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INTEGRATING TECHNOLOGY: LEARNING FROM MINE WORKER PERCEPTIONS OF PROXIMITY DETECTION SYSTEMS

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ABSTRACT

This study sought to identify changes in continuous mining machine (CMM) operators' risk perception and risk behaviors as a result of adding a proximity detection system (PDS) into their environment. To accomplish this research task, 9 CMM operators from 5 locations were interviewed. Interviews were thematically analyzed for constructs including patterns in risk perception and behavior before and after PDS integration and the process of adapting to the PDS. Operators discussed standing in the red zone less than they did before using the PDS; however, they also discussed other risky decisions they made while learning how to operate their CMM with the PDS technology such as "cheating" the technology and working faster to meet production goals. The process of relearning job tasks with technology and unintended behaviors as a result of that relearning process need to be taken into account when introducing new technology into the mine environment. The study results show an in-depth view of mine workers' perspectives and how their job tasks and environment could be or are affected when learning how to use new technology that are relevant to companies and mine operators when introducing new technology into the mine environment.

INTRODUCTION

Established "red zones" can help prevent striking and pinning incidents by providing guidance to continuous mining machine (CMM) operators about where they should stand and not stand while operating a CMM. Although red zones influence operator placement positions, these guidelines are not foolproof safety mechanisms. Depending on the job task and circumstances of the mine environment, a CMM operator may unintentionally or intentionally stand in a red zone. For example, CMM operators may work in close proximity to their CMM for better visual attention cues and the ability to work at a higher rate of production [1-3]. To further enhance protection and prevent collisions between vehicles and mine workers, a proximity detection system (PDS) was developed for the industry. The PDS determines an individual's position relative to a specific piece of machinery, issues visual and/or audible warnings to the mine worker to change positions, and, if necessary, disables machine motion [4].

The introduction of new technology within other sectors has been identified as a factor that influences work decisions. Specifically, previous research demonstrates that when technology debuts there can be an initial intrinsic risk perceived among users about how the technology will interact with their current environment and behaviors; however, these ambiguities, including the possible risks and benefits, are seldom studied [5]. Some research suggests that the constant presence of technology can disrupt situation awareness and decision-making capabilities by increasing worker responsibilities and worker cognitive demands [6-8]. Further, if workers' perceived risks both with and without technology are misjudged, unsafe decisions that result in human error and injury may be more likely [9-11]. Although these statements are provided within a broad contextual framework, they support the need to study how technology is perceived among end users in their own environment. Because research about technological impact on worker behaviors has suggested both positive and negative consequences of technology, this issue is worth addressing in the mining industry. Specifically, research has not determined whether CMM operators view their placement choices in the red zone as safe or risky and what effect PDS technology has, if any, on risk perception and subsequent risk behavior.

Given the likelihood of upcoming regulatory changes, it is particularly timely to study ways that the PDS technology influences CMM operators' assessment of their environment, perception of risk, and risk behaviors. In the near future, it is likely that all mobile mining equipment in underground coal mines, not just CMMs, will be equipped with a PDS.[1] Also, exploring individuals' responses to the PDS and any changes in their ability to perceive, understand, and project safe decisions may help minimize preventable incidents among CMM operators and inform future safety training and communication around the PDS. Therefore, a qualitative study was completed with CMM operators who both have and have not used a PDS while operating their CMM. Before the methods and results of the study are presented, a brief review of the situation awareness and risk perception literature is provided to further justify and provide an analytic framework for this study.

Situation Awareness

Situation awareness (SA) is an individual's understanding of his or her active environment including "perception and interpretation of both environmental and personal stimuli, and making predictions of the status of various elements of the situation in the near future" [12, p. 2]. Endsley [13-15] discussed three levels to SA: perception, comprehension, and projection.

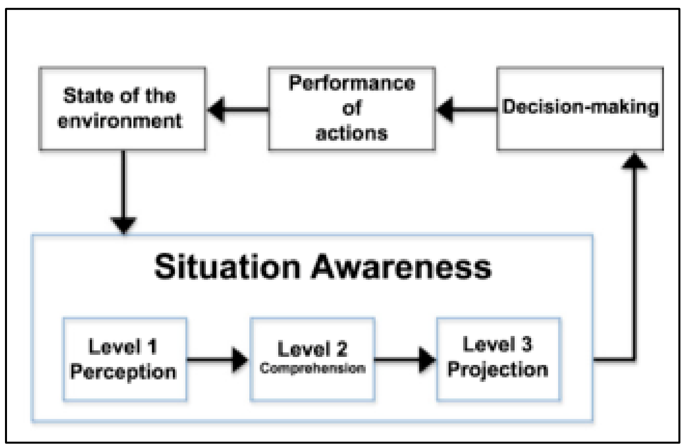

Figure 1. Endsley's (2000) model for situation awareness.

