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Original Article

Automated Systems and Trust: Mineworkers' Trust in Proximity Detection Systems for Mobile Machines

LaTasha R. Swanson*, Jennica L. Bellanca, Justin Helton

Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, Pittsburgh Mining Research Division, USA

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A B S T R A C T

Background: Collisions involving workers and mobile machines continue to be a major concern in underground coal mines. Over the last 30 years, these collisions have resulted in numerous injuries and fatalities. Recently, the Mine Safety and Health Administration (MSHA) proposed a rule that would require mines to equip mobile machines with proximity detection systems (PDSs) (systems designed for automated collision avoidance). Even though this regulation has not been enacted, some mines have installed PDSs on their scoops and hauling machines. However, early implementation of PDSs has introduced a variety of safety concerns. Past findings show that workers' trust can affect technology integration and influence unsafe use of automated technologies.

Methods: Using a mixed-methods approach, the present study explores the effect that factors such as mine of employment, age, experience, and system type have on workers' trust in PDSs for mobile machines. The study also explores how workers are trained on PDSs and how this training influences trust.

Results: The study resulted in three major findings. First, the mine of employment had a significant influence on workers' trust in mobile PDSs. Second, hands-on and classroom training was the most common types of training. Finally, over 70% of workers are trained on the system by the mine compared with 36% trained by the system manufacturer.

Conclusion: The influence of workers' mine of employment on trust in PDSs may indicate that practitioners and researchers may need to give the organizational and physical characteristics of each mine careful consideration to ensure safe integration of automated systems.

1. Introduction

Mobile machines such as coal hauling machines and scoops are vital to underground coal mining operations. These machines are used to support a variety of standard job tasks including coal and equipment transport. Even though mobile machines offer a number of benefits, working with and alongside these machines places mineworkers at risk of being struck, pinned, or crushed. According to the Mine Safety and Health Administration (MSHA), over 200 pinning, crushing, and striking accidents and injuries occurred in underground coal mines between 1984 and 2014, and 42 of these injuries were fatal [1].

Proximity detection is an automated technology that helps to prevent machine–human collisions by alerting workers and slowing or disabling the machine when someone is in an established warning or hazard zone. In an effort to prevent injuries and fatalities involving mobile machines, MSHA proposed a rule that would require mine operators to equip mobile hauling machines and scoops in underground coal mines with proximity detection systems (PDSs) [1]. MSHA estimated that the proposed rule would prevent approximately 70 injuries and 15 fatalities over the next 10 years [1]. Even though this rule has not been enacted, some underground coal mines have installed PDSs on all or some of their mobile machines. In June of 2015, MSHA [1] reported that 155 of 2,116 coal hauling machines and scoops had been equipped with PDSs. Despite this progress, some mine operators have found integrating PDSs into the underground coal mine environment to be challenging [2].

Though PDSs have the potential to prevent injuries and fatalities, a number of issues need to be addressed to ensure safe integration of the technology. Some of these issues have included implementation costs, technical integration, system interference,

* Corresponding author. 626 Cochrans Mill Road, Pittsburgh, PA 15236, USA.
E-mail address: lswanson@cdc.gov (L.R. Swanson).

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and nuisance trips (e.g., unwarranted warning alerts or machine shutdowns) [2]. As with other automated systems, some of these issues may involve or influence human operator use (e.g., activation or disengagement), misuse (e.g., overreliance), disuse (e.g., neglect or underutilization), and abuse (e.g., design or implementation without regard for consequences) [3].

Many of the issues that adversely affect mine operators' ability to safely and effectively integrate PDSs into underground mines may be influenced by mineworkers' trust in PDSs. Trust can be greatly influenced by system performance [4]. For example, poor system performance and false alarms can lead to distrust [3]. For many years, researchers have recognized that automation will only be used to the extent to which it can be trusted [4]. In fact, trust has been shown to be a causal factor in workers' use of automation [5]. Past findings suggest that ensuring that workers maintain the correct level of trust in automation is essential to maintain safety and productivity [6]. Insufficient levels of trust can result in disuse [3], which could have a negative impact on workers' safety. A 2017 fatality illustrates the tragic consequences of automation disuse. In this case, a miner was fatally injured after activating the override function of a PDS installed on a continuous mining machine [7]. Similar to a lack of trust, excessive trust or overreliance could also result in an increased risk for injury. For example, workers who demonstrate an overreliance on a PDS may be at greater risk for injury in situations where the system is unknowingly compromised by electromagnetic interference [8].

