



HHS Public Access

Author manuscript

Int J Min Sci Technol. Author manuscript; available in PMC 2022 August 02.

Published in final edited form as:

Int J Min Sci Technol. 2019 May ; 29(3): 371–378. doi:10.1016/j.ijmst.2019.02.001.

Using self-determination theory to identify organizational interventions to support coal mineworkers' dust-reducing practices

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Abstract

Advancing the application of safety and health (S&H) technologies is likely to remain a value in the mining industry. However, any information that technologies generate must be translated from the organization to the workforce in a targeted way to result in sustainable change. Using a case study approach with continuous personal dust monitors (CPDMs), this paper argues for an organizational focus on technology integration. Although CPDMs provide mineworkers with near real-time feedback about their respirable coal dust exposure, they do not ensure that workers or the organization will continuously use the information to learn about and reduce exposure sources. This study used self-determination theory (SDT) to help three mines manage and communicate about information learned from the CPDM technology. Specifically, 35 mineworkers participated in two mixed-method data collection efforts to discuss why they do or do not use CPDMs to engage in dust-reducing practices. Subsequently, the data was analyzed to better understand how organizations can improve the integration of technology through their management systems. Results indicate that using the CPDM to reduce sources of dust exposure is consistent with mineworkers' self-values to protect their health and not necessarily because of compliance to a manager or mine.

Keywords

Autonomous organization; Continuous personal dust monitor; Respirable coal mine dust; Safety and health management system; Self-determination theory

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Conflict of interest

The authors declared that there is no conflict of interest.

1. Introduction

The development and advancement of protective safety and health (S&H) technologies has been of importance to the mining industry for quite some time. Within the National Institute for Occupational Safety and Health (NIOSH), a vast amount of mining research has focused on advancing the development or improving the reliability of technologies such as proximity detection systems, personal dust monitors, applications to better identify ergonomic and noise risks, and assessment software to link exposures of various contaminants to their root causes (see NIOSH Mining) [1]. Like any new technology, the goal is to streamline information in a way that improves individual and organizational work processes as well as to prevent incidents through risk reduction [2]. In some cases, production is even improved through adopting such technology [2].

Through meta-analyses, three broad factors have been revealed that heavily influence technology integration with workers: technical, social, and organizational [3–5]. Rather than focus on the technical factor (i.e., usability and performance), this study focused on the social and organizational aspects to help foster a more holistic approach to technology integration. This focus is critical because to date, research has emphasized individual technology acceptance and barriers to technology use, which has helped to target the individual worker; however, for sustainable change to occur in the workplace, this information must be translated to the organization in a usable way [6–8]. Using continuous personal dust monitors (CPDMs) as the technology of interest, this paper argues for an organizational focus on technology implementation and integration.

1.1. Technology integration as a change management process

Occupational safety and health management systems (SHMS) are different from typical S&H programs in that they are more proactive and integrated by incorporating elements of evaluation and continuous improvement [9]. An SHMS also holds everyone accountable and responsible within an organization [10]. There can be many variations to an SHMS, based on company size, tenure, and current challenges and goals. Commonly used frameworks include OHSAS 18001, ANSI Z-10, the Occupational Safety and Health Administration's (OSHA) Voluntary Protection Program (VPP), and CORESafety, developed specifically for mining by the National Mining Association (NMA).

These frameworks share common features, including change management. For example, CORESafety discusses the importance of working with equipment manufacturers during product development, working with management to mitigate any deviations from standard practice, and incorporating already-established safety and health requirements to prevent incidents [11]. The ANSI Z-10 manual also focuses on management of change, defined as: The process to identify and manage changes to minimize the introduction of new hazards and risks into the work environment [12]. Examples include changes in technology, equipment, facilities, work practices and procedures, design specifications, raw materials, organizational staffing changes, and standards or regulations [11].

One part of effective change management is the determination of interventions and practices that can be used by organizations to integrate technology; however, this topic has received

little attention in the literature [13]. There are a few reasons that this gap exists. First, systematic literature reviews argue that research to date has resulted in a lack of actionable data that is needed to understand internal and external influencers [14]. Second, there has been a lack of concerted efforts toward theoretically informed research in this area [5,14,15]. Finally, technology acceptance research has lacked a longitudinal dimension although more current research is promising in advancing this area [16,17]. This research aimed to address these gaps using CPDMs as the technology of interest.

