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Key stakeholder perceptions of select forward mobile equipment pedestrian alarms

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ABSTRACT

Introduction: Workplace interactions between pedestrians and industrial mobile equipment often result in workplace fatalities. Employers are normally required to provide pedestrian warning alarms for reverse travel only, though forward travel accidents may comprise as much as 50% of all related fatalities. *Method:* This study was conducted to compare unique configurations of common pedestrian warning alarms to determine whether worker role or equipment configuration were significant independent variables of worker perception of forward alarm irritation and excellent warning characteristics, and whether forward alarms are perceived to be important. *Results:* While worker role was not found to be a significant variable, select alarm configuration properties were found to be significant. *Practical Applications:* The results of the study suggest that a combination of broadband and light emitting diode devices are preferential to all other configurations studied.

1. Introduction

The Bureau of Labor Statistics (BLS) reports 313 worker fatalities in 2017 from pedestrian contact with mobile and materials handling equipment, or 7.2% of all workplace fatalities (excluding violence and other injuries by persons or animals; BLS, 2019). Surprisingly, there are limited regulatory requirements imposed on U. S. employers to install or maintain devices on mobile equipment to automatically warn pedestrians, and where found, the regulatory requirements are exclusively specified for reverse direction travel (Cornell, 2018; OSHA, 2018a, 2018b). Forward direction equipment versus pedestrian incidents may comprise as much as 50% of all non-roadway fatalities (BLS, 2018). Also surprising is the paucity of research illuminating options and the possible benefits of alarms for warning pedestrians when equipment is operated in a forward direction. Very limited research was found to evaluate worker perception of alarm excellence or effectiveness (quick and correct pedestrian response), irritation or nuisance (tuning-out phenomena), or importance of common forward equipment direction alarms.

1.1. Common alarm types

Three mobile equipment pedestrian warning systems are frequently encountered in industrial workplaces: tonal, broadband, and visual alarms. Audible tonal alarms are most commonly encountered and are highly recognizable due to their distinctive high-frequency (beep, beep) sounds (Redel, 2012). Tonal alarms for reverse direction travel alone are not proven to be adequately effective as pedestrian fatalities persist despite their long-term use (Purswell & Purswell, 2001). Several factors provide insight to the concerns associated with tonal alarms. Worker use of hearing protection or worker hearing loss at high frequencies can lower the likelihood of the worker from hearing the tonal alarm or hearing it loudly enough (Army Corps of Engineers, 2009; Brammer & Laroche, 2012; Vaillancourt et al., 2014). Additional concerns with tonal alarms are worker fatigue i.e., pedestrians may 'tune-out' an alarm because of its omnipresence, or workers may defeat alarms experienced to be annoying (Withington, 2000; Brammer & Laroche, 2012). A startle reaction can occur from 30 dB sound level increases in 0.5 s (ISO, 2015). Tonal alarms are criticized for causing a momentary startle reaction resulting in the pedestrian remaining still rather than moving away from the hazard (Valls-Solé et al., 1995).

More recently, broadband audible alarm technology provides an alternative to traditional tonal alarms. Broadband alarms simultaneously emit an audible alert using three parts of the sound fre-

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quency spectrum, each providing its unique benefit (Brigade Electronics, 2009). Two separate studies provide evidence that broadband alarms may be both technically superior to tonal alarms and worker preferred (Vaillancourt et al., 2014; Kilpatrick, 2017). Broadband alarms uniquely permit pedestrians to identify the hazard's location and direction of travel utilizing: (1) low frequencies to allow the human brain to determine the differing sound arrival times at each ear; (2) mid frequencies to allow the brain to determine the differences in sound intensity at each ear, thus which ear is closest to the sound; and (3) higher frequencies to allow the brain to determine the sound's location whether it be the front of rear of the head (Brigade Electronics, 2009). Additionally, broadband alarm sound dissipates quickly as distance increases, a benefit not shared with tonal alarms (Brigade Electronics, 2009).

