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## USE OF COGNITIVE TASK ANALYSIS TO INFORM FUTURE RESEARCH AND IDENTIFY SOLUTIONS FOR HAUL TRUCK SAFETY

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### ABSTRACT

Each year, haul truck accidents account for a large portion of mining injuries and fatalities. To better understand why these accidents continue to occur, researchers from the National Institute for Occupational Safety and Health (NIOSH) utilized a cognitive task analysis methodology to identify the user requirements of surface haul truck operators and assess differences in perceptions between operators, managers, health and safety professionals, trainers, and maintenance personnel. Additionally, researchers used the critical decision method to focus on better understanding the cognitive demands, decision-making, and problem solving during nonroutine incidents. The preliminary results of this study identify and explore themes within the broad categories of hazards, skills & expertise, and training and provide detailed accounts of nonroutine incidents such as near-misses, loss of control, and collisions. These accounts reveal insights into operator decision making and event progressions that can then be used to build more realistic training scenarios and address hidden hazards and root causes of these incidents. These results, along with potential solutions offered by study participants, can inform future research and help identify creative interventions that can be used by mine operators to address haul truck safety issues.

### INTRODUCTION

In July of 2021, the Mine Safety and Health Administration (MSHA) hosted a national stand down for safety day focusing on best practices related to powered haulage and vehicle rollovers. In an associated news release for the event, MSHA reported, “So far this year, nine miners have been killed and 185 have been injured in accidents involving powered haulage… Year to date, this is the highest number of powered haulage fatalities since 2006” [1]. Unfortunately, this trend has been seen repeatedly in recent years as powered haulage often accounts for the greatest number of fatalities each year. In 2020, 21% (6 of 28) of fatal incidents were related to powered haulage [2]. Likewise, in 2018, powered haulage accounted for 48% (13 of 27) of the fatalities and 50% (14 of 28) of the fatalities in 2017 [3].

Powered haulage is one of 21 accident classifications defined by the U.S. Mine Safety and Health Administration (MSHA) and includes haulage units of all types such as rail cars, conveyor belts, belt feeders, service trucks, haulage trucks, etc. [4]. However, when looking closer at the equipment type, mobile equipment, such as service trucks, haul trucks, and front-end-loaders, account for most of the incidents. Nearly 40% (10) of the 28 overall fatalities in 2017 involved mobile equipment, and 6 of these were related to haul trucks [2, 5]. Similarly, a recent analysis by MSHA showed that accidents involving mobile equipment (including classifications other than powered haulage) accounted for more than 50% of all fatalities in 2020 and 2021 year to date [6].

Despite many past initiatives to analyze and prevent these incidents, haul truck accidents continue to occur. Previous analyses have attributed these accidents to loss of vehicle control, lack of hazard recognition ability, and human performance [7-12]. Similarly, a recent analysis by the National Institute for Occupational Safety and Health (NIOSH) of 91 haul-truck-related fatalities from 2005 to 2018 revealed that most of the accidents resulted in a haul truck colliding with the environment, and many of these events were initiated by loss of situational awareness or loss of control [13]. These analyses have been useful in identifying the root causes and frequency of accident types; however, more work needs to be done to clarify why haul truck accidents continue to occur.

Therefore, the goal of this work is to gain a better understanding of how haul truck operators perceive hazards, their skills and expertise, their training, and how they respond to challenging or nonroutine scenarios. Researchers aim to gain a greater depth of knowledge about how haul truck operators make decisions and to determine what strategies have been successful in coping with real-world challenges. To do this, researchers utilized a cognitive task analysis (CTA) methodology and the critical decision method (CDM) to gain a thorough understanding of how haul truck operations are carried out both in routine and nonroutine situations.

#### Cognitive Task Analysis

Cognitive Task Analysis (CTA) is a common method used to identify and understand the cognitive processes, communication, and situational awareness requirements of a task [14]. Various forms of CTAs have been employed to support designs in many domains including military [15], aviation [16], driving [17], and manufacturing [18]. CTA methods help researchers extract, organize, and represent the knowledge and cognitive skills that workers in various roles with varying levels of experience and expertise rely on to execute tasks. In general, CTA methods help elicit the following information: How do expert operators differ from novice operators? What do they pay attention to? How do they know what is important? How do they diagnose problems? How do they make sense of and mentally organize their work?

