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Operators' views of mobile equipment ingress and egress safety

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Abstract

A large proportion of non-fatal slips, trips, and falls (STFs) at surface mining facilities are associated with mobile equipment. Ingress and egress from mobile equipment can pose a fall risk to mobile equipment operators. The objective of this study was to determine mobile equipment operators' views of STF risks from mobile equipment, and to ascertain what factors, tasks, and conditions they perceive as contributing to these risks. A thematic analysis of 23 individual interviews and 2 group interviews was conducted, with 10 overarching themes identified from the transcripts. Mobile equipment operators indicated that being unable to see their feet or the ladder rungs during descent and the presence of contaminants on the ladders caused by normal operation make egress more dangerous than ingress. The flexible rails and high heights of the lower rungs identified over 40 years ago as issues for mobile equipment operators still pose a perceived STF risk. Further, the requirements of routine maintenance tasks such as oil and filter changes, greasing, and cleaning windows pose fall risks due to inadequate access and the need to carry supplies up and down equipment ladders. In addition to the mobile equipment, hazardous ground conditions and insufficient lighting were found to be key issues around the mobile equipment and in parking areas. The findings of this work indicate that mobile equipment operators feel at risk for STFs due to the design and condition of their equipment, and would like to see ladders replaced with safer stairways as the primary ingress/egress system.

Keywords

Mining; Ingress; Egress; Falls; Slips

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Disclaimer

The findings and conclusions in this report 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.

Conflict of interest

The authors have no competing interests to declare.

1. Introduction

Slips, trips, and falls (STFs) are the second leading cause of non-fatal injuries in the U.S. mining industry (Mine Safety and Health Administration, 1995–2015). Most non-fatal STFs at surface mining facilities are associated with mobile equipment (Mine Safety and Health Administration, 1995–2015). Analyses of U.S. mining injury data have highlighted the prevalence of falls from mobile mining equipment and the scenarios surrounding these accidents. One study found that most falls from mobile mining equipment occur during ingress (climbing into the cab from the floor/ground) or egress (exiting from the cab to the floor/ground) (Moore et al., 2009). A recent analysis of STFs from front-end loaders during ingress and egress revealed that over 60% of the injuries occur during egress and 25% occur during ingress (Nasarwanji et al., 2018). This is slightly higher than statistics previously reported for haul truck operators, where most nonfatal injuries (46%) occurred during egress, with a smaller but still large portion (23%) having occurred during ingress (Santos et al., 2010).

Egress from mobile mining equipment poses a greater risk for an injury than ingress, and the reason for this discrepancy remains unknown. Of the 1291 front-end loaders associated with injuries from a previous analysis, 78.4% were found to use vertical ladders as the ingress/egress system and another 10.7% used inclined ladders. Only 3% used stairs or a combination of stairs and ladders (Nasarwanji et al., 2018). When ladders are used, personal, environmental, and design-related factors affect safe outcomes (Cohen and Lin, 1991; Shepherd et al., 2006). Personal factors, including climbing or walking style or carrying items in the hand, can contribute to injuries (Cohen and Lin, 1991; Shepherd et al., 2006; Pliner et al., 2014, 2017). Environmental factors such as the presence of contaminants can contribute to hazardous conditions, and inadequate illumination can reduce the likelihood of hazard detection. Nonfatal STFs on haul trucks and front-end loaders have been associated with environmental conditions such as wet, icy, and muddy ground and ladders (Santos et al., 2010; Nasarwanji et al., 2018). Design-related factors, such as the inclination of the ladder, the location and type of handrails, and the length of the ladder also contribute to STF risks (Chang et al., 2004; Axelsson and Carter, 1995).

