



Lessons Learned From Haul Truck Operator Near-Miss Events: Use of the Critical Decision Method to Identify Strategies to Improve Operator Safety in Mining

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Abstract

Accidents involving powered haulage and mobile equipment such as haul trucks often account for the greatest number of fatalities in the mining industry each year. Despite previous analyses that have identified root causes and other contributing factors, there is still a need to better understand the events leading up to these types of accidents, what lessons may be learned, and what strategies can be employed to prevent fatal accidents from occurring. This study examines naturalistic decision-making (NDM) using the critical decision method (CDM). The CDM is a retrospective interview approach used to explore time-limited, high-stakes decision-making that has not been often used in the mining industry. In this study, the CDM is used to obtain more information about what happens prior to, during, and after a potentially fatal situation such as a near-miss event, loss of control, or minor accident involving equipment damage. Researchers captured first-hand accounts from 21 haul truck operators involved in near-miss events from mine sites of various sizes and commodities throughout the USA. These accounts provide rich and detailed narratives from the perspective of haul truck operators themselves and reveal insights into what decisions haul truck operators make, what sensory cues they perceive, and what strategies they employ during challenging and non-routine situations so that haul truck operators can be better prepared in the future. Themes critical to operator decision-making emerged from the data with the top three including, *know your truck*, *situational awareness*, and *safety first*. These themes suggest that haul truck operators need to have a mastery level understanding of how their truck works in order to effectively react, that haul truck operators need to maintain an understanding of conditions and their environment, and that haul truck operators should prioritize safety when making decisions. To support haul truck knowledge acquisition and retention, mine operators may consider providing more detailed and hands on training including practice time in a variety of conditions. To support situational awareness, mine operators may consider investing in collision warning technologies and emphasizing good communication practices. Lastly, mine operators may consider continually emphasizing safety and their commitment to safe practices to help all mine workers internalize safety as a value, thereby reducing or eliminating related conflicts in decision-making. These results, along with potential solutions offered by study participants, can help to inform future research, raise awareness about hidden hazards, and build more creative interventions and realistic training scenarios for use by the industry to address haul truck safety issues.

Keywords Critical decision method · Cognitive task analysis · Near-miss · Non-routine · Mining · Haul trucks

1 Introduction

Accidents involving powered haulage and mobile equipment continue to be one of the most significant safety concerns for mine workers in the United States and often account for more than 50% of the fatal injuries at surface mines each year [1]. These accidents typically involve equipment such as front-end loaders, skid-steers, service trucks, and haul trucks [2, 3]. Given the persistence and often severe nature of these accidents, the regulatory body for the US

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mining sector, the Mine Safety and Health Administration (MSHA), has launched several initiatives in recent years to reduce the occurrence of accidents involving powered haulage and mobile equipment, including providing technical assistance to mine sites, developing training materials and gathering information from industry organizations and other interested parties [3, 4]. To further address the issue, MSHA has published a final rule, effective January 19, 2024, which requires mine operators to develop and implement written safety programs to evaluate and address the risks of surface mobile equipment used at their mines [5].

In addition to industry regulators, academic and research organizations have also sought ways to reduce the risks associated with powered haulage and mobile equipment. Previous analyses have attributed these accidents to loss of vehicle control, the lack of hazard recognition ability, and human performance [6–11]. Similarly, a recent analysis by the National Institute for Occupational Safety and Health (NIOSH) of 91 haul-truck-related fatal incidents 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 by the operator [12]. These analyses have been useful in identifying contributing factors and frequency of accident types; however, more work needs to be done to clarify why haul truck accidents continue to occur and how they might be avoided. Specifically, one challenge in the analysis of haul-truck-related fatal incidents is that the operator's first-hand account is often missing. This is because, most frequently the victim, the operator's voice and perspective are entirely lost.

Therefore, the goal of this work is to gain a better understanding of how haul truck operators perceive hazards and how they utilize their skills and expertise to react to challenging or non-routine 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, the critical decision method (CDM) was used to gather insights from individual operators regarding actual near-miss events they have experienced.