CTA data collection can be carried out in several ways including interviews, self-reports, or observations. However, structured interviews offer several advantages, such as collecting rich data sets and capturing key dynamics or critical elements that could be missed by observations or self-reports [19]. Likewise, there are several ways to analyze and represent data collected by CTA methods. Results can be presented by capsulizing incidents, cataloging cues and patterns, identifying themes, coding themes, and describing sequences. CTA results can also be represented in products such as narrative descriptions, tables, illustrations, qualitative models, flowcharts, simulations, and other computer models [19]. The preliminary analysis described in this paper focuses on the identification of themes and solutions to address haul truck safety issues.

### Critical Decision Method (CDM)

The Critical Decision Method (CDM), as defined by Klein et al. [20], is "a retrospective interview strategy that applies a set of cognitive probes to actual nonroutine incidents that required expert judgement or decision making." In other words, the CDM allows researchers to elicit information from experienced personnel about actual incidents that have occurred in real life. By exploring these situations, researchers can document specific details, challenges, subtle cues, and mental strategies (e.g., decision making, planning, and sensemaking) that might not be uncovered using other methods [19]. During a CDM interview, participants are asked to recall a specific incident in which they were directly involved that was particularly challenging or when their knowledge and skill played a role in the outcome of the incident. Once an incident is identified, a timeline is constructed to establish a precise sequence of events. Later phases of the interview use different kinds of probes and strategies to help the participant recall the events in detail, with the end goal of documenting the incident from the perspective of the interviewee.

The CDM not only explores decision making of actual events, but according to Klein et al., the CDM was also designed to "have applied value in terms of training, system design, or development" [20]. The application of CDM to develop training programs has been shown to be beneficial in various domains including ambulance dispatchers, aircraft pilots, and white-water rafting guides [21]. The analysis of personnel in challenging or nonroutine events provides valuable information to support improvements in the outcomes of similar situations through training or changes in process design. Additionally, the process of establishing precise timelines through the retelling of these events in CDM interviews can be useful in developing realistic training scenarios [21]. The preliminary analysis described in this paper focuses on characterizing hazards, necessary skills, and training opportunities and the development of training scenario narratives.

## METHODS

Researchers developed two semi-structured interview instruments to gain an understanding of both the baseline user requirements for haul truck operators and how operators respond to challenging or nonroutine situations. The first interview instrument utilized a general CTA interview method to gain understanding of the overall (i.e., big picture) goals, skills, hazards, and user requirements for haul truck operators. The second interview instrument utilized the CDM interview strategy to gain an understanding of how haul truck operators respond to challenging or nonroutine scenarios and to gain a greater depth of knowledge about these scenarios. Participants for the CTA interviews included haul truck operators, managers, health and safety professionals, trainers, and maintenance personnel, whereas the CDM was only used with haul truck operators.

Data collection, at the time of writing this paper, is currently ongoing. An in-depth analysis of the full dataset, to include seven mine sites, will be discussed in a future publication. For this paper, we explore preliminary results and themes identified from three mine companies (six mine sites). Data gathered from these initial interviews were reviewed by NIOSH researchers to create a list of insights and emerging themes that could be applied towards actionable outcomes such as operational changes, training development, and technology solutions that may be of value to the industry.

### Participants

The focus of this study relied on gaining perspectives from haul truck operators, managers, health and safety (H&S) professionals, trainers, and maintenance personnel currently employed at surface mine sites in the United States. To achieve this, researchers utilized convenience and snowball sampling methods [22]. Mining companies were first contacted via email or phone communication to determine interest in participating in the study. If a mining company expressed interest, NIOSH researchers worked with the mine management (e.g., mine manager or H&S professional) to identify additional potential study candidates. If the potential candidate agreed to participate, a 1-hour meeting time was scheduled for the interview to be conducted over Zoom for Government. Prior to the start of the interview, researchers obtained informed consent according to the NIOSH Institutional Review Board (IRB) approved protocol.

Participants included 36 employees from one small surface coal mine located in the Western United States and five small surface stone, sand, and gravel mines in the Eastern United States, four of which are run by the same management structure and located in the same state. Small is defined as less than 25 employees. Each participant was currently employed at the respective mine site and held one of the positions related to haul truck operations including haul truck operator, manager, H&S professional, trainer, or maintenance personnel. As shown in Table 1, the median mining industry experience of all participants was 21.5 years. The median haul truck operator experience (i.e., operating a haul truck as part of normal mining operations) was 2.6 years. Notably, participants not classified as operators often reported some experience related to haul truck operation, but non-operational driving (e.g., moving a haul truck inside the shop area) was not included.