1. **Perception.** An individual perceives information and cues within the environment (e.g., auditory, visual cues) to help form a picture of one's surroundings.

[1] The Mine Safety and Health Administration has a proposed rule titled, "Proximity Detection Systems for Continuous Mining Machines in Underground Coal Mines" that would be under CFR 30 Part 75.

2. **Comprehension**. An individual combines and interprets the external stimuli to inform a universal understanding of the situation and determine the relevance of the information to individual goals, experience, and knowledge.

3. **Projection.** An individual predicts future actions within aspects of a situation. Based on personal experiences and predictions, decision-making occurs in response to various stimuli.

Individual judgment and confident decision-making is dependent upon previous observations and experiences. Accordingly, if SA is disrupted, it becomes more difficult for individuals to predict their future state of control, make appropriate decisions, and mitigate hazards [16]. The ongoing cycle of accurate SA, decision-making, and performance can be enhanced or decoupled through various workplace factors, such as new technology, and can alter perceived risks and risk behaviors in the environment [14]. For instance, research shows that industrial operators often do not have difficulty performing routine job tasks with new technology; however, they become overburdened by understanding a new, unexplored situation if something goes wrong and they cannot accurately assess risks [13]. Thus, the impact that new technology, such as the PDS, has on mine workers' SA, and subsequent perceived risks and risk decisions, should be assessed to better understand the worker/technology interaction process and prevent unintended consequences referenced in other industries.

Risk Perception

Changes in SA can influence individuals' perceived risks, including their recognition of hazards, decision-making, and safety behaviors [17]. Risk perception is an individuals' personal assessment of the probability of a specific incident occurring and subsequently, how concerned the individual is with the consequences of that incident [18-20]. Based on the degree of probability and associated concern about the severity of consequences, an individual makes specific decisions to engage in risky or safe behaviors on the job. It is common for perceived risks to be influenced by a dynamic work environment. However, risk perception and its relationship to risk-taking behaviors has received little attention in worksite and specifically mining research [21]. This project sought to study this issue with CMM operators and the PDS technology that is placed on the CMMs, to help inform the safest integration of PDS technology into the mine environment, with the mine worker.

METHODS

National Institute for Occupational Safety and Health (NIOSH) researchers developed a semi-structured interview guide using theoretical and empirical research on risk perception and risk behaviors within an SA framework. Health behavior [22,23] and social psychology theories [24] informed questions related to risk perception, hazard identification and mitigation, and behavioral response to new technology.

Participants

Nine CMM operators (operator experience 1.5–33 years, M = 11.8 years) from five locations were interviewed during January and February 2014. Mining experience ranged from 3 to 33 years (M = 20.8 years). Six CMM operators were using a PDS (7 months–2 years, M = 1.2 years) and the other three had knowledge of but no experience using a PDS. In addition, mine locations had varying types of PDS equipment on their CMMs and several CMM operators had experience using more than one type of PDS. Two participants were under 30 years of age; one was in the 30 to 39 years of age range; two were from 40 to 49 years of age; and four were 50 years or older. After the first five interviews were conducted, the subsequent four provided no new information, indicating saturation of content [25]. Because the researchers were comfortable with the breadth and depth of data collected to answer the study's questions, the recruitment ended here.

Data Analysis

Interview notes were used to thematically code the data using a grounded theory approach [26]. The analysis steps included:

1. *Initial coding.* Data were classified by their units of meaning [27] in which short sequences of words were identified that could potentially be meaningful and that could show patterns of similar perceptions.

2. *Axial coding.* Data were further refined with respect to the initial codes and study questions [27]. Full passages from the data that were noted and assigned during initial coding were read, and linkages within and between these codes were further identified.

3. *Constant comparison.* Various sections of data throughout the interviews were compared for similarities and differences because the interview probed perceptions and behaviors pre- and post-PDS integration as well as predicted reactions and experiences upon integration [26]. Conceptually similar incidents were grouped together.

4. *Theoretical comparison.* A final reading was undertaken using a theoretical comparison framework to help inform the discussion in the area of mine workers' risk perception and behaviors and technology acceptance.

A validation process occurred in which an additional researcher participated in reliability coding, known as inter-rater reliability [28]. Discussions about the analysis and the meanings of the coded themes that surfaced throughout the analysis took place. One code was removed and the analysis codebook was finalized.

RESULTS

Results highlight ways in which PDS technology temporarily altered CMM operators' situation awareness and subsequent risk perception, influencing their risk decisions and behaviors as they adapted to the technology.

CMM Operators' Previously Established Situation Awareness

The first section of the interview assessed CMM operators' current perceptions of risk and hazards in their surrounding environment. As referenced earlier, the three levels of SA are comprised of perception, comprehension, and projection, which allow individuals to make quick, safe decisions on the job. Results indicate that CMM operators' had an established and automatic SA, which resulted in fewer perceived risks on the job. The following sections detail results that depict the SA of CMM operators before the PDS and how this SA contributed to their perceived risks and risk behaviors.