1.2. Background of CPDMs to mitigate dust risks and reduce morbidity

Recent data suggests that after a consistent decline in coal workers' pneumoconiosis (CWP) or "black lung disease," the prevalence of new cases is increasing. For example, a recent NIOSH study found that 2% of examined surface coal mineworkers—most of whom had never worked in underground mines—had some degree of CWP [18]. In addition, there has been a sharp increase in progressive massive fibrosis (PMF), a more serious form of CWP, among young mineworkers in the Appalachian region [19].

Prior to this newfound data, the Mine Safety and Health Administration [MSHA] passed a multi-phase law on May 1, 2014, titled *Lowering Mineworkers' Exposure to Respirable Coal Mine Dust, Including Continuous Personal Dust Monitors* (30 CFR Parts 70, 71, 72, 75, and 90) [20]. Under the new law, the dust level may not exceed 1.5 mg/m³ (previously 2 mg/m³ for any work shift). Another phase of the regulation required mine operators to start using a continuous personal dust monitor by February 1, 2016, for designated occupations (DO) and other designated occupations (ODOs) to monitor and comply with regulatory exposures. As defined in the new rule, the DO is the occupation on a mechanized mining unit (MMU) that has been determined by results of respirable dust samples to have the greatest respirable dust concentration [20]. The ODO is another occupation on an MMU that is also designated for sampling. Underground coal mines are required to use the CPDM to collect 15 valid sampling shifts each for the DO and ODO per quarter per MMU, all while complying with this lower standard. The DO and ODO cannot be sampled concurrently, so a minimum of 30 shifts of sampling must be conducted on each MMU. If blowing face ventilation is used, the face haulage operator (e.g., shuttle car operator) must also be sampled as another ODO, so a minimum of 45 sampling shifts must be completed for these MMUs. Table 1 shows the primary DOs and ODOs who are defined in the new rule for continuous mineworker MMUs and are required to wear the CPDM.

Although CPDMs provide mineworkers with near real-time feedback about their level of respirable coal dust exposure through dust data output that is updated every 30 min, they do not ensure that workers or the organization will continuously use the information to learn about and reduce exposure sources. Training-related interventions on technology acceptance are more often the norm, but there is little research on how to best integrate the technology within the organizational system and its respective processes [22]. Therefore, upon understanding how coal mineworkers interpreted their dust exposure data, rather than train on this information, researchers sought to analyze workers' individual perceptions and work practices to help holistically integrate this technology with the organizational workforce.

As Table 2 shows, the regulations in other countries vary from the United States with almost all countries having a higher regulatory limit (all dependent upon silica content at each mine). However, more recently other countries, such as Australia, have placed an added emphasis on reducing workers' exposure to respirable dust and as a result, the findings in the current study can translate to how all organizations can respond to dust data and work together to mitigate exposures.

1.3. Theoretical framework

This study design incorporated self-determination theory (SDT) [24]. SDT has three assumptions, including that individuals: (1) are proactive; (2) are naturally prone toward growth and improvement; and (3) have psychological needs that are innate, universal, and essential for health maintenance [25]. In addition, SDT posits that there are two types of motivation that influence health-related behaviors: intrinsic (or autonomous) and extrinsic (or controlled) [26]. Both intrinsic and external motivations have been shown to directly impact the use or misuse of technology [27,28].

When individuals are intrinsically motivated, they will likely complete an activity if they find it to be helpful, interesting, or personally enjoyable [29]. Alternatively, if an individual is extrinsically motivated, then more often an activity is completed to receive external rewards. Extrinsic motivation involves acting with some sense of pressure such as to gain approval from others, to avoid punishment, or feelings of guilt [24]. In other words, people are persuaded into action only when that action is instrumental to those ends (e.g., I work when my boss is watching) [26]. By this theory, extrinsically motivated actions are completed on an as-needed basis and are likely to persist only as long as the external contingency is present.

1.3.1. Intrinsic and extrinsic motivation—These two psychological needs are examined and satisfied by determining factors associated within the individuals' environment including autonomy, relatedness, and competence [30,31]. These three components of SDT are discussed below.