Because the primary goal of mobile PDSs is to improve mineworkers' safety, ensuring that workers establish and maintain appropriate levels of trust is critical to PDS integration and use. However, to establish appropriate trust levels, stakeholders must first understand how much workers trust mobile PDSs and identify factors that influence workers' trust. To the authors' knowledge, few studies have investigated mineworkers' trust in PDSs. To address this gap, the current study aims to explore how individual, mine, and training characteristics influence mineworkers' trust in PDSs for mobile machines. In this article, the authors will briefly review literature on trust, summarize the study methods, present the results, and discuss the findings and implications.

Trust has been studied across a variety of disciplines including anthropology, economics, marketing, sociology, psychology, political science, strategic management, and organizational behavior [see [9]]. Even though the concept has been extensively studied, there is still limited consistency across the various definitions [5,10,11]. Past definitions do, however, present three consistent themes. First, trust is subjective. Trust in technology is based on the user's perceptions of functionality [12]. It has been said that the perception of trustworthiness drives behavior—not necessarily trustworthiness itself [4]. Therefore, because trust has been associated with user beliefs and perceptions, individual characteristics may influence a worker's level of trust. Second, trust is based on specific expectations. Several definitions of trust focus on individual or organizational expectations. For example, Ratnasingam and Pavlou [13] described trust as "the subjective probability by which organizations believe that the underlying technology infrastructure is capable of facilitating transactions according to their confident expectations" (p. 316). Specifically for automation, Muir [11] described trust as the "expectation of technical competence" as our intuitive understanding of trusting a machine (p. 1910). Third, trust in technology is influenced by the performance and functionality of that technology. Trust represents the degree to which the user believes that the technology has the necessary attributes to properly function in situations where improper performance could result in adverse consequences [14]. In other words, when new technologies are introduced, individuals are often asked to rely on the technology and accept a certain level of risk and uncertainty relative to the way that the technology will perform. Moreover, Lee and See [15] reconciled 14 of the major definitions of trust into three summary dimensions: purpose, process, and performance.

Additionally, the term *trust* has been closely associated with the term *confidence*. Giddens [16] defined system trust as "having confidence in abstract systems" (p. 680). Dow and Leitch [17] described confidence as being "directly related to a user's belief in the likelihood that a new system will support their specific information needs and lead to the achievement of organizational objectives" (p. 140). Therefore, the terms *trust* and *confidence* will be used synonymously throughout this paper.

For this study, trust in mobile PDSs will be conceptualized as *workers' confidence in the system's ability to prevent collisions while not exposing them to additional risk*. The definition encompasses the subjective nature of the term *trust* by privileging the workers' self-evaluation of confidence. The definition also captures the specific expectation that the system performs its primary function or purpose.

Researchers explored how training, mine of employment, age, experience, and system type influenced workers' trust in mobile PDSs. The following section provides a brief overview of the variables of interest. Additionally, Table 1 lists the research questions and hypotheses used to address each area of interest and the data collection methods. The authors' found conflicting or limited research findings to adequately support the use of hypotheses that

Table 1
Study research questions and hypotheses

Topic	Question	Data collection
Training and trust	**RQ1**: How do workers characterize their training on PDSs for mobile equipment?	Semistructured interview question
	H_1: There are significant differences in trust ratings across the reported training types.	Semistructured interview question responses coded and transformed to binary variables
	H_2: There are significant differences in trust ratings based on who facilitated the training.	
	H_3: There are significant differences in trust ratings for workers who learned through practice compared to workers who did not.	
Mine and trust	**H_4:** There are significant differences in trust ratings across the different mines.	Structured interview question
Age and trust	**H_5:** There are significant differences in trust ratings across the different age groups.	
Experience and trust (Mining experience and PDS experience)	**H_6:** There are significant differences in trust ratings across the different levels of mining experience.	
	H_7: There are significant differences in trust ratings across the different levels of mobile PDS experience.	
System make and trust	**H_8:** There are significant differences in trust ratings across the different system makes.	

PDSs, proximity detection systems.

would predict the nature (i.e., positive or negative) of the variables effect on trust. As a result, researchers followed the recommendations of Cho and Abe [18] and developed non-directional research hypotheses to investigate differences.

Training and Trust. In regards to automation, training has been found to have a positive effect on the users' trust [19]. More engaging types of training have been found to be more effective than others [20]. For example, when compared with other forms of training, individual hands-on training and step-by-step visual guides were found to be more effective at improving learners' confidence in technology use [21]. These findings prompted the authors to develop a research question to explore how mineworkers are trained to use mobile PDSs.

Research Question 1: How do workers characterize their training on PDSs for mobile equipment?

In addition, authors predicted that training would have a significant influence on mineworkers' trust in mobile PDSs. Moreover, the authors investigated the influence of training types (e.g., hands-on), training source (e.g., mine company, equipment vendor), and learning through practice on mineworkers' trust.

Hypothesis 1. There are significant differences in trust ratings across the reported training types.