2 Objective

The objective of this study is to identify strategies haul truck operators have used to manage challenging or non-routine situations. This study specifically focuses on decision-making, lessons learned, heuristics, sensory cues, and mental strategies utilized by haul truck operators during these challenging events such as minor accidents or near-miss events. The study results can be used to inform the development of

training and safety solutions to avoid or mitigate haul truck accidents.

3 Methodology

As part of a larger study to characterize haul truck health and safety issues [13, 14], NIOSH researchers developed and utilized a semi-structured critical decision method (CDM) interview guide to better understand how haul truck operators respond to challenging or non-routine situations. The CDM, as outlined by Klein et al. [15] and Crandall et al. [16], is a multi-pass retrospective interview technique intended to gain more detailed insight into why an event occurred. The CDM has been shown to be effective in a case study with mobile equipment operators [17] as well as other industries [18], but specifics around haul truck events are still lacking. The CDM is used to examine real-world, high-stakes, time-limited decisions with the goal of identifying patterns, strategies, and cues that influenced the decision-making. By examining challenging and non-routine events using a timeline reconstruction approach that is augmented with probing questions, the CDM can elicit tacit knowledge that might not be otherwise articulated by the interviewee when describing their decision-making process. In this study participants were asked to recall a specific haul truck incident in which they were directly involved, one that was particularly challenging, and where their knowledge, skills, and decision-making abilities played a role in the outcome of the incident. They first described the incident in detail to the interviewer while a notetaker began building a timeline of each decision and action that took place during the event. The interviewer then asked clarifying and probing questions to elicit additional details about each decision and action. These probing questions helped the participant recall not only the intricate details of the event, but their internal thoughts as the event unfolded. As the timeline of decisions and actions was constructed, corresponding contextual elements, such as sensory cues, perceptions, and cognitions, were added. The initial timeline created during the interview served as a visual aid during the discussion. It also provided a scaffold for adding additional details during the post-interview. Overall, the strategy aims to clearly document the incident from the interviewee's perspective.

3.1 Participants

To recruit haul truck operators from surface mine sites in the USA, researchers utilized convenience and snowball sampling methods [19]. 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

Table 1 Participant experience demographics ($N=21$)

	Median [years]	First quartile [years]	Third quartile [years]	Interquartile range [years]
Mining experience	20	6.5	26	19.5
Mine site experience	5	3	20.5	17.5
Haul truck experience	15	3.75	21	17.25
Haul truck experience at current site	4.5	3	11.25	8.25

management (e.g., mine manager or health and safety professional) to identify potential study candidates.

The CDM participants included 21 employees from a variety of surface mines of differing geographic regions, sizes, and commodities throughout the USA including one medium coal mine; one large coal mine; three small stone, sand, and gravel (SSG) mines; one medium SSG mine; and one large metal mine. In this study, small was defined as fewer than 25 employees, medium as between 26 and 100 employees, and large as over 100 employees [12]. Each individual participant was currently employed as a haul truck operator at one of the mines. As shown in Table 1, the median mining experience was 20 years, and the median haul truck operating experience was 15 years. The protocol was reviewed and approved by the Centers for Disease Control and Prevention (CDC) as exempt human subject research¹ and reviewed for public burden and cleared by the Office of Management and Budget (OMB).

3.2 Data collection

When volunteers agreed to participate, a 1-h meeting was scheduled during their work hours and interviews were conducted over Zoom for Government (Zoom Video Communications, Inc.). Prior to the start of the interview, all participants provided oral consent to participate in the research. Each interview was conducted individually. There were three or four researchers present for all interviews, one serving as the interview lead, one building the timeline using Lucidchart (Lucid Software Inc.) on a shared screen, and the other(s) serving as notetaker(s). All interviews were audio recorded and transcribed for data analysis.

¹ See 45 C.F.R. Part 46.104.

4 Data analysis and example

The analysis plan used in the study is adapted from Wong [20]. Wong outlines two complementary analysis approaches for CDM data that allow for both structured and emergent theme analyses. A combination of these approaches is applied in this study as described below.

4.1 Step 1: create a decision chart and summarize the event

Following the interview, the draft timeline was imported into Visio (Microsoft, v2302). The event chronology was verified by reviewing interview transcripts and audio recordings. During this step, NIOSH researchers also captured additional relevant information to transform the timeline into a decision chart. As illustrated in Figure 1, the decision chart adds context to the decisions, such as sensory cues and perceptions, cognitions, and actions, as described by the haul truck operator when recounting the incident. These decision charts are standalone summaries which served as the foundation for the next step.