Autonomy: First, autonomy is the degree to which individuals choose and initiate their behaviors with a high sense of value. Individuals are more likely to initiate behavior change if they feel the choice is aligned with their central values and lifestyle [30,32]. This internal process of self-regulation, or autonomy, comprises both intrinsic and extrinsic motivation [25]. Regarding coal miners' decisions to monitor and respond to their CPDM readings, an individual may be more motivated to change behaviors to preserve personal health or ensure support for his/her family as long as possible.

Competence: Second, competence is confidence and belief in one's ability to perform a desired behavior [33]. Individual competence can be enhanced by offering feedback and providing skills and tools needed to sustain protective behaviors [30]. The current study provided feedback and fostered skill development in the form of discussions about dust data cards to help build miners' confidence in their ability to operate and respond to the output displayed on their CPDMs. Ryan and colleagues also argued that competence is

facilitated by autonomy [30]. Specifically, if individuals make the choice to engage in the target behavior, they are more likely to develop the necessary competencies to complete that behavior change [34].

Relatedness: Finally, relatedness entails how close individuals feel to other people [35]. The quality of relationships with people, including being accepted and understood, impacts relatedness. Other studies have termed relatedness as autonomy support [36,37]. In medical settings, autonomy-supportive environments facilitated by providers have been linked to positive effects on patients' health status and health-promoting behaviors [37]. Therefore, the level of support a mining organization provides to facilitate lower levels of respirable dust, in addition to how peer coal mineworkers view the effects of respirable dust and utilize their CPDMs, may affect how another mineworker chooses to utilize and respond to the output on his/her monitor.

When these three factors (i.e. autonomy, competence, and relatedness) are addressed, individuals are more likely to feel that their psychological needs are met and subsequently, adhere to a recommended behavior change [30]. Research argues that intrinsic and extrinsic motivation are intentional and that actions can be characterized along a continuum, serving as a potential predictor in the workplace [26].

1.4. Research objectives

Previous research involving the CPDM found promise in stimulating workers' self-protective behaviors to lower exposure to respirable dust [38]. Peters and colleagues found that, despite barriers related to the design of the CPDM, some participating mineworkers were able to decrease their exposure to respirable dust [38]. In addition, others who did not have a good frame of reference for interpreting their numbers could still base their actions on whether the numbers were going up or down. The ultimate goal, however, is to have an informed workforce within a proactive organization that can take advantage of the CPDM's capabilities. Therefore, this intervention used SDT to identify intrinsic and extrinsic needs of using CPDMs to preserve workers' health and subsequently, identify ways to help organizations manage technological change. In response, the following research questions were considered:

1. Why do (or don't) coal mineworkers use their CPDMs to identify and engage in dust-reducing work practices?
2. How can management improve organizational integration of technology?

2. Methods and materials

2.1. Participants and data collection

NIOSH obtained Institutional Review Board (IRB) and Office of Management and Budget (OMB) approval to visit three mines on two separate occasions during 2016 and 2017 to talk with mineworkers and members of management. Two of the mines were considered average seam height and one was considered low-coal [39]. The mines were located in West

Virginia and Virginia. The study recruited 35 rank-and-file mineworkers who have worn and responded to the dust data provided via the CPDM.

The 35 mineworkers completed a survey and participated in an interview or focus group during the first visit. The discussions allowed mineworkers to share their experiences with the CPDM. Each of the participating workers was currently or had just finished a sampling period using the CPDM, or would be sampling in the near future. This allowed NIOSH researchers to debrief their personal dust data cards with workers or a dust data card that was the same DO or ODO. During these dust data card debriefs, workers shared repeated situations in which respirable dust was higher, thoughts on sources of higher exposure, and then actions they could take to reduce exposure. In addition, workers also shared what actions, if any, had been maintained over time to sustain a lower exposure. There were usually 3–4 workers from a crew present for the focus groups. Of the 35 underground coal mineworkers, all were male and 37% ($n = 13$) were continuous mining machine operators; 37% ($n = 13$) were shuttle car operators; and 26% ($n = 9$) were roof bolters.