In addition to auditory alarms, visual warning systems offer a distinct choice over the traditional audible alarm paradigm. Visual warning systems can incorporate, for example, blue-light emitting diodes (LEDs) that shine onto the ground ahead of the equipment's travel path (Stone, 2016). Improvement in mobile equipment detection speed is a significant advantage of visual warning systems. One study reported a 75% improvement to average speed of equipment detection by pedestrians when a visual alarm system was incorporated to the mobile equipment studied (Sammarco, Gallagher, Mayton, & Srednicki, 2012). However, the operation of mobile equipment in day-light conditions may be a significant limiting factor to the utility of these devices.

1.2. Worker role & hazard exposure

Worker role and hazard exposure has been extensively studied and found to be significant independent variables influencing risk perception (Arezes & Miguel, 2005; Flin, Mearns, Gordon & Fleming, 1996; Hallowell, 2010; Stewart-Taylor & Cherrie, 1998). Related, it is observed that three worker groups are primarily exposed to mobile equipment alarms: mobile equipment operators, pedestrians, and those who both operate mobile equipment and interact with mobile equipment as pedestrians. It is posited that those who primarily operate mobile equipment may perceive alarm excellence, irritation, and importance differently than their counterparts who experience them less frequently. There also may reasonably be differences in perception based on whether one is at risk (i.e., the pedestrian or the person who works as both a pedestrian and equipment operator) versus the operator who is not at significant risk of harm.

1.3. Worker perceptions

Perception surveys are commonly used for research within the social sciences, including safety sciences (Hallowell, 2010; Kim, An, Kim, & Yoon, 2007; O'Toole & Nalbone, 2011; Rundmo, 2000). Janicak and Zreiqat recently observed that perception surveys "play a vital role in safety program management" and "have been used to assess employee perceptions of the safety culture, safety climate, perceptions of the leading indicator effectiveness, incident risk perceptions and measurement of safety management system components (2019, p. 32)." O'Toole and Nalbone summarize that worker perception measures can predict behavior probability and may even be predictive of safety results (2011); and, especially relevant to this study, Kilpatrick (2017) analyzed the relationship between worker perception of locatable sound for pedestrian injury and fatality prevention. The perception survey format, therefore, has been adopted herein. Specifically, understanding operator and pedestrian perceptions of mobile equipment forward alarms based upon role and alarm configuration are posited to be basic determinants of their successful adoption. The worker is the ultimate customer and clearly the most important one. Their preferences may be rooted in factors other than technical characteristics and that must be understood. Such factors are further posited to be alarm: excellence (pedestrian correct and quick response); irritation (not subject to being defeated or disregarded); and importance (recognition of forward alarm value and necessity). This may seem a strained argument as all effective alarms are necessarily irritating.

The importance of alarm nuisance as a study factor can be derived by recognizing that mobile equipment pedestrian alarms are frequently activated and, thus, are normally experienced in the industrial work environment by equipment operators and workplace pedestrians. This is in stark contrast to a fire alarm, for example, that is infrequently experienced and which must be extremely irritating for greatest effect to, for example, awake sleeping hotel guests or continuously disrupt mental focus upon all other activities but escape; note that a combination of sound and light is normally incorporated. An effective fire alarm would not be well tolerated as a mobile equipment alarm, however, as it would increase workplace risk by creating a physical health hazard through hearing loss and permanent confusion that impairs effective operational decision making. There must be a balance. The goal, therefore, is for mobile equipment alarm configurations to have excellent warning properties and irritating enough, but not more so. The relationship between these characteristics therefore becomes a compelling area of study.

2. Methods

All experimental procedures were reviewed and approved by the Murray State University Institutional Review Board (IRB).

