing alarm.

Homer (2008) measured the sound pressure levels of both tonal and broadband reversing alarms on a vehicle at high idle (alarm off) and a vehicle at low idle (alarm on) per ISO 9533 entitled *Earth-moving machinery -- Machine-mounted audible travel alarms and forward horns -*

- *Test methods and performance criteria* (ISO 9533, 2010). The sound levels were used to determine each alarm's signal to noise ratio (SNR). The SNR is defined by Homer (2008) as the ratio of desired sound to the existing background noise (represented in decibels), a ratio greater than 1:1 (> 0 dB) indicates more desired sound than background noise. The results of the study determined the SNR was met; ratio greater than 1:1, 86% of the time by the tonal alarm but only met 43% by the broadband alarm (Homer, 2008). Improved SNR results can be achieved by selecting a broadband reversing alarm with a greater dB(A) output. The researcher did note the tonal alarm emitted a sound that covered an area 45% larger than the broadband reversing alarm which supports previous research that identified increased noise pollution outside of the immediate warning area from the use of tonal alarms. Vaillancourt et al. (2013) compared the performance of broadband sound emitting reversing alarms to tonal reversing alarms and a custom made multi-tone alarm by measuring the sound pressure levels directly behind mobile equipment in actual work environments. In addition to the field measurements, human subjects were evaluated in a laboratory setting to identify the ability to locate the sound source of each alarm type, the listener's perceived urgency to each alarm type and sound detection thresholds. The researchers determined tonal reversing alarms had slight advantages in sound detection (loudness), urgency at low levels and a significant disadvantage due to its varied sound pressure level variations directly behind mobile equipment (15-20 dB variations in the immediate area). The researchers determined the broadband alarm generated a more uniform field of sound behind the mobile equipment in the work environment, was easier for participants to localize the sound source and was determined by participants to be louder at representative alarm levels. The custom made multi-tone alarm had results in between the tonal and the broadband alarms.

Noise Pollution

The noise pollution associated with tonal reversing alarms can be greatly reduced through the use of broadband reversing alarms (Brigade Electronics, 2009; Holzman, 2011). Reduced noise pollution is possible as broad spectrum sounds appear louder than sounds emitted as single frequency tones. Broadband alarms can therefore be utilized at 5 dB(A) lower than tonal reversing alarms while maintaining the same loudness, therefore, reducing potential noise pollution. Brigade Electronics, (2009) notes the broad sound spectrum and higher frequency signal provides increased directionality of the sound and the broadband sound is more easily absorbed by the ground and other structures which confine the warning alarm more to the actual hazard area. Unlike tonal alarms, the broad sound spectrum of broadband alarms tends to attenuate rapidly with distance allowing the sound to be masked by background noise which limits its pollution footprint. If a broadband alarm can be installed with an output 5 decibels less than that of a tonal reversing alarm, and because the signal is more contained to the hazard area, their use on mobile equipment will decrease noise pollution and the associated complaints common to tonal reversing alarms (Brigade Electronics, 2009; Holzman, 2011).

Organizations and municipalities agree with the reduction in noise pollution claim, as the Society of Automotive Engineers presented an award of excellence for broadband technology. Broadband alarms are also being included as options within regulations, one example being the City of New York's requirement for quieter reversing alarms when equipment is operating outside of normal business hours and at all times when working near hospitals and schools (City of New York, 2007).

Hearing Protection and Hearing Loss

As previously referenced, Laroche & Lefebvre (1998) expressed concerns regarding tonal alarms potentially being less effective due to hearing loss. The authors also determined the use of hearing protection could cause the tonal alarm sound to not be loud enough to overcome the ambient background noise. Robinson & Casali (1995) were able to determine that a tonal alarm could remain audible at low SNRs with the use of hearing protection.

Several additional studies have documented the reduced ability for individuals to localize sound while wearing passive hearing protection (Abel & Hay, 1996; Atherley & Noble, 1970; Berger, 2003; Berger & Casali, 1997; Bolia, D'Angelo, Mishler, & Morris, 2001; Noble, Murray, & Waugh, 1990; Simpson, et al., 2005). Conversely, there has been limited study on the use of hearing protection devices and the effect on a user's ability to locate sound comparing tonal alarms to broadband alarms (Casali & Alali, 2010; Alali, 2011; Alali & Casali, 2011; Vaillancourt, et al., 2013). In the primary study reviewed, Alali, (2011), compared a tonal reversing alarm (Preco model 6003) with a broadband reversing alarm (BBS-97 model) in an experimental study that involved individuals actively listening for each alarm type individually while wearing no hearing protection, wearing passive hearing protection, and while wearing active level-dependent hearing protection (which filter loud noises but allow sounds to be heard at lower decibel levels). Results of this study determined the hearing protection devices did not decrease audibility of either reversing alarm in a controlled environment. The author did note the tonal alarm could be heard at 1600.9 feet in comparison to the broadband alarm at 1379.4 feet, which that study interpreted to be a positive characteristic of the tonal alarm. There was no mention of the issues identified in previous research regarding the excessive propagation of tonal alarms (1600.9 feet vs. 1379.4 feet) or their ability to generate significant noise pollution. In the

2010 study by Casali and Alali, individuals with normal hearing were exposed to both tonal and broadband sound while wearing one of seven styles of hearing protection. The intent of this study was to determine the impact of sound localization due to the use of hearing protection. The overall results identified minimal variation in results based on type of hearing protection used though left to right sound localization was deemed better in low noise versus high noise environments. In regards to the impact of sound localization from broadband alarms, the results were inconclusive as the authors stated the ability to localize a broadband alarm while wearing hearing protection remain unclear.

Hearing loss of the exposed occupational pedestrian is another significant area of concern. As identified by Laroche, Ross, Lefebvre, & Larocque (1993), a tonal alarm should be broad range with sound components in the 500Hz to 2000 Hz range, and not be a single pure tone in the 1,000 to 1,250 Hz range. The wide range of output is beneficial for those with noise-induced hearing loss, though ranges above 2000 Hz provide limited additional benefit.

Improper Installation

Issues with alarm performance due to improper mounting and installation have been identified in many studies (Brigade Electronics, 2009; Heckman, et al., 2011; Laroche & Lefebvre, 1998; Laroche et al., 1993; Vaillancourt et al., 2013). Most of the concerns are related to mounting the reversing alarms inside engine cowlings or other locations on the mobile equipment where the emitted alarm sound is muffled or blocked. Improper mounting locations can negatively impact sound propagation and the signal-to-noise ratio, which can decrease the occupational pedestrian's auditory perception of the alarm. Heckman et al. (2011) validated this concern, as they could determine the listener's ability to locate the sound of the backup alarm was significantly impacted by the alarm's mounting. The most significant localization issue caused by improper mounting was when the alarm sound was generated either directly in front of or behind the listener, a key location for those intended to be warned. Additionally, the authors validated previous concerns with tonal alarms relating to their ability to travel long distances beyond the area of protection, resulting in noise pollution for the general public and other workers not in the immediate warning area.

This review has determined that neither the tonal alarm nor the broadband alarm present advantages with all positive characteristics identified. The broadband alarm can be implemented at an approximate 5 dB(A) lower output than a conventional tonal alarm, achieve equal sound output, and is much easier to localize the point of sound generation. The tonal alarm was determined to be easier to detect in workplaces with higher ambient background noise levels and was judged to have a slightly more urgent effect on the listener, resulting in increased responsiveness when the alarm was heard. The broadband alarm may have a greater sound masking effect in ranges of high frequencies, but this is a minor deficiency in comparison to the tonal alarms variations in sound pressure levels within the immediate hazard area, directly behind the mobile equipment.

While broadband alarms are intriguing, there are few published and peer-reviewed studies that validate the benefits and weaknesses of the technology, or look at user's perceptions regarding the technology's ability to improve the safety of occupational pedestrians (Nelisse et al., 2011).

CHAPTER 3

METHODS

The purpose of the study was to analyze the perceptions of steel industry occupational pedestrians, forklift operators, maintenance employees and location leaders to determine if the use of broadband sound emitting reversing alarms was perceived to improve safety in the workplace more so than traditional tonal sound emitting reversing alarms. The study methodology will be detailed in this chapter, which will include the following key sections: (a) research method and design, (b) research population, (c) overview of the survey instrument, and (d) data collection procedures. Further described within this chapter is the research hypothesis, statistical tests determined to test the hypotheses, and criteria for test assumptions.

Research Method and Design

A quantitative research approach was used to analyze the perceptions of the participants to determine if the use of broadband sound emitting reversing alarms was perceived to improve safety in the workplace more so than traditional tonal sound emitting reversing alarms. Quantitative research provides the ability to analyze the underlying perceptions that impact the behavior of the study population and to identify the varying factors that cause the population to either believe or disbelieve that broadband reversing alarms make their workplace safer (Kothari, 2004).

Research Population and Sample

The subjects in the study were from business units of a single steel manufacturer with multiple facilities located throughout the United States. These business units included fifty-five separate facilities, with production output that includes fabricated reinforcing steel, epoxy coated reinforcing steel, railroad spikes, drawn wire, and wire mesh. All sites have been using broadband reversing alarm technology for at least two years. All employees at these sites were surveyed.

The population for the study was occupational pedestrians, forklift operators, maintenance employees, and location leaders who have exposure to broadband reversing alarm technology in the workplace. Based on mailing information provided by the steel manufacturer, 1211 employees were sampled in the study. For all four groups, the inclusion criteria were: (a) currently employed with the surveyed steel manufacturer, (b) who have exposure to broadband reversing alarm technology in the workplace, (c) are willing to participate in study survey, and (d) can read the survey questions and respond independently. The exclusion criteria are occupational pedestrians, forklift operators, maintenance employees, and location leaders who: (a) have already completed their work at the time of the study, or (b) have no exposure to broadband reversing alarms in their workplace.

The steel company studied provided the researcher a list of potential subjects along with required contact information for the purposes of survey instrument distribution.

Research Measures

The following independent and dependent variables and the rational for these variables were identified from the literature review. The dependent variables in the study were: perception of broadband alarm benefits (PBB), perception of tonal alarm benefits (PTB), and the type of reversing alarm selected by the respondents (AT). The independent variables in this study were respondent forklift near miss/ injury experience (FIE), employee classification (EC), years of experience (YE), familiarity with reversing alarms (FA), and the eight perceived benefits of reversing alarms (AB). Table 1 (below), summarizes the independent variables (IV) and dependent variables (DV), the related research question(s), variable type and the variable range.