In addition, 15 members of mine management discussed current interventions at their respective sites in response to the CPDM dust data output. They shared ways that they help support dust control practices on site and how they communicate the CPDM dust data to their workforce. Due to confidentiality and compliance issues, the details on what each dust sample entailed during the study is not being debriefed. However, the general sources that workers identified as well as corrective actions to reduce exposure are more useful to both the domestic and international mining industry, thus, this is the information discussed throughout the paper.

2.2. Data instruments

Because individuals are more likely to initiate a change if they feel the choice is aligned with their values, it was important to develop a targeted, self-regulation questionnaire [30,32]. Self-regulation questionnaires assess domain-specific individual differences in the directive of a particular behavior (e.g., using a CPDM, wearing a respirator) or a class of behaviors (e.g., engaging in several behaviors to reduce dust exposure). A “Learning Self-Regulation Questionnaire” (SRQ-L) questionnaire was adapted from Williams and Deci as well as Black and Deci to help researchers understand how and why mineworkers use the CPDM to learn about and reduce their respirable dust exposure [34,37].

The questionnaire measured the two SDT subscales—intrinsic and extrinsic motivation to take into account why coal mineworkers may decide to learn a specific behavior. The 13 survey items were retained but basic terminology was changed to reflect mineworkers’ use of the CPDM. The only change made to the original scale was the use of a 6-point Likert scale rather than a 7-point scale, so the participating mineworkers would have to select one side or the other in relation to “not true at all” and “very true.” Previous studies have rendered Cronbach’s alpha reliabilities of approximately 0.75 for controlled and 0.80 for autonomous [37]. The current study rendered similar results with the alpha for extrinsic regulation (7 items) being 0.85 and the alpha for intrinsic regulation (6 items) being 0.77.

2.3. Follow-up visits

Follow-up visits occurred approximately 8 weeks later at each site in order to reevaluate if any new dust sources had been identified via the CPDM or any new dust controls were put in place. Participants discussed any maintained changes in response to the CPDM dust data output. The same mineworkers were asked if they continued using information gleaned from the CPDM to sustain protective work practices, even when they did not have to wear the technology to comply with the regulation. Individual responses were linked to workers' surveys. Two of the workers were not available at the follow-up visit to provide a yes/no response to this question. Fig. 1 shows a flowchart of the intervention process.

2.4. Data analysis

The surveys were entered into SPSS and coded for future analysis. For the purposes of this paper and the smaller sample size, only averages are reported for the survey constructs in addition to one correlation analysis. The interview data was analyzed and coded in a series of stages. Initial coding of the data occurred while typing the interview and focus group notes. Then, more focused efforts took place to identify codes under the respective theoretical constructs of SDT –autonomy, competence, and relatedness [30,40,41]. This allowed a better understanding of what influenced workers to engage in certain dust-protective behaviors and maintain those behaviors. Themes that continually emerged under each of the three theoretical codes are reported in the results section.

3. Results

3.1. Survey results

After adding the seven controlled regulation survey items and averaging them, the mean was 3.27 (on a 6-point scale from “not true at all” to “very true”). Using the same process for the six-item autonomous regulation scale, the average among participants was 4.29. This approximately 1-point difference between the two scale averages illustrates first, that mineworkers are more intrinsically rather than extrinsically motivated to use and respond to the CPDM dust data to protect their health and second, that extrinsic motivation does not play a large role in mineworkers' health decisions related to dust exposure on the job, considering the “not true” average being below a 4.0. Results for each item are listed in Tables 3 and 4.

Even with the small sample size, much can be gleaned from looking at the responses to the survey items. For example, mineworkers trended toward “true” responses to items that asked if the CPDM is a good way to try to improve their health and its utility in identifying main sources of respirable dust. Alternatively, for the controlled items, it is apparent that mineworkers do not necessarily value what others think of them in terms of motivating a health-related action. This is evident in the 2.66 average (not true), “Others would think badly of me if I didn't [use my CPDM].”

The survey results showed little difference in averages among the DO/ODO groups (see Table 5). Due to the small sample, statistical significance cannot be determined among the

three groups. However, we can still learn something from these averages regarding all DOs and ODOs being more influenced through intrinsic means rather than extrinsic factors.