Laboratory research suggests that ladder descent will result in a more severe injury than what would occur given the same perturbation in ladder ascent, but it still does not explain the higher proportion of injuries during mobile mining equipment egress. Pliner et al. (2014) conducted a laboratory investigation of ladder climbing with a simulated slippery rung. In their study, participants were exposed to one rung that would spin on ascending and descending trials. If ladder descent (egress) is more dangerous than ladder ascent (ingress) for this scenario, then there would have been more falls during the descent trials. The authors did not find any statistically significant differences between falls during descent versus ascent and argued that ladder descent is not any more dangerous than ladder ascent. In a later study, Pliner et al. (2017) examined fall severity for ladder climbing with unexpected ladder missteps. Fall severity was determined by the amount of force on the fall arrest harness, with a higher force being associated with a more severe fall (Yang and Pai, 2011). Participants were exposed to six unexpected ladder rung failures (where the rung

broke away) with three glove conditions and two climbing directions. Results found a higher fall severity during ladder descent than ascent and no effect of gloves on fall severity.

One field investigation of actual mining equipment aimed to determine the contribution of vibration exposure to egress risks. Pollard and colleagues (2017b) hypothesized that exposure to hand-arm and whole-body vibration from haul truck operation would result in reduced touch sensation threshold and balance impairment, which may lead to increased fall risks when exiting equipment after prolonged exposure. Their results, however, did not find any statistically significant changes in touch sensation threshold or balance during a regular work day. They did, however, find that haul truck operators had lower touch sensation than what would be expected for their age, and the authors proposed that long-term exposure to hand-arm vibration may have contributed to the lower touch sensation. This diminished touch sensation threshold could result in a decreased ability to maintain grasp of handrails, thereby increasing fall risks. Cornelius et al. (1994) conducted a simulation experiment to determine the effects of whole body vibration exposure on postural stability. Six male participants were exposed to vertical vibration levels representative of those experienced during operation of an underground mining shuttle car. The researchers argued that both vibration frequency and duration likely affect postural stability but were unable to find any statistically significant changes in balance measures following vibration exposure.

While the exact mechanism for the increase in fall risks during egress is still not well understood, general recommendations have been made to improve safety for mine workers during ingress and egress from mobile equipment. A previous research effort by the U.S. Bureau of Mines sought to develop safer ingress/egress systems for large haulage trucks (Gavan et al., 1980). In their research, the authors highlighted four key deficiencies with the ingress/egress systems of operating haul trucks: inadequate handrails and guardrails, excessively flexible lower section supports for lower steps or rungs, inappropriate ground level to first step distances, and poor step designs which permit mud, snow, ice, grease, and oil accumulations. Additional hazards were found to be due to the lack of proper maintenance of the ladder systems and the operators carrying items on and off the truck. The authors proposed several ladder redesign suggestions, but no information is available on the implementation of these redesigns in the field. Most recently, Nasarwanji et al. (2018) recommended improved maintenance and housekeeping of ladders and safe parking areas to improve safety during ingress and egress from mobile mining equipment.

Redesigning mobile equipment ingress/egress systems to safe standards will improve the safety of the work environment, but safe work outcomes still require safe work behavior (Albin, 1988; Albin and Adams, 1989). While injury narratives have been used successfully to determine the causes or contributing factors to injuries, the narratives do not provide adequate information or indicate if workers' behaviors played a role in initiating an incident or influencing the severity of the outcome. Understanding worker behavior, the workers' perceptions of the safety of the environment, and alternative strategies they employ to ensure their safety in potentially unsafe environments requires direct communication with the workers. Further, little is known regarding mobile mining equipment operators' perceptions of what causes or contributes to injuries during ingress and egress. A holistic characterization of STF risks during mobile mining equipment ingress and egress needs

to consider equipment design, environmental conditions, and common tasks performed by workers as they together contribute to causing or preventing STF injuries.

With the above background in mind, the purpose of this study was to determine mobile equipment operators' views of mobile equipment ingress and egress safety, and to ascertain what features of the ingress/egress system or stages of the ingress/egress process mobile equipment operators feel place them at the highest risk for an STF. A better understanding of the operators' perceptions on where, how, and why STF incidents could occur during ingress and egress on mobile mining equipment will lead to a better characterization of the problem, which can be used to inform the redesign of these systems and the development of safe work practices.