Table 1

Summary of Dependent and Independent Variables

Variable	Variable Description	Research Question(s)	Variable Type	Range
Perception of Broadband Alarm Benefits (PBB)	DV	1,3,5, & 7	Ordinal	1 to 5
Perception of Tonal Alarm Benefits (PTB)	DV	2,4 & 6	Ordinal	1 to 5
Type of reversing alarm selected by the respondents (AT)	DV	8	Categorical	1 to 2
Employee Classification (EC)	IV	1 & 2	Categorical	1,2,3,4, or 5
Forklift Near Miss/Injury Experience (FIE)	IV	3 & 4	Categorical	1,2,3, or 4
Years of Experience (YE)	IV	5 & 6	Categorical	1,2, or 3
Familiarity with Reversing Alarms (FA)	IV	7	Ordinal	1 to 5
Eight perceived benefits of reversing alarms (AB)	IV	8	Categorical	1 to 8

Survey Instrument and Procedures

Survey Description

An original questionnaire, as found in Appendix A, was developed by the researcher to obtain information from the survey participants. The survey consisted of fifteen items and was designed to specifically answer the eight research questions proposed in the study. Two of the four dependent variables were evaluated using a Likert scale, due to its preferred method for measuring opinions, product satisfaction, and beliefs (Rogers, Sharp, & Preece, (2011). The two remaining dependent variables were evaluated using ranking questions, as this method ensures respondents must correlate each listed characteristic only once (Vannette, 2015). The survey instrument was administered as a paper (hard) copy to ensure the entire study population had an opportunity to participate.

Data Collection Procedures

Prior to the survey's distribution, an email correspondence was distributed to the potential respondents from the corporation's Director of Health & Safety. The intent was to ensure potential respondents were aware of the survey and signaled them to look for it in their mail box. The communication was also intended to ensure respondents would be looking for the communication and be comfortable completing and returning the survey instrument.

A cover letter, included as Appendix B, was developed and provided along with the survey instrument. The purpose of the cover letter was to introduce the researcher, including name, address and phone; describe the study's purpose; and to ensure respondents were aware their participation and responses to the survey were confidential. Participants provided implied consent to utilize their responses for the purposes of this research by returning their completed survey instrument to the researcher.

All survey instruments were distributed on the same date. Email reminders were sent to the organization's leadership on day seven, fourteen, and twenty one requesting leaders remind their employees to complete and return their surveys. At day fourteen, a reminder letter, included as Appendix C, and a second survey instrument was distributed to the potential respondents to ensure the surveys were received, and to encourage those yet to respond to do so.

Once completed survey instruments were received, each was labeled consecutively beginning with Case #1. As fifteen responses from each survey required manual entry into an excel spreadsheet, included as Appendix D, this allowed the researcher the ability to locate a specific survey if a data issue was identified.

Research Question 1

Research Question

The researcher posited there were significant differences in the perceptions of the benefits of broadband sound emitting (“quack-quack”) reversing alarms when comparing forklift operators, occupational pedestrians, maintenance employees and leadership.

Hypothesis

Null Hypothesis: The median (distribution) of all groups were equal.

Alternative Hypothesis: The median (distribution) of all groups were not equal.

Variables

The independent variable is the employee classification: forklift operator, occupational pedestrian, maintenance employee or leadership. The dependent variable was the perception of the safety benefits provided by broadband reversing alarms.

Statistical Procedures and Assumptions

A Kruskal-Wallis Test, according to Field (2009), is a non-parametric test used to determine if a statistically significant difference exists between two or more groups (independent variables) on an ordinal or continuous dependent variable.   Lund & Lund (2013a) identify four assumptions for the Kruskal-Wallis test:

Assumption 1: The dependent variable should be measured at the continuous or ordinal level. This assumption is met as the dependent variable measured the survey populations’ perceptions of broadband reversing alarms benefits using a five point Likert scale; not beneficial at all to very beneficial.

Assumption 2: The independent variable should consist of two or more categorical, independent groups. This assumption is met as survey respondents select the one option that best describes their role when working around forklifts in their workplace; pedestrian, forklift operator, leadership or maintenance employee.

Assumption 3: The study population should have independence of observations meaning there is no relationship between the groups themselves or the observations from each group. This assumption is met as there were different respondents in each of the groups and no respondent was in more than one group.

Assumption 4: Confirm that each group of the independent variable had a distribution of scores with the same shape; the same variability. If the scores have the same shape, when plotted as a curve, the Kruskal-Wallis test can compare the medians of the dependent variable for the four different independent variable groups. If the distributions have a different shape, the Kruskal-Wallis test can only be used to compare mean ranks.

Significance

Significance will be determined using an alpha level of .05.

Post Hoc Test

Zaiontz (2016) notes if the Kruskal-Wallis H test identifies significant differences, i.e., $p <.05$, a Dunn-Bonferroni post hoc will identify significant differences between the pairs.

Research Question 2

Research Question

The researcher posited there were significant differences in the perceptions of the benefits of tonal sound emitting (“beep-beep”) reversing alarms when comparing forklift operators, occupational pedestrians, maintenance employees, and leadership.

Hypothesis

Null Hypothesis: The median (distribution) of all groups were equal.

Alternative Hypothesis: The median (distribution) of all groups were not equal.

Variables

The independent variable is the employee classification; forklift operator, occupational pedestrian, maintenance employee or leadership. The dependent variable was the perception of the safety benefits provided by tonal reversing alarms.

Statistical Procedures and Assumptions

A Kruskal-Wallis Test and post hoc tests will be performed following the procedures described in Research Question 1.

Research Question 3

Research Question

The researcher posited there was a significant relationship between the value respondents place on the benefits of broadband sound emitting ("quack-quack") reversing alarms and their previous experiences with injury/near miss events resulting from forklift-pedestrian interactions.

Hypothesis

Null Hypothesis: There was no association between the value respondents place on the benefits of broadband sound emitting ("quack-quack") reversing alarms and their previous experiences with injury/near miss events resulting from forklift-pedestrian interactions.

Alternative Hypothesis: There was a significant association between the value respondents place on the benefits of broadband sound emitting ("quack-quack") reversing alarms and their previous experiences with injury/near miss events resulting from forklift-pedestrian interactions.

Variables

The independent variable was the respondents forklift near miss/injury experience. The dependent variable was the perception of the safety benefits provided by broadband sound emitting reversing alarms.

Statistical Procedures and Assumptions

Lund & Lund (2013) identify the chi-square test of association is utilized to identify if a relationship exists between two categorical variables. The chi-square test of association is also called the chi-square test for independence or Pearson's chi-square test. Lund & Lund identify three assumptions that must be met for the use of the chi-square test of association.

Assumption #1: The two variables should be measured at the nominal or ordinal level; categorical data. This assumption is met as the independent variable consists of categorical data and the dependent variable is measured at the ordinal level.

Assumption #2: The independent variable should consist of two or more categorical, independent groups. This assumption is met as survey respondents select the one option that best describes their role when working around forklifts in their workplace; pedestrian, forklift operator, leadership or maintenance employee.

Assumption #3: A relatively large sample size with expected frequencies for each cell that are at least 1 with 80% of cells exceeding 5. This assumption was met as all frequencies exceeded five with 698 respondents.

Post Hoc Test

Field (2009) identifies Cramer's V as a post hoc test for Chi-square test as Cramer's V is able to measure the strength of association between the two variables. Kruskal's lambda, as identified by Field (2009), will identify the probability improvement percentage of the dependent variable given the value of other variables.

Significance

Significance will be determined using an alpha level of .05.

Research Question 4

Research Question

The researcher posited there was a significant relationship between the value respondents place on the benefits of tonal sound emitting ("beep-beep") reversing alarms and their previous experiences with injury/near miss events resulting from forklift-pedestrian interactions.

Hypothesis

Null Hypothesis: There is no association between the value respondents place on the benefits of tonal sound emitting ("beep-beep") reversing alarms and their previous experiences with injury/near miss events resulting from forklift-pedestrian interactions.

Alternative Hypothesis: There is a significant association between the value respondents place on the benefits of tonal sound emitting ("beep-beep") reversing alarms and their previous experiences with injury/near miss events resulting from forklift-pedestrian interactions.

Variables

The independent variable was the respondents forklift near miss/injury experience. The dependent variable was the perception of the safety benefits provided by tonal sound emitting reversing alarms.

Statistical Procedures and Assumptions

A chi-square test of association was performed following the procedures described in Research Question 3.

Research Question 5

Research Question

The researcher posited there was a significant relationship between the respondents' years of work experience and their perceived benefits of broadband sound emitting ("quack-quack") reversing alarms.

Hypothesis

Null Hypothesis: There is no association between the respondents' years of work experience and their perceived benefits of broadband sound emitting ("quack-quack") reversing alarms.

Alternative Hypothesis: There is some association between the respondents' years of work experience and their perceived benefits of broadband sound emitting ("quack-quack") reversing alarms.

Variables

The independent variable was the respondents' years of work experience. The dependent variable was the perception of the safety benefits provided by broadband sound emitting reversing alarms.

Statistical Procedures and Assumptions

A chi-square test of association was performed following the procedures described in Research Question 3.

Research Question 6

Research Question

The researcher posited there was a significant relationship between the respondents' years of work experience and their perceived benefits of tonal sound emitting ("beep-beep") reversing alarms.

Hypothesis

Null Hypothesis: There is no association between the respondents' years of work experience and their perceived benefits of tonal sound emitting ("beep-beep") reversing alarms.

Alternative Hypothesis: There is a significant association between the respondents' years of work experience and their perceived benefits of tonal sound emitting ("beep-beep") reversing alarms.

Variables

The independent variable was the respondents' years of work experience. The dependent variable was the perception of the safety benefits provided by tonal sound emitting reversing alarms.

Statistical Procedures and Assumptions

A chi-square test of association was performed following the procedures described in Research Question 3.

Research Question 7

Research Question

The researcher posited there was a significant relationship between the respondents' familiarity with reversing alarms and their perceived benefits of reversing alarms.

Hypothesis

Null Hypothesis: There is no association between the respondents' familiarity with reversing alarms and their perceived benefits of reversing alarms.

Alternative Hypothesis: There is a significant association between respondents' familiarity with reversing alarms and the perceived benefits reversing alarms.

Variables

The independent variable was the respondents' familiarity with sound emitting reversing alarms. The dependent variable was the perception of the safety benefits provided by sound emitting reversing alarms.

Statistical Procedures and Assumptions

Lund & Lund (2013b) notes the Spearman's rank-order correlation (Spearman's correlation) will calculate a coefficient identified as r_s. This coefficient will measure the direction and strength of the association between two ordinal variables. Lund & Lund (2013b) identify three assumptions that must be met for use of Spearman's correlation.

Assumption #1: There are two continuous or ordinal variables measured on a continuous or ordinal scale in any combination. This assumption was met by the use of the variable familiarity with reversing alarms in comparison to the respondents' perceived value of reversing alarms using a five point Likert interval scale. The respondent's familiarity with reversing alarms will be measured on the ratio scale, which is continuous and meets the assumption of the test.

