Published in final edited form as:
Min Metall Explor. 2019 August ; 36(4): 647–655. doi:10.1007/s42461-018-0045-3.

Mineworkers' Perceptions of Mobile Proximity Detection Systems

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Abstract

Accident data indicates that mobile haulage poses a significant pinning, crushing, and striking risk. Proximity detection systems (PDSs) have the potential to protect mineworkers from these risks. However, unintended consequences of mobile PDSs can undermine the safety benefit they provide. Soliciting iterative user input can improve the design process. Users help provide a critical understanding of how mobile PDSs may hinder normal operation and endanger mineworkers. Researchers explored users' perspectives by conducting interviews with mineworkers from seven mines that have installed mobile PDSs on some of their haulage equipment. Mineworkers reported that mobile PDSs affect loading, tramming, section setup, maintenance, and general work on the section. Mineworkers discussed the operational effects and increased burden, exposure, and risk. Mineworkers also suggested that improved task compatibility, training, logistics, and PDS performance might help address some of these identified issues. This paper also gives additional insights into mobile PDS design and implementation.

Keywords

Proximity detection; Mining; Usability; Task compatibility; Unintended consequences

1 Introduction

Pinning, crushing, and striking accidents are a large problem in underground coal mines, especially for mobile haulage. Between 1984 and 2014, there were 179 nonfatal and 42 fatal pinning, crushing, and striking accidents involving mobile haulage vehicles, including coal

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

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hauling machines and scoops [1]. Proximity detection systems (PDSs)—automated systems that decelerate and stop a vehicle in order to prevent a collision—have the potential to protect mineworkers in these situations. In fact, PDSs are now required on all place change continuous mining machines as of March 16, 2018, as a result of the final rule published in January 2015 (30 CFR 75.1732) [2]. To address mobile haulage, later in 2015 the Mine Safety and Health Administration (MSHA) also proposed a new rule that would require PDSs on mobile haulage vehicles [3]. Though there has been no additional actions related to the proposed rule and this technology is not currently required, it can still help to save lives. MSHA estimates that the adoption of mobile PDSs could prevent approximately 70 injuries and 15 fatalities over the next 10 years [4]. As of June 2015, the underground coal industry had already equipped 155 of the 2116 mobile haulage vehicles currently in use [1].

In order to capitalize on the projected safety gains afforded by PDSs, it is important that the systems are designed and implemented effectively. Along with others, researchers at the National Institute for Occupational Safety and Health (NIOSH) have been exploring PDSs for more than two decades [5–7]. Throughout this time, NIOSH has also held several stakeholder meetings (2010,2014,2016, and 2017) in order to disseminate information and provide an opportunity to discuss ongoing issues and concerns. Despite some progress, human factors remain a key concern. Previous research examined mineworkers' attitudes towards PDSs on continuous mining machines [8] as well as how continuous miner operators' perceptions of risk have changed as a result of PDSs [7]. However, stakeholders have still expressed a need to better understand how *mobile* PDSs affect the mining process, the mineworker, and whether and how they may present previously unidentified risks.

2 Background

As is the case with mobile PDSs, reliability and safety are often driving factors towards automation [9]. Consequently, many technologies have been developed with the intention of eliminating human error under the assumption that some human action can be directly substituted with automation. However, actions within a complex system are not so easily decoupled, often resulting in unanticipated problems and failures [10]. A user-centered design approach (e.g., humancentered design) can help minimize these challenges [11]. User-centered approaches underscore the importance of understanding the users and the underlying system as a framework around which to design, instead of a technology-driven approach. Horberry, Burgess-Limerick, and Steiner advocate for this in an iterative design process with a "continual focus on mine site users, their actual tasks, and the mine site environment/use context" in order to make products more usable [11]. Ideally, this would lead to technology that is compatible with mineworkers' tasks, minimizes any unintended adverse consequences, and is easy to use. Unfortunately, human- and system-based design approaches have not been widely adopted in the mining industry [11, 12].

In addition, lack of user and system knowledge in the design processes can result in task incompatibility. For example, researchers found that mineworkers testing the continuous personal dust monitor (CPDM) had difficultly sitting down while wearing the unit [13]. Increased user involvement in the design process may have allowed for earlier identification of this compatibility issue, as many mineworkers have to ride for an hour or more just to reach their work location. Further, complicating task compatibility are the expectations of mineworkers. Apart from individuals' resistance to change (e.g., due to primacy or habit) [14], researchers have noted that mineworkers in particular have displayed a strong resistance to new technology even if it only required negligibly small changes in routine and behavior [15]. There are many other barriers to good design, including the dynamic nature of the mining environment, the variability of mining conditions, the diversity of stakeholders and end-users, and limited access to mine sites [12]. Increasing the designers' understanding of users and context may help to address these issues.