2.1. Study population

A multi-worksite international manufacturer provided the worker and industrial mobile equipment population required to carry out this study. The organization's related challenges and goals are believed to be generalizable to many non-roadway workplaces and, so, provides an important study population opportunity. The organization utilizes industrial lift trucks in many of its facilities. The equipment is principally utilized indoors where worker pedestrians conduct their tasks in proximity to lift-truck travel (i.e., there is the possibility of pedestrian vs. mobile equipment interaction). A population of 35 industrial lift trucks underwent installation of the three alarms being studied in accordance with the configurations outlined in Table 1.

The four unique forward alarm configurations were derived using the following reductive logic. First, redundant audible alarm combinations were eliminated due to the expected confusion and possible hazard creation that scenario could yield. Secondly, visual warning device only configurations were eliminated. This was done to provide a level of worker protection at least as greater than or better than historically afforded by rear direction audible alarms. Note: pre-existing rear travel activated pedestrian alarms were not altered for legal and ethical reasons.

Table 1
Response group alarm configuration assignments.

Response Group	# of Lift Trucks	% of N	Forward Alarm Configuration*
1	5	18%	Tonal & LED
2	7	26%	Tonal & LED
3	13	30%	Broadband
4	10	26%	Broadband & LED
Total	35	100%	

The researchers randomly assigned the identified configurations to the populations groups provided by the sponsoring organization. The primary goal was to achieve an approximate study representation of 25% for each alarm configuration. This goal was not 100% achievable due to varying numbers of lift-trucks deployed within groups for operational reasons. A practical decision was made to outfit all lift-trucks with the same alarm configuration within each response group, even when this resulted in greater than 25% study proportion relative to other response groups. This was done to minimize worker confusion and other factors potentially confounding to study results. Similarly, the four response groups were intentionally isolated from one-another by utilizing geographically separate plant populations. The population was instructed that a study was being done to determine their perceptions of various alarm configurations, but not of the study's specific hypotheses.

The lift trucks were Toyota model 8FGCU25. The model is equipped with a four-cylinder overhead valve propane fueled engines and has a lifting capacity rated at 5,000 pounds. Approximately 476 individuals who operate or normally work in proximity to industrial lift trucks were provided a survey instrument three months after alarm installation.

2.2. Survey instrument

An original survey instrument was developed for the conduct of this study, and accepted standards for survey design were incorporated (Harvard University, 2016). The survey was administered in the workplace using a paper and pencil format. It consisted of five items designed to elicit the data from the surveyed population needed to answer the study's research questions. All respondents were asked to respond to all items.

Item 1. Indicate the response group to which you are assigned.
Item 2. Which of the following best reflects your current job position?

a. Forklift operator (normal assignment, i.e., greater than 50% of routine workday).
b. All other personnel (pedestrian worker walking or standing near fork-lift operation, including supervision, managers and maintenance personnel).
c. Both (subgroups a and b).

Item 3. The forward motion warning system currently installed on the lift truck(s) in your work area provides an excellent level of pedestrian warning:

1 = Strongly Disagree
2 = Disagree
3 = Neither agree or disagree
4 = Agree
5 = Strongly agree

Item 4. The forward motion warning system currently installed on the lift truck(s) in your work area is unnecessarily irritating or a nuisance for effectively warning pedestrians: (same Likert Scale as provided in Item 3).

Item 5. The law requires the use of fork-lift reverse motion warning system but not a forward motion warning system. How important is a forward motion warning device to ensure pedestrian protection?

1 = Not at all important
2 = Low importance
3 = Neither unimportant or important
4 = Important
5 = Very important

The categorical independent variables identified were: role (mobile equipment operator; pedestrian; or both mobile equipment operator and pedestrian); and alarm configuration (T & LED; T; BB; and BB & LED). The dependent variables were worker perception of alarm configuration excellence, alarm configuration irritation or nuisance and importance of forward direction mobile equipment pedestrian warning devices. Likert scales were utilized for non-demographic items because their efficacy has been well demonstrated in social sciences and attitude research projects; five-point scales were utilized to increase discriminating power and internal reliability (Croasmun & Ostrom, 2011).