As mentioned earlier, each mineworker was asked during the follow-up visit if he continued to act upon information he learned through the CPDM, whether he was wearing the technology or not. Of the 33 responses (2 were not present on our follow-up visits), 21 workers (64%) said “yes” and 12 workers (36%) said “no.” A chi-square for independence was completed to identify if there was any association between workers who were either more autonomously motivated or externally motivated and workers’ continued application of dust-reducing practices learned through the CPDM. The chi-square test for independence (reporting Fisher’s Exact Test) indicated a significant association between a workers’ motivation and continuous dust-reducing behaviors, $\chi^2 (1, n = 30) = 0.00, p = 0.00$, Cramer’s $V = 0.850$. Fig. 2 shows the breakdown of responses. Fisher’s Exact Test is reported instead of Yates Continuity Correction because 1 cell (25%) had a count less than 5, which violated minimum expected cell frequency.

In summary, the survey results indicate that using the CPDM to identify and reduce sources of dust exposure is consistent with mineworkers’ self-values to protect their health and not necessarily because of compliance to a supervisor or mine. This result provides insight into the organization catering toward mineworkers’ intrinsic values rather than focusing on extrinsic rewards or consequences. The qualitative data analysis below sheds more insight into this topic.

3.2. Mineworker feedback

The qualitative data collected illustrated reasons why using the CPDM stemmed more from intrinsic rather than extrinsic motivation. Specifically, when participants were asked to discuss how they have used the CPDM, their perception of the technology, and the impact it has had on their work processes and practices, virtually all of the responses focused on the newfound control mineworkers had in identifying and mitigating their risks (i.e. increasing personal autonomy). Specifically, all 35 workers referenced at least one thing that they did not know about their dust exposure sources or levels, prior to wearing the CPDM. Most mineworkers expressed that they often look at their CPDM output to see what they might be able to learn and that they are still learning, even after wearing the CPDM multiple times. For example, one mineworker said, “*I always like looking at my readout. It’s nice to see what the feedback was so you can prevent exposure later ... if I know where or when I got a spike last time, and if that means I can stand in a different spot or something.*” Most mineworkers indicated that they look at their output and ask questions about their exposure to their fellow coworkers or direct managers. Several also stated that they cannot deny that they work in a dusty environment but over time, this technology helps deal with that. Table 6 illustrates a variety of abridged comments to highlight some of the discussions with workers.

Due to an enhanced sense of control and efficacy, many mineworkers reported increased learning about their exposures and mitigation strategies. Specific corrective actions that mineworkers learned are outlined elsewhere [42]. However, continuous mining machine operators often reported four scenarios that most often impacted their dust exposure and five corrective actions in response to this exposure including changing one’s position while

completing a specific task; being more aware of dust that is respirable; avoiding walking through certain areas of dust clouds; and creating and sustaining new habits based on their dust data feedback. Similarly, roof bolters identified three common scenarios that exposed them to more respirable coal dust and five corrective actions [42].

Finally, responses during focus groups revealed a sense of relatedness among the work crews. Specifically, 19 of the 35 participants (54%) mentioned learning and informing each other about dust hazards, which they indicated happened on a minimal level prior to using the CPDM [43]. In general, mineworkers said that they try to help each other more, especially during shift changes, to prevent out-of-compliance samples. One mineworker said, *“We all look at each other’s cards or talk about our readings. Everyone in the mine is more aware of each other’s behaviors and how it can affect each other underground.”* In addition, mineworkers discussed holding each other accountable to communicate when their specific DO or ODO was wearing the CPDM. For example, one roof bolter said, *“Whoever is wearing it [the CPDM] at the time, it’s their responsibility to tell us what’s going on down there.”*

Although mineworkers discussed an enhanced awareness and communication among their work crews, their end goal was to stay in compliance while wearing the CPDM rather than adhering to any sort of internal or external value. Related to external motivations, however, the dust regulation in place provided no choice but to try to comply with new standards. To illustrate, throughout the interview notes for the 35 participating workers, references to compliance, fear of being overexposed or out of compliance, and being distracted because they are worried about exposure levels, was referenced 42 times. This means that several workers mentioned their fear of being out of compliance more than once throughout the interview or focus group, showing how prominent this topic was on their sites. Specifically, supervisors’ communication with the workers followed a similar tone related to compliance. However, most supervisors referenced that the CPDM caused initial distractions because workers were afraid to be out of compliance. Although most mineworkers had no complaints about their organizational and supervisor support for dust control resources, they also had little to report about communicative support and information from their management.