2. Methods

Mobile equipment operators were invited to participate in the study from four different mine sites - three sand mines from Virginia and North Carolina and one crushed stone mine from Pennsylvania. The only requirement was that participants operate mobile mining equipment on a regular basis or as part of their daily work activities. The intent was to conduct private interviews with each of the operators; however, in two cases, group interviews were conducted due to time constraints of the operators. A total of 23 individual interviews, one group interview with five operators, and one group interview with three operators were conducted. The study was approved by the Internal Review Board (IRB Number: 15-OMSHR-04XP) of the National Institute for Occupational Safety and Health (NIOSH) and the Office of Management and Budget (OMB Control Number: 0920–1125) through the Centers for Disease Control and Prevention.

A semi-structured interview approach was adopted to elicit information covering the five research questions. Participants were asked a series of opening questions to determine the type of equipment they operate, whether they have experience operating other types of equipment, and how long they have been a mobile equipment operator. They were also asked to provide their history with slips or falls from equipment. Following these opening questions, each participant was then asked a series of standardized questions (examples included below) pertinent to the five research questions (RQs) guiding this study. Probing questions were used to gain deeper details from participants.

RQ1 - What portion of the ingress or egress process leads to slip, trip, or fall injuries?

- At what point during the process of getting on the equipment do slips, trips, or falls occur?
- At what point during the process of getting off of equipment do slips, trips, or falls occur?

RQ2 - What features or conditions of the ingress/egress system contribute to slips, trips, and falls?

- In your opinion, is there anything else that makes getting on and off mobile equipment more difficult or increases the chances of falling?

RQ3 - What features of differing ingress/egress systems are con-sidered superior?

- Is any ingress/egress system superior (either different make/model/or other type of equipment) to the system on the mobile equipment you currently operate and why?
- If there was some part of the ingress/egress system that you could change, what would it be?

RQ4 - What tasks, other than ingress or egress, lead to slips, trips, and falls?

- In your opinion, what tasks may commonly lead to slips, trips, or falls from mobile equipment?

RQ5 - What conditions not directly related to the ingress/egress system contribute to STFs during ingress or egress?

- In your opinion, are there any environmental conditions (e.g., weather, parking location, seasonal effects) which make getting on or off the equipment more difficult or increase the chances of a slip, trip, or fall occurring?

Interviews were conducted in a private room at the mine site (e.g., a conference room, break room, lunch room). On arrival, participants were given a brief verbal overview of the study, given an opportunity to ask questions of the researchers, and then verbally consented to participate. During the interview, operators were asked to provide their opinions based on their personal experiences. Similarly, during the group interview, the focus was on individual responses as compared to group consensus; however, operators were allowed to take cues from and follow up on other operators' experiences. In most cases, only one interviewer was in the room with the operator and the entire interview was audio recorded. The interviews were scheduled for 40 min, but most were completed within 12–15 min, with the group interviews taking about 30 min each. The interviews were transcribed verbatim based on the audio recorded during the interview.

The transcribed interviews were analyzed to determine themes using thematic analysis (Braun and Clarke, 2006). This analysis was conducted by two researchers, and involved the researchers independently reading the interview transcripts for familiarity of content and then re-reading the transcripts to identify codes (Morgan et al., 2016). These codes were used as labels to identify operator responses that were deemed relevant to the individual research questions. In many cases, the operators provided details that were relevant to multiple research questions. In these situations, their responses were listed under multiple research questions. Once all responses were organized into codes, themes were then created by grouping codes that conveyed patterns in the operators' responses to each of the five research questions. Together, the researchers compared the codes and themes they had developed separately and worked to resolve discrepancies. They ultimately developed a final set of themes and sub-themes and definitions for each research question.

3. Results

The five research questions resulted in ten overarching themes (one of which - 'Ladder design and condition' - was associated with two research questions). The thematic map with all themes and subthemes is presented in Fig. 1. Appendix A provides all developed themes and subthemes with their definitions and exemplar quotations. The themes associated with RQ1 were 'Egress is more dangerous than ingress' and 'Getting in and out of cab.' The themes associated with RQ2 were 'Ladder design and condition' and 'Contaminants.' The themes associated with RQ3 were 'Ladder design and condition,' 'Traction,' and 'Lighting.' The theme associated with RQ4 was 'Maintenance and repair.' The themes associated with RQ5 were 'Ground Conditions,' 'Disrepair of unrelated parts,' and 'Footwear.' These themes and their associated subthemes are presented in detail in the following subsections.