**Table 1.** Participant Experience [Median (Interquartile Range)].

| Classification | Count | Mining Experience [yrs.] | Mine Site Experience [yrs.] | Haul Truck Experience [yrs.] | Haul Truck Site Experience [yrs.] | Time in Current Role [yrs.] |
|---|---|---|---|---|---|---|
| **HT Operator** | 16 | 18.5 (6.1 – 30) | 6.8 (3.5 – 23.2) | 7.2 (2.7 – 18.8) | 4.5 (1.7 – 14.5) | |
| **Management** | 10 | 25.0 (13.2 – 37.0) | 11.5 (2.8 – 31.8) | 1.8 (0.0 – 4.2) | | 5.5 (2.8 – 20.5) |
| **H&S Professionals and Trainers** | 5 | 6.0 (4.0 – 31.5) | 6 (2.0 – 24.5) | 0.0 (0.0 – 7) | | 22 (3.5 – 24) |
| **Maintenance** | 5 | 10.0 (7.0 – 31.0) | 6.0 (3.0 – 30.5) | 0.0 (0.0 – 5.0) | | 7.0 (4.5 – 20.0) |
| **Total** | **36** | **21.5 (6.6 – 30.8)** | **7.0 (3.0 – 28.0)** | **2.6 (0.0 – 9.8)** | **4.5 (1.7 – 14.5)** | **7.0 (3.0 – 21.5)** |

### Interview Guides

**Cognitive Task Analysis (CTA)**: The CTA semi-structured interview was designed to gain a general understanding of participants' perceptions of their goals, skills, hazards, and current training for haul truck operators and non-operators. Researchers were looking specifically for what differentiates excellent and poor haul truck operation, in terms of recognition of common and uncommon hazards, skills needed for the job, and safety incidents. Additionally, researchers collected information on operator training, communication, and policies and procedures.

**Critical Decision Method (CDM)**. The Critical Decision Method (CDM) semi-structured interview was designed to elicit operators' expert knowledge by asking them to talk through a particularly challenging event from their own experience. During these interviews, researchers constructed a timeline to highlight critical decision points and identify cues that helped the operators make sense of and respond (effectively or ineffectively) to the situation. Researchers were looking for events that were not only difficult, but also that prompted the use of expert skills and decision making. Examples of challenging events include a near-miss, a collision involving property damage, or loss of control due to environmental conditions.

### Data Collection

All interviews took place using the Zoom for Government platform during each participant's regular work shift and lasted approximately one hour. Each interview was conducted one-on-one with the research team. There was a minimum of two researchers present, one serving as the interview lead, and the other acting as notetaker for all interviews. All interviews were audio recorded and transcribed for data analysis. Each volunteer only participated in one interview utilizing either the CTA or CDM, where the CDM was only used with haul truck operators and the CTA contained questions tailored for the participant's level within the organization (i.e., operator, manager, H&S professional, trainer, or maintenance personnel).

### Data Analysis

For this paper, researchers employed an embedded mixed methods design containing both quantitative and qualitative analyses. The quantitative results focused on explicit hazard identification that was expanded upon with the qualitative data. Namely, as a part of the CTA, participants (n = 31) were explicitly asked to list what they believe are the top five personal and external risk factors to haul truck operators (i.e., In your opinion, what are the top five personal/external risk factors that haul truck operators face?). Researchers combined the results of these questions and then thematically grouped the results using group consensus. The quantitative results were reported using descriptive summary statistics to characterize the results and compare haul truck operators with non-operators (i.e., managers, H&S professionals, trainers, and maintenance).

To build on these identified areas and capture greater themes, researchers qualitatively analyzed both the CTA and CDM interviews (n = 36) using the grounded theory approach. The grounded theory approach allows theories or hypotheses about behavioral phenomena to emerge from collected data, rather than applying an existing framework [23]. Grounded theory builds from raw data to codes. Coded data is then organized into concepts and categories that build up a larger framework to understand a phenomenon [24].

To qualitatively analyze the data, three researchers independently reviewed the interview transcriptions in search of major themes related to the three interview question categories including "hazards," "skills and expertise," and "training.". Researchers paid particular attention to examining the similarities and differences in perceptions between haul truck operators and managers, as well as differences between work areas (e.g., operations, maintenance, training). This phase of the data analysis allowed for the discovery of as many themes as possible to capture the full depth of the data.