Assumption #2: The two variables are paired for observation. This assumption will be met by collecting each respondent's familiarity with reversing alarms allowing for dependent variable data to be paired for each respondent.

Assumption #3: The two variables have a monotonic relationship. This assumption was met by visually inspecting a scatter plot graph produced from SPSS.

Significance

The significance of the Spearman correlation coefficient was determined using a t-test and an alpha level of .05.

Research Question 8

Research Question

The researcher posited there were relationships between the respondents' perceptions of the key benefits of reversing alarms and the types of reversing alarms.

Hypothesis

Null Hypothesis: There is no association between the respondents' perceptions of the key benefits of reversing alarms and the type of alarm.

Alternative Hypothesis: There is a significant association between the respondents' perceptions of the key benefits of reversing alarms and the type of alarm.

Variables

The independent variable was a list of eight perceived benefits of reversing alarms. The dependent variable was the type of alarm selected by the respondent that best describes the perceived benefit.

Statistical Procedures and Assumptions

Van den Berg (2014) identifies the one-sample chi-square is used to test whether a single categorical variable follows a hypothesized population distribution.

Assumption #1: The variables are independent or identically distributed (independent observations). This assumption was met as respondents could only select one categorical variable.

Assumption #2: No expected frequencies are <5. This assumption was met as all frequencies exceeded five with 698 respondents.

Significance

Significance will be determined using an alpha level of .05.

CHAPTER 4

DATA AND ANALYSIS

The purpose of the study was to analyze the perspectives of key stakeholders to determine if the use of broadband sound emitting reversing alarms is perceived to improve safety in the workplace more than traditional tonal sound emitting reversing alarms. The setting of the study included multiple workplaces of one North American steel company that had been using broadband sound emitting reversing alarms for a period exceeding two years. The survey population consisted of steel industry occupational pedestrians, forklift operators, maintenance employees, and location leaders working at varying locations throughout the United States.

The research objectives in this study were designed to be investigated via a survey instrument. The research objectives were examined by analyzing the resulting data using descriptive statistics, Kruskal-Wallis non-parametric test, chi-square test of association, Spearman's rank order correlations and one sample chi-square tests. This chapter includes a summary of the results of these analyses.

Study Population Characteristics

The study population consisted of 1,211 employees of one North American steel company. The population was spread throughout 55 unique locations where broadband sound emitting reversing alarms were in use and had been in use for a period exceeding two years.

Response Rate

The number of surveys distributed in this research study was 1,211. The total number of respondents to the survey was 698 for a response rate of 57.6%.

Descriptive Statistics

Three independent variables of the study were the respondent's occupation, their years of service in their identified occupation, and the number of forklift near miss/injury events the respondents had witnessed. Table 2 provides a summary of the study population's occupations as selected by study participants.

Table 2

Summary of the Study Population's Occupations

Occupation	Frequency	Percent
Occupational Pedestrian	369	52.9
Forklift Operator	249	35.7
Leader	42	6.0
Maintenance	38	5.4

Table 3 below provides a summary of the years of experience in the selected occupation as selected by the respondent; (a) pedestrian, (b) forklift operation, (c) leader or (d) maintenance.

Table 3

Summary of the Study Population's Years of Work Experience

Experience	Frequency	Percent
Less than 3 years	209	29.9
Between 3 and 5 years	125	17.9
Over 5 years	364	52.2

The number of forklift near miss/injury events witnessed by the respondents, while employed, is summarized in Table 4.

Table 4

Summary of the Study Population's Witnessed Forklift Near Miss/Injury Events

Events	Frequency	Percent
None	418	59.8
1 to 2 events	187	26.8
3 to 5 events	43	6.2
Greater than 5 events	50	7.2

Inferential Statistics

Inferential statistics were used to evaluate the research questions posited by the researcher. An alpha level of 0.05 was identified as significance for all tests.

Research Question 1

Kruskal-Wallis Non-Parametric Test

A Kruskal-Wallis non-parametric test was used to determine if a significant difference exists in the perceptions of the benefits of broadband sound emitting reversing alarms when comparing forklift operators, occupational pedestrians, leadership, and maintenance employees. Table 5 identifies the mean rank and sample size for each occupation:

Table 5

Mean Ranks; Perceptions of Broadband Alarm Benefits by Exposure Group

Occupation	N	Mean Rank
Pedestrian	368	349.08
Forklift Operator	249	348.96
Leader	41	382.71
Maintenance	38	302.96

The mean ranks of perceptions were not statistically significantly different between the groups, Kruskal-Wallis H = 3.685, df = 3, p =.298.

Research Question 2

Kruskal-Wallis Non-Parametric Test

A Kruskal-Wallis non-parametric test was used to determine if a significant difference exists in the perceptions of the benefits of tonal sound emitting reversing alarms when comparing forklift operators, occupational pedestrians, leadership, and maintenance employees.

Table 6 identifies the mean rank and sample size for each occupation.

Table 6

Mean Ranks; Perceptions of Tonal Alarm Benefits by Exposure Group

Occupation	N	Mean Rank
Pedestrian	368	361.63
Forklift Operator	249	330.21
Leader	41	355.84
Maintenance	38	286.16

There is a statistically significant difference in the median rankings across groups for the perceptions of the benefits of tonal sound emitting reversing alarms when comparing forklift operators, occupational pedestrians, leadership, and maintenance employees, Kruskal-Wallis H = 8.307, df = 3, p = .040.

Pairwise comparisons were performed using Dunn's procedure with a Bonferroni correction for multiple comparisons. Statistical significance was accepted at the $p < .0083$ level (.05 divided by 6). The post hoc analysis revealed no statistically significant differences among the pairwise comparisons.

Research Question 3

Chi-Square Test of Association

The Chi-Square test of association was used to identify if a significant relationship exists between the survey group's forklift near miss/injury experience and their perception of the benefits of broadband sound emitting reversing alarms. When the analysis was initially conducted, the data did not meet the assumptions of Chi-Square Test of Association as four cells were identified with frequencies less than five. To address this issue, the dependent variable (Benefits of Broadband Reversing Alarms) responses were collapsed from five categories to four, as the responses to 'Not Beneficial' and 'Slightly Beneficial' were combined.

The Chi-Square Test of Association was conducted between forklift near miss/injury experience and their perception of the benefits of broadband sound emitting reversing alarms. All expected cell frequencies were greater than five. There was a statistically significant association between near miss/injury experience and perception of the benefits of broadband reversing alarms, $X^2 = 21.018$, df = 9, p = .013

There is a strong association between near miss/injury experience and respondent's perceptions of the benefits of broadband sound emitting reversing alarms, Cramer's V = 0.100, p = .013. The association is identified as decreases in the near miss injury experience resulted in overall increases in the perceived benefits of broadband reversing alarms.

Research Question 4

Chi-Square Test for Association

The Chi-Square Test of Association was used to determine if a significant relationship exists between the survey group's forklift near miss/injury experience and their perception of the benefits of tonal sound emitting reversing alarms. When the analysis was initially conducted, the data did not meet the assumptions of Chi Square Test for Association as four cells were identified with frequencies less than five. To address this issue, the dependent variable (Benefits of Tonal Reversing Alarms) responses were collapsed from five categories to four, as the responses to 'Not Beneficial' and 'Slightly Beneficial' were combined. The independent variable (Forklift Near Miss/Injury Experience) was also collapsed from four categories to three; "1 to 2 events" and "3 to 5" events were combined. The resulting cross-tabulation analyzed the association between 'events;' (a) none, (b) 1-5 events, and (c) >5 events and 'benefits;' (a) not or only slightly beneficial, (b) somewhat beneficial, (c) moderately beneficial and (d) very beneficial.

After confirming the assumptions for Chi Square Test for Association were met, the association between forklift near miss/injury experience and respondent's perceptions of the benefits of tonal sound emitting reversing alarms was evaluated. There is a statistically significant association between near miss/injury experience and perception of the benefits of tonal reversing alarms, $X^2 = 28.594$, df = 6, p = <.001.

There is a strong association between near miss/injury experience and respondent's perceptions of the benefits of tonal sound emitting reversing alarms, Cramer's V = 0.144, p = <.001. The association is identified as decreases in the near miss injury experience resulted in overall increases in the perceived benefits of broadband reversing alarms.

Research Question 5

Chi-Square Test for Association

The Chi-Square Test of Association was used to identify if a significant relationship exists between the survey group's years' experience in their identified role - (a) pedestrian, (b) forklift operator, (c) leader or (d) maintenance - and their perception of the benefits of broadband sound emitting reversing alarms.

There is no statistically significant association between years of work experience and the perception of the benefits of broadband reversing alarms, $X^2 = 5.194$, df = 6, p = .519.

Research Question 6

Chi-Square Test for Association

The Chi-Square Test of Association was used to identify if a significant relationship exists between the survey group's years of work experience in their identified role; (a) pedestrian, (b) forklift operator, (c) leader or (d) maintenance and their perception of the benefits of tonal sound emitting reversing alarms.

A statistically significant association between years of work experience and perception of the benefits of tonal reversing alarms does not exist, $X^2 = 7.571$, df = 6, p = .271.

Research Question 7

Spearman's Rank-Order Correlation

Spearman's rank-order correlations were run to determine if a significant relationship exists between respondent's familiarity with reversing alarms (broadband and tonal) and respondent's perceived benefits of reversing alarms (broadband or tonal). The data met all of the test assumptions, and the results are presented in Table 7.

Table 7

Spearman's Rho Summary Results

Dependent Variable	Independent Variable	Correlation of Coefficient	Significance
Perception of Broadband Alarm Benefits	Familiarity with Broadband Alarms	$r_s = .327$	$p < .001$
Perception of Broadband Alarm Benefits	Familiarity with Tonal Alarms	$r_s = .087$	$p = .022$
Perception of Tonal Alarm Benefits	Familiarity with Tonal Reversing Alarms	$r_s = .417$	$p < .001$
Perception of Tonal Alarm Benefits	Familiarity with Broadband Alarms	$r_s = .100$	$p = .009$

Spearman's rank-order correlations identified all four relationships to be significant with positive correlations; the greater the familiarity with an alarm resulted in an increase in the perceptions of the benefits of an alarm. A strong correlation exists between respondents' familiarity with tonal alarms and their perceptions of tonal alarm benefits, $r_s = .417$, as well as a strong correlation between the respondents' familiarity with broadband reversing alarms and their perceptions of broadband alarm benefits, $r_s = .327$. Though surprising, a strong correlation also exists between respondents' familiarity with broadband reversing alarms and their increased perceptions of tonal alarm benefits $r_s = .100$. An increase in familiarity with tonal reversing alarms was strongly associated with increased perceptions of broadband alarm benefits $r_s = .087$.