3.1. What portion of the ingress or egress process leads to slip, trip, or fall injuries?

Researchers identified two themes in relation to this research question:(1) egress is more dangerous than ingress and (2) getting in and out of cab. In addition to operators identifying egress as being more dangerous than ingress, they also identified it as being more likely to lead to an STF. The operators described the need to "*be a little more cautious getting off the equipment than you would getting on*." Equipment operators attributed the increased risk of egress to one emerging subtheme: 'backward vs. forward.' 'Backward vs. forward' describes requiring the operator to move backwards, facing the ladder and moving downward, during egress or when descending the ladder, as compared to moving forward, facing the ladder and going upward, when ascending the ladder during ingress. Operators described "*stepping out coming backwards so you might lose your footing.*" The lack of visibility of the rungs, steps, or ground when facing the ladder during descent was identified as being a challenge during egress: "*It's harder to find my step or you can't see it when you're standing above it".*

From the second theme - getting in and out of the cab - two subthemes emerged: carrying items in the hands and opening the cab doors. Carrying items in the hands refers to situations when operators are holding items, such as lunch containers, water bottles, coffee cups, etc., while attempting ingress and/or egress, which eliminates three points of contact (always having one foot and two hands or one hand and two feet in contact with the ladder). One operator commented, "*If you're trying to carry a magazine, a water bottle, and lunch box and something like that all at the same time. You know you're not having good contacts.*" Another operator acknowledged the increase in risk caused by carrying items and recommended to "*use a backpack or just use something that will contain your stuff a little better.*" The second subtheme, cab doors, refers to the risks caused by opening and closing the cab door and the unintentional movement of the doors. One operator commented, "*If you're getting in, a lot of times you're pushing the door open. You get halfway in and you're bending over and it comes around and catches you in the tail or you know. Same way when you're climbing out. You back out of the cab when you're coming out so you're so you know the door comes shut it could get you in the shoulder, the arm or something like that.*"

3.2. What features or conditions of the ingress/egress system contribute to slips, trips, and falls?

Researchers identified two themes in relation to this research question: (1) the design and condition of the ladder and (2) the presence of contaminants. Within the design and condition of the ladder theme, four subthemes were identified: 'flexible rails,' 'distance from ground,' 'traction,' and 'bent/damaged.' The first subtheme, flexible rails, refers to ladders with rails or sides made from cable, rubber, or chains. These flexible rails are designed to allow the ladder to move and flex when bumped, increasing the likelihood that the ladder will remain intact when the operator is driving through the mine. The operators described the flexible rails as being a feature or condition of the ingress/egress system that contributes to STFs because the rails can become excessively flexible over time to the point where "y*ou could damn near swing.*" They also described how the rungs with flexible rails have more movement and are less stable than the rungs with the rigid rails because "*the very bottom step has rubber supports and it wants to flop*."

The second subtheme within the design and condition of the ladder theme, distance from ground, refers to instances when the distance from the ground to the first rung is too great. Participants indicated that this height was a feature of the ingress/egress system that could contribute to STFs with statements including, "*going from the ground up to the first step because it's normally higher*" and "*well most of them [mobile equipment], the first step is pretty high."*

The third subtheme, traction, refers to the amount of slip resistance provided by the walking surface of the ingress/egress system. Operators indicated that the surfaces provide inadequate traction for the mining environment, therefore contributing to STFs. Operators identified "*flat painted surfaces*" as becoming "*very slick*" when exposed to water or dust and posing a hazard: "*anytime it's wet, it's you know painted surfaces are wet they're slippery. I think that's your fastest danger of falling.*" Additionally, old and worn-down metal walking surfaces were identified as not having "*a real grip contact anymore*" and creating a hazard of slipping.