Because technologies are typically a part of a highly complex environment and deployed to a wide variety of users, intended actions may result in unintended consequences. For example, while remote operation of the continuous mining machine reduced operators' vibration and dust exposure by moving them away from the cutting face, it also unintentionally increased pinning, crushing, and striking accidents [16]. Another example of unintended consequences is how the addition ofPDSs to continuous mining machines increased operators' exposure to dust and rib rolls as a result of changes in operator positioning [7]. However, there is limited work looking specifically at how mobile vehicles are used and what might be affected by the addition of mobile PDS. Designers should not assume that a particular technology works the same for a different set of users in different use cases.

Applied appropriately, user and system design approaches, as well as PDS technology, can be successfully implemented. Various forms of PDSs are commonly used in the automotive industry to prevent collisions with pedestrians and other vehicles. Designers in this domain rely heavily on human factors methodologies and user interaction and testing during the design process [17–20]. These systems have also been reasonably scoped. For example, automatic cruise control and traffic jam assist (forms of PDSs) were designed to only prevent collisions with the vehicle in front of the one using the systems, and they also have the ability to alert the user in situations where they may fail [21, 22]. Lessons learned from other industries could be applied to the development and implementation of mobile PDSs.

In an effort to address stakeholder concerns expressed during stakeholder meetings and identify possible design and implementation improvements, the aim of this study was to investigate the usability of the available mobile PDSs in the USA. More specifically, this work looks to answer two questions: (1) Do mobile PDSs hinder normal operation? (2) Do mobile PDSs cause unintended consequences?

3 Methods

Researchers developed a semistructured interview guide using a problem discovery usability study design, where researchers used open-ended questions in order to identify the top usability concerns [23]. The interview guide was composed of demographic information, 5 open-ended questions (Table 1), and two 11-point rating scales that will be discussed in another publication. For this paper, we focus on the qualitative data derived from interviews. The interviews lasted approximately 10 min and were conducted individually in a location that was most convenient for the worker (i.e., break room on the surface, lunch area underground, work location underground). Following the interviews, researchers also observed a subset of the participants working on the sections equipped with mobile PDSs while performing their normal duties. The observations were used to provide context and clarification to the interview data. The protocol was approved by both the local Institutional Review Board for protection of subjects and the Office of Management and Budget in accordance with the Paperwork Reduction Act [24].

3.1 Participants

Researchers used a convenience sampling technique and began by recruiting early adopters of mobile PDSs from the 12 mines identified by MSHA as current or previous users of mobile PDSs.[1] From the population of mines with mobile PDSs, mines were targeted based on their PDS model (i.e., Matrix IntelliZone/ Joy SmartZone, Strata HazardAvert) and geographic region (i.e., West, Illinois Basin, and East). Researchers attempted to achieve equal representation for mines in each region and using each PDS model. Recruited mines varied in size, mobile PDS system use, and degree of implementation. Table 2 presents the mine descriptive information.

Recruitment of individual participants occurred either at a mine site or at training facility following an invitation from operations and safety management contacts. Researchers obtained verbal consent to participate from each individual, while stressing that participation was voluntary and that mineworkers would not receive any compensation for their participation. Participation was open to all mineworkers. However, mineworkers who routinely interacted with mobile PDSs were targeted, including mobile haulage operators, continuous mining machine operators, section foremen, and maintenance workers. Two hundred and twenty-three individuals from seven different mines participated in the study. Of these, 6 participants were excluded due to incomplete data, leaving data from 217 participants for analysis. Table 3 displays participant demographic information by mine site.

3.2 Data Analysis

Interview notes from three of the open-ended questions (see Table 1) were coded using a method of inductive quantitative and qualitative content analysis [25] in order to address the two research questions by identifying situations that would either hinder normal operation or endanger mineworkers. Codes were framed as mining or PDS tasks. The coding process included the following steps:

1. *Open coding:* Three researchers reviewed all of the interview data and generated preliminary lists of codes. During open coding, new codes were generated for any new task category that emerged from the data.
2. *Preliminary code formation:* Three researchers met to discuss and review the preliminary lists of codes resulting in a unified list of codes to be used for the formal coding. The unit of analysis (phrases taken from the interviews) and coding rules were also formalized (no double coding within proximity and mining tasks) through discussion.