Research Question 8

One Sample Chi-Square Test

The One-Sample Chi-Square was used to determine if a significant relationship exists between the respondents' perceptions of reversing alarm benefits and either type of reversing alarm: (a) broadband or (b) tonal. The key benefits of reversing alarms provided to respondents are identified in Table 8 along with the variable name used for the analysis.

Table 8

Key Benefits of Reversing Alarms

Survey Question	Variable Name
Only heard when the forklift is near.	Audible
I can tell the forklift's direction of travel without seeing it.	Direction
The backup alarm automatically becomes louder or softer depending on other shop noises.	Adjustability
People with hearing loss can hear the alarm.	Loss
I can tell where the forklift is without looking.	Locate
The backup alarm is hard to ignore, I can't tune it out.	Ignore
Shop noise does not hide or interfere with the backup alarm.	Masking
I am not frightened when I suddenly hear the alarm.	Fright

The data met all test assumptions and the results of the analysis are presented in Table 9.

Table 9

One Sample Chi-Square Summary

Variable	Chi-Square Value	N	df	Sig	Observed frequencies Neither Alarm	Observed frequencies Broadband	Observed frequencies Tonal	Observed frequencies Both Alarms
Audible	526.138	698	3	.000	29	395	235	39
Direction	535.203	698	3	.000	32	395	239	32
Adjustability	513.266	698	3	.000	54	395	228	21
Loss	464.831	698	3	.000	60	380	233	25
Locate	581.461	698	3	.000	38	428	190	41
Ignore	507.788	698	3	.000	36	400	217	45
Masking	584.648	698	3	.000	28	418	217	35
Fright	540.361	698	3	.000	42	420	189	47

The One-Sample Chi-Square was again analyzed to validate the significance level of each variable but with the omission of the variable 'neither alarm.' The intent was to determine if the significant chi-square values identified in Table 9 above were influenced due to the majority of respondents selecting broadband alarms and a low number of respondents who selected 'neither alarm.' The results of the additional One-Sample Chi-Square are presented in Table 10.

Table 10

One Sample Chi-Square Summary; omitting variable 'Neither Alarm'

Variable	Chi-Square Value	N	Df	Sig	Observed frequencies Broadband	Observed frequencies Tonal	Observed frequencies Both Alarms
Audible	285.130	669	2	.000	395	235	39
Direction	298.730	666	2	.000	395	239	32
Adjustability	327.040	644	2	.000	395	228	21
Loss	299.213	638	2	.000	380	233	25
Locate	348.282	660	2	.000	428	190	41
Ignore	285.647	662	2	.000	400	217	45
Masking	328.678	670	2	.000	418	217	35
Fright	324.168	656	2	.000	420	189	47

A significant association exists between each listed trait (the independent variable) and broadband reversing alarms as an average of 61% of responses identified broadband alarms as best correlating with the alarm traits listed. In contrast, an average of only 33% of respondents identified tonal reversing alarms as providing the listed traits of reversing alarms.

CHAPTER 5

DISCUSSION

The purpose of this quantitative study was to determine if the use of broadband sound emitting reversing alarms are perceived to improve occupational pedestrian safety more than traditional tonal sound emitting reversing alarms. The independent variables were the employee's classification - (a) occupational pedestrian, (b) forklift operator, (c) leader or (d) maintenance employee - years of experience within the previous classification, their forklift near miss/injury event experience, and their familiarity with both types of reversing alarms (broadband and tonal). The dependent variables studied were the two types of reversing alarms (broadband and tonal), and the respondents' perceptions of both types of reversing alarms. The results of this study provide a perspective based on a quantitative analysis and will serve as the basis for future studies.

This chapter consists of seven sections. The first three sections discuss the study's importance, data review and analysis, followed by each research hypothesis. The next two sections review the study's strengths and limitations, followed by the conclusion and future research opportunities.

Study Importance

Prior to this study, a large scale empirical examination of stakeholder perceptions regarding the potential to improve workplace safety using broadband reversing alarms had not been conducted. Past researchers who have studied broadband reversing alarms explored the relationships of hearing protection and the user's ability to detect the broadband sound emitted from the alarm or investigated the sound propagation of various types of reversing alarms; including broadband (Vaillancourt et al., 2013; Alali, 2011; Nelisse, Laroche, Giguere, Boutin, Vaillancourt, & Laferriere, 2011; Withington, 2000). Withington (2004) documented the results of a United

Kingdom nonempirical comparative study to validate the sound localization benefits of broadband reversing alarms. All findings from previous research omitted respondent perceptions of the benefits of broadband alarms based on stakeholders' experiences with the technology (Vaillancourt et al., 2013). This study was conducted specifically to bridge this gap.

Data Review and Analysis

The researcher collected data via a survey of employees who use or are exposed to forklifts equipped with broadband reversing alarms. In order to obtain the largest potential number of responses, the research provided paper surveys to the population. Unlike online surveys, where software controls can prevent respondents from leaving questions blank or prohibit duplicate responses to a single question, the paper survey presented a challenge for the study in that these issues, though minor, did occur. The first seven questions were Likert ranges and only 13 responses of the 4,886 (or 0.26%) were marked incorrectly. The final eight questions required the respondents to select one alarm type over the other for eight key traits of reversing alarms. This question type, a form of force rank, was the most challenging for respondents, as 361 responses of the 5,584 had selected neither alarm type or both alarm types. Though this created an error rate of 6.46%, it allowed the researcher to account for two additional responses ('neither' or 'both') within the analysis. Even though the question specifically asked respondents to 'select the one alarm type…', the researcher believes some respondents chose to leave the question blank as opposed to being forced to pick one over the other, whereas other respondents who could not choose, or actually believed both alarm types fit the listed trait, marked both options.

Surveys were distributed to employees of one company in manufacturing facilities located in twenty-five states. As respondents only selected their job title, the researcher is not able to quantify response rates based on facility name or address. In retrospect, this information could have been beneficial within the study design for determining the significance of geography (northeast, pacific North West, the south, etc.) on respondent perceptions of reversing alarms.

Research Hypotheses

The following summarizes the research hypotheses and results.

The researcher posited there were significant differences in the perceptions of the benefits of broadband sound emitting reversing alarms when comparing forklift operators, occupational pedestrians, maintenance employees and leadership.

Research Hypotheses #1

Test results indicated no statistically significant differences between the groups regarding their perception of the benefits of broadband reversing alarms (Kruskal-Wallis H=3.685, df = 3, p=.298). This is most likely explained by all employees having similar perceptions regarding the benefits of broadband alarms due to the structured implementation process of the studied organization including a pilot study, alarm installation instructions, employee trainings, etc.

Research Hypotheses #2

The researcher posited there were significant differences in the perceptions of the benefits of tonal sound emitting reversing alarms when comparing forklift operators, occupational pedestrians, maintenance employees, and leadership.

Test results indicated a statistically significant difference in the median rankings across groups regarding the perceptions of the benefits of tonal reversing alarms when comparing forklift operators, occupational pedestrians, maintenance employees and leadership (Kruskal-Wallis H = 8.307. df = 3, p = .040). However, the pairwise comparisons performed using Dunn’s procedure with a Bonferroni correction for multiple comparisons revealed no statistically significant differences among the pairwise combinations. This is most likely due to the differences in the shapes of the distributions.

This may also be explained by the ubiquitous presence of tonal reversing alarms and the study population's exposure to tonal reversing alarms outside of their current employment. Tonal reversing alarms are commonly encountered in public settings, so individuals tend to be conditioned to the "beep-beep" sound which can lend itself to similar perceptions among the group regarding the benefits of tonal reversing alarms.

Research Hypotheses #3

The researcher posited there was a significant relationship between the value respondents place on the benefits of broadband sound emitting reversing alarms and their previous experiences with injury/near miss events resulting from forklift-pedestrian interactions.

Results from the Chi-Square Test of Association identified a statistically significant association between near miss/injury experience and perceptions of the benefits of broadband reversing alarms ($X^2 = 21.018$, df = 9, p = .013). The post hoc test revealed a Cramer's V = 0.100, p = .013 identifying a strong association between near miss/injury experience and respondent perceptions of the benefits of broadband sound emitting reversing alarms. Interestingly, as near miss/injury experience decreases, the perceived benefit of broadband reversing alarms increases. This is most likely due to 59.9% of all respondents identified as having no forklift near miss/injury experiences. In addition, the respondents' lack of experience with near miss/injury events may lead them to conclude the broadband reversing alarm is effective in preventing such events. Conversely, those who have witnessed a forklift/near miss event may have assumed the reversing alarm failed to provide adequate warning thus their decrease in the perceived benefits of broadband alarms.

Research Hypotheses #4

The researcher posited there was a significant relationship between the value respondents place on the benefits of tonal sound emitting reversing alarms and their previous experiences with injury/near miss events resulting from forklift-pedestrian interactions.

Results of the Chi-Square Test of Association identified a statistically significant association between near miss/injury experience and perception of the benefits of tonal reversing alarms ($X^2 = 28.594$, df = 6, p = <.001). The post hoc revealed a Cramer's V = 0.144, p = <.001 identifying a strong association between near miss/injury experience and respondent's perceptions of the benefits of tonal sound emitting reversing alarms. As with research question #3, as near miss/injury experience decreases, the perceived benefits of tonal reversing alarms increase. As before, this is most likely due to 59.9% of all respondents having no forklift near miss/injury experience. Additionally, lack of experience with near miss/injury events may cause them to conclude tonal reversing alarms are effective. Conversely, those who have witnessed a forklift/near miss event may have assumed the reversing alarm failed to provide adequate warning, thus their decreased perception of the benefits of tonal alarms.

Research Hypotheses # 5

The researcher posited there was a significant relationship between the respondents' years of work experience in their identified role and their perceived benefits of broadband sound emitting reversing alarms.

There was no significant relationship between the survey group's years of work experience in their identified role; (a) pedestrian, (b) forklift operator, (c) leader or (d) maintenance employee, and their perception of the benefits of broadband sound emitting reversing alarms ($X^2 = 5.194$, df = 6, p = .519). These results suggest that work experience in the identified role neither improves nor decreases respondent perceptions of the benefits of broadband alarms. Any perceived benefits may be influenced by factors other than experience.

Research Hypotheses # 6

The researcher posited there was a significant relationship between the respondents' years of work experience in their identified role and their perceived benefits of tonal sound emitting reversing alarms.

There was no statistically significant association between years of work experience and perception of the benefits of tonal reversing alarms ($X^2 = 7.571$, df = 6, p = .271). These results also suggest that work experience in the identified role does not affect respondent perceptions of tonal alarm benefits. Any perceived benefits may be influenced by factors other than experience.