Hypothesis 2. There are significant differences in trust ratings based on who facilitated the training.

Hypothesis 3. There are significant differences in trust ratings for workers who learned through practice compared with workers who did not.

Mine and Trust. Cultural [22] and organizational factors [23] also have been found to have an impact on trust. For example, cultural factors such as social norms have been found to influence operators' trust in automated systems [24]. Because cultural and organizational factors as well as mine characteristics vary across underground coal mines, it is also important to examine trust ratings by mine. Additionally, mine characteristics such as the roof height of the mine (influenced by the thickness of the coal seam) or method of coal extraction (e.g., longwall; room and pillar) may affect how PDS for mobile machines are used and implemented. The following hypothesis was developed to examine if there were significant differences in mineworkers' trust in mobile PDSs across mines.

Hypothesis 4. There are significant differences in trust ratings across the different mines.

Age and Trust. Workers' trust in mobile PDSs may also be influenced by individual characteristics such as age. Research findings have shown that older adults exhibit a greater amount of trust in automation [25] and may be more likely to demonstrate overreliance on a system compared with younger adults [26]. Meanwhile, other studies have described mistrust as a barrier to technology acceptance among older adults [27]. Based on these findings, the authors' predicted that mineworkers' age would have a significant influence on trust.

Hypothesis 5. There are significant differences in trust ratings across the different age groups.

Experience and Trust. Similar to findings about age, findings from past studies have also revealed mixed results for the effects of experience on trust. Trust has been shown to increase with system-specific experience [4,28]. However, general experience in a domain tends to reduce trust. Sanchez et al. [29] found that farmers with experience operating agricultural machines had lower trust in automated alarms of a novel collision avoidance system than inexperienced college students. In other words, increased experience with similar equipment led to decreased levels of trust in the new system. Similarly, Lee and See [15] identified that operators with extensive domain knowledge felt that they did not need additional automation to do their jobs or believed that they could do their jobs better than the automation. In regards to mining, mineworkers' trust in mobile PDSs may be affected by overall mining experience and actual experience with the system. The authors' put forth a nondirectional hypothesis to identify any differences in trust across the two types of experience.

Hypothesis 6. There are significant differences in trust ratings across the different levels of mining experience.

Hypothesis 7. There are significant differences in trust ratings across the different levels of mobile PDS experience.

System Make and Trust. MSHA has approved some mobile PDS models for use in underground coal mines [30]. The current study focused on two system models commonly being used on scoops and coal hauling machines in underground mine in the United States. Even though both systems are designed to warn of and prevent crushing and pinning accidents, the systems offer distinct features and functions. For example, one system gives users the ability to use programmable warnings and hazard zones that vary in shape and size, while the other system offers a more simplified zone set-up procedure. Differences such as these may result in increased trust in a particular system. Through Hypothesis 8, the authors explored the effect of mobile PDSs on mineworkers' trust.

Hypothesis 8. There are significant differences in trust ratings across the different system makes.

2. Materials and methods

2.1. Mine recruitment

In 2017, MSHA reported that 12 underground coal mines were using PDSs installed on mobile machines [31]. National Institute for Occupational Safety and Health researchers used convenience sampling techniques to recruit seven active US underground coal mines that currently had or previously had at least some of their mobile machines equipped with PDSs. Mines were selected for recruitment based on their PDS make (i.e., Matrix IntelliZone®/Joy SmartZone®, Strata HazardAvert®) and geographic location (i.e., West, Illinois Basin, East). Recruited mines varied in size and PDS implementation level. Table 2 provides a summary of the participating mine attributes. The mines represented various mining companies. However, some mines were owned by the same company. To protect the confidentiality of the mines, identifiable information was removed. The study was reviewed and approved by the National Institute for Occupational Safety and Health Human Subjects Review Board and Office of Management and Budget.

2.2. Participant recruitment

Individual mineworkers were recruited for participation through operations or safety management contacts. Recruitment occurred either at the mine site or mine training facility. Participation was voluntary, and mineworkers did not receive compensation for their participation. Mineworkers of all job titles were invited to participate in the study. However, haulage machine operators, continuous mining machine operators, section foremen, and maintenance workers were specifically targeted. These occupations were of interest because their job duties most likely

Table 2
Characteristics of participating underground coal mines

Mine information			Production statistics			Accident incidence rate		PDS implementation	
Mine	PDS	Mining method	UG workers	Hours	Tons of coal	Fatal*	NFDL**	Haulage	Scoop
A	A	Longwall	598	1,586,445	12,123,618	0	2.27	Partial	Partial
B	A	Longwall	481	1,391,106	5,352,731	0	1.15	Partial	Partial
C	A	Longwall	595	1,438,550	9,180,468	0	3.61	None	None
D	B	Room and Pillar	162	381,890	2,498,918	0	2.62	Partial	None
E	A	Longwall	225	547,314	4,805,028	0	1.83	Partial	None
F	B	Longwall	201	619,954	5,327,442	0	0.65	Full	None
G	B	Room and Pillar	266	557,959	1,462,854	0	5.38	Partial	None