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3. *Data coding (session 1):* Two researchers independently coded all of the interview data based on the agreed-upon codes.

4. *Code revision:* Coding was compared by the third researcher. Then, all three researchers met again to discuss, review, group, and redefine codes. Final definitions, inclusion and exclusion criteria, and typical and atypical examples were generated for each code.

5. *Data coding (session 2):* Two researchers independently recoded all of the interview data using the revised codes.

6. *Categorization and theme development:* The third researcher compared the final coding, and disagreements between coders were discussed as a group until agreement was reached. After reviewing all of the final codes, quotations, and materials, codes were grouped into higher-level categories and the main themes and subthemes were identified (discussed below).

4 Results

4.1 Quantitative Analysis

Mineworkers indicated that mobile PDSs predominantly affected four major mining tasks, including (1) loading coal; (2) tramming of mobile vehicles; (3) maintenance on mobile vehicles; and (4) section setup, where maintenance tasks were mentioned most frequently (27.6% of the mineworkers). Interestingly, mineworkers from different geographic regions tended to highlight different task concerns as depicted in Fig. 1. For example, mineworkers in region B more frequently identified difficulties loading coal, and mineworkers in region C more frequently identified section setup as a concern.

Mineworkers also identified usability challenges for mobile PDSs. Over 80% of the mineworkers talked about how mobile PDSs generally made working in the area more difficult, regardless of task. Additionally, nearly 70% of mineworkers were concerned about how and when the mobile PDS takes control of the vehicles, and 30% of the mineworkers found some aspects of interacting with the specific systems burdensome. Furthermore, the usability trends appeared to be fairly consistent across mobile PDS models (Fig. 2).

4.2 Qualitative Analysis

4.2.1 Task Compatibility—A more in-depth qualitative analysis of the data revealed how mineworkers expressed concerns that mobile PDSs hindered loading, tramming, maintenance, and section setup. Mineworkers discussed how mobile PDSs interfered with how they previously performed tasks, causing them to be in different locations and changing how they performed work. The three themes of these changes included changes to the information available, a reduction in task flexibility, and an increase in the time and resources required to complete tasks. Each of these are discussed in more detail below.

Concerns About Changes in the Information Available: Mineworkers indicated that by changing where they were able to stand, mobile PDSs changed what they were able to see, hear, and touch. Mineworkers reported that reduced visibility, reduced machine accessibility, and impaired communication changed how they had to complete their tasks. For example, as a part of section setup, mobile PDSs require mineworkers to stand farther away from the scoop bucket while loading supplies. The new positioning both reduces the visibility of the load and eliminates the ability of mineworkers to guide the load into the bucket. With a mobile PDS in use, in order to complete the task, mineworkers have to either shut down the scoop in order to approach the bucket to reposition the supplies or risk damaging them. Similarly, while loading coal, mobile PDSs require mobile haulage vehicles to load farther away from the tail of the continuous mining machining, again reducing visibility because of distance and operator positioning behind ventilation controls such as brattice cloth. The reduction in visibility requires mineworkers to find alternative methods of feedback (e.g., sounds) in order to complete the same task. Related to communication during loading, one mineworker talked about how the new loading and waiting positions of mobile haulage vehicles actually eliminated sight lines to the continuous miner operator, preventing cap lamp signaling. The increased distance between the two operators also hinders verbal communication. As a result, the mobile haulage and continuous miner operators must use the radio or walk into the entry to communicate. Lastly, mineworkers detailed instances where the mobile PDSs hinder maintenance tasks by limiting access to the mobile equipment. For example, when diagnosing a mechanical problem (e.g., intermittent transmission failure), a mechanic needs to be able to see the machine run. With mobile PDSs, mechanics are not able to get close enough to observe the problem, forcing them to find another means of identifying the problem.

Concerns About Reductions in Task Flexibility: Several mineworkers reported that by limiting the locations they were able to stand, mobile PDSs reduced the flexibility, adaptability, and control in completing tasks. For example, mineworkers talked about how—because the yellow zones on the mobile vehicles were so large—they were no longer able to turn a crosscut while bolting the straight entry; this change effectively limited the cut sequencing possibilities. Also related to loading coal, mineworkers indicated that mobile PDSs shrink the area that continuous mining machine operators are able to stand, preventing them from adapting their position to changing conditions at the face. Mineworkers also discussed how the size and shape of yellow zones delayed speed-up of mobile vehicles tramming away from the continuous mining machine, reducing their control and causing vehicles to get stuck when the bottom was soft.