The fourth subtheme, bent/damaged, refers to the physical disrepair of the ladder systems, which may occur because of regular use or due to the age of the equipment. Operators identified bent ladder rungs as being something that needs to be repaired or "*something you have to watch for.*"

The second theme that emerged from this research question - the presence of contaminants - refers to situations when contaminating materials such as water, mud, snow, ice, grease, etc., accumulate on components of the ingress/egress system. One subtheme within the presence of contaminants theme emerged: 'on ladders and platforms.' This subtheme refers to situations when contaminants are present on the walking or foot placement surfaces of the ladders and platforms that are part of the ingress/egress systems. One operator commented, "*if you have a lot of dust build up from travelling up and down quarry roads or whatever it can make it very slippery getting in and out also.*" One operator described a recent slip from a ladder due to muddy conditions where he "*start[ed] to step up on it and my foot slipped off*". Additionally, operators indicated that the presence of contaminants on ladders

and platforms leads to increased risk during egress (as opposed to ingress) because "*when you're getting on you can clean the steps and getting off, after you've ran it and traveled it gets clogged back up with mud.*" Handrails were also identified as being contaminated from the loading process - "*if it's wet stuff … it sloshes out and gets on the hand rails*" - and contaminated handrails were something to be attentive to as a mobile equipment operator.

3.3. What features of differing ingress/egress systems are considered superior?

The mobile equipment operators interviewed had experience operating multiple different types and brands of equipment and were asked to identify the 'superior' features of different ingress/egress systems they had encountered. The operators also provided a wish list of components that would be preferable and these were also included with features that were considered superior.

Three themes related to superior ingress/egress systems emerged: 'ladder design and condition,' 'traction,' and 'lighting.' The first theme, ladder design and condition, refers to the design of the ladder component of the ingress/egress system. This theme had two subthemes: 'greater rigidity is superior to flexibility' and 'stairs are superior to ladders.' For the greater rigidity is superior to flexibility subtheme, operators identified a preference for ladders with more rigid rails over those with the flexible rails. While operators understood the purpose of the flexible rails, they felt that they should be "*a little stiffer*" and "*not swing so much*" to ease the ingress/egress process. Equipment operators also indicated a preference for rubber-sided rails by indicating that "*rubber might be a little bit better than the cable."*

For the second subtheme, stairs are superior to ladders, operators indicated a preference for the newer ingress/egress systems equipped with stairs and steps instead of ladders, and they felt they were safer on stairs. One operator stated, "*everything should have a more or less a set of steps instead of a fixed ladder … if it was a set of steps, you'd have a lot less chance of falling or you know losing your footing.*" Additionally, one operator indicated that on the ingress/egress systems with combinations of stairs and ladders, greater tread depth is superior to lesser tread depth. Specifically, the treads on the newer equipment with greater depth results in you being able to "*feel 'em better."*

Traction was identified for a second time as a theme - this time as a superior component of ingress/egress systems. Specifically, operators indicated that increased traction on the walking surfaces and handrails would improve the ingress/egress systems and wanted "*more grip on everything.*" Specifically, operators wished to be provided with more "*bite*" from the walking surfaces and also identified some equipment as having "*more of a gapping so material wouldn't build up on them like say mud, dirt. It would just fall right through.*"

The third theme identified as a superior component of ingress/egress systems was lighting - specifically, equipment-mounted lighting that illuminates the ingress/egress system and surrounding areas. Operators identified systems designed such that "*you could turn the master key on from the ground level and then you'll have lights on your stairs and everything. So you can see early in the mornings or late at night getting on and off.*"

3.4. What tasks other than ingress and egress lead to STFs?

From this research question, one theme emerged: 'maintenance and repair.' This theme refers to tasks that must be undertaken in order to maintain or repair the working condition of the mobile equipment. During their interviews, operators identified four specific maintenance and repair activities as risky: changing oil filters, greasing, window washing, and changing air filters. Changing oil filters on the equipment was identified as hazardous activity because "*you're carrying oil jugs up and down it [the ladder]. You drag hoses up and down.*" Operators also identified greasing parts of the equipment as risky because of the locations of the grease fittings, because they needed to assume awkward postures, and because of the need to carry the grease can to multiple locations. In addition, window washing was identified as risky, specifically for some pieces of equipment that do not have platforms in close proximity to windows that operators can stand on while cleaning. On these pieces of equipment, mine operators are "*out there hanging onto the rail trying to wipe their window or something.*" Changing cabin air filters was considered an STF risk for reasons similar to window washing - the lack of a safe access: "*you're basically standing on the bumper to change out the cabin air filters but you don't have a work platform and you're not able to keep three points of contact by changing out a cabin air filter*".