To ensure that the data interpretation was consistent between researchers, several meetings were held to review the discovered patterns and themes and discuss agreements and rectify any disagreements. To establish trustworthiness of the analysis, researchers provided rich descriptions, including direct quotes, to verify the interpretation of the data [25]. Researchers also assigned greater confidence to themes that were found to be repeated across interviews from one participant to another [19].

## RESULTS AND DISCUSSION

The following sections discuss the quantitative results and preliminary qualitative themes that emerged during the analysis of the CTA and CDM interview data related to hazards, skills and expertise, and training. Potential solutions to address the identified safety concerns are provided along with a summary of solutions provided by participants to improve haul truck health and safety.

### Hazards

A hazard is defined as "an unsafe condition or activity that, if left uncontrolled, can contribute to an accident," [26]. Despite being provided the risk factor questions ahead of the interview, many participants had difficulty identifying workplace hazards, and operators identified less than other participants. On average, haul truck operators identified 8.1 (5 to 10) of a possible 10 hazards, and non-operators (i.e., managers, H&S and trainers, and maintenance) identified 9.2 (7 to 10).

Overall, the participants identified hazards that generally fell into eight categories including): attention, mine site conditions, environmental conditions, preparedness for work, operator skill level, state of equipment, communication, and operator characteristics. Attention hazards included distractions (e.g., cell phones, radio), focus, complacency, situational awareness, rushing, and boredom. Mine site conditions included roadway conditions, geologic conditions, roadway design (e.g., width, grade, curves), ground controls (e.g., berms), and changes to the mine site (e.g., changes in roads/routes). Environmental conditions included weather (e.g., rain, snow, fog), darkness, and environmental visibility issues (e.g., glare). Preparedness for work included fatigue, home life, and substance use. Operator skill level included operation skill, decision making, training, and knowledge (e.g., limits of machine capabilities). State of equipment included mechanical failures, vehicle blind spots, maintenance, and pre-shift inspections. Communication included lack of communication (e.g., not signaling intentions), the uncertainty created by others (e.g., operators, external contractors), and safety culture. Lastly, operator characteristics included attitude, risk tolerance, and honesty.

**Differences between Operators and Non-operators**. Not only did operators identify fewer hazards than non-operators, but they also identified different types of hazards. Figure 1 shows that almost all participants (i.e., operators and non-operators) talked about attention (93.5%) and environmental conditions (83.9%). However, non-operators also more often identified big picture hazards such as the state of equipment (74.0% versus 41.7%), mine site conditions (89.0% versus 66.7%), preparedness for work (79.0% versus 58.3%), and communication (68.0% versus 50.0%). It is possible that some of these differences arise from a lack of exposure to these hazards. Many of the participants talked about how they do not directly engage with other areas (e.g., maintenance, road crews). Additionally, some operators believe that hazards like fatigue and communication were not a problem at their site when discussed later in the interview (e.g., everyone communicates well so it is not a problem).

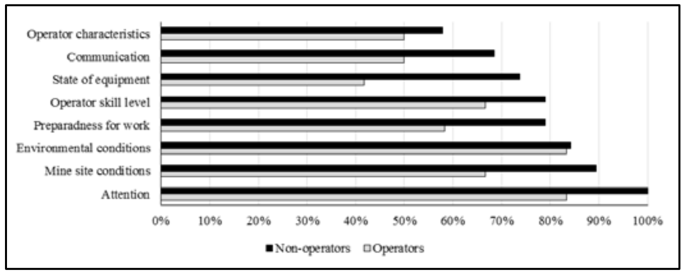


**Figure 1.** A bar chart displaying the percentage of haul truck operators (n = 12) and non-operators (n = 19) (i.e., managers, H&S professionals and trainers, and maintenance personnel) that identified one or more risks related to each of the hazards categories.