1. Perception: Ability to Perceive Hazards in a Familiar Environment

One reason that CMM operators formed a strong SA is because of the comfort in their current environment and ability to recognize and mitigate typical hazards on the job. They discussed "typical hazards" they have to be aware of including rib rolls, roof falls, the location they choose to position themselves in proximity to the CMM, and other workers' risky behaviors that may compromise their personal safety. Possessing an accurate working knowledge of where to watch and how to identify and respond to potentially hazardous conditions increased operators' SA and lowered their risk perception. However, when discussing a new situation, such as being surrounded by a new hazard in which the operators had little working memory on how to respond, they reported an increase in their perception of risk until they became accustomed to the new situation.

2. Comprehension: Knowing their Environment Influences Optimism on the Job

In general, CMM operators expressed that their risk of experiencing an injury while performing job tasks was fairly low due to their confidence responding to external stimuli on the job. For example, Operator 8 said, *"It is not really risky for me because each individual will make it risky or dangerous. It's the way they are doing their job and the way they think."* Operator 1 said, *"I've been doing this for 16 years. I'm pretty experienced and capable. But really, anything is risky in mining so this job is no different. I don't feel like I am at a bigger risk than anyone else down there. But I also know how to do my job."* Unless operators were faced with a new scenario in which they had little experience, they did not feel a sense of risk because of their perceived knowledge and ability to comprehend any given situation while operating their CMM.

3. Projection: Experience Impacts Perceived Control over Personal Safety Outcomes

CMM operators communicated that they were equipped to appropriately respond to a hazard, whether their preparation stemmed from experience, training, or personal efficacy. Based on CMM operators' ability to perceive environmental cues and draw these stimuli together to understand the environment, they discussed being able to predict future aspects of their situation and make appropriate decisions. In other words, they felt in control of their situation. However, due to this perceived ability to make quick decisions, sometimes these operators participated in riskier behaviors, such as standing in the red zone. This notion is illustrated by Operator 6:

> "I probably would stand in the red zone about 20% of the time. It's really all about balance- what makes my job easier between not. When I'm standing in the red zone I always think about that [it being risky]. You're always weighing the pros and cons when you're doing it or thinking about doing it. You usually think about being more productive than being safe though. But, if I felt it was in my best interest, I would definitely do that [not stand in red zone]...People get comfortable and do take chances."

However, if a near-miss accident occurred (e.g., almost struck by the CMM), the operators' SA was disrupted, their perceived risk increased, and behaviors were safer for a while. As Operator 4 stated, *"I got out of the way just in time. I was lucky. I didn't stand there [in the red zone] for a while. Then you kind of forget and get back up there over time. You say you will never do it again but then time passes."* This quote illustrates that one's sense of control and perceived risk often is based on personal experience.

Impact of PDS Technology on Situation Awareness

CMM operators who were using the PDS indicated that, at some point in time, they had less control over their exposure(s) to certain hazards. However, others commented that after they became familiar with the new technology, they had an even more accurate SA of their environment. Findings are further explained in the sections below, using the SA framework to illustrate the shifts in risk perception and risk behavior as a result of adding the PDS to their environment.

Risk Perception

1. Perception: Difficulty Recognizing and Troubleshooting "New" Hazards

CMM operators indicated that the PDS generated situations for which they had little working knowledge, which tended to increase their perceived risks on the job. This topic emerged as they discussed prior experiences of the technology malfunctioning. Operators indicated that, when or if the PDS malfunctions, such as shutting down machine operation when it should not, they have less control over certain risks based on where they are placed at the time.

Operator 9 demonstrated a hypothetical scenario in which unintended consequences could occur, using a trainer CMM above ground: "*So, if I'm in, pillaring the miner [here] and the shuttle car will trap me [here] and I can't get out. But then if the roof falls and the miner won't start because of prox, I'm trapped.*"[2] Other common responses included, *"In general, I feel like I have less control over my environment now because I have to be aware of so much more. I can't ensure I'm in the safest place I should or could be"* (Operator 1).

Specific hazards mentioned included visibility issues and being under unsupported roof. When operators noted that the PDS functioned as intended most of the time, they focused on the process of re-acclimating themselves with these new situations. This topic moves into the next level of SA in which individuals begin to comprehend a more unique situation to their job after perceiving new cues in their environment.

[2] It should be noted that all of the proximity detection systems on the market have an emergency override that can be used in scenarios like this to disable the system for a short duration to move the CMM and free a trapped mine worker.