Concerns About the Increase of the Time and Resources Required: During the interviews, mineworkers also touched on how mobile PDSs hinder normal operation by increasing the time required to complete tasks. For example, one mineworker talked about how mobile PDSs prevented him from following mobile haulage vehicles into and around the section. Because mineworkers can no longer walk closely behind the haulage vehicles, they would have to wait longer to enter and exit the section safely, also increasing their risk of shutting down other haulage vehicles when crossing their routes. Mineworkers similarly discussed how they had to stand much farther into a crosscut to let vehicles pass because of the size and shape of mobile PDSs zones. Standing further away resulted in increased time to complete other tasks as well as delay in the tramming of mobile haulage vehicles when there was an unintended shutdown. Related to maintenance, mineworkers also discussed how mobile PDSs are complicated and therefore add to the complexity of the already complex vehicles. Additional time and resources are required to provide mechanics with appropriate training for servicing and maintaining the PDS-equipped vehicles.

4.2.2 Unintended Consequences—

Three themes also emerged when further exploring how mobile PDSs could endanger mineworkers. Mineworkers expressed concerns about the unintended consequences of increased cumulative physical exposure, increased traumatic injury risk, and interference with emergency response during loading coal, tramming, maintenance, and section setup.

Concerns About the Increase of Cumulative Physical Exposure: Mineworkers discussed how changes and limitations in operator and equipment positioning due to mobile PDSs led to increased cumulative physical exposure such as increased walking and manual material handling. For example, as discussed above, the inability to have a helper stand at the bucket of the scoop resulted in scoop operators more frequently loading materials by themselves and increasing their manual handling exposure. Without a helper, scoop operators also had to walk more, because they had to get in and out of their cabs in order to line the scoop up correctly. Additionally, mineworkers raised concerns about how mobile haulage operators are exposed to a higher frequency of jarring and jolting incidents due to the high number of false alarms and sectionwide shutdowns, both resulting in abrupt vehicle stops. Mineworkers reported that current mobile PDSs unnecessarily shut down vehicles anywhere from once a day up to 15 times during a single cut of coal. On top of the frequency, mineworkers were also concerned about the forceful nature of these stops.

Concerns About the Increase of Traumatic Injury Risk: In addition to the cumulative risk of increased physical activities, mineworkers talked about how mobile PDSs increase their risk of immediate injury. For example, mineworkers stated that because mobile PDSs caused them to stand closer to other non-PDS-equipped machines and freshly cut rib, they felt they were in greater danger of being struck by these vehicles (e.g., a loader) or falling rock. During section setup, mineworkers felt that mobile PDSs increased their slip, trip, and fall risk, because it required them to get on and off the vehicle more frequently while hanging cable and tubing. Slip, trip, and fall risks were also identified as a problem when loading coal. Mineworkers discussed how when a continuous miner operator was checking sight lines, he or she could unintentionally trigger a haulage vehicle's PDS, preventing the haulage vehicle from moving to accommodate the operator. Several mineworkers reported that this problem had resulted in the continuous miner operator actually walking backwards into the tailgate of the haulage vehicle. Entanglement risks were also mentioned, as mineworkers talked about how big the miner-wearable component (MWC) was. They indicated that they were concerned that the MWC could get caught on equipment. Lastly, mineworkers expressed concern over the lack of machine-to-machine collision protection. Specifically, several mineworkers described a situation where a vehicle could collide into another and crush or pin a mineworker on the other side of the second vehicle. While this situation could still occur without mobile PDSs, mineworkers expressed the concern that mineworkers may rely too much on the system, making an incident like this more likely. Furthermore, at many of the mine sites, mineworkers mentioned that they did not have a clear understanding of the scope of mobile PDSs' protection and reliability. Mineworkers cited this lack of understanding as the cause for their elevated concern over injury risk and expressed a desire for additional information and training.

Concerns About Interference with Emergency Response: Mineworkers also raised concerns related to emergency response. Namely, mineworkers discussed the possibility of a PDS-equipped machine breaking down in the middle of the escape route, potentially hindering escape. If this were the case, the mobile PDS would make it more difficult to move the disabled vehicle in order to tram out of the section. Mineworkers also raised concerns about how mobile PDSs prioritized pedestrians' safety. For example, mineworkers talked about escaping a roof fall at the face—because a pedestrian mineworker (e.g., a continuous miner operator) could trip the haulage vehicle's PDS, it would take longer for the mobile equipment operator to exit the face, placing the haulage vehicle operator in greater danger.

