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

Cassandra L. Hoebbel
Jennica L. Bellanca
Jonathan K. Hrica
Centers for Disease Control and Prevention (CDC)
National Institute for Occupational Safety and Health (NIOSH)
Pittsburgh Mining Research Division
Pittsburgh, PA, USA

DISCLAIMER

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. 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 United States. 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. Decision-related themes that emerged from the data are presented and discussed. 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.

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 percent 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 U.S. 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 proposed a new regulation that would require mine operators with six or more workers to develop and implement written safety programs to evaluate and address the risks of surface mobile equipment in the mining industry. As of this writing the most recent rule-making action was in 2022 when the proposed rule was reopened for public comment [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, 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.

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.

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. 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 note taker 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 it 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.

Participants

To recruit haul truck operators from surface mine sites in the United States, researchers utilized convenience and snowball sampling methods [17]. Mining companies were first contacted via email or phone communication to determine interest in participating in the study. If a mining company

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

expressed interest, NIOSH researchers worked with the mine 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 United States 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 as exempt human subjects research* and reviewed for public burden and cleared by the Office of Management and Budget.

Data Collection

When volunteers agreed to participate, a 1-hour 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.

DATA ANALYSIS AND EXAMPLE

The analysis plan used in the study is adapted from Wong [18]. 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.

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.

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.

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 [19], 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

*. See 45 C.F.R. Part 46.104.