2. Comprehension: Relearning Safety

After using the PDS, CMM operators who previously made riskier placement choices began modifying their work routine. CMM operators disclosed that they stood in the red zone much less than they did before [the PDS]. They were surprised to learn how much they stood in the red zone. For those who had more time and experience using a PDS, they mentioned relearning where to stand while doing their job. For example, Operator 5 said:

> "I am less likely to be struck now than I was before, I would say. I have had near misses in the past, not with my miner, but just in general. Now I don't think I'll have any with the machine. It has shut off many times while I've been using it and I've had to move out of a bad spot. Honestly, I was surprised when we started using this. I eventually learned to do things different. I learned what I shouldn't be doing but was. I was surprised how many times it shut off on me at first."

For operators who did not have experience with a PDS, they anticipated standing in the red zone much less as well. Operator 6 said, *"Oh I'm sure I would change [my behaviors]. I couldn't get as close to the machine if it keeps turning off…With this, we'll relearn it; they'll be able to relearn. But you're relearning your job with new limits. It really exposes you and your bad habits. You're relearning and that's hard."* Similarly, Operator 9 said, *"For the experienced ones it is frustrating and you're learning all over again. You may be more apt to adjust but it's tough. It's a mindset. At first, I felt like there was no way I could run a miner with a PDS. But it's just about retraining yourself. Any bad habit can be broken if you try."*

Even if a long integration process occurred due to comprehending new information in their environment, most operators recognized the positive outcomes of the technology and eventually felt safer on the job. After adapting to a new cue in the environment and using new information to re-inform their personal understanding of the situation, CMM operators indicated they were able to project certain work task situations again.

3. Projection: Reestablishing Situation Awareness

Regardless of the new technology, CMM operators said that they still have to be aware of the same hazards (e.g., loose rock) even though they may be re-acclimating themselves with these potential hazards. In general, as CMM operators became more comfortable with the PDS and began to comprehend their new surroundings, in their new placement(s), their SA was reestablished. Then, personal feelings of risk decreased again, as illustrated in the following excerpts:

> "It's shown me where I was when I shouldn't have been. So obviously my risk is lower since I can't stand there anymore and still be able to do my job. Before you kind of know you shouldn't be there but now you really know and you can't be there." (Operator 5)

> "I think my chances of getting mashed have decreased a lot. I mean, the miner had shut down and then I realized I was standing in the red zone. So, it's made me realize I was standing in an unsafe area. Sometimes I knew it sometimes I didn't." (Operator 4)

Comments by CMM operators indicate that, in general, perception of risk is highly dependent on their personal experiences with the technology. Therefore, although some of the comments may illustrate a higher sense of anxiety in response to technology integration, their subsequent experiences with the PDS provide a more accurate view of how the technology may be received and helpful in the future. For instance, Operator 3 said in reference to the PDS as a device that can help call attention back to hazards in the mine environment: "*In my opinion, I think it can be easy to get distracted, there is so much to watch for, you can always watch for the wrong thing one time."*

These results reveal that a disruption in SA can cause an increase in perceived risks. When CMM operators' perceived risks were high, they discussed behaviors to help increase protection or avoid potential hazards. The next section highlights some general changes in risk behavior that occurred when the PDS was just being introduced, SA was disrupted, and perceived risks were higher.

Risk Behaviors

The results of this study support previous research indicating that, as SA is altered with the addition of new technology, perception of risk and risk behaviors may increase. In some cases, these behaviors were safer or riskier, depending on the situation of the CMM operator at the time. Specific behaviors are discussed next.

Position Placement

A common behavior discussed throughout the interviews was placing oneself in a different spot while operating the CMM. CMM operators mainly talked about how often or where they would stand in the red zone. They discussed that, instead of standing in the red zone, where they were at risk for pinning or striking injuries, they were standing in another position that presented new or different risks, such as a roof fall, rib roll, or a location where they could not be easily seen by other workers, such as shuttle car drivers.

For instance, Operator 3 said, *"…making sure I'm out of the red zone. But then instead I'm under bad roof conditions. There's not much I can do. I just have to keep tramming and hope for the best."* Thus, perceived risk and risk behaviors increased because of where they were standing at certain times while tramming.

"Cheating" Technology

When frustrated with the outcomes associated with PDS, operators discussed what they would do to "cheat" the technology system so they could either complete their job task or complete their job task as desired. For instance, Operator 1 said, *"So, I have to cheat the system. I have to put it [the remote] on top of the CMM so the machine will run. I wear it as much as I can [I wear it around my neck] but if it is not working right then I have to put it on top so the CMM will run."* [3] In other instances, CMM operators referenced someone else cheating the technology, such as another co-worker or supervisor. Even the operators who did not have experience using a PDS indicated that they already knew ways to cheat the system.