4.2 Step 2: Make a decision analysis table

Next, for each interview, NIOSH researchers created a decision analysis table. The objective of creating decision analysis tables is to connect the data extracted from the decision chart with corresponding justifications and objectives gathered from probing questions during the interview. These tables serve as a more elaborate resource for understanding the actions taken and decisions made in response to the incident. First, NIOSH researchers took data from the decision chart to populate columns for “sensory cues/perceptions,” “situational assessment/cognitions,” and “decisions/event.” Next, NIOSH researchers conducted further review of the interview data to extract corresponding information about “situational assessment,” “why was the action/decision selected?,” and “what for?”. An example decision analysis table is provided in Table 2.

4.3 Step 3: Identify Emergent Themes

Researchers next used the decision charts and decision analysis tables to identify emergent decision-related themes. Using emergent thematic analysis [21], three researchers independently reviewed the decision charts, decision analysis tables, and interview transcripts in search of initial themes. This phase of the data analysis allowed for the discovery and development of as many themes as required to capture the full depth and breadth of the data. Next, NIOSH researchers held several meetings to review the themes, identify commonalities, and rectify any disagreements. Eight

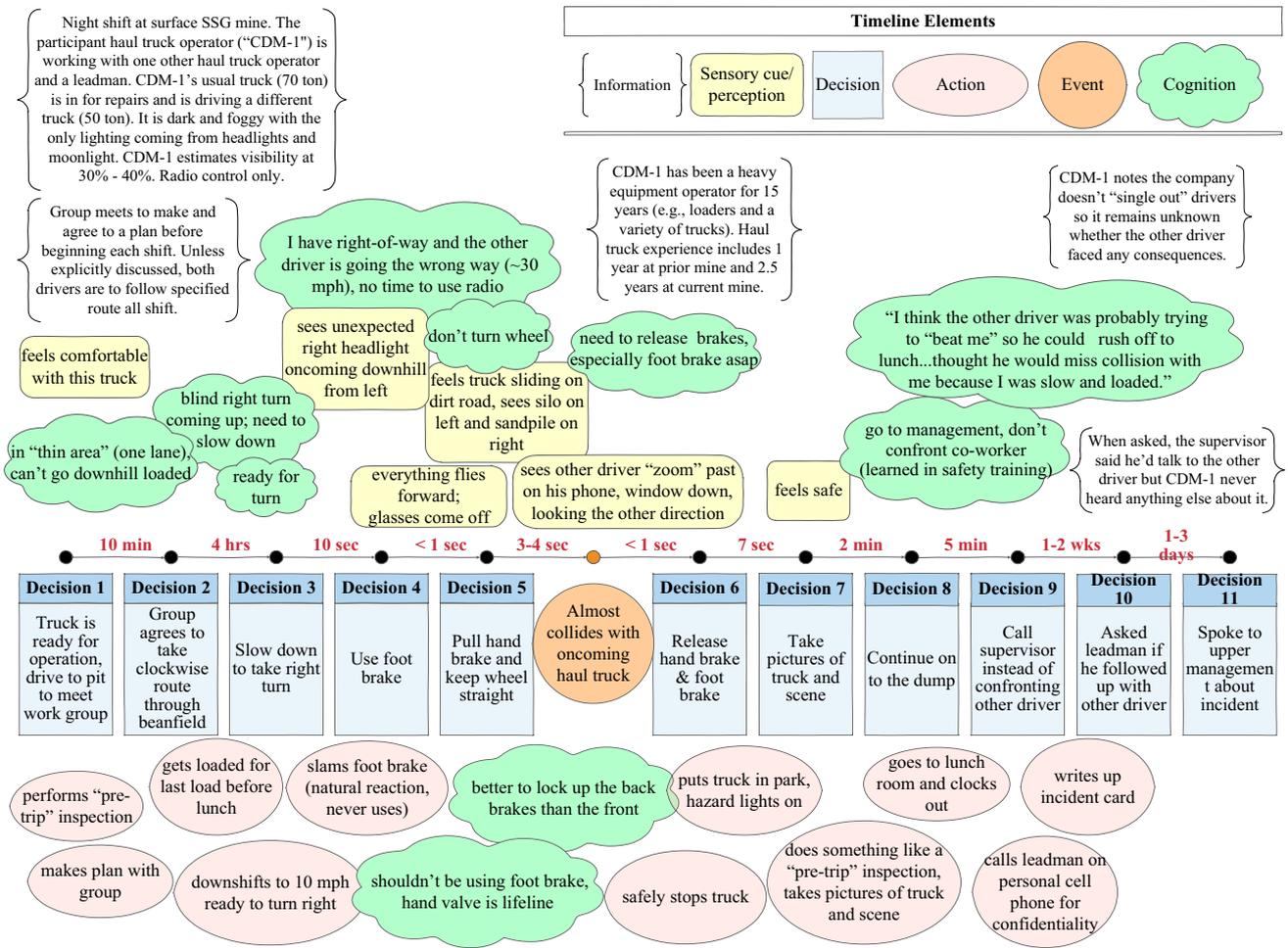


Fig. 1 Example of a decision chart: an event timeline that incorporates perceptions, cognitions, actions, and decisions identified by the participant as well as additional contextual information

decision-related themes were identified. Brief definitions of these themes are contained in Table 3 and more detailed descriptions are provided in the discussion section.

4.4 Step 4: Collate and Quantify Themes Across Incidents

The goal of step 4 is to examine the context and prevalence of themes identified in step 3 when looking at the data set holistically. To do so, NIOSH researchers used the eight emergent themes (Table 3) as codes for each decision of each incident (i.e., each row in each decision table). Each participant described one incident. Therefore, there were a total of 21 incidents with an average of 10.9 decisions per incident and 203 decisions in total. To assign a code, NIOSH researchers considered the contextual information provided in the decision chart, decision analysis table, and referred to the original transcripts as needed. To ensure trustworthiness of the coding and reduce potential bias, two researchers performed

the coding independently [22]. The coding results were compared between the two researchers, and all disagreements were resolved through discussion, with a third researcher serving as a tiebreaker. The agreement between the original two researchers was substantial with a Cohen Kappa of 0.654 ($p < 0.0001$) [23].

5 Results and discussion

5.1 Theme prevalence