**Explicit versus Tacit Knowledge.** There are differences in the number and type of hazards identified by haul truck operators versus non-operators. One potential explanation for this finding is the difference between explicit and tacit knowledge as Sherehiy and Karwowski write that, "individual [tacit] knowledge of employees is strongly tied with work context; it is difficult to formulate and verbalize but is easily operated and applied by the owner" [27]. Operators may have internalized hazards such as the state of the equipment that they would typically check during their pre-shift inspections. Most operators interviewed at least mention doing a pre-shift inspection as a part of their day, and many others talked about proper maintenance of the vehicles. Furthermore, when operators were asked about hazards in general, they commonly used phrases like, "I know it when I see it" or "common sense" and found it difficult to explain what that meant to them. However, tacit knowledge is subjective and may not align with the perceptions and actions that management would want an operator to take. This in evidenced in some of the non-operator interviews, where they suggested that some operators "pencil whip the inspections" or "don't understand what qualifies as tire damage versus a surface scratch." For example, one participant described a situation where "the truck's throwing codes, and we go and check the engine oil and it's low on engine oil. Obviously, they didn't check that engine oil in the morning. But if you look at the book it says that they did." This suggests that while some operators may or may not have internal awareness of these hazards, they may not follow through and mitigate them without explicit knowledge of the expectation. Knowledge management models suggest that tacit knowledge needs to be converted to explicit knowledge to ensure hazard awareness and pro-safety behavior [28]. As described in this example, cutting corners or not paying attention can lead to increased safety risk.

**Differences in Perceptions.** Another concern with tacit hazard knowledge is different perceptions and ambiguity. Individual employees may perceive situations differently—for example, one operator talked about how fires are a significant hazard. However, none of the other participants at the mine felt it was a critical safety risk. When we followed up with an H&S professional at the site, the person acknowledged that it is a hazard but felt that it was well controlled by the mechanisms they had in place. "[I]f you keep your wits about you, and you hit that fire suppression system, in my experience, it's always put it out… So, I guess I've never been around it where it's been a close call ever." Different experiences such as these can lead to different perceptions and ultimately affect behavior. Therefore, it is important that hazard knowledge be captured and discussed to ensure that operators and non-operators have the same perceptions and take the same action with regard to hazards [29].

**Hazard Identification and Mitigation Solutions.** Shared knowledge can help to minimize differences, clarify knowledge, and unify perspectives; however, increased formal safety training may not be the best solution to improve hazard identification. Research suggests that relying on formal training and professionalism to teach hazard recognition and mitigation increases the number of unsafe behaviors [30].

Making training holistic (i.e., training with the system or context in mind) and engaging (i.e., training that requires workers to play an active role in the learning process) has been shown to improve learning [28, 31]. For example, teaching through storytelling helps relate tacit knowledge to context as well as build community and relationships; similarly, experiential learning such as simulation or virtual reality allow employees to naturally explore hazards [28]. The participants recognized this as well. For example, a H&S professional talked about how he/she integrated a "field trip" around the mine with classroom training to show employees what they were talking about. Another suggestion was to allow operators to have preliminary training, then operate for a week or so, and then follow up with a trainer. The independent time to experience operating a haul truck could improve the operator's context and understanding for any knowledge that was either added or represented. Lastly, participants talked about the need to get on the same page with each other. One participant suggested that they could have toolbox talks that focus on getting the right people to do the job at hand and discuss the risks and plans to mitigate the hazards together. These context-specific solutions would ensure that everyone involved has the same shared perceptions. Other participants talked about the need to get all the perspectives on an issue or even bring in people from other areas to get a fresh perspective. Participants suggested that by bringing in different perspectives together, it is more likely to holistically capture an issue.

**Skills & Expertise**

**Ability to Maintain Situational Awareness.** One of the most common skills identified by research participants as important was situational awareness. Interviewees strongly emphasized the need for haul truck operators to stay vigilant, avoid complacency, and look out for hazards. At first, many haul truck operators described their jobs as routine or mundane (i.e., not many changes from day to day, a very repetitive task). However, when asked about what changes occur in the mine, they often spoke about hazards such as rock spillage on the road, ground conditions around the dump area, changing weather, and slick roads. Haul truck operators noted that they not only need to pay attention but also be able to anticipate what could happen. One haul truck operator gave an example of this when describing a hazard at the dump area: "If you notice that [a] berm is not the same height as when you were just back there at your last load, that's an indication that something's going on underneath the dump that we can't see." In this case, the operator described the need to identify a hazard that could lead to a bigger problem in the future. Similarly, non-operators also spoke of the need for situational awareness. One manager indicated that haul truck operators need to keep an eye on their work area "because things change throughout the shift. I can't be everywhere all the time. And so they're good about pointing out things that may become a hazard. And then, we get them addressed, even if it means shutting down production and fixing holes in the road or moving to a different area."