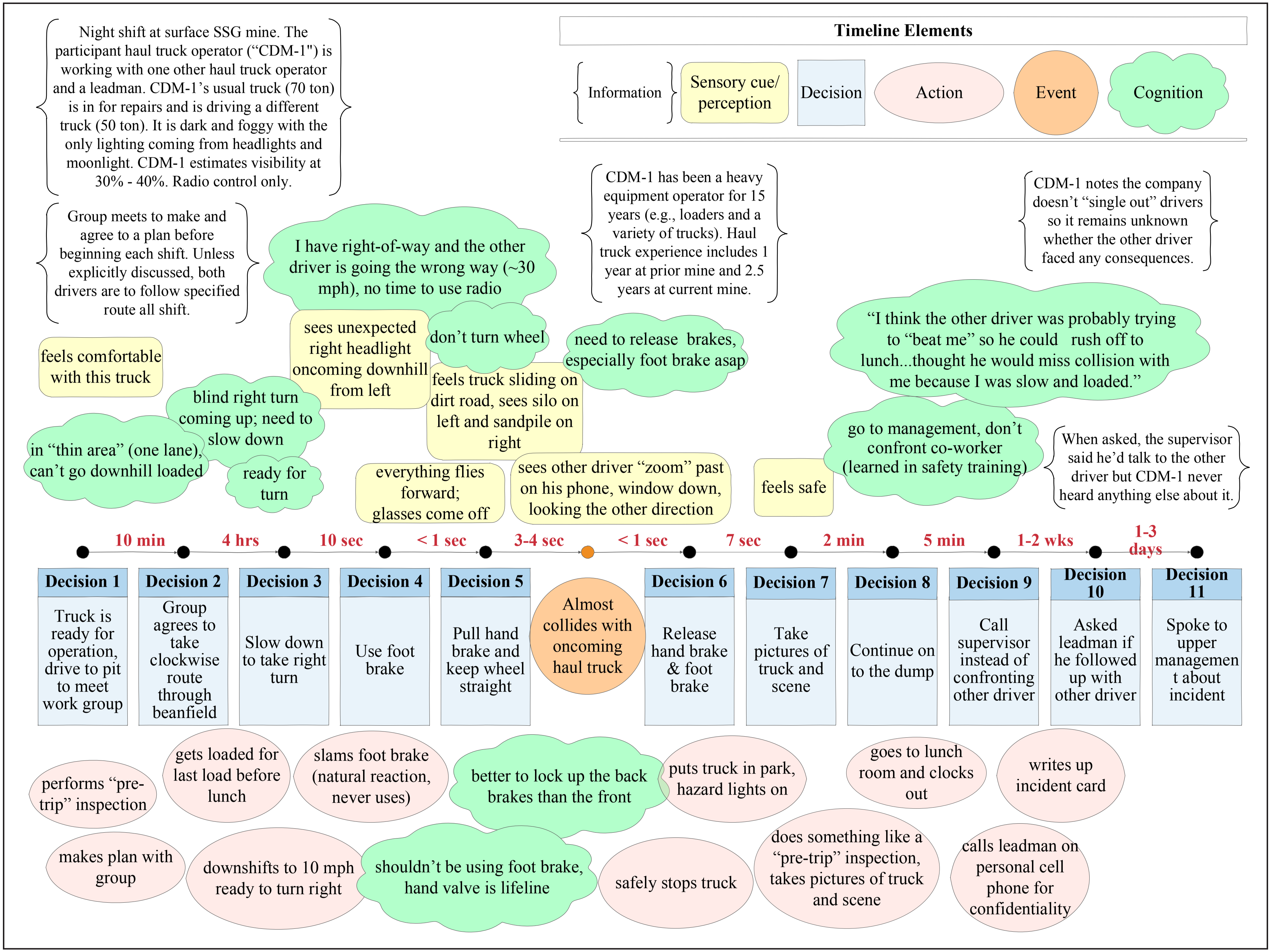

Figure 1. Example of a decision chart: an event timeline that incorporates perceptions, cognitions, actions, and decisions identified by participant as well as additional contextual information

Table 2. Example of a decision analysis table

Sensory Cues / Perceptions	Situational Assessment / Cognitions	Preceding Action(s)	Decisions / Event	Why was the action / decision selected?	What for? (i.e., Higher Goals)
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.
	In thin area and can't go downhill loaded. Plan made, ready to start.		Group decides to take clockwise route through beanfield all night.	Situation assessment called for counterclockwise route.	To ensure truck traffic can proceed safely while loaded and though thin area.
Sees right turn coming up	Lunchtime is approaching. There is still time to get one more load before break. Blind right coming up.	Downshift.	Slow down to take right turn.	Blind turn.	To navigate turn safely.
Sees unexpected oncoming right headlight approaching from left	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.
Feels truck sliding	Front wheels are locking up. Need to pull the hand brake and not turn wheel.		Pull hand brake.	"Hand valve is lifeline". Better to lock up back brakes than front brakes.	To avoid skidding out of control and colliding with silo or sand pile.
	Other driver on his phone, window down, looking the other direction.		***Event: Almost collides with oncoming haul truck.***		
Sees the other driver "zoom" past	Now that other truck has passed, need to release brakes - especially foot brakes.		Release hand brake and foot brake.	To come to controlled stop.	To stop safely without incident.
Feels safe	Safely stopped; can leave truck to take pictures of truck and scene.	Stop truck, park, put hazards on.	Exit truck to take pictures of truck and scene.	Safe to document near miss (Standard operating procedure)	For debriefing/follow-up action/BDS card.
	Out of danger. Safe to continue shift.		Continue to the dump.	Finish last run before lunch.	To meet production goals.
		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.
	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 reoccurring and to hold the other operator accountable.

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

Code	Definition
Communicate Effectively	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).
Share your Stories	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).
Stay Calm	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).
No Distractions	Decisions to maintain focus on the task at hand (or failure to maintain focus). (e.g., look for a fallen water bottle).
Be a Team Player	Decisions to look out for the safety of others (or failure to do so). (e.g., get out of the way of other traffic).
Safety First	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., shuts down a road that is too slippery).
Know your truck	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).
Situational Awareness	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).

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

CDM - 1	CDM -2	CDM-3
Situational Awareness		
"…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..."
Know Your Truck		
"Once I was slowing down, I pulled the handbrake 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…"
Safety First		
"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."

disagreements. Eight 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.