To illustrate, when asked what he knew about the CPDM, one worker said, *“We weren’t really told anything, just that we were going to have to wear it.”* There was consistent feedback from workers about minimal planning, communication, and coordination on behalf of organizational management about this upcoming change. Upon using the technology, these same workers expressed minimal communication and feedback about their dust data cards. In addition, some workers were disappointed in the lack of a coordinated response plan to maintain low exposures. These results show multiple intervention points for a stronger technology integration and response process that also leverages workers’ intrinsic health values.

4. Discussion

As referenced earlier, several SHMS standards discuss the necessity of managing changes on the mine site, including whenever a new or modified technology is introduced [12].

However, research has not been able to provide useful interventions that can be applied when organizations integrate new technology [13]. Results support previous research that has shown the value in knowledge building through involving the workforce in the integration of technology [44]. However, even if initial involvement with mineworkers encourages them to make early changes in awareness and behavior, the likelihood of sustained change is less likely. For example, several participating managers noted that workers are very interested and proactive when first learning about their dust exposure, but that this interest eventually wanes. Therefore, rather than continue focusing on the individual worker, a shift in how the technology is implemented and used provides a more sustained support structure for the organization.

4.1. Autonomous supportive organizational-worker-technology interventions

A primary takeaway from this study is the understanding of workers' main motivations for utilizing their CPDMs, which are intrinsic. A similar finding was revealed relative to occupational inspectors on worksites, whose use of autonomous communication with workers resulted in fewer compliance orders [45]. This study shows similar promise in that, through a better understanding of the intrinsic motivations toward using the CPDM, not only can quicker technology implementation and integration occur at mine sites, but a possibility also exists for sustained reductions in exposure to respirable silica dust. Therefore, during any technology integration and related planning, it would behoove managers to use autonomy supportive tactics with mineworkers to understand primary motivations for making both health and compliance-related decisions on the job. In response, it may be easier to develop more targeted interventions that seek to elicit these internal motivations. One method is to apply participatory ergonomics, which actively involves workers in developing and implementing workplace changes to reduce safety risks [46,47]. In other words, fitting a technology integration intervention with the needs of workers and the organization through a constant feedback loop during implementation may help facilitate workers' motivation to participate in a new safety activity or adopt a technology [48].

Interdependent with this consideration is the value of using managerial interventions as a powerful tool for organization-wide technology adoption [22]. The data revealed specific content that can be included in such interventions that come from management. Such tactics should include both transformative and transactional leadership styles to include rational discussions with workers about their exposure to respirable dust; involvement in decision making to improve engineering controls and work practices; and generating a sense of enthusiasm that workers have this newfound "control" to protect their health on the job. Examples of potential intervention points to address these areas are discussed below [49].

4.1.1. Discussions that increase autonomy and control—First, because participating mineworkers' responses both in the survey and during interviews heavily focused on the CPDM being able to improve skills and ultimately protect their health, these are two key points that should be communicated by management on a consistent basis. Previous research has shown that empathetic, educational communication from management can encourage health compliance on behalf of the workforce [45]. Therefore, if management can relay the value in new and sustained self-protective behaviors, workers may be more

likely to follow-through with changes based on the technology feedback [30]. This initial communication can shape mineworkers' motivations and perceptions that form the bases for intentions and technology use over time.

Although developing proactive mechanisms between managers and workers helps to integrate and adopt practices in response to technology output, these mechanisms need to be formally integrated within an organization's SHMS to be self-sustaining. Specifically, research has shown that although workers may actualize their potential in a proactive way, they still need a supporting environment to sustain participation [50]. Much research shows that coercive communication such as imposing deadlines on workers and using surveillance can actually hinder workers' engagement and investment in solutions [51]. In addition, SDT proposes that there is an interaction between individual, proactive growth and the social environment that can either support or hinder development [52]. Current data support these previous findings in that mineworkers' survey responses were very low for questions that pertained to what others thought of them and their protective behaviors. Therefore, a concerted effort on behalf of the organization to minimize any power imbalances between workers and managers may facilitate an increased sense of worker control and implementation of dust-reducing practices.