Theme prevalence was measured in two ways; first by the number of cases from which the theme emerged and, second, by the number of times the theme appeared within the full data set. "Know your truck," "situational awareness," and "safety first" were the most prevalent themes across all participant incidents. All three occurred in 20 of the 21 participant incidents. They were also the most frequently occurring across all incidents (Figure 2). "Share

Table 2 Example of a decision analysis table

<i>Sensory cues/perceptions</i>	<i>Situational assessment/cognitions</i>	<i>Preceding action(s)</i>	<i>Decisions/event</i>	<i>Why was the action/decision selected?</i>	<i>What for? (i.e., higher goals)</i>
Dark with no light structures, only headlights and moonlight	Night shift. 30% visibility. Driving different truck this shift. Comfortable with truck	Perform pre-shift inspection	Truck is ready for operation, drive down to pit to meet work group	Standard operating procedure. All shifts start with group meeting to make plan for shift	To ensure truck is safe to operate and to begin workday
Sees right turn coming up	In thin area and can't go downhill loaded. Plan made, ready to start	Downshift	Group decides to take clockwise route through beanfield all night	Situation assessment called for counterclockwise route and though thin area	To ensure truck traffic can proceed safely while loaded
Sees unexpected oncoming right headlight approaching from left	Lunchtime is approaching. There is still time to get one more load before break. Blind right coming up		Slow down to take right turn	Blind turn	To navigate turn safely
Feels truck sliding	The other haul truck is approaching from the wrong direction. Need to stop turning to avoid collision. Silo on left, sand pile on right. No time to radio		Use foot brake	To stop quickly—natural reaction	To avoid collision with oncoming haul truck
Sees the other driver "zoom" past	Front wheels are locking up. Need to pull the hand brake and not turn wheel		Pull hand brake	"Hand valve is your lifeline." Better to lock up back brakes than front brakes	To avoid skidding out of control and colliding with silo or sand pile
Feels safe	Other driver on his phone, window down, looking the other direction		Release hand brake and foot brake	To come to controlled stop	To stop safely without incident
	Now that other truck has passed, need to release brakes—especially foot brakes		Exit truck to take pictures of truck and scene	Safe to document near miss (standard operating procedure)	For debriefing/follow-up action/ BDS card
	Safely stopped; can leave truck to take pictures of truck and scene	Stop truck, park, put hazards on	Continue to the dump	Finish last run before lunch	To meet production goals
	Out of danger. Safe to continue shift	Go to lunchroom, clock out	Call supervisor instead of confronting the other driver	Confidentially report (SOP)	Trained to go straight to management and avoid confronting co-workers
Was told supervisor would talk to the other driver	Other driver was probably trying to rush to lunch. Assumed he could beat loaded truck to intersection		Asked leadman if he followed up with the other driver		To prevent incident from recurring and to hold the other operator accountable