4.2.3 Usability—In the interviews, mineworkers identified usability concerns specific to mobile PDSs that affected general work on the section. Independent of the system they were using, mineworkers identified lack of consistency and unclear functionality as barriers to use. Mineworkers described instances where, vehicle-to-vehicle and MWC-to-MWC, the mobile PDSs performed differently. This variability generated increased concerns over system logistics (e.g., is the system being managed correctly? are there different setups?) and system performance (e.g., how should the system work? is the system working?). Exemplifying mineworkers' uncertainty of the systems' functionality, in the interviews, many of the mineworkers also expressed desires for the addition of existing features or incorrectly described mobile PDS functions.

Independent of a specific task, mineworkers also identified several instances of increased risk and exposure, including physical burden, attentional burden, and increased exposure time in high-risk situations. The physical burden of mobile PDSs appeared to be explicitly driven by the MWC. Many of the mineworkers complained about its size and weight. Some mineworkers also talked about the added attentional burden of mobile PDSs. They described how they found themselves thinking about the mobile PDS instead of concentrating on working safely. For them, the mobile PDS was more of a distraction. Lastly, mineworkers were concerned that mobile PDSs could add costly time in the event of an emergency. They expressed concern about the cost benefit of the system overall in terms of mineworker safety.

Finally, mineworkers described that using the mobile PDSs caused frustration. The frustration was predominantly linked with poor system performance (e.g., nuisance trips and interference). They described how mobile PDSs made their tasks more difficult, especially when the systems were not reliable. In these situations, mineworkers frequently could not offer solutions as to how to make the systems better. They simply acknowledged that they were difficult to use.

5 Discussion

Assessing mineworkers' perceptions of the usability of mobile proximity detection systems, the current study had two objectives. First, the study aimed to identify any task compatibility issues with mobile PDSs that may hinder normal mine operation and second, to identify any unintended consequences of mobile PDSs that may endanger mineworkers. This section discusses the study results and insights for key stakeholders.

Overall, the results of this study indicate that specific mining tasks influenced the usability of mobile PDSs. Mineworkers identified compatibility issues with tasks including loading, tramming, maintenance, and section setup. However, the regional differences in the percentage of mineworkers who reported specific task compatibility issues suggest that the issues may be site-specific. For example, section setup tasks often change based on coal seam height. Highseam mines may use a different method of ventilation (e.g., tubing or curtain) or a different procedure to hang cable that may or may not depend on haulage vehicles (e.g., mobile platform). System features such as specific worker zone setups may improve the compatibility with these tasks, if for example one mine has a continuous miner helper where another may not. This is in agreement with the recommendations by Horberry, Burgess-Limerick, and Steiner, citing how differences in environment, climate, policies, and experiences can greatly affect usability [12]. Mine operators and manufacturers could consider performing site-specific investigations as described in [12], focusing on these four tasks to help address compatibility issues.

The minimal differences between mobile PDS models across task concerns suggest that the majority of usability issues identified extend beyond model-specific features. Given compatibility and cost-benefit concerns, current mobile PDSs may only be appropriate for specific situations. One way to potentially improve mobile PDS development could be incremental deployment similar to the modular nature of the automotive market (e.g., forward collision avoidance, traffic jam assist). For example, mobile PDS could potentially be limited to specific areas (e.g., on the section), limited to certain machines (e.g., only shuttle cars), or limited to defined activities (e.g., production coal transportation). While some of these examples were observed at the mine site, a more directed effort may help address the mineworkers concerns. Furthermore, changes in scope could be achieved through both technical and administrative solutions, such as integration with communication and tracking systems, modifications of MWC distribution logistics, or authorized overrides. An independent evaluation of underground mining PDSs that included one of the systems in this analysis, along with others that are available internationally, similarly concluded that there is a mismatch between PDS use cases and PDS performance [26]. Mobile PDS manufacturers could consider narrowing the scope of their systems in order to help improve performance and clarify expectations.