PDS, proximity detection system; UG, underground.
* National Fatal Incidence Rate = 0.024
** NFDL = Nonfatal Days Lost; National NFDL Incidence Rate=*3.66*
Source: MSHA, Mine Data Retrieval System [30].

involved continually working with or around PDSs. Before data collection, the researchers reviewed information about the study with participants. Following the summary, each participant was asked to provide verbal consent. Data were collected from 223 participants. However, 14 cases were excluded from data analysis because of missing valid data on trust. One additional case was excluded because the participant reported being employed at a mine that was not included in the sample. The final sample for this study included $N = 208$ participants. Table 3 provides a summary of the participants demographic information by mine site.

2.3. Study design

A concurrent embedded mixed-methods design was used for this study. This mixed-methods strategy prioritizes qualitative or quantitative data and allows researchers to answer questions with greater perspective [33]. In this case, the approach privileged quantitative data. The qualitative data and results were used to gain a richer understanding of training practices related to mobile PDSs.

2.4. Data collection

Interviews were used to collect mineworkers' perspectives on mobile PDSs. The interviews included both structured and semi-structured questions. Interviews were conducted on mine property, during training, or before or during a mineworker's normal shift. The interviews lasted approximately 5 to 10 minutes. As a part of a larger set of questions, participants were asked to share their age, years of total mining experience, years of experience using mobile PDSs, training relative to mobile PDSs, and level of trust in mobile PDSs. More specifically, participants were asked, "*How confident are you that mobile proximity detection will prevent a collision?*" Participants were asked to rank their responses on a scale from "0" (the system will never prevent a collision) to "10" (the system will always prevent a collision). For the training question, participants were asked, *"How did you learn about mobile proximity detection systems?"* Researchers manually recorded workers' structured or short responses.

2.5. Data analysis process

Quantitative data were analyzed by conducting an independent samples *t* test, one-way analysis of variance (ANOVA), Welch's F test, or descriptive statistics. Data were analyzed by IBM SPSS©. For this study, all of the data with the exception of the responses collected for the training question were quantitative.

Qualitative data (i.e., participants' response to the training question) were coded following the recommendations of Campbell et al. [34]. The researchers coded responses to the training question in three phases [34]. These phases involved (1) developing a coding scheme, (2) discussing coding disagreements and establishing high intercoder agreement through negotiation, and (3) employing the coding scheme on all data [34].

During phase I, three coders individually reviewed the participant responses and identified emerging themes. The coders met to discuss their findings and, as a group, developed a coding scheme. The coding scheme included three major themes that described the training each participant had received relative to mobile PDSs. During phase II, the three coders individually coded 54 participant responses using the agreed-upon coding scheme. The coders met to discuss and resolve any remaining disagreements. For the final phase, the remaining responses were individually coded using a

Table 3
Participant demographic information by mine

Mine	Workers (*N*)*	Age (*Mean*/yrs)	Age (*SD*/yrs)	Mining experience (*Mean*/yrs)	Mining experience (*SD*/yrs)	Mobile PDS experience (*Median*/yrs)
A	19	40.21	9.16	10.84	6.87	1-2
B	23	43.23	9.79	19.59	11.20	1-2
C	18	35.94	12.70	10.42	12.88	>1
D	44	41.05	12.69	14.77	12.36	1-2
E	20	40.45	10.36	10.98	8.58	>1
F	67	40.94	10.68	12.93	8.97	1-2
G	17	35.94	10.31	11.30	9.18	>1
All workers	**208**	**40.23**	**11.10**	**13.30**	**10.42**	**1-2**

PDS, proximity detection system; SD, standard deviation.
* Owing to the inclusion of cases with missing data, reported values for age, experience, and mobile PDS may not be based on the total number of workers at the mine or in the study.

finalized version of the coding scheme. The guide included three major coding categories and 10 supporting themes that described the training workers had received: (1) *type*—type of training, (2) *who*—who facilitated the training, and (3) *practice*—whether the workers learned about the system by actually interacting with the system through formal training or on their own.

Fig. 1 summarizes the coding themes and subcategories. For each coding category (i.e., type, who, practice), a response could be coded using multiple themes. For example, the response "*Our safety department gave both hands-on training and a class*" would have been coded as (1) *type*—"hands on" and "classroom", (2) *who*—"mine", (3) *practice*—"yes".