Table 2 (continued)

<i>Sensory cues/perceptions</i>	<i>Situational assessment/cognitions</i>	<i>Preceding action(s)</i>	<i>Decisions/event</i>	<i>Why was the action/decision selected?</i>	<i>What for? (i.e., higher goals)</i>
	Company doesn't single out drivers so consequences for the other driver are not known	Write up incident on BDS card	Spoke to upper management about incident		To prevent incident from recurring and to hold the other operator accountable

your stories,” “communicate effectively,” “stay calm,” “be a team player,” and “no distractions” emerged in 17, 14, 8, 4, and 2 of the 21 cases, respectively. The examples in Table 4 illustrate interview quotes researchers associated with the top three emergent themes. The following sections further explore these themes and ideas proposed by participants.

5.2 Know your truck

This theme exemplifies the critical requirement that haul truck operators possess domain-specific knowledge and skills. Given the rapidly changing environment, short timeframes, and complex situations, haul truck operators need to be able to make quick, definitive decisions and execute them at a mastery level. This includes performing pre-shift inspections, assessing the truck's status, understanding the truck's capabilities, appreciating the truck's size, knowing how the truck responds, and understanding how this all applies to the current situation. Overall, haul truck operators talked often of different aspects of operator competencies, where competency is defined as the observable ability of a person to integrate their knowledge, skills, values, and attitudes to achieve a specific goal [24]. In this case, the goal is to safely operate a haul truck. Operators often spoke about how their decisions and actions were motivated by how they “knew” the truck would respond with respect to different conditions, taking into consideration things such as truck type, truck condition (e.g., age, maintenance), road conditions (e.g., slope, material), weather conditions (e.g., rain, ice, snow), and load. For example, one haul truck operator spoke to the importance of appreciating the enormity of the truck and its capabilities: Operators also suggested that some decisions might not be based on the familiarity of a given “rule” but rather on understanding developed through their experience with the truck. Several participants spoke about needing to know which and how much brake to use when stopping in an emergency. For example, it was mentioned that sometimes even though an alarm might sound, it would be necessary to use the service brake to stop quickly to avoid a collision or that depending on road conditions, too much braking could send the truck into an uncontrolled slide. Additionally, many operators mentioned the need to make these decisions often in fractions of a second. This suggests operators need to be competent enough in predicting their truck's behavior so that they are able to react reflexively.

These findings suggest that competency-based training (CBT) which focuses on outcomes rather than training time and performance over knowledge could be one effective solution for improving operator safety [25]. Since

Table 3 The final eight emergent themes used to code each decision from each incident

Code	Definition
<i>Communicate Effectively</i>	Decisions to communicate (or failure to communicate) with co-workers in the moment to prevent an incident from occurring (e.g., pre-shift communication, honk horn at worker)
<i>Share your Stories</i>	Decisions to tell (or failure to tell) management or other co-workers after an incident happens for the purpose of sharing knowledge or making changes to prevent similar incidents (e.g., report near-miss)
<i>Stay Calm</i>	Decision to stay calm (or failure to stay calm). This includes decisions to not take any action or panicking and taking the wrong action (e.g., stay in the cab)
<i>No Distractions</i>	Decisions to maintain focus on the task at hand (or failure to maintain focus) (e.g., look for a fallen water bottle)
<i>Be a Team Player</i>	Decisions to look out for the safety of others (or failure to do so) (e.g., get out of the way of other traffic)
<i>Safety First</i>	Decision to put safety first (or failure to do so). This includes decisions derived from attitudes, beliefs, and established procedures related to safety such as risk taking, following standard operating procedures, or cutting corners to keep things moving (e.g., shut down a road that is too slippery)
<i>Know your truck</i>	Decisions made based on specific knowledge, training, or standard procedures on how to operate a haul truck (or lack of knowledge and training) (e.g., pre-shift inspection, know what brakes to use)
<i>Situational Awareness</i>	Decisions made based on the ability to perceive elements in the environment, comprehend their meaning, project their status in the future, and planning accordingly (or failure to do so), (e.g., plan route around other vehicles, slow down to meet changing conditions)