Cutting Corners to Meet Production

Some CMM operators discussed a loss in production time as a result of using their PDS. Regardless of whether the PDS shuts down due to an operator's placement error or malfunctions due to environmental stimuli, CMM operators indicated that it might just take a few minutes to get their CMM running again but in some instances, can take up to 15 minutes. As a result, CMM operators said they sometimes work faster to make up production time. This situation is demonstrated in the following statement:

> "I mean, if it would only happen a couple times and it takes a few minutes here and there to get up and running again, that's fine. But when you have a problem and it keeps going off and on, that time really adds up. If this gets repeated and I lose a lot of time, you sometimes have to work faster, cut corners, to catch up."

These results highlighted ways that the introduction of the PDS temporarily altered CMM operators' SA, perceived risks, and risk behaviors.

DISCUSSION

Reestablishing Situation Awareness

The results of these interviews illustrate that CMM operators experience a change in some type of external stimuli when first learning how to use and integrate PDS technology into their job. Whether mine workers begin to perceive loose rock, the level of dust around them, have new visual attention cues, or can communicate using a new medium, these newly identified stimuli alter some aspect of their individual environment. The subsequent sections provide considerations relevant to levels of SA for manufacturing companies and mine operators to proactively address when introducing new technology into the mine environment.

Mine Technology Manufacturers: Assist with Accurate Perceptions of the New Environment

Research in pilot traffic safety found that 76% of SA errors among pilots were traced to problems in their perception of necessary information within their environment [29]. Just as pilots experienced failure due to shortcomings in their information system, mine workers can experience the same problems when surrounded with new cues to recognize. Mine technology manufacturers should be aware of how technology can and may change mine workers' perception of their environment and be able to offer specific information and training to proactively help mine workers understand what hazards may be less of an issue or more of an issue for them on the job.

Provide Realistic Expectations Training

Even if mine technology is flawless or works well most of the time; the technology still has to be interpreted and used correctly by the worker. CMM operators asserted that each individual has different mindsets, habits, perceptions, behaviors, and past experiences that influence how they may react and adapt to new technology. They suggested that creating and delivering more realistic training about the technology and how their new surroundings may look when using the technology, may help to address some of these varying perceptions and experiences. They felt that allowing mine workers to more rigorously pre-test technology throughout its development and during training would be helpful in beginning to learn what changes may occur in their job tasks and hazards they may have to be more aware of than prior to the technology.

Realistic and practical training were suggested throughout the interviews, as demonstrated by the following from Operator 6: "You need training before it [the PDS] is being introduced into the mine. The tactile skills are needed. They need to understand how it actually works. Miners need to know it's a process, it's not magic. They need to know exactly how and why it's working the way it is so they understand that process and can respect that…We need more practice with it before it's introduced into the mine."

CMM operators who participated in this study expressed that if the training they were provided were improved, they would have more realistic expectations of the technology. Therefore, developing and implementing various types of simulated training scenarios may be useful to help CMM operators understand how the PDS may affect their surroundings and different tasks they perform as they operate their CMM.

Proactively Address Glitches to Prevent Negative Communication

Results support the need for proactively understanding and responding to problems, which may help prevent negative communication about new mine technology such as the PDS. Particularly, CMM operators who did not have experience with the PDS had a more negative perception toward the system based on what they had heard from workers at other mine sites who did have experience with a PDS.

Negative communication before the technology is disseminated can halt workers' willingness to adapt to and appropriately use the technology [30]. Because negative communication often is repeated more often than positive communication, research suggests creating communication that attempts to correct the critical "bugs" in the end users' beliefs [31]. When individuals hold inaccurate or negative beliefs, it could lead to inappropriate or, in this case, riskier actions.

Therefore, understanding exactly what CMM operators think about and may communicate about the PDS may help positively alter perceptions of end-users' experience when the technology debuts. Understanding what communication and subsequent behavioral consequences may result is helpful in determining what accurate and positive messages are needed on behalf of manufacturing companies when they conduct pre-training or initial check-ins with a mine site.

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[3] The example provided by the operator is an issue with older proximity detection systems that the manufacturer has since fixed.

Be Prepared for a Long Integration Process

Interview results indicate that substantial human/technology integration can take a long time, especially when workers are exposed to new perceptual cues to identify and respond to on the job. Therefore, if technology is either perceived as not working or not working as guaranteed, negative experiences can influence mine workers' willingness to accept the new technology.

Specifically, several CMM operators said that, as the PDS is functioning now (i.e., inconsistently), they are more hesitant to accept it as a part of their daily routine. For instance, Operator 1 said, *"I'm not against the PDS but it needs perfected better. Sometimes it works and sometimes it doesn't…The intention is good, but it's not there yet."* Technology acceptance contributes to personal risk perception and risk behavior [32]. Therefore, it was not surprising when CMM operators continued to say that all technology needed to be foolproof well before implementation with workers.