The results of our interviews also highlight how mobile PDSs changed how mineworkers perform their tasks by limiting their positioning. According to the mineworkers, areas where they previously safely stood are now off limits because of the implementation of mobile PDSs. These positioning changes resulted in decreased information availability, flexibility, and responsiveness. However, it is unclear whether the changes in positioning are necessary in every situation, or if there are other limiting design factors. As discussed in the results section, many of the mineworkers expressed concern about how far into the crosscuts they had to stand to avoid triggering the mobile PDSs. Changing the shape or setup of the zones by task (e.g., tramming vs. loading) may elevate these concerns. For example, the iPD system for continuous mining machines [6], proposes selective function control and additional zone setups However, the added complexity of such a system may also generate performance concerns. Mine operators and manufacturers could review the intent and features of their systems in order to optimize the tradeoffs between direct and indirect safety.

The results of the study also emphasize mineworkers' concerns over new and increased hazards caused by the implementation of mobile PDSs. Many of the unintended consequences identified by mineworkers relate to task incompatibilities. For example, the shut-off of vehicles' power take-offs (PTOs) increased mineworkers' cumulative physical exposure. When mobile PDSs are triggered (incursion into the red zone) in addition to the shut-off of the vehicle pump (in order to prevent motion), mobile PDSs also disable the PTOs that are often used to run power tools or other devices. Losing the use of these devices requires mineworkers to do more unnecessary manual material handling. In this case, specifically shutting off the PTOs should not be necessary to avoid a collision—it is simply a consequence of the design. While losing small functionalities like the PTOs does not prevent task completion, it does hinder it, and could negatively impact the safety of the mineworker. Mine operators and manufacturers could consider working together to identify and mitigate issues such as these to ensure mineworkers have the right tools to do their jobs safely.

Finally, it is important to note the limitations of the results of this study. First, these conclusions are based on self-reported data. While the researchers did observe a subset of the participants, it was not possible to verify all of the scenarios discussed in the interviews. Additional efforts to ground the validity of the data included discussions with mine operators and manufacturers, which allowed researchers to identify any misconceptions of mobile PDSs. Another limitation of the study was the lack of equal representation for each region and mine size. However, the current population of mine sites that have adopted mobile PDSs is small, and researchers were able to include over 50% of the population in the study at a fairly equal rate. For this reason, the quantitative content analysis was limited to counts.

6 Conclusion

While it is clear that proximity detection systems on mobile equipment have the potential to save lives, it is necessary to critically evaluate their implementation in order to identify incompatibility issues and unintended consequences. This study aimed to explore mineworkers' perceptions to better understand how the implementation and systems themselves can be improved to address mineworkers' usability and safety concerns. Overall, mineworkers reported that mobile PDSs can (1) make mining tasks more difficult, (2) create additional safety concerns, and (3) increase mineworkers' exposure and risk. In order to combat these unintended consequences, mineworkers have expressed a need for (1) improved system-task compatibility, (2) additional training, (3) improved mobile PDS system logistics, and (4) improved mobile PDS performance. The results of this research also suggest that the human-systems integration and user acceptance of mobile PDSs in the mining industry could be improved through (1) additional site-specific usability testing, (2) narrowing the scope of mobile PDS application, and (3) mitigating task incompatibilities.