Fig. 2 Percentage of emergent themes coded for all decisions (N = 203) across all participant incidents (N = 21)

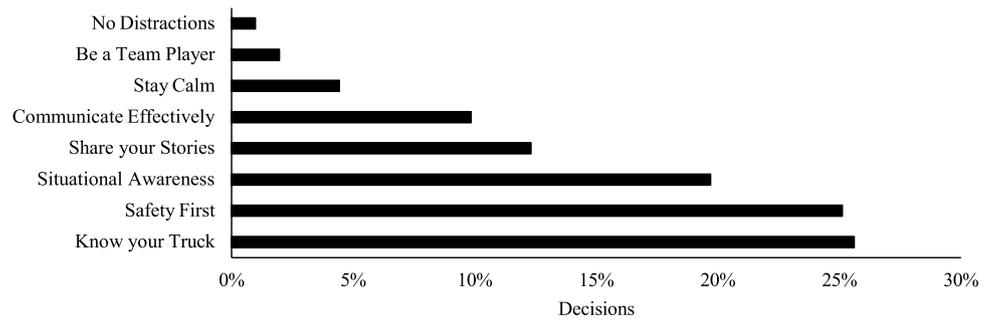


Table 4 Examples of quotes associated with the top three emergent themes from three participants

CDM-1	CDM-2	CDM-3
<i>Situational awareness</i>		
“...and that’s the thing, I had obstacles on each side, and all I had was that much room, and I knew I had to stop before, you know, I got to him...”	“It didn’t take me long to recognize what, where I was at and what was going on, you know? If I would have maybe tried to steer down off it, the berm might have collapsed...”	“...I saw one pickup driving up the hill. Looking around for the mechanic...I didn’t see him anywhere. I looked in the mirror, started the truck, took off, and I took the side of the pick-up off...I should have been aware of the fact that only one pick-up left...”
<i>Know your truck</i>		
“Once I was slowing down, I pulled the hand-brake and it, you know...it locks everything up...”	“...the steering is really sensitive on these, especially on a new machine... “ “I just felt the left front wheel riding up on the berm, you know...”	“...they get out of gear and stuff breaks, so I just shut truck off...”
<i>Safety first</i>		
“Especially, for what we do for a living, it’s a dangerous job. But you can make it safe with a good team that we have and a good supervisor and also good management that keeps everyone safe”	“No, I didn’t say a thing. Maybe I should have, but this was like 20 years ago...so yeah, kind of a silly thing, but those kinds of things can get you in trouble out here. Just the little things, overlooking the little things”	“I always...I have a habit of doing that...I look in the mirrors before I move...before you move forward you hit your horn twice, and that’s what I did”

competencies are observable, critical knowledge, skills, and abilities could be assessed through observation on the job in a variety of conditions and changing weather throughout the year. This approach could also attenuate the effects of differences in training content and technique that have been reported across instructors and sites [13] by making successful performance of a set of critical skills a requirement before allowing operators to drive on their own. This approach is consistent with interviewee suggestions that more hands-on training in various conditions could enable the development of a better understanding of how the truck will respond. In addition to more and varying opportunities for hands-on practice, it could be useful for operators to gain a better understanding of how and why the truck operates the way it does through technical training sessions devoted to the mechanics and capabilities of the truck.