Several CMM operators said that adding the PDS to their environment was a difficult adjustment. However, they eventually formulated a new SA relevant to their surroundings. For instance, CMM operators were quick to say that, once the PDS was working better than when it was first introduced at their mine site, they preferred using it over not. Operator 4 said, *"Everybody hates change at first, including me. But this is a good thing; I think we can all agree on that."* Understanding the target group for any new technology is helpful to craft information for that audience about new technology.

Mine Operators and Safety Personnel: Assist with Comprehending a New Environment and Projecting Future Situations to Maintain Awareness and Safety

Even if workers perceive the necessary cues as a result of their environment changing, after technology is introduced into the actual mine environment and mine workers begin using it during actual job tasks, it is likely that all of the new external stimuli, together, will interrupt the current understanding of their environment. Flach [33] indicates that if workers can maintain a sense of ecological realism when trying to understand and construct a situation, timely decision-making (i.e. projecting) is more possible. Therefore, the following considerations are offered for mine operators and safety personnel to try to maintain workers' comprehension and ability to continue making safe decisions on the job. These ideas may help workers combine, interpret, and store new information so they can maintain a high level of SA and project future scenarios and make decisions.

Frame Technology as a Learning Tool

First, CMM operators commonly expressed that mine technologies, including the PDS, are better tools for learning safety behaviors rather than changing safety behaviors. Although learning ways to be safer while operating a CMM may lead to behavior change, CMM operators indicated that, when framing the PDS as a learning device and not a safety device, they were more receptive to the technology.

There could be several reasons for how this subtle terminology difference influences technology acceptance. For example, it may be off-putting for mine workers to use a technology if it was communicated to them in a way that they need to use it because they are either not engaging in safe behaviors or that they need more protection during their job. Specifically, experienced operators who are more habitual in their work practices may react more adversely toward something that has the intention of changing those habits.

Instead, mine operators and safety personnel are encouraged to discuss new mine technology, when applicable, as an aid to help their employees either learn or refresh the nuances of their job-related tasks, while emphasizing that operators are likely performing their job as safely as possible. Particularly, when making a new cut in a new section of the mine, varying geologic conditions and thus, new hazards, may be present that the operator has not worked in for an extended amount of time. Framing the PDS as a tool to help recognize and avoid those hazards may be received more positively than framing the PDS as a tool that does not let an operator stand in the red zone. This learning-oriented communication approach may encourage a more positive response to the technology.

Be Aware of Worker Complacency

Research shows that a lowered sense of risk is more likely to occur as experience and confidence increase while performing routine tasks [34]. CMM operators' responses support this point: Upon adaption to mine technology and the reconfiguration of situation awareness, risk perception generally decreased [after a temporary spike]. At this point, however, the CMM operators who were interviewed became concerned with complacency and subsequent errors in behavior. In response, mine operators and safety personnel should be attentive to the possibility of reliant and complacent behaviors once technology integration occurs on site.

Regardless of the technology used, workers can become complacent and momentarily lose focus. Mine operators and safety personnel should be attentive to this possibility when the PDS and other new technology enter the mine and employees adapt the technology into their daily work practices. Therefore, extra inspections, communication, and safety meetings related to the technology should not end once the technology is fully integrated. Rather, communication with mine workers should continue to encourage on-the-job awareness and learning.

Learn Lessons from Past Technologies

It is important to learn from past experiences to prevent a negative, ongoing cycle of technology integration problems. Specifically, research shows that the brain responds to positive and negative information in different hemispheres [35]. These researchers noted that negative feelings and experiences usually require more thinking, and the information is processed more thoroughly than information associated with positive feelings and experiences. In response, individuals often remember and describe negative experiences more often than positive ones.

CMM operators expressed similar problems with previous technology that had been introduced into the industry. Specifically, CMM operators experienced many of the same issues with CMM wireless remote technology as with the PDS. These negative experiences stuck with several of the operators and contributed to their apprehensive attitude toward PDS technology at the onset of its introduction into the mine environment. However, as with the PDS, these CMM operators also became reacquainted with new surroundings and new placement in response to the wireless remote technology. For example, Operator 8 commented, *"It will be a fight with people when the system is introduced to change behaviors. It will be aggravating. But it will happen. Look at the 20 pound remote we had to get used to. That was aggravating."* Every mine site is different. However, mine operators and safety personnel are encouraged to reflect on past experiences of new technology being integrated at their specific site, among their employees, to learn if anything could be done differently to prevent negative experiences.

Specifically, upon introduction of new technology, a goal should be to engage in a realistic dialogue with mine workers about how the technology is affecting their work environment and ability to make decisions. For example, related to the PDS, mine operators or safety personnel can have the following dialogue with their CMM operators regarding their new technology:

- **Gauge perception:** What is different about your environment than before? What is different about your surroundings? Visual cues? Noise level?
- **Inform understanding:** How have these factors affected your job? Are you doing anything differently? Have you learned anything new about your job tasks since using this technology? Is there anything I can help with?
- **Discuss decision-making strategies:** What are some problems you anticipate in the future, based on using the technology? What are some decisions you may have to make based on these varying factors/stimuli?