Research Hypotheses # 7

The researcher posited there was a significant relationship between the respondents' familiarity with reversing alarms and their perceived benefits of reversing alarms.

The analysis indicated a significant relationship exists between respondent's familiarly with both types of reversing alarms (broadband and tonal) and perceived benefits of both types of reversing alarms. Surprisingly, the analysis identified all four relationships to be significant with positive correlations; the greater the familiarity with either alarm resulted in an increase in the perceptions of the benefits of the alarm: familiarity with tonal alarms and perceptions of tonal alarm benefits, $r_s = .417$; familiarity with broadband reversing alarms and perceptions of broadband alarm benefits, $r_s = .327$; familiarity with broadband reversing alarms and perceptions of tonal alarm benefits $r_s = .100$; and familiarity with tonal reversing alarms and the perceptions of broadband alarm benefits $r_s = .087$.

The expected result was that familiarity with broadband alarms would yield a greater perceived benefit of broadband alarms, and that familiarity with tonal alarms would provide an increased perception of tonal alarm benefits. It was not expected that familiarity with tonal reversing alarms would yield an increase in the respondent's perceptions of the benefits of broadband alarms, and that familiarity with broadband reversing alarms would yield an increase in the respondent's perceptions of the benefits of tonal reversing alarms. Familiarity is assumed to derive from awareness, experience, insight, knowledge, and understanding. If respondents derived their familiarity selection based on these factors, it is expected they would also have increased perceptions of the alarm's benefit. Therefore, increased familiarity with either alarm can be derived from increased awareness, experience, insight, knowledge and understanding which translates to increased perceptions of the benefits of either alarm type.

Research Hypotheses # 8

The researcher posited there were relationships between respondents' perceptions of the commonly assumed reversing alarms benefit traits and the type of reversing alarms. The reversing alarm benefit traits included in the study were:

- only heard when the forklift is near
- I can tell the forklift's direction of travel without seeing it
- the backup alarm becomes louder or softer depending on other shop noises
- people with hearing loss can hear the alarm
- I can tell where the forklift is without looking
- the backup alarm is hard to ignore, I can't tune it out
- shop noise does not hide or interfere with the backup alarm
- I am not frightened when I suddenly hear the alarm

Results from the analysis identify significance for each listed reversing alarm trait (p = <.001). By average, 61% of the responses associated the listed traits with broadband reversing alarms. 33% of the responses associated the traits with tonal reversing alarms. Considering the large response rate, it is clear that the key stakeholders surveyed identify broadband reversing alarms as being superior to tonal reversing alarms when evaluating both alarms based on the provided benefit traits.

Study Strengths

This study had several strengths. This is the only large scale empirical investigation known to the researcher that investigates individuals exposed to both broadband and tonal reversing alarms in an uncontrolled setting. In particular, it is the first known to the researcher to investigate perceptions of the benefits of both alarms types while controlling for employee position, years of experience in the position, and forklift near miss/injury experience.

The researcher was privileged to have knowledge of, and access to, a large number of employees within a single employer, representing various work processes at numerous workplaces throughout the United States. The steel company surveyed had conducted pilot studies to determine the specific alarms best suited for forklifts and had provided guidance to all locations within a documented ‘best practice document’ that identified how broadband reversing alarms should be installed to provide the greatest protection to their occupational pedestrians. Reversing alarms were also listed on the organization’s quarterly safety assessment conducted by the company’s safety professionals to ensure the alarms were of the appropriate model, were mounted per the internal best practice guidance, were functioning properly, and that the backup alarm was only emitting sound when the forklift was in reverse.

Only 6.1% of respondents identified as being unfamiliar with tonal reversing alarms, and only 7.2% identified as being unfamiliar with broadband reversing alarms. The duration of broadband reversing alarm use was superior to other studies, as all sites surveyed had been using broadband reversing alarms on their forklifts for a period exceeding two years. This two-year period is anticipated to have better allowed respondents to rate their perceived benefits and to determine which alarm type best correlated with the reversing alarm benefit traits.

Most studies conducted on broadband reversing alarms focused on quantitative methods in controlled environments, which can yield findings based on conclusions about relationships of cause and effect without in-depth explanation (Vaillancourt et al., 2013). This study sought to gain the perspectives of key stakeholders working in manufacturing environments throughout the United States where broadband reversing alarms had been in use for a period exceeding two years.

The large number and variety of operations included in the research should allow for generalization across other manufacturing companies and may support the benefits of broadband reversing alarms in the prevention of serious injuries and fatalities in many industrial and manufacturing environments.

Study Limitations

Limitations pertain to the methodological weaknesses of the study that can affect the transferability and dependability of the results (Simon, 2011). One limitation of the study was broadband reversing alarm effectiveness was not tested using a cause and effect study design. Experiments were not conducted to establish the effects of either alarm type for serious injury and fatality prevention.

Respondents selected their work experience based on their identified role, but it is not known how many total years the respondents had been in the workforce. For example, an employee may have recently moved into a role where they were trained as a forklift operator and so might have selected less than three years' experience in that role. In actuality, such an employee could have worked in other roles for many years. As the study found no significant relationship between the survey group's years of work experience in their identified role and their perceptions of either alarms benefits, this limitation may have minimal impact on the results.

Another limitation considered by the researcher was not including hearing protection use - or type - as an independent variable in the study. The researcher understood, due to ambient background sound pressure levels, the significant majority of all employees surveyed would utilize hearing protection throughout their work shifts. The researcher had determined that past analysis of broadband reversing alarms has employed various methods to explore the relationships of hearing protection and the user's ability to detect the broadband sound emitted from the alarm and so the need to incorporate hearing protection use within the study was determined unwarranted (Alali, 2011; Withington, 2000).

The potential noise pollution caused by reversing alarms was also not included within the study. Many other studies, including Brammer & Laroche, 2012; Burgess & McCarty, 2009a; Burgess & McCarty, 2009b; Edworthy & Stanton 1995; Holzman, 2011 have explored this cause and effect relationship, and thus additional investigation was not included within this research. Regardless, the researcher believes this concern could have been included within respondents' rating of the benefit of both types of reversing alarms.

Conclusions

The researcher believes this research fills a void in the literature specific to the perceptions of key stakeholders regarding the benefits of broadband reversing alarms, and has also identified numerous opportunities for additional research. The results of this study should be important to safety professionals, to companies that operate mobile equipment, mobile equipment manufacturers, and to organizations considering the implementation of broadband reversing alarms or continued reliance on tonal alarms. There are several key findings identified in this study. First, it is clear that key stakeholders identify broadband reversing alarms as being superior to tonal reversing alarms when evaluating both alarms, based on the common reversing alarm benefit traits.

Another key finding is that increased familiarity with reversing alarms provides for an increased perception regarding the benefits of reversing alarms. In order to have familiarity, one must have knowledge; thus, increased knowledge would yield increased familiarity, which would yield increased perception of the benefits of reversing alarms. Broadband reversing alarms have many strengths, which should be conveyed to individuals working on or around broadband equipped mobile equipment. By educating those exposed, they have increased knowledge of why the alarms are being used and of their benefits. This knowledge, as stated above, yields increased familiarity and can thus lead to increased perceptions regarding the benefits of broadband alarms. Organizations considering the implementation of broadband alarms are advised to meet with the equipment vendor and study available published materials to understand and control for the key success variables of selection, mounting and operation. By conducting a pilot implementation, this will ensure the alarms are correctly selected, installed, and functioning properly. The researcher has determined that proper training of those tasked with installing the alarms is critical. Though not a simple off-the-shelf alarm swap, it takes upfront work to ensure the transition will be successful to ensure additional protection is provided to the exposed occupational pedestrians in the work area.

Recommendations for Future Research

The researcher identifies the following future research opportunities:

1. The researcher posited there was a significant relationship between the respondents' familiarity with reversing alarms and their perceived benefits of reversing alarms, with the expectation that an increased familiarity with broadband alarms would yield increased perception of the broadband alarms benefits; likewise, for tonal. However, the findings identified an increased familiarity with broadband alarms yielded an increase in the perceptions of tonal reversing alarms, while an increase in familiarity with tonal alarms yielded an increase in the perceptions of broadband reversing alarm benefits. Additional exploration of this finding, including what respondents identify as factors that influence 'familiarity,' would assist in understanding the aforementioned relationships.
2. The analysis identified a strong association between near miss/injury experience and the respondent perceptions of the benefits of reversing alarms. The association was identified as a decrease in near miss/injury experience results in an increase in the perceived benefits of broadband reversing alarms. Additional exploration could provide significant insight into this finding, and could also reveal why increases in near miss/injury experience results in decreased perceptions of the benefits of reversing alarms.
3. For every two backover fatalities that occur, there are five forward motion 'run over' fatalities (BLS, 2016). In an effort to protect occupational pedestrians from forward motion fatalities, broadband reversing alarms can also be utilized for forward motion. In

this situation, the forklift, or other type of mobile equipment, is equipped with two broadband alarms, one forward facing and one rear facing. The forward alarm only sounds during forward motion and the rear facing alarm is only activated during reverse motion. An empirical analysis to assess the perceptions of key stakeholders regarding the benefits of using broadband sound emitting alarms for forward motion would be very insightful and could potentially be a significant addition to this body of knowledge.

4. Another (independent) variable to include in a future study would be to factor in the environment in which the forklift, or other mobile equipment, is being used. Do the perceptions of the benefits differ for the stakeholders if the equipment is always indoors, always outdoors, or a combined use indoors and outdoors?
5. Much has been written regarding the ability to hear reversing alarms, with and without hearing protection, while utilizing participants with normal hearing. The manufacturers of broadband reversing alarms tout their ability to be heard by individuals with certain hearing impairments (Brigade Electronics, 2009). The opportunity to include an identified population with known and documented frequency loss would be insightful. The perceptions of this group regarding the benefits of both broadband and tonal alarms could yield key information for decision makers considering their implementation.
6. A qualitative case study to generate in-depth explanations related to the findings of this study could be very insightful. Through interviews, more could be determined regarding influences that impact alarm familiarity and perceptions of benefits, as well as the identification of barriers involved in adopting the broadband alarm technology. Rogers (2003) identifies a diffusion of innovations theory, which explains how and why a new technology spreads within a specific organization. This diffusion of innovations theory

could be used as the framework to assess why companies have made the proactive decision to implement broadband reversing alarms, why broadband reversing alarms were adopted, and whether their use has been sustained.

7. The use or lack of use of backup alarms is typically referenced in OSHA accident investigations (2016). OSHA's identification of the type of reversing alarm (broadband or tonal) in evidence would be insightful for future researchers to evaluate the alarm type in use and, potentially, their effectiveness.