5.3 Situational awareness

Beyond domain-specific knowledge, the goal of maintaining situational awareness requires “the ability to perceive elements in the environment, comprehend their meaning, and project their status in the future” [26]. This includes decisions related to identifying and acting on changing conditions such as weather, road conditions, or other drivers, and understanding the big picture beyond the mechanics and capabilities of the trucks themselves. Operators often mentioned engaging in decisions and actions because they noticed and identified something unusual, understood what was about to happen, and chose an action or plan they believed would bring about the outcome they wanted. Loss of situational awareness has also been identified as a contributing factor to many haul truck accidents [12]. To maintain situational awareness and understand the big picture during challenging situations, operators need to be highly attentive to cues and respond effectively to unfolding events. They should ask themselves questions such as “Did something change?” or “Do I know where everyone/everything is?” and “What does all of this mean?” Furthermore, this skill is linked to successful performance in that actions need to be taken immediately—often within seconds. There might not be time to, for example, use the radio to inquire about other traffic or warn other drivers about what is transpiring. Several operators mentioned watching out for developing hazards. As noted during one participant’s account, “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.”

Training specific to situational awareness may also be a potential strategy to enable haul truck operators to maintain awareness about what is occurring around them. The CDM data set suggests that training should include teaching operators to identify potential hazards, anticipate risks,

and make informed decisions based on their observations. Another solution that was discussed during the interviews was decision support technologies such as collision warning systems that help operators better identify objects, people, or vehicles near a haul truck. One operator mentioned that they specifically requested a camera for their haul truck to help eliminate blind spots. Operators generally agreed that these technologies may be able to help avoid serious incidents but should not be relied upon exclusively. An emphasis on hazard recognition training which includes changing traffic patterns and weather conditions could help operators better anticipate and respond to hazards in dynamic mining environments.

5.4 Safety first

Another prevalent theme was the importance of putting safety first and having a positive safety culture, which has been defined as “a set of safety-related attitudes, beliefs, and practices shared between employees, supervisors, and managers within an organization” [27]. Operators frequently discussed their decisions and actions in the context of prioritizing safety (or not). Many cited their adherence to safety protocols, a personal sense of what felt safe, a desire to protect others, a wish to be seen as safety-conscious, or simply following safety habits. Some operators even took individual measures to enhance safety. For instance, one operator said, “I got backup cameras...two of them. I had to install them myself, but I did.” However, there were also mentions of risky decisions and actions arising from a lack of emphasis on safety. Some operators pointed to the absence of safety rules or training to guide them, while others felt that making a safer decision might lead to negative perceptions by peers or employers. One haul truck operator who was new to the worksite reported not shutting down an unsafe road out of concern for what others might think. This reluctance on the part of the operator was explained this way: “I hate to say this, I wouldn’t say repercussion from my co-workers, but I guess it’d be like the peer pressure. You’re feeling, you know, inadequate to do that.” In retrospect, many operators suggested that if they had stopped to consider “safety first” over just “getting it done,” some of these incidents might have been avoided altogether.

Related to safety culture, it is important to note that communication goals including “effective communication” and “share your stories” were coded separately. Though these are also related to safety culture, researchers wanted to explicitly capture effective and ineffective communication decisions and examine them in isolation. While not a focus of this paper, the importance of effective communication, often inspired by a strong safety culture, is also critically important.

The critical nature of safety culture is also supported in the literature. Horberry and Cooke [28] similarly found that

safety culture affected mineworkers' perspectives on incidents, where interviewees tended to blame individuals rather than exploring other options. Promotion of safety has also been shown to have the greatest effect on safety behaviors [29]. To improve safety culture, sites should consider repeating safety messages frequently to better achieve recall [27] and ultimately allow their mineworkers to internalize safety as a value [30] which could reduce conflicts in decision-making at critical decision points. Some potential topics supported by the current study include the importance of reporting near-miss incidents, following established safety protocols, and encouraging open communication about safety concerns. The introduction of key safety performance indicators or "safety KPIs" and their emphasis over production KPIs could solidify operator perceptions of the company's commitment to safety above all else.