Interrater reliability was calculated for 169 coding results from phase III, or 85% of the overall data, using Fleiss' kappa *K* for each of the 10 coding themes [35]. Interrater reliability for all themes was above $K = 0.81$, which can be interpreted as "almost perfect agreement" [36]. Coded qualitative responses were transformed into quantitative binary variables for each of the subcodes. The subcode variables were analyzed to evaluate mineworkers' trust relative to the training they had received. Any cases missing training data were removed for this analysis.

3. Results

3.1. Workers' training and trust

Research question 1 and hypotheses 1-3. Researchers conducted two-tailed independent samples *t* tests to analyze data from the three coding themes: (1) *training type* or *type*, (2) *training provider* or *who*, and (3) *training through practice* or *practice* (see section 2.5 Data Analysis Process for further explanation of coding categories). The purpose was to compare the means for trust for participants who reported receiving or not receiving each form of training. For the major coding theme *training type*, the five subcategories were (1) *minimal to no training,* (2) *classroom training,* (3) *hands-on training,* (4) *verbal training*, and (5) *written training*. For the major coding theme *training provider*, the two subcategories were (1) *mine* and (2) *manufacturer*. For the major coding theme *training through practice*, there were no subcategories (see Fig. 1).

Before statistical analysis, each subcategory and training through practice was transformed from qualitative data into binary variables. Each response was coded as "yes" or "no" based on whether the worker's response was characterized as that specific form of training. For example, if a worker stated that he had received hands-on training, then his response was coded as "yes" for the hands-on training subcategory. Table 4 provides a summary of the results for all of the coding themes. Based on the results from the independent samples *t* tests, there were no significant differences identified between the mean trust ratings across the subcategories.

3.2. Mine and trust

Hypothesis 4. The effect of mine on workers' trust in PDSs was assessed. Based on results from a Levene's test, the assumption of homogeneity was not met ($p < .05$). Because homogeneity of variance was not met, a *Welch's F* test was conducted to compare the effect of the mine on workers' trust in PDSs for mobile machines. At an alpha level of .05, a significant effect was found, ($F_{6, 65} = 3.34$, $p < .05$, est. $\dot{\omega}^2 = .058$.

A Game-Howell post-hoc test was run to identify which mines had significantly different means for workers' trust. Table 5 shows that the mean for workers' trust for Mine B ($M = 8.04$, $SD = 2.29$) was significantly different from the mean for Mine D ($M = 5.66$, $SD = 2.26$) and Mine A ($M = 6.05$, $SD = 1.68$). A comparison of mean values across the seven mines is also represented in Fig. 2. To determine the effect size, Cohen's d was calculated for Mine B and Mine D and Mine B and Mine A at, $d = 0.23$ and $d = 0.25$, respectively. Both results for Cohen's d indicate a small effect size [37].

3.3. Workers' age and trust

Hypothesis 5. Researchers evaluated the effect of age on workers' trust in PDSs. Six cases were removed because of missing worker's age. *Age* was treated as a categorical variable for this analysis, rather than a continuous variable, to offer more practical implications. However, the lead researcher did not observe a linear relationship on the scatter plot for *age* and *trust*. Based on results from a Levene's test, the assumption of homogeneity was met, $p = .48$. A one-way ANOVA between subjects was conducted. There was not a significant effect $F_{2, 199} = .89$, $p = .41$, $p < .05$. Table 6 presents the mean values for workers' trust by age group.

3.4. Workers' mining experience and trust

Hypothesis 6. Researchers assessed how workers' overall mining experience influenced trust in PDSs. Five cases were not included in data analysis because of missing worker's mining experience. Similar to *age*, researchers treated *mining experience* as a categorical variable for this analysis to offer more practical implications. However, the lead researcher did not observe a linear relationship on the scatter plot for *mining experience* and *trust*. Based on results from a Levene's test, the assumption of homogeneity was met, $p = .57$. A one-way ANOVA between subjects was conducted. There was not a significant effect $F_{4, 198} = 1.37$, $p = .25$, $p < .05$. Table 7 presents the means for trust by grouped years of experience.

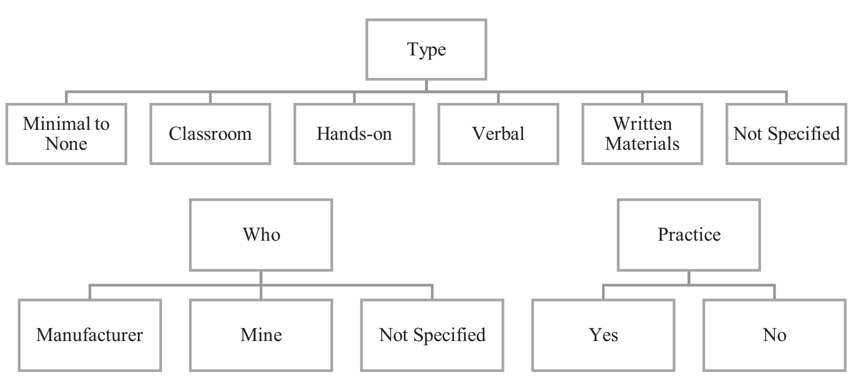

Fig. 1. Final coding theme hierarchy for type, who, and practice.