3.5. What conditions not directly related to ingress/egress systems contribute to slips, trips, and falls during ingress and egress?

When considering operators' responses to this research question, three themes emerged: 'ground conditions,' 'disrepair of unrelated parts,' and 'footwear.' The first theme, ground conditions, refers to the condition of the ground an operator must traverse when entering or exiting mobile equipment. Mobile equipment operators indicated that the condition of the ground or walking surface at the locations where they entered or exited the equipment leads to STF.

Within the ground conditions theme, two subthemes emerged: weather and uneven ground. The first subtheme, weather, refers to weather situations, such as drought, snow, rain, and ice accumulations that result in dusty, slippery, and/or muddy conditions. Operators described needing to be "*real careful*" when egressing if it had snowed or rained during shift.

The second subtheme, uneven ground, refers to ground conditions such as ruts, slopes, holes, or rocks that create ground conditions that are not level. One operator commented that, "*if you exited a piece of equipment while out in the quarry, you take a chance of stepping on an uneven surface and twisting an ankle or something like that.*" Another operator described the need to seek out clear areas for parking, stating, "*I always try to pull in to the higher area where it's pretty clear, where I can get out and you know, make sure there's no rocks when I step down.*" Operators also commented on parking on sloped ground, making the height of the first step significantly greater than expected: "*you know you got to watch if you're parked on an angle 'cuz you'll be a couple feet higher than where you've started.*"

The second theme, disrepair and condition of parts of the equipment other than the ingress/egress system, refers to the condition of parts of the mobile equipment that are not considered to be components of the ingress/egress system. Operators once again indicated

that the cab door could contribute to STFs because "*sometimes they don't stay open all the way so you get halfway in and it comes swinging shut and knocks you a good one.*" Additionally, operators suggested that the operator's seat could lead to STFs because it sometimes requires adjustments prior to getting all the way into the cab, "*I have to reach down in there and open the latch [slide] and get it back before I can get in and sit down.*"

The third theme associated with this research question, footwear, refers to the types and conditions of footwear worn by operators. Three subthemes emerged: 'metatarsal boots,' 'traction,' and 'muddy boots.' The subtheme metatarsal boots refers to safety toe boots with additional protection over the metatarsal bones. Operators indicated that wearing metatarsal boots when climbing the ladders "*makes it difficult sometimes because your ankle, your foot don't flex up and down like it should because all that stuff over the tongue of it.*" Operators also described getting their toes hung up on some equipment because of the reduced spacing between steps and because the metatarsal boots are "*more bulky and not as flexible*" as the boots without metatarsal protection.

The second subtheme, traction, refers to the condition of outsole of the boot and how worn out the outsole is, impacting the boots' ability to provide traction on the various surfaces of the ingress/egress systems. One operator commented that, "*a lot of time the real comfortable shoe that somebody will wear, there's not much traction on the bottom of it and it makes it slippery too.*"

The third subtheme, muddy boots, refers to the cleanliness of operators' footwear - specifically the accumulation of dirt, mud, and debris on and in the outsole of the footwear. Operators indicated that mud accumulation on the outsole of footwear was a concern because there's "*no way of cleaning feet off getting in*" and the mud "*makes it a little slippery.*"

4. Discussion

The aim of this research was to determine operators' perceptions regarding the factors, conditions, and activities contributing to slips, trips, and falls from mobile mining equipment. Operators' responses to interview questions guided by five key research questions were examined, revealing ten themes. These themes were defined based on quotations from the interview transcripts and also have strong support from existing research.