In essence, many of the interviewees were describing the need to maintain situational awareness. Situational awareness is defined as the ability to perceive elements in the environment, comprehend their meaning, and project their status in the future [32]. Haul truck operators and non-operators likely identified this skill as critical due to the dynamic nature of the mining environment where both imminent and future hazards could occur [33]. Not only do haul truck operators need to continually assess their work area for hazards but also make decisions about how to prioritize and manage risks [34]. Finding ways to improve situational awareness could help haul truck operators both identify and manage hazards. Previous research suggests that formalizing risk management practices could help improve mine workers' situational awareness of hazards [35].

Participants offered several solutions for improving operator situational awareness. First, they suggested developing a workplace culture that strives for continuous improvement to combat operator complacency. Other participants spoke of the need to prepare oneself physically and mentally for the workday ahead with proper rest and attitude. Participant solutions also related to improving skills and expertise focused on getting operators to think about the "big picture." Participants suggested that operators that understand the whole operation are better able to safely adapt to the changing conditions, rather than just knowing how to get from the loading point to the dump. To help combat complacency, operators also suggest changing up routines. Numerous participants suggested randomizing the sequence of items checked during a pre-shift inspection or including a second operator in the process.

**Ability to Position Truck at Loading and Dump Points.** When asked about the most challenging or stressful parts of the job, many haul truck operators talked about backing into the loading area and backing up to the dump point. The task of backing into the loading area was described as stressful because of the need to orient the truck correctly, often in tight spaces, without colliding with the loader or shovel while avoiding other hazards (e.g., running over a rock and causing tire damage or driving over the shovel power cable). Operators also talked about negative interactions they have had with loader operators. For example, the loader operator calling over the radio to provide overly critical feedback to haul truck operators. This could add to the overall stress of the situation (i.e., feeling social embarrassment or pressure associated with having to do a task correctly under time constraints and in view of a coworker). Similarly, the task of backing up to a dump point was described as stressful because of the need to position the truck correctly on the dump while also looking out for hazards (e.g., soft spots, settling cracks, low berm heights). Again, similar to haul truck operators' descriptions of interactions with loader operators, haul truck operators also described negative interactions with dozer operators at the dump area as being stressful. In both cases, operators described the need for skill and knowledge (e.g., proper use of mirrors, knowing the size and positioning of the machine) to effectively navigate these areas.

Operating a haul truck requires a complex combination of skills that could potentially improve over time and with experience and training. One operator described this by stating: "backing up can be something that people struggle with, or be good at, and it's something that you can improve on [with] time and experience… There's an element of expertise in making sure you understand the distances and spacing of the loader and the truck you're driving." Other participants echoed this sentiment by reporting that learning "on the job" or "by doing" the task is the best way to learn properly. There were also suggestions about improving driving optimization, not just basic operation. Ensuring that operators in the fleet have consistent behavior, communication, and expectations is key to maintaining an efficient and safe operation.

**Proactive Communication.** When asked about steps that are most likely to cause mistakes or breakdowns in performance, many participants talked about the importance of communication. More specifically, participants talked about communication in the context of an operator's willingness or motivation to enact certain safety-related behaviors or tasks. For example, taking the time to do a proper pre-shift inspection (i.e., communicating mechanical issues with the truck), actively calling their location over the radio, and reporting hazards such as spillage in the roadway. One manager talked about communication in terms of looking out for one another: "Basically being their brother's keeper, you know, looking out for each other… I want everyone to be proactive."

The motivation to communicate is likely a combination of an individual's personal attributes (e.g., personality, risk aversion, personal values) and factors specific to their work environment (e.g., immediacy, need, incentive) [36]. Several participants offered suggestions for improving proactive communication, such as adding post-shift inspections and improving communication with the maintenance staff by using written inspections and getting timely feedback. Changing traffic patterns, surface conditions, visibility, or narrow sections of road were also some issues that participants thought could be improved through more effective positive communication. Operators could be better at letting others know their intentions or warning them about nonroutine situations. In other words, strengthening policies and procedures related to proactive communication could help operators mitigate these hazards.