Research suggests that if the new representation of the environment is discussed (e.g., during the second level of SA, comprehension)—meeting the challenge of helping individuals analyze their new workload, work tasks, and acquire the necessary knowledge—then the initial at-risk decisions are less likely to occur [16]. These types of discussions can allow workers to reference previous problems they had when using old technologies and any similarities. Or, workers at least have the opportunity to discuss general concerns for their safety, because they are not yet comfortable with the technology and as a result are engaging in some riskier behaviors.

To demonstrate, one barrier referenced by CMM operators when new technology is introduced is the loss in production time. Several CMM operators noted that, even if there is new technology and it is difficult to use at first, they are still expected to make a quota. Rundmo [17] indicated that the more management emphasizes production goals, the more employees may tend to take chances and break rules. Perhaps production quotas should be lower during times of technology introduction and integration into the mine. This lower expectation may communicate to workers that the technology is important for them to learn and they may feel like they have more time to learn how to use it safely.

Interview results indicate that if technology is not consistently working as designed, mine workers' SA can be disrupted. However, the results also revealed that if the PDS technology is working properly and individuals receive realistic training and communication about it, then PDS technology can be a useful tool to enhance the spectrum of workers' SA by adding potential scenarios to their working memory. Specifically, PDS technology allows operators the opportunity to notice and adapt to additional hazards of which they may not be aware. Therefore, reliable safety technology may help to further develop the SA of workers while performing their job tasks.

LIMITATIONS AND CONCLUSIONS

Some of this information may already be known by manufacturers and mine site leadership. More specifically, because several versions of the PDS exist, feedback may vary based on the type of PDS being used and its current capabilities within each specific mine environment. For this study, mine sites with varying proximity detection systems were recruited in an effort to gather the most universal sample possible for analysis. However, because the focus of the study was on the effects of the mine technology on risk perception and behavior, the types of PDS used at each mine site were not the focus of the current project. Thus, manufacturers and mine operators should consider this information when interpreting the results.

This article discussed the importance of assessing mine workers' perception of risk before and after introducing PDS technology into the mine environment. Although the results of this study are only part of a small pilot and cannot be generalized across the industry and across technologies, data from CMM operators supports the argument that unintended consequences, such as a disruption in situation awareness, risks, hazards, and decision-making capabilities, can be avoided if human factors considerations are engaged and integrated into each stage of the technology design and implementation process. Specifically, gaining an in-depth view of mine workers' perspectives and how their job tasks and environment could be or are affected may help to prevent accidents and injuries that have been labeled as human error in the workplace.

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REFERENCES

1. Bartels, J.R., Gallagher, S., and Ambrose, D.H. (2009a). Continuous mining: A pilot study of the role of visual attention locations and work position in underground coal mines. *Professional Safety,* 54(8), pp 28-35.

2. Bartels, J.R., Jobes, C.C., DuCarme, J.P., and Lutz, T.J. (2009b). Evaluation of work positions used by continuous miner operators in underground coal mines. *Proceedings of the human factors and ergonomics society.* Annual Meeting; 53rd Human Factors and Ergonomics Society.

3. Steiner, L.J., Turin, F.C., and Hamrick, C.A. (1994). Ergonomic and statistical assessment of safety in deep-cut mines. Pittsburgh, PA: U.S. Department of the Interior, Bureau of Mines, SP 18-94,Jan, 1-179.

4. Ducarme, J., Carr, J., and Reyes, M. (2013). Smart sensing: the next generation. *Mining Magazine,* July/August Issue, pp. 58-66.

5. Sjöberg, L. (2002). Attitudes toward technology and risk: Going beyond what is immediately given. *Policy Sciences,* 35, pp. 379-400.

6. Militello, L.G. and Hutton, J.B. (1998). Applied cognitive task analysis (ACTA): A practitioner's toolkit for understanding cognitive demands. *Ergonomics,* 41(11), pp. 1618-1641.

7. Militello, L.G., Hutton, R.J.B., Pliske, R.M., Knight, B.J., Klein, G., and Randel, J. (1997). Applied cognitive task analysis (ACTA) methodology. Navy Personnel Research and Development Center. San Diego, CA. Contract No.: N66001-94-C-7034.

8. Naderpour, M., Lu, J., and Zhang, G. (2014). A situation risk awareness approach for process systems safety. *Safety Science,* 64, pp. 173-189.