4.1. Egress

The operators participating in this research perceived egress as being more dangerous than ingress. This is consistent with injury data from mobile mining equipment and general ladder use. Nasarwanji et al. (2018) determined that over 60% of the STF injuries to mining front-end loader operators occur during egress, 25% occur during ingress, and another 11% occur during maintenance or other activities. Santos et al. (2010) found a similar proportion in mining haul truck operators, with 46% of all non-fatal injuries to haul truck operators occurring during egress and 23% occurring during ingress. A prior study examining the biomechanics of ladder ascent and descent did not find an increased

slip or fall risk during descent as compared to ascent (Pliner et al., 2014). However, there are several possible explanations as to why egress could be more hazardous than ingress, including gravity (making it easier to fall when going down instead of going up) and diminished proprioception of older workers, which reduces the ability to detect the ladder rungs under one's feet or adequately grasp handrails (Nasarwanji et al., 2018; Robbins et al., 1995; Pollard et al., 2017b). Additionally, based on this analysis, the orientation of descent (i.e. backwards) and the lack of visibility also make egress more hazardous. Not only does descending backwards make it challenging to see the location of the feet and ladder rungs, but it also makes it difficult to identify potentially hazardous ground and ladder conditions.

Operators participating in the current study indicated that normal operation of the equipment over the course of a shift can result in contaminants such as dust, mud, and rocks collecting on the equipment, which poses an STF risk. In addition, changes in the weather during the shift and precipitation on the ingress/egress system also pose an STF risk. Further, hazardous ground conditions such as ruts, rocks, and holes were identified by the operators as posing an STF risk. These findings are consistent with a recent NIOSH investigation of injuries from front-end wheel loaders during ingress and egress, which found that material contaminants, snow, and ice on equipment and ground conditions were some of the leading contributing factors to non-fatal STF injuries (Nasarwanji et al., 2018). The reasoning for the higher prevalence of injuries during egress may therefore be due to the condition of the ingress/egress system and ground at the time of egress, which, as the operators in this study identified, may be different and more hazardous than its condition at the time of ingress.

4.2. Use of ladders

The design and condition of the ingress/egress system was identified by the operators in this study as both contributing to and helping to prevent STFs. The operators were accustomed to mobile equipment with ladders as the primary ingress/egress system and indicated that the ladder itself posed a hazard. Operators suggested that stairs would be safer than ladders and that if ladders were used, then the rungs should be deeper and the flexible rails on the lower rungs should be redesigned and maintained to ensure they remain relatively stiff. Unfortunately, three of the four deficiencies identified in this study were reported almost 40 years ago by Gavan et al. (1980) - including flexible lower rungs, high first steps, and inadequate treads – yet these same factors still lead to STFs in mining today. Flexible lower rails are common on mobile mining equipment and are designed to reduce the height of the lower rungs while ensuring the rails are not damaged while the operator is driving through the rough, undulating terrain of mine pits and quarries. They also, however, create additional risks. While the operators participating in this study understood the purpose of these flexible rails, they still asserted that the bottom rungs were too high, making it harder to get on the equipment, and they were often too flexible, becoming unstable. This over-flexibility could be a design or maintenance issue. It is possible that when initially installed, the flexible rail (usually wound wire cable, chain, or rubber) is stiff, but becomes more flexible and swings more over time. These rails, although flexible, also get bent and damaged, requiring maintenance. Operators also expressed concerns with the worn condition of ingress/egress systems. The worn ladder rungs and platforms make the surfaces slippery, especially when exposed to common mining contaminants. Operators suggested

that safety might be enhanced by improved surfaces on the ingress/egress systems that would prevent contaminants from collecting on the surface while simultaneously increasing available traction.

4.3. Non-ingress/egress system components

There are situations when components of the mobile mining equipment that are not usually considered to be components of the ingress/egress system contribute to increased risk of STFs during ingress and egress. Multiple operators participating in this study had experienced the cab doors hitting them when they were attempting to exit or enter the cab. When the door closes unintentionally this can be a serious hazard, and this unintentional movement of doors was identified as the cause of injuries from a previous investigation (Nasarwanji et al., 2018). In addition, mobile mining equipment such as haul trucks and front-end loaders may not have a landing platform, requiring operators to enter directly into the cab from the ladder.