The survey instrument was designed to answer the following research questions:

Worker Role:

1. Does role determine if there are significant differences in respondents' perception of the newly installed mobile equipment alarm excellent warning properties; level of irritation or nuisance; and importance?
2. Is role a significant predictor of worker perception of forward mobile equipment pedestrian warning alarm excellence?
3. Is role a significant predictor of worker perception of forward mobile equipment pedestrian warning alarm irritation?
4. Is role a significant predictor of worker perception of forward mobile equipment pedestrian warning alarm importance?

Alarm configuration:

5. Does alarm configuration assignment determine if there are significant differences in respondents' perception of the newly installed mobile equipment alarm excellent warning properties; level of irritation or nuisance; and importance?
6. Is forward alarm configuration a significant predictor of worker perception of forward mobile equipment pedestrian warning alarm excellence?
7. Is alarm configuration a significant predictor of worker perception of forward mobile equipment pedestrian warning alarm irritation?
8. Is alarm configuration a significant predictor of worker perception of forward mobile equipment pedestrian warning alarm importance?

2.3. Data collection and analysis

The survey instrument was distributed and collected under the direct supervision of one of the investigators. All responses were anonymous. Resources required to enter survey data, conduct statistical analyses and reporting were overseen by the project's principal investigator. Descriptive statistics were analyzed using Microsoft Excel 2016. The IBM Statistical Package for the Social Sciences (SPSS) version 21.0 or greater was used for all other statistical tests. Statistical significance was determined using an Alpha level of 0.05 unless otherwise specified.

2.3.1. Statistical analyses

A Kruskal-Wallis H test was used to evaluate research questions one and five that regarded respondent perceptions of the specific new alarm configuration provided. It is a rank-based nonparametric test for identifying differences between two or more groups, and where significant differences are found (Lund & Lund, 2019a). All requisite assumptions were applied.

A Cumulative Odds Ordinal Logistic Regression with proportional odds test was used for question two through four and six through eight that regarded respondent perceptions not specific to the new alarm configuration provided. This test is used to predict an ordinal dependent variable using one or more independent variables (Lund & Lund, 2019b). All requisite assumptions were applied.

Descriptive statistics additionally complement the results, where useful.

2.3.2. Study assumptions

1. The instrument used in this study includes scales that accurately measure participant perceptions.
2. The workers selected for participation in this study and who responded to the survey are representative of the sponsoring organization's workers.

3. Results

Table 2 illustrates there were 345 collected responses, or approximately 72% of the study population. The lowest contribution of any sub-group as a proportion of its population was 66%. It also portrays the survey respondents by job role. The majority of study participants identify as 'pedestrians' (57%), followed by 'both' lift-truck driver and pedestrian (26%) and lift-truck operator (15%). The sample size provides 95% confidence level and 2.8 confidence interval; the average confidence level across all groups is 5.8. Approximately 35 lift-trucks were utilized for normal plant operations throughout the three-month study period, January through March, 2019. Questions not answered or incorrectly submitted or unable to be understood were coded '99.'

3.1. Research question 1 results

A Kruskal-Wallis H test was conducted to determine if there were job role differences in respondent perception of mobile equipment alarm properties: excellent warning; level of irritation or nuisance; and the importance of forward alarms. None of the responses were statistically significant. Excellent Warning: $\chi^2(2) = 3.411$, $p = 0.182$; Irritating: $\chi^2(2) = 1.416$, $p = 0.493$; and Importance: $\chi^2(2) = 1.066$, $p = 0.587$.

3.2. Research question 2 results

A cumulative odds ordinal logistic regression with proportional odds was conducted to determine if job role was a significant predictor of worker perception that forward alarms provide an excellent level of pedestrian warning. The assumption of proportional odds test was met, as assessed by a full likelihood ratio test comparing the fit of the proportional odds location model to a model with varying location parameters, $\chi^2(6) = 2.909$, $p = 0.820$. However, the final model did not statistically significantly predict the dependent variable over and above the intercept-only model, $\chi^2(2) = 3.434$, $p = 0.180$.