**Training**

Like most other tasks at a mine site, haul truck operation simply requires task training as defined in 30 CFR § 46.7, which only requires that health and safety training be provided and observed by a competent person unless miners have similar training and can demonstrate competence [37]. Therefore, depending on the size of the mine, size of the company, and available funds and resources, the amount of formal training haul truck operators can receive is variable. Operators from smaller operations have reported minimal "on the job" training where they received one or two days of riding with an experienced operator followed by a short period of supervised driving. Operators from larger operations have reported as much as two weeks of classroom training, followed by ride-a-longs, and then supervised driving. However, despite receiving formal training, most operators felt that many of the skills needed to operate haul trucks are learned on the job and through experience. This has left some of the operators feeling unprepared for certain situations. For example, participant operators receiving training in the summertime when roads are relatively dry felt unprepared for the first snowstorm. Operators were not alone in feeling unprepared as many non-operators also expressed concern about the lack of training for operators, especially at sites where the haul truck operators were brand-new employees. One participant summarized his feelings as such: "I know they do have some training, but sometimes I think we turn them loose before they should be turned loose."

**Training Timing and Types.** Beyond the initial training, many participants also suggested that training could be improved by spacing out the training. As discussed earlier, this would allow operators to try some things on their own and then have devoted training time to go back and ask questions, thus, more effectively spacing out the training. Similar to avoiding cramming before a test, better spacing and time for practice has been shown to lead to better results and better retention [38].

Many operators also talked about the potential of experiential training. The idea being that operators could have with a safe area to practice sliding and turning or experimenting with speed. However, managers and H&S professionals were concerned about resources (e.g., not having an extra truck to spare) and added risk (e.g., added exposure to the operator or risk of capital damage to the equipment). One manager described how they have this for the loaders but not for the haul truck because they didn't think it was necessary. Given that so many of the participants expressed that most aspects of being a haul truck operator were learned on the job, experiential training may help to bridge that gap in a safer way.

**Training Consistency.** Another common theme brought up by participants was the lack of consistency in training. Several participants shared concerns that there was no set trainer at their mine site or within their companies. These participants suggested that operators may be getting a very different training experience depending on who trained them. While this variety can be a good thing, as discussed by some participants suggesting that a combination of various perspectives can give one a more holistic view, the lack of core knowledge may be problematic. Similarly, other participants talked about how there was not a formal list of topics or minimal information that was covered in training. This lack of basic requirements could lead to something critical being forgotten or overlooked (e.g., what brakes to use when). In situations where training time is limited, it could easily be the case that only hazards that are encountered that day are covered, leaving operators vulnerable to less common situations (e.g., fog, dump instability) that have led to fatal accidents in the past [13]. To address the problem on consistency, several participants suggested that mines should have a checklist of skills a haul truck operator needs to be proficient at or a set of training objectives to cover during training.

**Training Improvement Solutions.** Overall, many of the participants suggested that more training was needed with an emphasis on hands-on or experiential learning (e.g., experience with adverse events such as fire). They also expressed a need for consistency. In addition to the ideas presented above, some participants talked about solutions related to a specific topic or area. For example, some participants also felt that a simulator could be helpful, especially for new haul truck operators. Pre-shift inspections training was another area that several participants thought could benefit from more and clearer training. They indicated that operators may not know or remember the more technical aspects of the equipment and would need additional training (e.g., tire damage). Finally, several participants suggested the need for continual learning or refresher sessions, even for experienced operators, to improve the operation of haul trucks. Again, these reoccurring touch points could focus on driving optimization and how to be a good operator in general, allowing haul truck operators to continually improve throughout their careers.

**CDM and NIOSH Simulation Videos**

**Nonroutine Situations.** Five haul truck operators participated in the CDM interviews, describing and examining a variety of scenarios. Table 2 (see APPENDIX) describes the scenarios including accident type (see [13]), descriptions, and hazards. Interestingly, operators at some sites were more reluctant to discuss challenging or nonroutine scenarios than others despite similarities in size and mining process. This may have been due to the differences in safety culture and near-miss reporting in general. One of the H&S professionals suggested that operators at his/her site may have been more hesitant due to a termination following a reporting of a recent near-miss incident. Another possible explanation could be that operators have different risk perceptions and do not see these situations as near-miss events. For example, one operator describes sliding as a "daily occurrence," while another operator at the same site indicated that he/she never slid while operating a haul truck.