Table 4
Independent samples *t* tests results for training

Theme	Subcategory	Received training	Workers (*N*)	% who received training type*	Mean	SD	*t* value	Significance (*p* value)
Training type	Minimal to none	Yes	39	23%	6.97	2.10	*t* (165) = -1.26	p = .21
		No	128		6.41	2.57		
	Classroom	Yes	75	45%	6.48	2.81	*t* (138) = .27	p = .79
		No	92		6.59	2.19		
	Hands on	Yes	83	50%	6.60	2.44	*t* (165) = -.33	p = .74
		No	84		6.48	2.52		
	Verbal	Yes	14	8%	6.93	2.09	*t* (165) = -.61	p = .54
		No	153		6.50	2.51		
	Written	Yes	6	4%	6.00	3.46	*t* (165) = .54	p = .59
		No	161		6.56	2.44		
Training provider	Manufacturer	Yes	45	36%	6.07	2.51	*t* (122) = .86	p = .39
		No	79		6.48	2.63		
	Mine	Yes	91	73%	6.46	2.58	*t* (122) = -.94	p = .35
		No	33		5.97	2.60		
Training through practice	Practice	Yes	93	47%	6.65	2.38	*t* (196) = -.46	p = .65
		No	105		6.49	2.49		

SD, standard deviation.
**Mean difference is significant at alpha level of .05.
* Percentages rounded to nearest whole number.

3.5. Workers' mobile PDS Experience and Trust

Hypothesis 7. Five cases were excluded from analysis because experience with PDSs was not reported. Based on results from a Levene's test, the assumption of homogeneity was met, $p = .68$. A one-way ANOVA between subjects was conducted to compare the effect of grouped PDS experience on workers' trust in PDSs for mobile machines. There was not a significant effect $F_{2,\ 200} = .02$, $p = .98$, $p < .05$. The means for mobile PDS experience by group are presented in Table 8.

3.6. Workers' PDS make and trust

Hypothesis 8. A two-tailed independent samples *t* test with equal variances was conducted to compare the means for workers' trust for the two different PDS makes. The Levene's test showed that the assumption for equality of variance was met, $p = .10$. Results from the *t* test show no significant difference between the two systems, $t\ (206) = -.97$, $p = .33$. Mean values for workers' trust by mobile PDS make are presented in Table 9.

4. Discussion

Workers' trust is an important concept to consider when implementing or designing an automated system. Though trust is subjective and difficult to define, it has been shown to have a direct impact on acceptance, usage, and performance [6]. However, no system will ever be perfect, making it even more crucial for workers to maintain appropriate levels of trust [15]. Therefore, stakeholders should not expect workers to report a 10 (i.e., *complete trust*) in trust for a PDS for a mobile machine. However, given that the PDS is promoted as a safety system, researchers intuitively did expect workers to report trust values above 5 (i.e., *neutral* or *neither trust nor distrust*). With an overall average trust rating of 6.57, this appears to be true. However, individual ratings indicate that some workers may suffer from overtrust and distrust in mobile PDSs. Furthermore, as mobile PDSs are more widely adopted, it is important to identify appropriate trust levels and factors that affect trust such as system design issues.

The present study begins to address these gaps related to understanding trust and the factors that influence it by putting forth

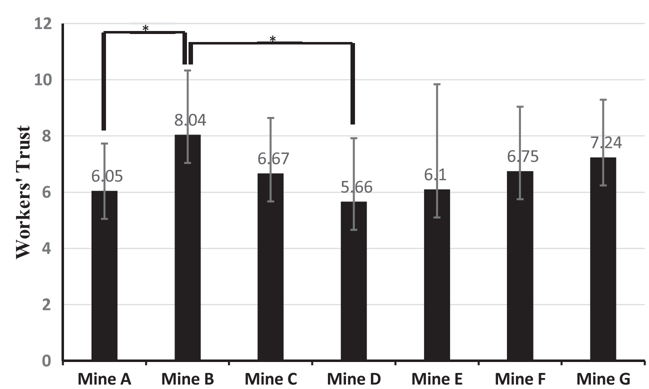

Fig. 2. Mean value comparison by mine for mineworkers' trust in their mobile PDSs' ability to prevent a collision. Error bars represent standard deviation. Statistically significant groups are linked (*). PDSs, proximity detection systems.