9. Rasmussen, J. (1993). Deciding and doing: Decision making in natural context. In Klein, G., Orasanu, J., Calderwood, R., and Zsamok, C.E., eds. *Decision making in action: Models and methods*. Norwood, NJ: Ablex. pp. 158-171.

10. Rasmussen, N.C. (1981). The application of probabilistic risk assessment techniques to energy technologies. *Ann Rev Energy*, 6, pp. 123-138.

11. Reason, J.T. (1990). *Human error*. New York, NY: Cambridge University Press.

12. Elliott, M.A., McColl, V.A., and Kennedy, J.V. (2003). Road design measures to reduce drivers' speed via "psychological" processes: A literature review (TRL Report 564). Crowthorne: Transport Research Laboratory.

13. Endsley, M.R. (2006). Situation awareness. In: G Salvendy (ed.), *Handbook of human factors and ergonomics.* John Wiley and Sons, pp. 528-542.

14. Endsley, M.R. (2000). Theoretical underpinnings of situation awareness: A critical review. In M.R. Endsley, D.J. Garland (eds.). *Situation awareness and measurement.* Mahwah, MJ: Lawrence Erlbaum Associates.

15. Endsley, M.R. (1995). Measurement of situation awareness in dynamic systems. *J Hum Fact Eron Soc:*65-84

16. Wong, B.L., and Blandford, A.E. (2001). Situation awareness and its implications for human–systems interaction. In W. Smith, R. Thomas, M. Apperley (eds.) *OZCHI 2001: Usability and usefulness for knowledge economies: conference proceedings* (pp. 181-186). Edith Cowan University: Perth, Australia.

17. Rundmo, T. (2001). Employee images of risk. *Journal of Risk Research*, 4(4), pp. 393-404.

18. Carter, G., and Smith, S. (2006). Safety hazard identification on construction projects. *Journal of Construction Engineering and Management,* 132, pp. 197-205.

19. Sjöberg, L., Moen, B.E., and Rundmo, T. (2004). Explaining risk perception. An evaluation of the psychometric paradigm in risk

perception research. Norwegian University of Science and Technology. Trondheim: Norway.

20. Rohrmann, B. (1998). The risk notion–epistemological and empirical considerations. In Stewart, M.G., & Melchers, R.E. (Eds.): *Integrative risk assessment*; Rotterdam: Balkema.

21. Weyman, A., Clarke, D.D., Cox, T. (2003). Developing a factor model of coal miners' attributions on risk-taking at work. *Work & Stress,* 17(4), pp. 306-320.

22. Janz, N.K., and Becker, M.H. (1984). The health belief model: A decade later. *Health Education Quarterly*, 11(1), pp. 1-47.

23. Petty, R.E., and Cacioppo, J.T. (1986). The elaboration likelihood model of persuasion. *Advances in Experimental Social Psychology,* 19, 123-205.

24. Kahneman, D. and Frederick, S. (2005). A model of heuristic judgment. In K.J. Holyoak, and R.G. Morrison (Eds.), *The Cambridge handbook of thinking and reasoning*. New York: Cambridge University Press. pp. 267-293.

25. Corbin, J. and Strauss, A. (2008). *Basics of qualitative research.* 3rd ed. Thousand Oaks, CA: Sage.

26. Glaser, B.G. and Strauss, A.L. (1967). *The discovery of grounded theory: Strategies for qualitative research*. Chicago, IL: Aldine Publishing Company.

27. Strauss, A. and Corbin, J. (1990). *Basics of qualitative research: Grounded theory procedures and techniques.* Newbury Park, CA: Sage.

28. Armstrong, D. (1997). The place of inter-rater reliability in qualitative research: an empirical study. *Sociology,* 31, 597–606.

29. Jones, D.G. and Endsley, M.R. (1996). Sources of situation awareness errors in aviation. *Aviation, Space, and Environmental Medicine,* 67(6), pp. 507-512.

30. Wahlström, B. (1992). Avoiding technological risks: The dilemma of complexity. *Technological Forecasting and Social Change*, 4*,* pp. 351-365.

31. Fischhoff, B., Bostrom, A., and Quadrel, M.J. (1993). Risk perception and communication. *Annu Rev Publ Health,* 14, pp. 183-203.

32. Fukuyama, F. (1995). Trust: Social virtues and the creation of prosperity. New York, NY: Free Press.

33. Flach, J.M. (1995). Situation awareness: proceed with caution. *Human Factors,* 37*(*1), pp. 149-157.

34. Slovic, P., Fischhoff, B., and Lichtenstein, S. (1982). Facts versus fears: Understanding perceived risks. In D. Kahneman, P. Slovic, & A. Tversky (Eds.), *Judgment under uncertainty: Heuristics and biases*. Cambridge: Cambridge University Press.

35. Nass, C. and Yen, C. (2010). *The man who lied to his laptop: What we can learn about ourselves from our machines*. New York, NY: Penguin Group.