4.1.2. Worker involvement—Previous research has shown that most technologies are initially frustrating for individual workers and organizations not only within mining, but also other sectors including healthcare and construction [6,7,53–56]. Therefore, besides increasing proactive communication between managers and workers, another important element is to involve workers in decision making, including throughout the development and design of such technologies. This concept emerged during interviews with workers, who appreciated problem-solving discussions with their supervisors about ways to respond to their dust exposure. This finding is consistent with other research that has found the value of involving workers in the discussion of risky behavior and potential solutions to change behavior [57]. Also termed as “empowerment,” Gielen and Sleet refer to this line of decision making as the “principle of participation” [57]. It is important to emphasize empowerment by allowing workers to tell their story, express their concerns with a specific work practice [or engineering control], and have the ability to choose a modified solution that works for them [58]. As a result of direct involvement throughout decision making processes, organizational change is more likely to occur as well.

4.1.3. Limitations—The small study sample produces results that cannot be generalized across the mining industry or other high-risk occupations that regularly adopt new technologies. However, the discussion provides targeted considerations that are applicable at any time for a company to improve technology integration within its SHMS. So, regardless of generalizability, the findings can be useful for organizational development. In addition, although mineworkers expressed information on this topic, this study did not formally address aspects of human-centered design (HCD), which is a critical element needed to better inform potential frustrations that end users may experience during new technology integration processes [59]. Even though HCD was not addressed in the current paper, organizational aspects of technology integration should be considered in the planning stage

of the SHMS. This would include heavy involvement from technology manufacturers and of course the end users to better complement these current results.

5. Conclusions and future research

Despite the study limitations, the results add information that can be used by researchers in future studies. This study begins to fill gaps referenced in organizational-worker-technology integration in the mining industry and shows that more studies are needed to address these interdependent relationships [13,14,60]. First, the quantitative and qualitative data collected from mineworkers produced actionable information that mine organizations can use in the future. The results illustrate the value of understanding the motivations of a target audience and how an organization can use this information to disseminate accurate messages that resonate with as many people as possible. Specifically, organizational and interpersonal factors should be considered in the future when determining ways to increase technology use and adherence of health-protective practices on the job.

In addition, this study begins to address the lack of theoretically informed research in this area and demonstrates the value of organizations adding features of autonomy, competence, and relatedness into their communication and interventions with the workforce [15]. By applying SDT or a similar theory, it is possible that workers will be more receptive to the positive benefits of the technology, whether mandated or not.

Finally, this longitudinal study shows the need for more concerted efforts to prepare organizations and their workers for an increase in technology development, adoption, and adherence to the information produced via the technology, particularly through improving health and safety management systems in some capacity [60]. Specifically, the involvement of HCD efforts coupled with behavior theory research would add much to the empirical literature on this topic [61]. There continue to be improvements in mine S&H technology, particularly in providing guidance in human-centered design, however, the engineering practices address worker integration as an afterthought [62,63]. In addition, this autonomy-supportive approach on behalf of management may have a better chance in helping workers not only in noticing and implementing dust-reduction controls, but in maintaining dust control efforts for a sustained period of time regardless of the location of the mine and current regulations in place.

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Fig. 1.
Intervention flowchart of data collection activities.