Table 5
Comparison of mine by trust (descriptives)

Mine	Workers (*N*)	Workers' Trust		Workers' Trust Mean Differences Across Mines						
		Mean	**SD**	**A**	**B**	**C**	**D**	**E**	**F**	**G**
A	19	6.05	1.68		**-1.99***	-.61	.39	-.05	-.69	-1.18
B	23	8.04	2.29	**1.99***		1.38	**2.38***	1.94	1.30	.81
C	18	6.67	1.97	.61	-1.38		1.01	.57	-.08	-.57
D	44	5.66	2.26	-.39	**-2.38***	-1.01		-.44	-1.09	-1.58
E	20	6.10	3.74	.05	-1.94	-.57	.44		-.65	-1.14
F	67	6.75	2.29	.69	-1.30	.08	1.09	.65		-.49
G	17	7.24	2.05	1.18	-.81	.57	1.58	1.14	.49	
All Workers	208	6.57	2.45							

**Mean difference is significant at alpha level of .05*

Table 6
Workers' age and trust (descriptives)

	Workers *(N)*	Workers' trust *(Mean)*	Workers' trust *(SD)*
19–29 years	43	6.53	2.76
30–49 years	112	6.42	2.32
50–69 years	47	6.98	2.32
All workers	**202**	**6.57**	**2.42**

SD, standard deviation.

three key findings. First, the study offers a way to characterize and classify mobile PDS training based on the experiences of mineworkers. Second, characteristics of the mine do have an influence on workers' trust in the systems. Third, study findings suggest that age, experience, training, and the make of the system do not have a great influence on workers' trust in mobile PDSs. These findings are discussed in greater detail in the following sections.

4.1. How underground mineworkers learn about mobile PDSs

Based on the results from this study, most workers learned to use a mobile PDS from their mine company through hands-on and classroom training, verbal interactions, written materials, and through some form of informal or formal practice. Results also show that many workers received more than one type of PDS training. Conversely, only 23% of workers described receiving training that could be classified as minimal to no training. These findings may indicate that mine operators are following recommended training practices by providing more engaging forms of training and incorporating practice [20].

4.2. How mine characteristics influence trust

This study also found that the mine where the worker was employed did have a significant influence on trust. More specifically, on average, mineworkers at *Mine B* reported significantly higher trust in their mobile PDS than those at *Mine D* and *Mine A*. Past studies have suggested that organizational factors have a strong influence on trust [15,23]. Sankowska and Paliszkiewicz [39] identified a relationship between organizational trust and innovation. This finding may suggest that mines with high levels of worker trust may be more willing and suited to navigate the uncertainties associated with integrating an automated technology

Table 7
Workers' mining experience and trust (descriptives)

Mining experience	Workers *(N)*	Workers' trust *(Mean)*	Workers' trust *(SD)*
0–5 years	44	6.16	2.44
6–10 years	69	6.68	2.56
11–20 years	54	6.22	2.39
21–30 years	12	7.25	1.77
31 or more years	24	7.29	2.51
All workers	**203**	**6.55**	**2.45**

SD, standard deviation.

Table 8
Workers' mobile PDS experience and trust (descriptives)

Mobile PDS experience	Workers *(N)*	Workers' trust *(Mean)*	Workers' trust *(SD)*
Less than 1 year	67	6.60	2.63
1-2 years	108	6.52	2.38
More than 3 years	28	6.57	2.38
All workers	**203**	**6.55**	**2.45**

PDS, proximity detection system; SD, standard deviation.

Table 9
PDS make and trust (descriptives)

Mobile PDS	Workers *(N)*	Workers' trust *(Mean)*	Workers' trust *(SD)*
System A	128	6.44	2.31
System B	80	6.73	2.64
All workers	208	**6.57**	**2.44**

PDS, proximity detection system; SD, standard deviation.

such as a PDS. Additionally, a number of factors such as the organizational culture including processes and practices and specific characteristics of the mine such as seam height, existing equipment, and mining conditions may also have an influence on workers' trust in a mobile PDS. In relationship to the results from this study, the authors consider work practices and mine culture in the following section.

First, variations in organizational work practices may have influenced mineworkers' evaluations of mobile PDSs. For example, past studies have shown that workload can have an effect on workers' self-reported trust of automation [40,41]. In line with these findings, trust ratings reported by workers at *Mine B* were significantly higher than those reported by employees at the largest and smallest mines in the sample. *Mine D* had the smallest number of underground workers and lowest production hours compared with the other six participating mines [32]. Conversely, *Mine A* had the most workers and reported the highest production hours [32]. Differences in mine size could cause increased variations in work practices and workloads, which could have an influence on workers' trust in PDSs for mobile machines. For example, Biros et al. [41] found that high task loads led to excessive trust or over-reliance. Mine health and safety managers need to consider ways that workloads and organizational practices may be influencing mineworkers' trust in mobile PDSs. During initial system integration, high workloads may not allow mineworkers to clearly evaluate the strengths and weaknesses of the system or to appropriately adjust their practices.