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,

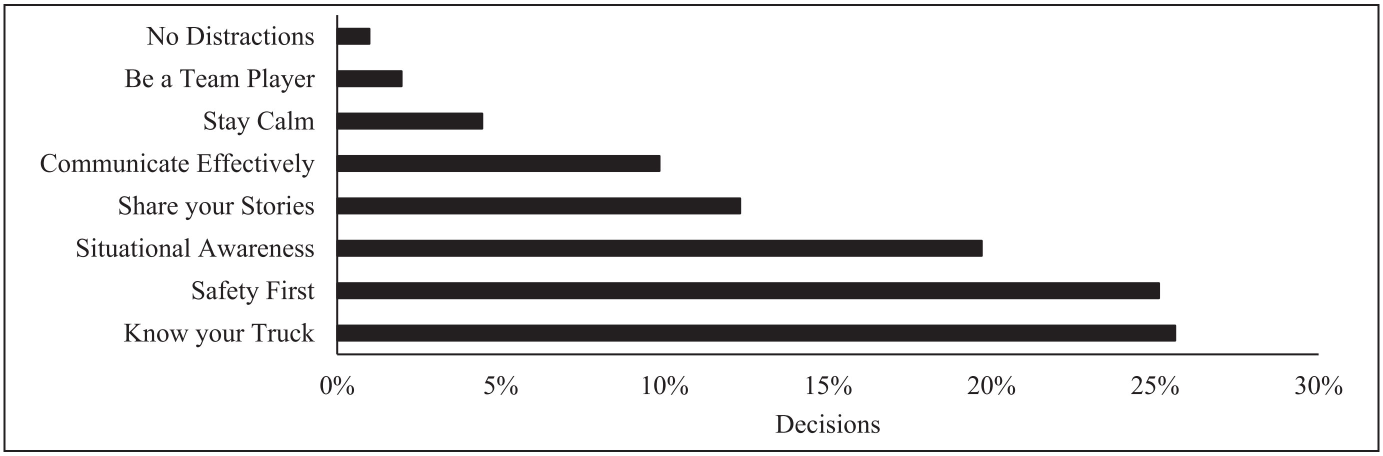

Figure 2. Percentage of emergent themes coded for all decisions (N = 203) across all participant incidents (N = 21)

and referred to the original transcripts as needed. To ensure trustworthiness of the coding and reduce potential bias, two researchers performed the coding independently [20]. 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 original two researchers was substantial with a Cohen Kappa of 0.654 (p<0.0001) [21].

RESULTS AND DISCUSSION

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 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.

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 [22]. 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: "if you think you can beat me or…you think that you're gonna sneak through…one of these days you won't. A truck doesn't stop on a dime...the maneuverability of it, when it's loaded is totally different than when it's empty." Operators also suggested that some decisions might not be based on the familiarity of 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 [23]. Since competencies are observable, critical knowledge and skills could be assessed through observation on the job in a variety of conditions. 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.

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" [24]. 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.

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" [25]. 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 coworkers, 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 [26] 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 [27]. To improve safety culture, sites should consider repeating safety messages frequently to better achieve recall [28] and ultimately allow their mineworkers to internalize safety as a value [29]. 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.

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. 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. 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's possible 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 is viewed as a safety risk to haul-truck operators can be calibrated and addressed. Using these narratives, researchers continue to develop outputs such as the accident re-creation videos described in Bellanca et al. [28] so 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 also can be used to inform additional training programs, such as simulation-based training exercises, that 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.

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's 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 [19]. In this study, previous literature (see 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.

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. 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 of effective interventions which take into consideration strategies used in real-world incidents from the perspective of haul truck operators themselves.

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MILP Production Scheduling Models for Evaluating Continuous Improvement Projects

Steven Hoerger
Peak View Mine Planning, Englewood, CO

SUMMARY

Mixed integer linear programming (MILP) production scheduling models can be used to evaluate if tonnage improvement projects will deliver value over all time periods and whether new bottlenecks will be created. These MILP models can evaluate the interconnected effects of mine and process capacities, mining locations, cutoff grades, stockpiles, and orebody grade/tonnage distributions.

A case study compares potential value creation from a mine capacity increase, a mill capacity increase, or a simultaneous increase in all capacities. For perspective, project valuations for capacity increases are compared against valuations for cost reduction projects, mine planning improvements such as phase design, dynamic cutoff grades and stockpiling, and the impact of geostatistics improvements in the areas of block model accuracy and ore control selectivity.

INTRODUCTION

Mine planners seek to create production schedules to maximize the value generated from an orebody subject to mining and processing constraints and defined cost structures. Continuous improvement (CI) leaders often focus on increasing value by expanding constraints and improving cost structures. Accurate prediction of the value to be created by constraint expansions requires understanding how production schedules will change as mine and process capacity changes interact with orebody grade-tonnage distributions. Accurate estimates of value creation allow CI investments to be prioritized against each other and against available capital budgets and organizational change bandwidth.

An open pit production schedule defines which locations are mined when—the mining sequence—and which mined material is sent to which destination at which time—the processing sequence (Clark and Dagdelen, 2023). The destinations could be a waste dump, stockpile or one or more processing facilities that generate a saleable product. At an operation with a single processing facility, the processing sequence is often expressed as a cutoff grade schedule: material above a time period's operating cutoff grade is sent to the processing facility; material below the operating cutoff is sent to the waste dump. A breakeven cutoff ensures that material above cutoff generates sufficient revenue to cover the costs of processing the material vs the alternative of sending the material to the waste dump. An operating cutoff should cover these costs plus the opportunity cost of delaying the processing of future material (Rendu, 2014). At many mines, a stockpile cutoff is also used to define material to be saved for processing at the end of the mine life or during periods of insufficient ore availability. The optimum mining and processing sequences often result in "balanced" operating cutoff grades where yearly tons mined equals the mining capacity constraint and yearly tons mined above the operating cutoff grade matches the processing constraint (Lane, 1988). In this situation, where both mining and processing are bottlenecks, translating constraint expansions into expected metal production increases becomes challenging because the capacity changes lead to cutoff changes in each time period.