**Implications for Training.** The CDM interviews provide insight into operator activity during nonroutine situations and can be useful for training program development. Detailed descriptions and timelines can be used to create realistic accident recreations within a simulated environment. NIOSH researchers are in the process of creating simulation videos based on a subset of these scenarios Table 2 (see APPENDIX)). The videos not only provide an opportunity to make these types of accidents more relatable by using a narrative form, but the data from the CDM allows the videos to capture and expand upon what the operators were thinking. These cognition points can serve as heuristics or rules of thumb for other operators to remember or points of emphasis of pitfalls or mental traps that operators might find themselves in.

**Limitations and Future Directions**

While this paper provides insight into haul truck safety issues, there are several limitations to consider. First, the results presented in this paper are based on the preliminary analysis of the data collected to date for a larger study on haul truck safety. The authors of this paper plan to continue data collection to allow for better representation of mines of various sizes, commodities, and regions. Secondly, the qualitative analysis of the data was compiled using researchers' preliminary analysis of the available data. Subsequent and iterative analysis using more sophisticated tools, such as qualitative analysis software, will allow for the emergence, identification, and exploration of more themes. The authors intend to publish the results of the full data analysis in future publications.

## CONCLUSION

The purpose of this study was to gain a better understanding of how various workers perceive haul truck hazards, skills and expertise, training, and how operators respond to challenging or nonroutine scenarios. Additionally, this study sought to identify what strategies have been successful in coping with real-world challenges and what solutions could be put in place to address haul truck safety issues. Identifying perceptions and differences are an important first step for developing intervention and strategies to reduce the number of haul-truck-related accidents and injuries in the mining sector. Participants of this study reported that some of the greatest hazards for haul truck operators include not paying attention to mine site hazards (e.g., road conditions, changes in weather, unexpected movement by other operators), operator skill level, and communication. When asked about skills and expertise needed for operating a haul truck, participants identified abilities such as situational awareness, proficiency at driving tasks (e.g., backing into loading and dump areas), and proactive communication (e.g. reporting location, hazards, and mechanical failures). Many of the participants suggested additional training could be helpful in preparing operators for mine hazards and building skills and expertise. However, much of the current training in place, as reported by participants, is highly variable and often without a dedicated trainer and/or formal objectives. Follow-up questions regarding training content revealed potential gaps in training such as lack of follow-up (e.g., being trained in the summertime and leaving operators unprepared for winter conditions), lack of haul truck maintenance information (e.g., what to look for during pre-shift inspections), haul truck capacities and limitations, and a lack of “big picture” understanding. Given these potential gaps in training content, the CDM data gathered in this study can be used for developing detailed simulation videos based on real-life situations. These simulation videos, which provide insight into haul truck operator decision making and expertise during nonroutine situations, could provide valuable information to operators facing similar situations in the future. Overall, this study reveals haul truck operator’s concerns for safety and potential solutions to address these concerns.

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## APPENDIX

Table 2. Nonroutine scenario descriptions and hazards from CDM interviews with haul truck operators.

| Accident Type | Description | Primary Hazard | Additional Hazards |
|---|---|---|---|
| Person – Vehicle – Environment* | A haul truck operator learned that his truck was on fire from a passing blade operator and exits the truck using his wheel as step after the fire suppression fails to activate. | State of equipment (Fire) | State of equipment (failure of fire suppression system); Attention (lack of situational awareness) |
| Vehicle – Environment | A haul truck was headed down a ramp in icy conditions when operator has to navigate road maintenance traffic on one side and a notch in the road on the other. As a result, the truck slid into highwall. | Mine site conditions (icy road conditions) | Other environmental conditions (weather); Communication (lack of communication of road maintenance vehicles); Mine site conditions (failure to fix notch in roadway); Operator skill level (failure to maintain control of the truck) |
| Vehicle – Environment | The brakes on a haul truck failed and the operator lost control as he was going down a hill. The operator regained control by zigzagging down the hill and drove into sand pile. | State of equipment (brake failure) | Operator skill level (failure to maintain control of the truck) |
| Vehicle – Environment* | A haul truck operator hit a rut in the road causing the passenger door to pop open. He reached out to close door, jerked steering, and nearly went through the berm into pit. | State of equipment (faulty door latch) | Mine site conditions (rut in roadway); Attention (distraction); Operator skill level (failure to maintain control of the truck) |
| Vehicle – Environment | A water truck was speeding up a ramp and with a hard turn at the top. During the turn, the truck tipped onto two wheels and almost rolled over water. | Operator skill level (speeding) | Mine site conditions (sharp turn and narrow roadway); Operator skill level (failure to maintain control of the truck) |

* denotes scenarios used to create simulation videos