References

Abel, S. M., & Hay, V. H. (1996). Sound localization. The interaction of aging, hearing loss and hearing protection. *Scandinavian Audiology*, *25*(1), 3-12.

Alali, K. A. (2011). *Azimuthal localization and detection of vehicular backup alarms under electronic and non-electronic hearing protection devices in noisy and quiet environments.* (Doctoral Dissertation, Virginia Polytechnic Institute and State University, Blacksburg). Retrieved from http://proxy-iup.klnpa.org/login?url=http://search. proquest.com.proxy-iup.klnpa.org/docview/1033506873?accountid=11652

Alali, K. A. & Casali, J. G. (2011). The challenge of localizing vehicle backup alarms: Effects of passive and electronic hearing protectors, ambient noise level, and backup alarm spectral content. *Noise and Health*, *13*(51), 99-112. doi:10.4103/1463-1741.77202

American Road & Transportation Builders Association. (2017). *Preventing backovers*. Retrieved from https://www.workzonesafety.org/data-resources/runover-backover/

Army Corps of Engineers (2009). Workplace safety: backup alarms. *Seattle District Safety Gram*. Retrieved from http://www.fqs-inc.com/sites/default/files/pdf/Army%20Corp%20Eng.%20-%20ENGSafety%20Gram%20Backup%20Alarms%20doc%20_3_.pdf

Atherley, G. C., & Noble, W. G. (1970). Effect of ear-defenders (ear-muffs) on the localization of sound. *British Journal of Industrial Medicine*, (3). 260.

Berger, E. H. (2003). Hearing protection devices. In E.H. Berger (Ed.), *The Noise Manual* (5th ed., pp. 379-454). Fairfax, VA: American Industrial Hygiene Association.

Berger, E. H., & Casali, J. G. (1997). Hearing protection devices. In M. J. Crocker (Ed.), *Encyclopedia of Acoustics* (1st ed., Vol. 2, pp. 967-981). Hoboken, NJ: John Wiley and Sons.

Bliss, J. P., Gilson, R. D., & Deaton, J. E. (1995). Human probability matching behavior in response to alarms of varying reliability. *Ergonomics*, *38*(11), 2300-2312. doi:10.1080/00140139508925269

Bolia, R. S., D'Angelo, W. R., Mishler, P. J., & Morris, L. J. (2001). Effects of hearing protectors on auditory localization in azimuth and elevation. *Human Factors*, *43*(1), 122-128. doi:10.1518/001872001775992499

Brammer, A. J., & Laroche, C. (2012). Noise and communication: A three-year update. *Noise and Health*, *14*(61), 281-286. doi:10.4103/1463-1741.104894

Brigade Electronics (2009). *Broadband sound; The safer and noiseless* back-up alarm*. South Darenth, Kent, UK: Author.

Bureau of Labor Statistics. (2016). *Occupational injuries and illnesses and fatal injuries profiles*. Retrieved from https://data.bls.gov/gqt/ProfileCharacteristics

Burgess, M., & McCarty, M. (2009a). *Effectiveness of non-tonal audible movement warning alarms for construction sites. Proceedings of Acoustics*. Retrieved from https://www.researchgate.net/publication/267226723_Effectiveness_of_non-tonal_audible_movement_warning_alarms_for_construction_sites

Burgess, M., & McCarty, M. (2009). *Review of alternatives to "beeper" alarms for construction equipment* (AVU-0129). Retrieved from University of New South Wales website: http://epa.nsw.gov.au/resources/noise/beeperalarm.pdf

Burt, J. L., Bartolome, D. S., Burdette, D. W., & Comstock, J. J. (1995). A psychophysiological evaluation of the perceived urgency of auditory warning signals. *Ergonomics*, *38*(11), 2327. Doi:10.1080/00140139508925271

Casali, J. G., & Alali, K. A. (2010*). Etymotic EB-15 (Lo Position) BlastPLG evaluation: Backup alarm localization appended experiment*. Retrieved from http://www.etymotic.com/downloads/dl/file/id/51/product/77/backup_alarm_localization_research.pdf

Casali, J. G., Robinson, G. S., Dabney, E. C., & Gauger, D. (2004). Effect of electronic ANR and conventional hearing protectors on vehicle backup alarm detection in noise. *Human Factors*, *46*(1), 1-10.

Casali, J. G., & Wright, W. H. (1995). Do amplitude-sensitive hearing protectors improve detectability of vehicle back-up alarms in noise? *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *39*(15), 994-998.

Catchpole, K. R., McKeown, J. D., & Withington, D. J. (2004). Localizable auditory warning pulses. *Ergonomics*, *47*(7), 748-771. doi:10.1080/00140130310001629739

Choe, S., Leite, F., Seedah, D., & Caldas, C. (2014). Evaluation of sensing technology for the prevention of backover accidents in construction work zones. *Journal of information technology in construction*, *19*, 1-19.

City of New York. (2007). *Notice of adoption of rules for citywide construction noise mitigation*. Retrieved from http://www.nyc.gov/html/dep/pdf/noise_constr_rule.pdf

Das, S. (2015). Occupational fatalities in the construction sector: A medico-legal viewpoint. *Medico-Legal Journal*, *83*(2), 93-97.

Department of Labor (n.d.): *Injury and fatality cost calculation worksheet*. https://arlweb.msha.gov/s&hinfo/costgenerator/costgenerator.htm

Edworthy, J., Loxley, S., & Dennis, I. (1991). Improving auditory warning design: Relationships between warning sound parameters and perceived urgency. *Human Factors*, *33*, 205-231.

Fan, W., Choe, S., & Leite, F. (2014). Prevention of back over fatalities in highway work zones: A synthesis of current practices and recommendations. *International Journal of Transportation Science and Technology, 3*(4), 311-338.

Federal Highway Administration. (2008*). Effective noise control during nighttime construction - FHWA work zone*. Retrieved from https://ops.fhwa.dot.gov/wz/workshops/accessible /Schexnayder_paper.htm

Field, A. P. (2009). *Discovering statistics using SPSS: (and sex and drugs and rock 'n' roll)*. (3rd ed., ISM (London, England)). Thousand Oaks: SAGE Publications.

Flannagan, C. A., Kiefer, R. J., Bao, S., LeBlanc, D. J., & Geisler, S. P. (2014). Reduction of backing crashes by production rear vision camera systems. *Journal of Ergonomics*, *3*(8), 1-4.

Gallagher, V. (2003). Backup alarms. Preventing injuries caused by reversing vehicles. *Professional Safety, 48*, 28-32.

Guillaume, A., Pellieux, L., Chastres, V., & Drake, C. (2003). Judging the urgency of nonvocal auditory warning signals: Perceptual and cognitive processes. *Journal Of Experimental Psychology*: Applied, *9*(3), 196-212.

Haas, E., & Edworthy, J. (1996). Designing urgency into auditory warnings using pitch, speed and loudness. *Computing & Control Engineering Journal*, 7(4), 193-198.

Hartmann, W. M. (1999). How we localize sound. *Physics Today*, *52*(11), 24-29.

Heckman, G. M., Kim, R. S., Khan, F. S., Bare, C., & Yamaguchi, G. T. (2011). Auditory localization of backup alarms: The effects of alarm mounting location. *SAE Technical Paper Series*. doi:10.4271/2011-01-0086

Hearing Health Matters. (2015). *Interaural time and intensity differences* [Image]. Retrieved from http://hearinghealthmatters.org/waynesworld/files/2015/03/ITD-and-IID-a.jpg

Hellier, E., & Edworthy, J. (1989). Quantifying the perceived urgency of auditory warnings. *Canadian Acoustics*, *17*, 3-11.

Holzman, D. C. (2011). Vehicle motion alarms: Necessity, noise pollution, or both? *Environmental Health Perspectives*, *119*(1), A30-A33.

Homer, J. P. (2008). Audible warning devices used in the mining industry. *Proceeding of the NOISE-CON 2008 conference*. Dearborn, MI: The Institute of Noise Control Engineering.

ISO. (2010). *Earth-moving machinery -- Machine-mounted audible travel alarms and forward horns -- Test methods and performance criteria*. Retrieved from https://www.iso.org/obp/ui/#iso:std:iso:9533:ed-2:v1:en

ISO. (2003). *Ergonomics -- Danger signals for public and work areas -- Auditory danger signals.* Retrieved from https://www.iso.org/obp/ui/#iso:std:iso:7731:ed-2:v1:en

Kazan, E. E. (2013). *Analysis of fatal and nonfatal accidents involving earthmoving equipment operators and on-foot workers* (Doctoral dissertation, Wayne State University, Detroit). Retrieved from http://proxy-iup.klnpa.org/login?url=http:// search.proquest.com.proxy-iup.klnpa.org/docview/1442894054?accountid=11652

Kothari, C. R. (2004). *Research methodology: methods & techniques*. (2nd rev. ed.)New Delhi: New Age International (P).

Lancaster, J., Alali, K., & Casali, J. (2007). Interaction of vehicle speed and auditory detection of backup alarms AKA: Can the construction worker get out of the way? *Proceedings Of The Human Factors And Ergonomics Society Annual Meeting*, *51*(20), 1421-1424.

Laroche, C. (2006). Investigation of an accident involving the reverse alarm on a heavy vehicle. *Proceedings IEA 2006*. Maastricht, Netherlands: International Ergonomics Association 16th World Congress.

Laroche, C., & Lefebvre, L. (1998). Determination of optimal acoustic features for reverse alarms: Field measurements and the design of a sound propagation model. *Ergonomics*, 41(8), 1203-1221. doi:10.1080/001401398186487.

Laroche, C., Ross, M. J., Lefebvre, L., & Larocque, R. (1993). Sound propagation of reverse alarms used on heavy vehicles. Canadian Acoustics, *21*(3), 29-30.

Lingard, H., Cooke, T., & Gharaie, E. (2013). The how and why of plant-related fatalities in the Australian construction industry. *Engineering, Construction and Architectural Management*, *20*(4), 365-380. doi:10.1108/ECAM-09-2011-0085.

Lovejoy, S. M. (2008). *Determination of backup alarm masked threshold in construction noise* (Master's thesis, Virginia Polytechnic Institute and State University, Blacksburg). Retrieved from https://vtechworks.lib.vt.edu/handle/10919/33419

Lund, A., & Lund, M. (2013a). *Kruskal-Wallis H Test in SPSS Statistics | Procedure, output and interpretation of the output using a relevant example*. Retrieved from https://statistics.laerd.com/spss-tutorials/kruskal-wallis-h-test-using-spss-statistics.php

Lund, A., & Lund, M. (2013b). *Spearman's Correlation in SPSS Statistics | Procedure, output and interpretation of the output using a relevant example*. Retrieved from https://statistics.laerd.com/premium/spss/sroc/spearmans-rank-order-correlation-in-spss.php

Morgan, H. (2007). *Back-up safety alarms minimize environmental noise exposure and focus warning signals*. Retrieved from https://www.researchgate.net/publication/293780107_Backup_safety_alarms_minimize_environmental_noise_exposure_and_focus_warning_signals

Morgan, H. P., & Peppin, R. J. (2008). "Noiseless" and safer back-up alarms. *Proceeding of the NOISE-CON 2008 conference*. Dearborn, MI: The Institute of Noise Control Engineering.