3.3. Research question 3 results

A cumulative odds ordinal logistic regression with proportional odds was conducted to determine if job role was a significant predictor of worker perception of forward alarm irritation. The assumption of proportional odds test was met, as assessed by a full likelihood ratio test comparing the fit of the proportional odds location model to a model with varying location parameters, $\chi^2(6) = 3.431$, $p = 0.753$. However, the final model did not statistically significantly predict the dependent variable over and above the intercept-only model, $\chi^2(2) = 1.399$, $p = 0.497$.

3.4. Research question 4 results

A cumulative odds ordinal logistic regression with proportional odds was conducted to determine if job role was a significant predictor of worker perception that forward motion alarm importance. The assumption of proportional odds test was met, as assessed by a full likelihood ratio test comparing the fit of the proportional odds location model to a model with varying location parameters, $\chi^2(6) = 8.783$, $p = 0.186$. However, the final model did not statistically significantly predict the dependent variable over and above the intercept-only model, $\chi^2(2) = 1.046$, $p = 0.593$.

3.5. Research question 5 results

3.5.1. Alarm excellence

As shown in Table 3, total respondent agreement (agree, strongly agree) the new forward alarm configurations provided excellent pedestrian warning was 56%. The greatest area of agreement was reflected by the BB & LED configuration group (80%) followed by T (69%) and T & LED (49%). BB and LED equipped industrial lift trucks strongly agree ratings were approximately 11% greater than the next highest rated configuration.

A Kruskal-Wallis H test was conducted to determine whether alarm configuration results in significant differences in respondents' perception of the newly installed mobile equipment alarm excellent warning properties: $\chi^2(3) = 68.499$, $p < 0.001$. A difference in scores was found between the following groups: T & LED (Mean Rank = 161.74) and BB & LED (Mean Rank = 224.14) ($p = 0.001$); BB (Mean Rank = 118.94) and T & LED (Mean Rank = 161.74) ($p = 0.005$); BB (Mean Rank = 118.94) and T (Mean Rank = 197.79) ($p < 0.001$); and BB (Mean Rank = 118.94) and BB & LED (Mean Rank = 224.14) ($p < 0.001$).

3.5.2. Alarm irritation

As shown in Table 4, total respondent agreement (agree, strongly agree) that forward alarm configurations were irritating was 66%. The BB configuration reflected an 88% agreement response (i.e., the alarm was irritating). The least irritating configuration (disagree and strongly disagree) was the combination of T & LED (33%), followed by the combination of broadband and LED (24%), and T (20%).

A Kruskal-Wallis H test was conducted to determine whether alarm configuration results in significant differences in respondents' perception of the newly installed mobile equipment alarm irritation properties: $\chi^2(3) = 77.481$, $p < 0.001$. A difference in scores was found between the following groups: T & LED (Mean Rank = 115.56) and T (Mean Rank = 165.71) ($p = 0.002$); T & LED (Mean Rank = 115.56) and BB (Mean Rank = 232.87) ($p = <0.001$); T (Mean Rank 165.71) and BB (Mean Rank = 232.87) ($p < 0.001$);

Table 2
Study participation proportions by response group and worker role.

Alarm Configuration	N	% of N	# Responses	% Response	Operator	Pedestrian	Both	99*	Total
T & LED	84	18%	57	68%	8	31	18	0	57
T	122	26%	93	76%	12	44	36	1	93
BB	144	30%	112	78%	25	61	23	3	112
BB & LED	126	26%	83	66%	7	59	14	3	83
Total	476	100%	345	72%	52	195	91	7	345

Table 3
Survey responses – alarm excellence.

Likert Response: Strongly Disagree (1) to Strongly Agree (5)							
Alarm Configuration	1	2	3	4	5	99*	n
T & LED	4%	26%	21%	47%	2%	0%	100%
Tonal	2%	18%	10%	57%	12%	1%	100%
BB	37%	18%	14%	24%	7%	0%	100%
BB & LED	2%	5%	13%	58%	22%	0%	100%
Total	14%	16%	14%	45%	11%	0%	100%

*Unable to answer.