In addition to organizational work practices, cultural factors such as social norms could cause variations in mineworkers' trust in mobile PDSs across mines. Workman [24] identified that a single coworker or supervisor can shape operators' perceptions of an automated system. Additionally, past studies have shown that individual trust in automation can be positively influenced when a system is presented as useful or reputable [43,44]. Consequently, a mine supervisor's perceptions of a PDS for a mobile machine could have an impact on how the technology is introduced and essentially evaluated by mineworkers. Attitudes and beliefs that led to the mines' decision to adopt the technology and the existing safety culture could also have an impact on these perceptions. Further research is needed to confirm or explore cultural factors that may be influencing workers' perceptions of mobile PDSs.

4.3. How individual characteristics and system make may not influence trust

Finally, training, age, total mining experience, mobile PDS experience, and PDS make did not have a notable influence on workers' trust in mobile PDSs. These findings do not necessarily mean that these factors are unimportant. Rather, findings suggest that other factors may have a greater influence on workers' trust. As previously noted, trust has been found to reduce uncertainty and risk perceptions [38], as well as increase technology acceptance [12,42]. Therefore, the finding may indicate that other factors may need to be considered to ensure the technology is safely integrated into the underground mining environment.

4.4. Limitations

Even though the study contributes to the body of literature on occupational safety and health, trust in automation, and mixed methodologies, it does have four notable limitations that may lessen the generalizability of the findings. First, the study results are based on a small number of mines recruited through convenience sampling and self-reported data. As a result of the sampling method, the study may not include a representative sample of the entire mining industry. However, researchers were able to include over 50% of mine sites that have currently adopted mobile PDSs. Second, the construct validity of the instrument used in this study was not evaluated. However, some validity can be assumed, as the instrument is similar to the dimension of responsibility (i.e. to what extent does the pump perform the task it was designed to do in the system?) used by Muir and Moray [28] as well as Lee and Moray [5], modified to capture the system and use case context. Additional research is also recommended to better understand various interpretations of the terms *trust* and *confidence* and to develop a more consistent definition of *trust* relative to technology. Third, though the study explores how several factors may influence workers' trust in mobile PDSs, the study does not account for how workers' familiarity and experiences with similar technologies such as a PDS for continuous mining machines may influence workers' trust. Finally, the study used a concurrent embedded, mixed-methods approach. Because this approach relies on various types of data, it can lead to findings with unequal support or evidence [33]. More specifically, the purposes of qualitative and quantitative data are distinct. Even though the qualitative data were transformed into quantitative data, findings from the transformed data describe the training that workers received rather than provide proof of the prevalence or use of the various training approaches. In other words, the transformed data provide a detailed description of training for PDSs, but may not necessarily provide quantifiable evidence even though the data were quantified.

5. Conclusions

To ensure the safe integration of automated systems, leaders should consider workers' trust and factors that may lead to overreliance and distrust in these technologies. Even though training and individual characteristics have been shown to influence trust in past research, [19,25] the present study identified the mine of employment as the only variable that had a significant influence on workers' trust in mobile PDSs. Based on this findings, the following suggestions have been provided for mine leaders currently or considering implementing a mobile PDS.

- To ensure the safe use of a mobile PDS, it is important for leaders to address behaviors that may indicate inappropriate trust such as overreliance or disuse.
- Consider how workloads may be influencing workers' trust. It may be beneficial for mine leaders to make adjustments to workloads and practices during system integration.
- Select mineworkers and supervisors with appropriate trust and an understanding of the system's strengths and weaknesses to lead implementation and training efforts. As one worker or supervisor can shape the attitudes and perceptions of others [24], it is important to evaluate the perceptions and system knowledge of workers in positions of influence.

In addition, this study identifies a need for future research that examines appropriate levels of trust relative to automated technologies and explores organizational characteristics that may have an effect on workers' trust in these types of technologies. In the meantime, practitioners should give special consideration to factors that may make their organizations unique during technology implementation. These factors could have a significant influence on workers' perceptions and adoption of new technologies.

Disclaimer

The findings and conclusions in this article are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health (NIOSH), Centers for Disease Control and Prevention. Mention of company names or products does not constitute endorsement by NIOSH.

Conflicts of interest

All authors have no conflicts of interest to declare.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.shaw.2019.09.003.

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