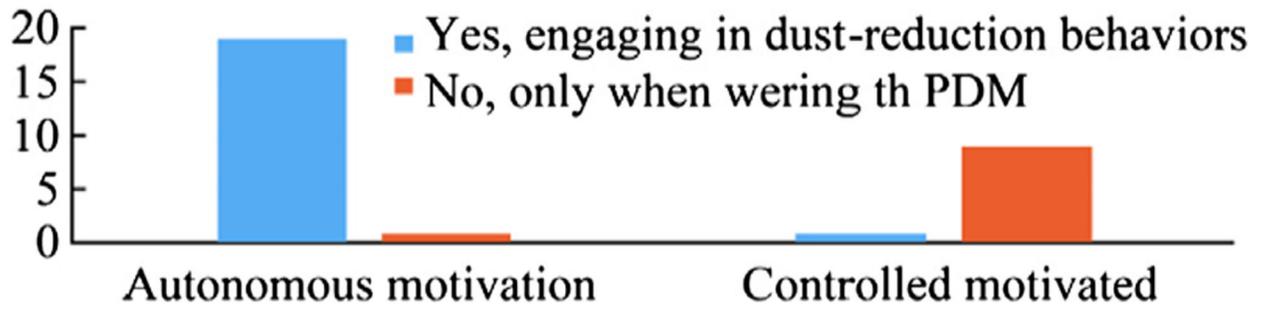


Fig. 2.
Association between motivation and behavior maintenance.

Table 1

DO/ODO occupations.

Occupation	Job description (taken from the Bureau of Labor) [21]	Designation
Continuous mining machine operator	Operate self-propelled mining machines that rip coal from the mine face and load it onto conveyors or into shuttle cars	Designated occupation
Roof bolter	Operate machinery to install roof support bolts in underground mines	Other designated occupation
Face haulage operator (blowing face ventilation)	Operate diesel or electric-powered shuttle car in underground mines to transport materials	Other designated occupation

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Highlights coal mining and underground miner exposure to respirable coal dust in other countries (retrieved from the International Energy Statistics) [23].

Table 2

Country	Rank and production (in tons)	Typical mining method	RCMID dust exposure limits (all dependent on silica content)	Required monitoring device
China	1 (4,376,984)	Longwall	Between 6 and 1 mg/m ³	Personal gravimetric sampler
United States	2 (896,941)	Room-and-pillar, longwall	1.5 mg/m ³	Continuous personal dust monitor
India	3 (643,720)	Room-and-pillar, longwall	2 mg/m ³	Monitoring device approved by Indian government
Australia	4 (560,714)	Longwall	New South Wales: 2.5 mg/m ³ Queensland: 3 mg/m ³	Personal gravimetric sampling
South Africa	7 (256,876)	Room-and-pillar, longwall	2 mg/m ³	Personal gravimetric sampling
Germany	8 (203,613)	Longwall	4 mg/m ³	Area gravimetric sampling used
Poland	9 (149,147)	Longwall	1 mg/m ³	Personal gravimetric sampling

Table 3

Average of DOs and ODOs autonomous motivations.

Survey item	Average
Autonomous item	
I feel like it's a good way to improve my skills and my understanding of exposure to respirable dust	4.38
Learning to use my CCPDM is an important part of being a coal mineworker	4.26
I believe my supervisor's/organization's suggestions will help me better use my CPDM	4.21
It's good to try to improve my health	4.76
It's hard to identify sources of respirable dust	3.76
It's helpful to use my CPDM to identify my main sources of respirable dust	4.61
Autonomous total average	4.29

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Table 4

Average of DOs and ODOs extrinsic motivations.

Survey item	Average
Controlled item	
Others would think badly of me if I didn't [use my CPDM]	2.66
I would feel bad about myself if I didn't use my CPDM	3.03
I would receive praise if I do what is suggested	2.75
I want others to think I am a safe worker	3.91
It's easier to do what I'm told than to think about it	3.03
I would probably feel guilty if I didn't comply with my supervisor's/organization's suggestions	3.70
I would feel proud if I continued to lower my exposure to respirable dust	4.55
Controlled total average	3.27

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Table 5

Breakdown of DO and ODOs responses to the SDT survey.

Mineworker occupation	Autonomous average	Controlled average
Continuous mining machine operator	4.20	3.34
Roof bolter	4.56	3.38
Shuttle car operator	4.17	3.10

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Table 6

Workers' interpretation and response to the CPDM.

Job position	Abridged comment
Shuttle car operator	I can look and get some kind of a warning and retreat to a better area I'm more likely to say 'hey it's getting dusty' so no one places themselves in a risky situation. We didn't do that before
Roof bolter	I've learned when the exposure is the worst, where to usually stand when this happens, and can move around a little bit to avoid some of the dust My biggest changes don't even have to do with my work stuff. It's more when I get to the mine, set-up, or eat lunch
CMM operator	Now I know when I can go back in. it's definitely shown me where and when to be somewhere which I didn't know before For us, it shows us which way and where to stand during certain times

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