Table 4
Survey responses – alarm irritation.

Likert Response: Strongly Disagree (1) to Strongly Agree (5)							
Alarm Configuration	1	2	3	4	5	99*	n
T & LED	4%	30%	28%	26%	12%	0%	100%
Tonal	3%	17%	14%	30%	34%	1%	100%
BB	5%	5%	2%	11%	77%	0%	100%
BB & LED	6%	18%	18%	41%	17%	0%	100%
Total	5%	16%	13%	26%	40%	0%	100%

*Unable to answer.

and BB & LED (Mean Rank = 137.61) and BB (Mean Rank = 232.87) ($p < 0.001$).

3.5.3. Alarm importance

Total respondent agreement (agree and strongly agree) of the importance of providing forward motion pedestrian alarms on mobile equipment was 58%, as shown in Table 5. The strongest level of agreement was represented by the BB & LED configuration group (84%), followed by T group (60%) and the BB only group (43%). The highest level of disagreement (disagree and strongly disagree) was found in T & LED group (47%).

A Kruskal-Wallis H test was conducted to determine whether alarm configuration results in significant differences in respondents' perception of the newly installed mobile equipment alarm importance properties: $\chi^2(3) = 36.309$, $p < 0.001$. A difference in scores was found between the following groups: T & LED (Mean Rank = 138.19) and BB & LED (Mean Rank = 217.18) ($p < 0.001$); T (Mean Rank = 169.46) and BB & LED (Mean Rank = 217.18) ($p = 0.001$); and BB (Mean Rank = 145.08) and BB & LED (Mean Rank = 217.18) ($p < 0.001$).

3.6. Research question 6 results

A cumulative odds ordinal logistic regression with proportional odds was conducted to determine if forward alarm configuration was a significant predictor of worker perception of forward mobile equipment pedestrian warning alarm excellence. The assumption of proportional odds test was not met, as assessed by a full likelihood ratio test comparing the fit of the proportional odds location model to a model with varying location parameters, $\chi^2(9) = 33.608$, $p < 0.001$.

3.7. Research question 7 results

A cumulative odds ordinal logistic regression with proportional odds was conducted to determine if forward alarm configuration was a significant predictor of worker perception of forward mobile equipment pedestrian warning alarm irritation. The assumption of proportional odds was not met, as assessed by a full likelihood ratio test comparing the fit of the proportional odds location model to a model with varying location parameters, $\chi^2(9) = 55.471$, $p = <0.001$.

3.8. Research question 8 results

A cumulative odds ordinal logistic regression with proportional odds was conducted to determine if forward alarm configuration was a significant predictor of worker perception of forward mobile equipment pedestrian warning alarm importance. The assumption of proportional odds test was met, as assessed by a full likelihood ratio test comparing the fit of the proportional odds location model to a model with varying location parameters, $\chi^2(9) = 10.757$, $p = 0.293$. The final model statistically significantly predicted the dependent variable over and above the intercept-only model,

Table 5
Survey responses – alarm importance.

Likert Response: Not at All (1) to Extremely Important (5)							
Alarm Configuration	1	2	3	4	5	99*	n
T & LED	12%	35%	7%	35%	7%	4%	100%
Tonal	9%	23%	3%	49%	11%	5%	100%
BB	15%	30%	9%	30%	13%	2%	100%
BB & LED	2%	8%	5%	57%	27%	1%	100%
Total	10%	24%	6%	43%	15%	3%	100%

*Unable to answer.

$\chi^2(3) = 37.822$, $p = <0.001$. Forward alarm configuration was a significant predictor of worker perception that forward alarms are important, Wald $\chi^2(3) = 34.912$, $p = <0.001$.

Parameter estimates are provided in Table 6.

3.9. Summary of statistical tests excluding descriptive statistics

Table 7 summarize the purpose and results of the applied statistical tests, excluding descriptive statistics.