Morse, J. M. (2015). Critical analysis of strategies for determining rigor in qualitative inquiry. *Qualitative Health Research*, *25*(9), 1212-1222.

Murray, M., Mills, J., & Moore, P. (1998). *Reversing accidents in UK transport fleets 1996-1997*. University of Huddersfield Report.

National Academy of Engineering. (2010). *Technology for a quieter America*. Washington, DC: National Academies Press.

Nelisse, H., Laroche, C., Giguere, C., Boutin, J., Vaillancourt, V., & Laferriere, P. (2011). *Comparison of different vehicle backup-alarm types with regards to worker safety*. Retrieved from https://www.researchgate.net/publication/283558564_Comparison_of_different_vehicle_backup-alarm_types_with_regards_to_worker_safety

NIOSH. (2004). *The worker health chartbook 2004*. Retrieved from http://www.cdc.gov/niosh/docs/2004-146/

Noble, W., Murray, N., & Waugh, R. (1990). *The effect of various hearing protectors on sound localization in the horizontal and vertical planes*. American Industrial Hygiene Association Journal, *51*(7), 370-377.

Noble, W. G., & Russell, G. (1972). Theoretical and practical implications of the effects of hearing protection devices on localization ability. *Acta Oto-Laryngologica*, *74*(1-6), 29. doi:10.3109/00016487209128419

Occupational Safety and Health Administration (n.d.). *Construction industry - preventing backovers*. Retrieved from https://www.osha.gov/doc/topics/backover/index.html

Occupational Safety and Health Administration. (2015). *Electric power generation, transmission, and distribution*. - 1910.269. Retrieved from https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=standards&p_id=9868

Occupational Safety and Health Administration. (2016, August 18). *Inspection detail*. Retrieved from https://www.osha.gov/pls/imis/establishment.inspection_detail?id=1170895.015

Occupational Safety & Health Administration. (2011, July 1). *Motor vehicles -1926.601*. Retrieved from https://www.gpo.gov/fdsys/pkg/CFR-2011-title29-vol8/pdf/CFR-2011-title29-vol8-sec1926-601.pdf

Occupational Safety and Health Administration. (2012, March 28). *OSHA seeks comments on how to prevent worker injuries and deaths from reinforcing concrete activities and vehicle backovers*. Retrieved from https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=NEWS_RELEASES&p_id=22071

Occupational Safety and Health Administration. (2012, November 26). *Standard interpretation; Powered industrial trucks equipped with flashing lights and/or back-up beepers.* Retrieved from https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=INTERPRETATIONS&p_id=29009

Preece, J., Rogers, Y., & Sharp, H. (2005). Interaction design: Beyond human-computer interaction. *Information Design Journal Document Design*, *13*(3), 264-266.

Purswell, J. P., & Purswell, J. L. (2001). The effectiveness of audible backup alarms as indicated by OSHA accident investigation records. In A.C. Bittner, P.C. Champney, & S.J. Morrissey (Ed.), *Advances in Occupational Ergonomics and Safety* (pp. 444-450). Amsterdam, Netherlands: IOS Press.

Redel, K. (2012). *Forklift backup alarms*. Retrieved from http://www.forkliftamerica.com/blog/forklift-backup-alarms

Robinson, G. S., & Casali, J. G. (1995). Audibility of reverse alarms under hearing protectors for normal and hearing-impaired listeners. *Ergonomics*, *38*(11), 2281-2299. doi:10.1080/00140139508925268.

SAE J994. (2014). *Alarm—Backup—Electric laboratory performance testing* (J994_201409). Washington, DC: SAE International.

Simon, M. (2011). Assumptions, limitations and delimitations. *Dissertation and scholarly research: Recipes for success*. Seattle, WA: Dissertation Success, LLC.

Simpson, D. B., Bolia, R. S., McKinley, R. L., & Brungart, D. S. (2005). The impact of hearing protection on sound localization and orienting behavior. *Human Factors*, *47*, 188-198.

Stanton, N. A., & Edworthy, J. (1999). *Human factors in auditory warnings*. Aldershot, England: Ashgate Publishing.

Swanson, R. B. (2004, September 27). *Alternatives to common back-up alarms on construction motor vehicles; use of other effective technology or observers/signal persons*. Retrieved from https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table= INTERPRETATIONS&p_id=24943

Triton Signal USA. (2016). *Corporate Profile*. Retrieved from http://www.triton-signal.com/corporate-profile.html

United States Patent Office. (1975, September 9). *United States patent: 3905016*. Retrieved from http://patft.uspto.gov/netacgi/nph-Parser?Sect2=PTO1&Sect2=HITOFF&p= 1&u=%2Fnetahtml%2 FPTO%2Fsearch-bool.html&r=1&f=G&l=50&d= PALL&RefSrch=yes&Query=PN%2F3905016

United States Patent Office. (2005, April 26). *United States patent: 6885295*. Retrieved from fhttp://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO1&Sect2=HITOFF&d=PALL &p=1&u=%2Fnetahtml%2FPTO%2Fsrchnum.htm&r=1&f=G&l=50&s1=6885295.PN.& OS=PN/6885295&RS=PN/6885295

Vaillancourt, V., Nelisse, H., Laroche, C., Giguere, C., Boutin, J., & Laferriere, P. (2014). *Safety of workers behind heavy vehicles – assessment of three types of reverse alarms*. Retrieved from IRRST website: http://www.irsst.qc.ca/media/documents/PubIRSST/R-833.pdf

Vaillancourt, V., Nélisse, H., Laroche, C., Giguère, C., Boutin, J., & Laferrière, P. (2013). Comparison of sound propagation and perception of three types of backup alarms with regards to worker safety. *Noise and Health*, *15*(67), 420.

Van den Berg, R. G. (2014, September 16). *SPSS one sample chi-square test*. Retrieved from https://www.spss-tutorials.com/spss-one-sample-chi-square-test/

Vannette, D. (2015, June 24). *Rating or Ranking: Choosing the Best Question Type for Your Data*. Retrieved from https://www.qualtrics.com/blog/rating-or-ranking-choosing-the-best-question-type-for-your-data

Washington State Department of Labor & Industries. (2009, July). *Road construction work zone safety. Protecting workers on road and highway construction sites*. Retrieved from http://wisha-training.lni.wa.gov/training/presentations/ WorkZoneSafetyRoad Construction.ppt

Withington, D. (2000). The use of directional sound to improve the safety of auditory warnings. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *44*(22), 726-729. doi:10.1177/154193120004402260

Withington, D. (2004). Reversing goes broadband. *Quarry Management*, *31*(5), 27-34.

Wood, J. M., Marszalek, R., Lacherez, P., & Tyrrell, R. A. (2014). Configuring retroreflective markings to enhance the night-time conspicuity of road workers. *Accident Analysis & Prevention*, *70*, 209-214.

Yin, R. K. (2014). *Case study research: Design and methods (*Fifth ed.). Thousand Oaks, CA: Sage Publications.

Zaiontz, C. (2016). *Kruskal-Wallis; Omnibus test*. Retrieved from http://www.real-statistics.com/one-way-analysis-of-variance-anova/kruskal-wallis-test/

Zeyher, A. (2007). Separation is a positive: good planning can prevent run-over accidents; technology can help too. *Roads and Bridges*, *45*(9), 52-55.

Appendix A

Survey Instrument

Circle one answer for questions 1 – 7.

1) When around forklifts, I am mostly a:

1.1 Pedestrian (daily exposures to forklift traffic)

1.2 Forklift Operator (daily operation)

1.3 Leader (supervisor or higher)

1.4 Maintenance

2) Thinking of your last answer, how many years have you been in this role?

2.1 Less than 3 years.

2.2 Between 3 and 5 years.

2.3 Over 5 years.

3) How many forklift near miss/injury events have you witnessed while employed?

3.1 None

3.2 1 to 2 events

3.3 3 to 5 events

3.4 Greater than 5 events

There are two common types of backup alarms:

- **High-pitch, beep-beep (tonal) alarms**
- **Quack-Quack (broadband) alarms**

4) How familiar are you with the broadband (quack quack) backup alarms?

4.1 Not at all familiar

4.2 Slightly familiar

4.3 Somewhat familiar

4.4 Moderately familiar

4.5 Extremely familiar

5) How familiar are you with the tonal (beep beep) backup alarms?

5.1 Not at all familiar

5.2 Slightly familiar

5.3 Somewhat familiar

5.4 Moderately familiar

5.5 Extremely familiar

6) Rate the benefit of broadband (quack quack) backup alarms in preventing pedestrian accidents:

6.1 Not beneficial at all

6.2 Slightly beneficial

6.3 Somewhat beneficial

6.4 Moderately beneficial

6.5 Very beneficial

7) Rate the benefit of tonal (beep beep) backup alarms in preventing pedestrian accidents:

7.1 Not beneficial at all

7.2 Slightly beneficial

7.3 Somewhat beneficial

7.4 Moderately beneficial

7.5 Very beneficial

Select (☑) the one alarm that best matches each statement below:

Check ✓ Broadband **OR** Tonal
for each question below:

Alarm Benefits:	**Broadband** Quack Quack	**Tonal** Beep Beep
8) Only heard when a forklift is near		
9) I can tell the forklift's direction of travel without seeing it		
10) The backup alarm automatically becomes louder or softer depending on other shop noises		
11) People with hearing loss can hear the backup alarm		
12) I can tell where the forklift is without looking		
13) The backup alarm is hard to ignore. I can't tune it out		
14) Shop noise does not hide or interfere with the backup alarm		
15) I am not frightened when I suddenly hear the backup alarm		

Appendix B

Survey Cover Letter

(distributed on IUP letterhead)

Research: Perceptions of Key Stakeholders Regarding the Utilization of Locatable Sound for the Prevention of Occupational Pedestrian Injuries and Fatalities

Dear Gerdau Employee:

Purpose of the study: You are being asked to take part in a research study to obtain your perceptions regarding the use of broadband sound (quack quack) backup alarms and their potential to prevent serious injuries and fatalities in a manufacturing environment. You are invited to take part in this research because your employer utilizes broadband sound reversing alarms and you are exposed to the alarms during your work day. The questions within the survey are related to your personal experiences and opinions with broadband sound emitting backup alarms.