5.5 Taking it further

What is particularly unique about this data set is that it provides a detailed account from the operator's perspective. Information related to what the operator was sensing and thinking is typically not available or included in traditional fatality or other incident reports [17]. The detailed accounts given by haul truck operators surrounding their decision-making processes during challenging situations provided valuable insights from which safety solutions might be developed or adopted by mine sites. For example, participant CDM-2 described a near-miss event that was initiated by reaching for a door that popped open due to an unreported faulty door latch. If that incident had ultimately resulted in fatal accident, it is possible that no one would have discovered this critical piece of information, leaving the cause of the incident open for speculation. By examining near-miss events, the degree to which something as seemingly minor as a "faulty door latch" can instead be viewed as a safety risk, recalibrating haul-truck operators risk perception and promoting reporting of risks. Mine operators should consider having these types of open discussions with their haul truck operators. Using these narratives, researchers continue to develop outputs such as the accident re-creation videos described in Bellanca et al. [14] so that these otherwise unknown details can be shared with the industry. These real-world scenarios can be used to prepare haul truck operators to make decisions based on shared experiences.

Beyond the critical themes discussed in this paper, these results can also be used to inform the creation of additional training programs, such as simulation-based training exercises, which allow for the development of problem-solving skills and practice of decision-making to improve operator ability to handle unexpected situations. However, it is critical to remember that corrective actions taken after safety incidents or improvement of operator performance do not

always require more or better training. Consideration should also be given to prevention and mitigation strategies that target processes, procedures, technologies, and systems, when appropriate, such as the backup cameras or collision warning systems discussed above.

6 Limitations

While this paper provides unique insight into haul truck safety issues, there are several limitations to consider. First, the CDM framework is generally designed for interviewees with considerable experience and are experts in the field of interest. While the median level of experience of the haul truck operators who participated in this study was 15 years, participants had a wide range of experience, and some participants were relatively inexperienced. Also noteworthy is that some of the near-miss events occurred decades ago, and there were differences in policies, procedures, and best practices on how to respond to these non-routine situations then as compared to now. Despite this, all participants reported having firsthand experience in a situation they recognized as a near-miss event and having learned from it.

Another limitation of this study is the small sample size. Additional themes and the frequency with which themes occur could be different in the full population. These limitations were partially mitigated by the breadth of mine types and sizes. However, the prevalence of the themes should be used with caution, and it is best to consider that additional themes may also be relevant. Similarly, as Braun and Clark (2006) highlight, high frequency of occurrence does not necessarily mean the themes themselves are the most significant [21]. In this study, previous literature (see "Results and Discussion") and the domain-specific knowledge of the NIOSH researchers support the importance of the identified themes. Finally, self-selection at both the organizational and individual levels could bias the data in that potential differences between participants and non-participants could negatively impact the generalizability of the results.

Overall, these limitations along with inherent limitations related to the subjective nature of qualitative data should be considered when interpreting the results of the study. Further research is needed to obtain a more comprehensive understanding of how best to prepare haul truck operators to avoid or mitigate accidents through sound decision-making.

7 Conclusion

These results provide valuable information to industry stakeholders interested in understanding how haul truck fatalities continue to occur. Oftentimes, a considerable amount

of information is lost, making it difficult to determine root causes. This is particularly true in fatal incidents because the operator is often the victim. These CDM interviews provide valuable information about haul truck safety that might not otherwise be revealed allowing for the identification of critical themes most salient to haul truck operators such as the importance of knowing their trucks, obtaining and maintaining situational awareness, and the paramount importance of putting safety first. The awareness that is raised by these accounts and lessons learned through this analysis shed some light on one of the most pressing health and safety issues facing the mining industry today. With these insights, there is great potential for the development and adoption of effective interventions which take into consideration strategies used in real-world incidents from the perspective of haul truck operators themselves. Although the mining industry has given increased attention to human factors and safety and health behavior, there is still considerable room for further investigation into ways the industry can benefit from first-hand accounts such as these. Researchers have been examining the utility of these accounts in developing more accurate and insightful accident reports [17] and emphasizing human centered design of mobile equipment [31] which can be expanded upon. Additionally, these perspectives can be used for the development of key safety performance indicators and measurable training objectives to be adopted and implemented through innovative efforts to reduce the troubling number of injuries and fatalities among mobile equipment operators more generally in the mining industry.

Declarations

Conflict of interest The authors declare no competing interests.

Disclaimer The findings and conclusions in this paper are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention. Mention of any company name or product does not constitute endorsement by NIOSH.

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