4. Conclusions

The following discussion is provided with the following limitations:

1. The sample used in this study is limited to those working for the sponsoring organization during the period of study.
2. The study is limited to the assessment of worker role and alarm configuration in terms of alarm characteristics of: warning excellence; irritation; and forward alarm importance.
3. The study relies upon data derived from respondents' self-reported perceptions.
4. Post exposure intervention measures (only) were used.
5. The possible relationships between worker perceptions and related incident frequency or severity were not studied.

4.1. Significance of worker role

None of the statistical tests administered identified worker role as a significant factor. Mobile equipment operators, pedestrians and those working in the capacity of both equipment operator and pedestrian do not perceive forward alarm excellence, irritation, or importance significantly differently. Organizations, therefore, may not need to consider worker role as a meaningful determinant when deciding either to install forward mobile equipment alarms or for selection of alarm type. Stakeholder input to both decisions is, of course, generally appropriate and considered a best practice by the researchers. Mobile equipment operators, pedestrians, and those in hybrid roles certainly should be considered important process stakeholders. It is also possible there may be some situations not considered in this study in which alarm systems and worker role deserve special consideration.

4.2. Excellence vs. irritation & forward alarm configuration

Descriptive statistics identify the most preferred configurations for alarm warning excellence to be BB & LED, T and T & LED and BB, respectively. The least favored configurations for alarm irritation were BB, T and BB & LED, and T & LED, respectively. The Kruskal-Wallis H Test confirms the differences identified via the descriptive statistics were, indeed, statistically significant, and specifically for numerous interactions between T, BB & LED and BB configurations. Forward alarm configuration significantly influences respondent perception of alarm excellence and irritation. The combination of agreement scores for all configurations for both alarm excellence and irritation are found in Fig. 1.

As with modern fire alarm systems commonly deployed in office, hotel, and other public spaces, this study observes that a combination of sound and light may be optimal in the industrial environment, specifically, BB & LED. Interesting to the researchers is the presence of a LED alarm in concert with either a T or BB alarm coincides with lower irritation estimates than T or BB alone. The reason for this is not obvious and is offered as an area of inquiry upon which future research may expound.

4.3. Forward alarm importance

This study broadly affirms the perceived importance of forward motion mobile equipment alarms, as a majority (57%) of all respondents agreed (agreed and strongly agreed) and only 34% reported some level of disagreement. It is clear that respondents desire more than is legally required in this respect. Descriptive statistics further identify the respondent group most agreeing that forward motion alarms are important to be the BB & LED group. The next group, T, was approximately 23% lower than the BB & LED group. The Kruskal-Wallis H Test performed confirms the differences identified via the descriptive statistics are, indeed, statistically significant, and specifically for numerous interactions between T, BB & LED and BB configurations. Forward alarm configuration significantly influences respondent perception of alarm importance.

It also was found that mobile equipment alarm configuration was a statistically significant predictor of respondents perceiving forward alarms as being important. Most notable is that the odds of this being true are 2.7 times greater for BB & LED configurations vs. T; 4.7 times greater for BB & LED vs. BB; and 5.2 times greater for BB & LED vs. T & LED. A combination of BB & LED devices should therefore be preferentially considered when selecting forward motion alarm configurations for industrial mobile equipment. An

Table 6
Parameter estimates.

Odds of workers considering forward alarms to be important				
Odds of workers considering forward alarms to be important when assigned:	Odd (Multiplier >)	Workers Assigned:	95% Confidence interval	Statistical significance
BB	0.366	BB & LED	0.206, 0.651	Wald χ^2 (1) = 29.172, $p < 0.001$
T & LED	0.527	T	0.284, 0.979	Wald χ^2 (1) = 4.116, $p = 0.042$
BB & LED	2.7341	T	0.536, 4.863	Wald χ^2 (1) = 11.704, $p = 0.001$
T	1.709	BB	1.019, 2.866	Wald χ^2 (1) = 4.123, $p = 0.042$
BB & LED	4.671	BB	2.670, 8.172	Wald χ^2 (1) = 29.172, $p < 0.001$
BB & LED	5.189	T & LED	2.6924, 10.000	Wald χ^2 (1) = 24.189, $p < 0.001$
BB	1.898	T & LED	1.022, 3.525	Wald χ^2 (1) = 4.116, $p = 0.042$

Table 7
Summary of statistical tests.