This research is being conducted by Rick Kilpatrick, a doctoral candidate studying in the Department of Safety Sciences, Indiana University of Pennsylvania. All information obtained will be used for dissertation research, and may be published in scientific journals or presented at meetings and conferences.

Completion of this survey is estimated to require less than 10 minutes. Please ensure the survey is completed within the next fourteen days and returned to the researcher within the self addressed stamped envelope provided.

Risks and benefits: I do not anticipate any risks to you participating in this study. Also, by participating, there are no benefits to you. Reversing mobile equipment poses additional risk to occupational pedestrians and we hope to learn more about the impacts of broadband reversing alarms on these individuals.

Compensation: You will receive no compensation for participating in the study.

Your answers will be confidential. The records of this study will be kept private. If you do participate, understand that information obtained is maintained confidentially and neither your name nor your employer's name will be included within any published results. No one other than the principal researcher will know who participated in the study and no one, including the researcher, will know the opinions provided by individual participants. Research records will be kept in a locked file and only the researcher will have access to the records. All records will be destroyed three years after the research is completed.

THIS PROJECT HAS BEEN APPROVED BY THE INDIANA UNIVERSITY OF PENNSYLVANIA INSTITUTIONAL REVIEW BOARD FOR THE PROTECTION OF HUMAN SUBJECTS (PHONE 724.357.7730).

Taking part is voluntary: Your participation is completely voluntary. If you decide to participate, please know that all surveys will be confidential.

Your consent to participate in the survey is implied if you return your completed survey to the researcher. If you have any questions, please contact me, or my dissertation Chairperson, at the email or mailing addresses below.

Sincerely,
Richard S. Kilpatrick
Doctoral Student and Principle Investigator

Dissertation Chairperson

Dr. Tracey Cekada
Associate Professor
Safety Sciences Department
125 Johnson Hall
Indiana University of Pennsylvania
Indiana, PA 15705
Phone: 724-357-3272
Email: cekadat@iup.edu

Principle Investigator

Richard S. Kilpatrick
Doctoral Student, Safety Sciences
213 Pier Point Drive
Connelly Springs, NC 28612
Phone: 865 719-2169
Email: pqft@iup.edu

THIS PROJECT HAS BEEN APPROVED BY THE INDIANA UNIVERSITY OF PENNSYLVANIA INSTITUTIONAL REVIEW BOARD FOR THE PROTECTION OF HUMAN SUBJECTS (PHONE 724.357.7730).

Appendix C

Survey Follow-Up Cover Letter

(distributed on IUP letterhead)

Research: Perceptions of Key Stakeholders Regarding the Utilization of Locatable Sound for the Prevention of Occupational Pedestrian Injuries and Fatalities

Dear Gerdau Employee:

Purpose of the study: This is a reminder that you are being asked to take part in a research study to obtain your perceptions regarding the use of broadband sound (quack quack) backup alarms and their potential to prevent serious injuries and fatalities in a manufacturing environment. You are invited to take part in this research because your employer utilizes broadband sound reversing alarms and you are exposed to the alarms during your work day. The questions within the survey are related to your personal experiences and opinions with broadband sound emitting backup alarms.

This research is being conducted by Rick Kilpatrick, a doctoral candidate studying in the Department of Safety Sciences, Indiana University of Pennsylvania. All information obtained will be used for dissertation research, and may be published in scientific journals or presented at meetings and conferences.

Completion of this survey is estimated to require less than 10 minutes. Please ensure the survey is completed within the next seven days and returned to the researcher within the self addressed stamped envelope provided.

Risks and benefits: I do not anticipate any risks to you participating in this study. Also, by participating, there are no benefits to you. Reversing mobile equipment poses additional risk to occupational pedestrians and we hope to learn more about the impacts of broadband reversing alarms on these individuals.

Compensation: You will receive no compensation for participating in the study.

Your answers will be confidential. The records of this study will be kept private. If you do participate, understand that information obtained is maintained confidentially and neither your name nor your employer's name will be included within any published results. No one other than the principal researcher will know who participated in the study and no one, including the researcher, will know the opinions provided by individual participants. Research records will be kept in a locked file and only the researcher will have access to the records. All records will be destroyed three years after the research is completed.

THIS PROJECT HAS BEEN APPROVED BY THE INDIANA UNIVERSITY OF PENNSYLVANIA INSTITUTIONAL REVIEW BOARD FOR THE PROTECTION OF HUMAN SUBJECTS (PHONE 724.357.7730).

Taking part is voluntary: Your participation is completely voluntary. If you decide to participate, please know that all surveys will be confidential.

Your consent to participate in the survey is implied if you return your completed survey to the researcher. If you have any questions, please contact me, or my dissertation Chairperson, at the email or mailing addresses below.

Sincerely,
Richard S. Kilpatrick
Doctoral Student and Principle Investigator

Dissertation Chairperson

Dr. Tracey Cekada
Associate Professor
Safety Sciences Department
125 Johnson Hall
Indiana University of Pennsylvania
Indiana, PA 15705
Phone: 724-357-3272
Email: cekadat@iup.edu

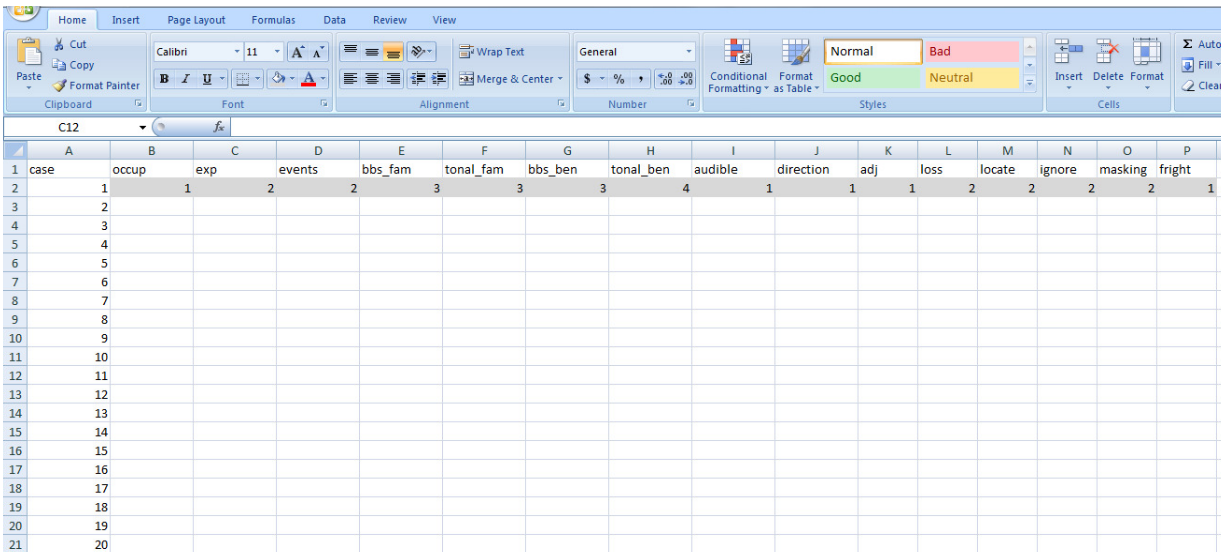
Principle Investigator

Richard S. Kilpatrick
Doctoral Student, Safety Sciences
213 Pier Point Drive
Connelly Springs, NC 28612
Phone: 865 719-2169
Email: pqft@iup.edu

THIS PROJECT HAS BEEN APPROVED BY THE INDIANA UNIVERSITY OF PENNSYLVANIA INSTITUTIONAL REVIEW BOARD FOR THE PROTECTION OF HUMAN SUBJECTS (PHONE 724.357.7730).

Appendix D

Survey Data Entry Worksheet



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	case	occup	exp	events	bbs_fam	tonal_fam	bbs_ben	tonal_ben	audible	direction	adj	loss	locate	ignore	masking	fright
2	1	1	2	2	3	3	3	4	1	1	1	2	2	2	2	1
3	2															
4	3															
5	4															
6	5															
7	6															
8	7															
9	8															
10	9															
11	10															
12	11															
13	12															
14	13															
15	14															
16	15															
17	16															
18	17															
19	18															
20	19															
21	20															

Appendix E

IRB Approval Letter

Indiana University of Pennsylvania
www.iup.edu

Institutional Review Board for the Protection of Human Subjects
School of Graduate Studies and Research
Stright Hall, Room 113
210 South Tenth Street
Indiana, Pennsylvania 15705-1048

P 724-357-7730
F 724-357-2715
irb-research@iup.edu
www.iup.edu/irb

April 6, 2017

Dear Richard Shawn Kilpatrick:

Your proposed research project, "Perceptions of Key Stakeholders Regarding the Utilization of Locatable Sound for the Prevention of Occupational Pedestrian Injuries and Fatalities," (Log No. 17-120) has been reviewed by the IRB and is approved. In accordance with 45CFR46.101 and IUP Policy, your project is exempt from continuing review. This approval does not supersede or obviate compliance with any other University requirements, including, but not limited to, enrollment, degree completion deadlines, topic approval, and conduct of university-affiliated activities.

<u>You should read this entire letter, as it contains important information about conducting your study</u>.

Now that your project has been approved by the IRB, there are elements of the Federal Regulations to which you must attend. IUP adheres to these regulations strictly:

1. You must conduct your study <u>exactly as it was approved</u> by the IRB.
2. <u>Any additions or changes</u> in procedures <u>must</u> be approved by the IRB <u>before</u> they are implemented.
3. You must notify the IRB promptly of <u>any</u> events that affect the safety or well-being of subjects.
4. You must notify the IRB promptly of any modifications of your study or other responses that are necessitated by any events reported in items 2 or 3.

The IRB may review or audit your project at random *or* for cause. In accordance with IUP Policy and Federal Regulation (45CFR46.113), the Board may suspend or terminate your project if your project has not been conducted as approved or if other difficulties are detected

Although your human subjects review process is complete, the School of Graduate Studies and Research requires submission and approval of a Research Topic Approval Form (RTAF) before you can begin your research. If you have not yet submitted your RTAF, the form can be found at http://www.iup.edu/page.aspx?id=91683 .

While not under the purview of the IRB, researchers are responsible for adhering to US copyright law when using existing scales, survey items, or other works in the conduct of research. Information regarding copyright law and compliance at IUP, including links to sample permission request letters, can be found at http://www.iup.edu/page.aspx?id=165526.

I wish you success as you pursue this important endeavor.

Sincerely,

Jennifer Roberts, Ph.D.
Chairperson, Institutional Review Board for the Protection of Human Subjects
Professor of Criminology

JLR:jeb

Cc: Dr. Tracey Cekada, Dissertation Advisor
Ms. Brenda Boal, Secretary