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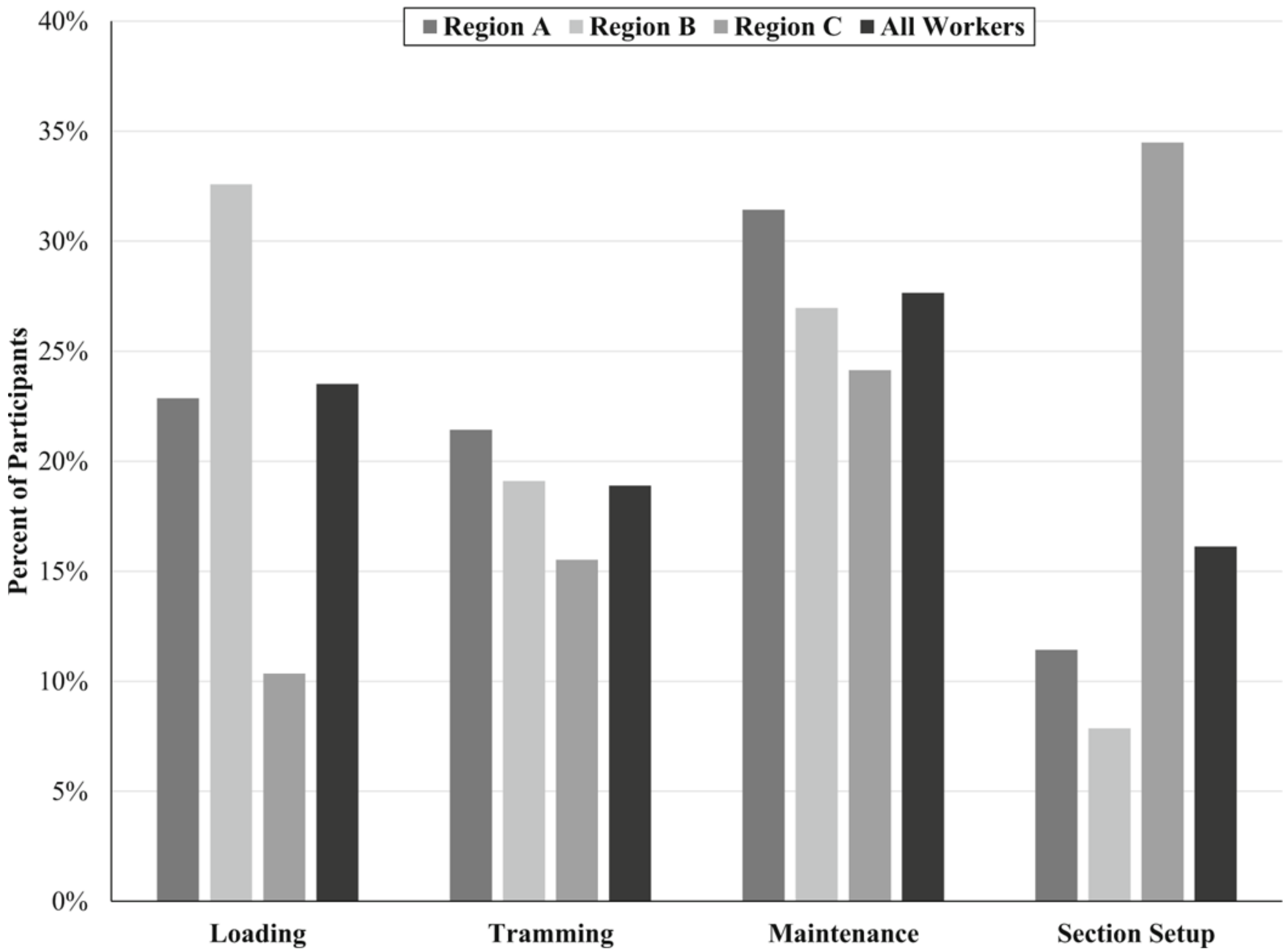

Fig. 1.

Graph depicting percent of participants grouped by region who indicated that mobile PDS hindered or endangered mineworkers performing each of four mining tasks