RQ	Focus	Statistical Test	Worker Perception of Forward Alarm Properties	Statistically Significant Result?
1	Worker Role	Kruskal-Wallis H*	Excellent	No
			Irritation	No
			Importance	No
2	Worker Role	Ordinal Logistic Regression**	Excellent	No
3	Worker Role	Ordinal Logistic Regression**	Irritation	No
4	Worker Role	Ordinal Logistic Regression**	Importance	No
5	Alarm Configuration	Kruskal-Wallis H*	Excellent	**Yes**
			Irritation	**Yes**
			Importance	**Yes**
6	Alarm Configuration	Ordinal Logistic Regression**	Excellent	No
7	Alarm Configuration	Ordinal Logistic Regression**	Irritation	No
8	Alarm Configuration	Ordinal Logistic Regression**	Importance	**Yes**

*Whether statistical differences between two or more groups and, if so, where the difference are found.
**Whether one or more independent variables are predictive of dependent variables and, if so, the relative predictive strength.

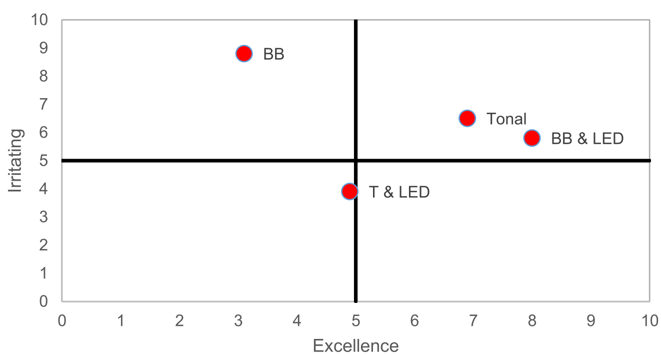

Fig. 1. Sum of forward alarm configuration respondent 'agreement,' i.e., "agree" and "strongly agree" ratings as a proportion of all ratings found in Tables 4 & 5, alarm excellence and irritation characteristics, respectively. One is least; 10 is most.

assessment of local workplace conditions is requisite, however, should mobile equipment be operated in day-light conditions in which pedestrians might be present, for example, in which LEDs may be contraindicated.

4.4. Practical applications

It is known that pedestrians are harmed by forward traveling industrial equipment, and perhaps as often as from reverse direction travel. Of course, elimination of the possibility of worker interaction with mobile equipment would be most preventive and, thus, preferred. But this goal remains elusive in many environments. Tragically, workers are harmed by contact with mobile equipment, the imminent and direct threat of which they are unaware. Thus, it becomes increasingly irrational for employers to maintain control strategies more rooted in habit than science. Improvement has been demonstrated to be possible.

This research has identified the ideal configuration for forward direction pedestrian alarms in indoor settings for the population studied. Importantly, tonal alarms were not found to be preferred. Given their ubiquitous use as reverse direction alarms (literally the world over), continued predominant reliance upon them should be challenged. This is especially true when their technical deficiencies are acknowledged in comparison to available competing alarms demonstrating equal or better warning properties, and now found preferable by workers. Better warning systems are available than tonal alarms that are well tolerated, and even preferred, by workers.

Further research is recommended to understand whether these results are broadly generalizable to:

1. All work environments (e.g., underground mining, road and building construction)
2. Rear direction alarms configurations,
3. All mobile and materials handling equipment types (e.g., overhead or mobile cranes, front-end loaders, haul-trucks, backhoes), and
4. Environments with complicating factors such as competing noise, dusty conditions, and highly variable lighting

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