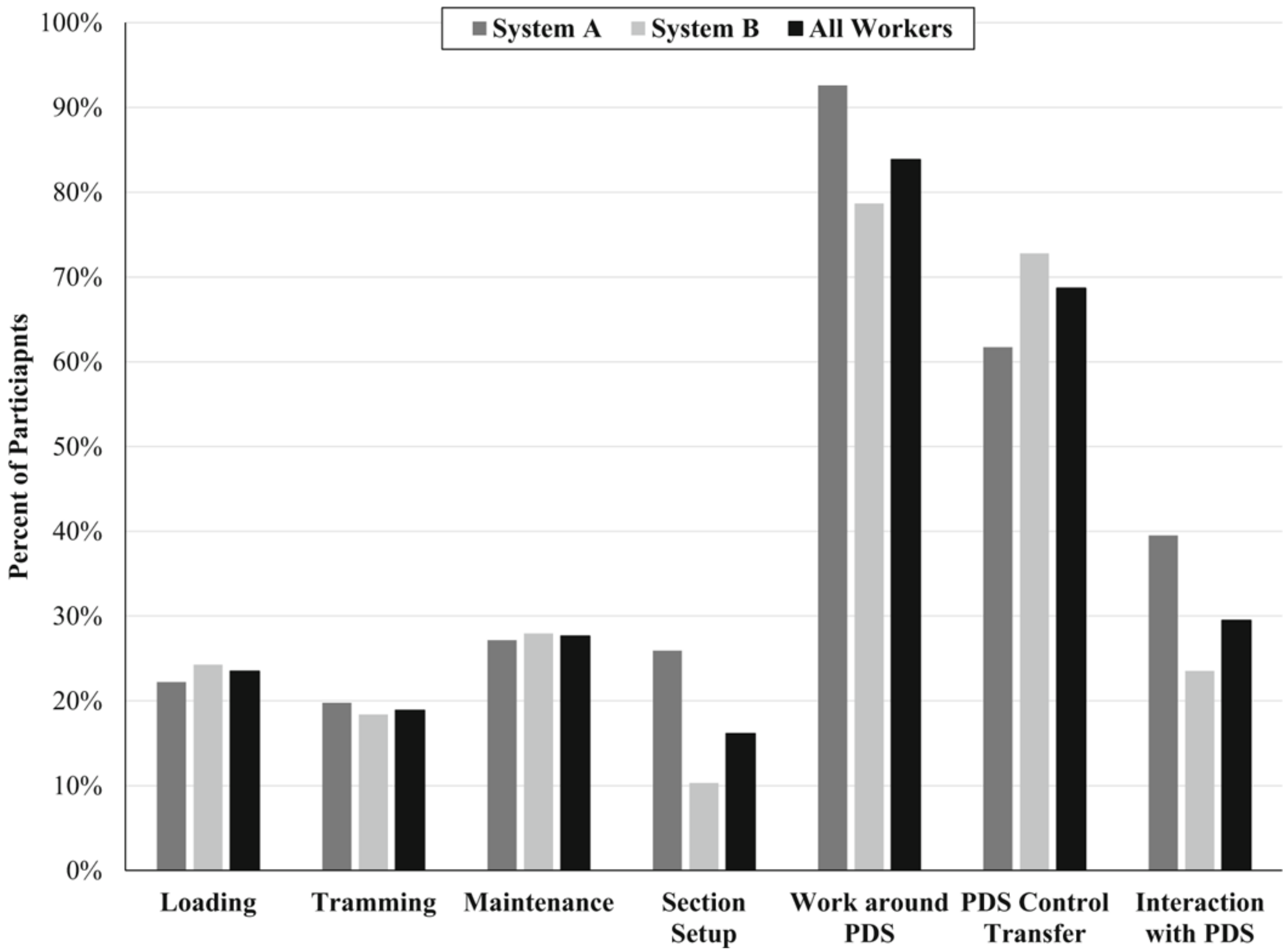

Fig. 2.

Graph depicting percent of participants grouped by mobile PDS model who indicated difficulty performing each of the mining tasks orusing their mobile PDSs

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Table 1

Open-ended interview questions

1.	What do you like about this mobile proximity system?
*2.	What do not you like about this mobile proximity system?
3.	How did you to learn how to use the mobile proximity system?
*4	Can you imagine a situation where the mobile proximity system could put you in danger?
*5.	What would you change about the mobile proximity system?

*Included in content analysis

Table 2

Mine demographic, production, and PDS information

Mine information				Annual production statistics[d]			PDS implementation	
Mine	PDS[a]	Method[b]	Region[c]	UG workers	Hours (millions)	Tons (millions)	Haulage	Scoop
A	A	LW	C	>500	1.6	12.1	Partial	Partial
B	A	LW	B	200–499	1.4	5.4	Partial	Partial
C	A	LW	C	>500	1.4	9.2	None	None
D	B	RP	B	50–199	0.4	2.5	Partial	None
E	A	LW	C	200–499	0.5	4.8	Partial	None
F	B	LW	A	200–499	0.6	5.3	Full	None
G	B	RP	B	200–499	0.6	1.5	Partial	None

[a] Anonymized PDS system brand

[b] LW, longwall; RP, room and pillar

[c] Anonymized geographic region

[d] Rounded production statistics from 2017; Source: MSHA, Mine Data Retrieval System

Table 3

Participant demographic information

Mine	*N*	Age[a] (years)	Experience[a] (years)		
			Mining	Mine	Mobile PDS
A	20	41.5 (10.5)	13.4 (10.8)	7.7 (3.5)	3.2 (2.4)
B	23	43.2 (9.8)	19.6 (11.2)	6.7 (4.8)	2.5 (2.4)
C	18	35.9 (12.7)	10.4 (12.9)	8.0 (7.7)	1.0 (1.3)
D	44	41.0 (12.7)	14.8 (12.4)	6.0 (4.6)	2.0 (1.9)
E	20	40.5 (10.4)	11.0 (8.6)	6.8 (2.9)	1.0 (0.9)
F	70	40.8 (10.8)	12.6 (8.9)	9.8 (4.6)	1.0 (0.3)
G	22	37.3 (9.8)	12.2 (9.0)	5.1 (2.5)	1.7 (1.7)
All workers	*217*	*40.3 (11.1)*	*13.5 (10.6)*	*7.6 (4.8)*	*1.6 (1.6)*

Italicized entries indicates total row

[a]Mean (standard deviation)