4.4. Footwear

Foot slips were previously found to be the primary cause of STFs from front-end loaders even when surface contaminants were not reported, and were found to contribute to nearly one-third of slips and falls from haul trucks (Nasarwanji et al., 2018; Santos et al., 2010). A slip will occur when the friction between the footwear and the rung is not sufficient for climbing (Chang et al., 2005). This can be due to the poor traction provided by the footwear, low friction provided by the walking surface, or a combination of both. In this study, the operators identified their footwear, in addition to the walking surfaces, as contributing to STFs. Specifically, they suggested that the worn outsoles of their boots make ingress and egress more difficult and may cause slips. Operators also mentioned mud on the outsoles of their boots creating slippery conditions. Mud is common in many surface mining facilities, and grated metal walkways help prevent the accumulation of debris on walking surfaces and also aid in the removal of contaminants from footwear. On older mobile mining equipment, however, the effects of muddy footwear are likely made worse due to worn-out ladder treads and platforms that do not provide adequate traction. Metatarsal boots were also described as being more stiff and heavier than safety toe footwear and restricting motion along with making driving more difficult. This has not been extensively studied, but one recent study found metatarsal protection to not increase fall risk during stair ascent (Pollard et al., 2017a). The effect of metatarsal boots during stair descent or ladder ascent and descent has not been examined and is an area for future research.

4.5. Maintenance activities

One principle of safe ladder use is to maintain three points of contact when ascending and descending ladders. Mine workers are trained and aware of the need to maintain three points of contact. However, the operators who participated in this study identified the need to carry items into and out of the cab and needing to carry items during routine maintenance activities as posing risks for STF. The operators listed cleaning windshields, changing oil and air filters, and greasing as hazardous activities, and they highlighted carrying items and pulling cables as contributing to the risks. Operators also identified the need to assume awkward postures due to poor access to grease fittings and filter locations as posing risks

for STFs. Without proper access systems, operators said they are forced to hang on and clean their windshields. The risks associated with these maintenance activities explain why up to 25% of the falls from mobile equipment are associated with conducting some form of maintenance activity (Moore et al., 2009). Moore et al. (2009) also identified cleaning of windows and changing filters as key tasks but did not provide an estimate of prevalence or risks during these activities.

4.6. Lighting

Finally, the operators stated that improved lighting on and around their equipment may help with improving safety during ingress and egress. In the recent decade, lighting has been a major focus of mine safety research as a means to prevent STF and struck-by accidents (Sammarco et al., 2012; Yenchek and Sammarco, 2010). However, much of this research has been focused on improving lighting for underground mines and replacing standard incandescent lighting with light-emitting diodes to improve the amount of light, improve visual performance, reduce glare, reduce power consumption, and reduce required maintenance (Sammarco et al., 2009). The Illuminating Engineering Society of North America recommends a minimum of 50 lux in and around buildings and a minimum of 100 lux for stairways. While there has been no recent research on mobile equipment lighting for surface mines to know the available levels of light during different times of day, the results of the current study make it clear that in many cases the provided lighting may be insufficient for the required activities.

5. Limitations

The scope of this study was limited because researchers were interested in the perceptions and past experiences of mobile equipment operators as they relate to STFs from mobile mining equipment. While this does not account for all factors related to STFs, the results of this study provide some explanation for the causes and contributors to the STF incidents reported to the Mine Safety and Health Administration (MSHA) annually. Although the mobile equipment operators interviewed had experience operating several types and sizes of equipment, they do not make up a representative sample for all mobile mining equipment. The sample was limited to somewhat small surface stone and sand mines. For example, larger mines, different commodities, and underground mining may have equipment of different designs and sizes than the equipment the operators in this study were accustomed to operating.

To minimize the shortcomings of thematic coding related to concerns with bias, interpretation, or misinterpretation of data, numerous safeguards were implemented. The first was the utilization of multiple, independent researchers at several stages of the research process: a behavioral scientist created the interview schedule; two engineers specializing in ergonomics conducted the interviews; two researchers, a behavioral scientist and a bioengineer, not previously involved in the research coded the interviews; and two additional engineers specializing in ergonomics performed a review and check of the coding. A total of seven researchers were involved throughout the research methodology, none performing more than one discreet task. Second, the interview data was independently coded. The

two researchers were not previously involved in the collection of the data and performed initial coding of the data independently. Once each had concluded initial coding, the two convened to compare codes, definitions, and exemplar quotes. Any discrepancies were discussed and consensus was reached. These first two safeguards were implemented to address researcher bias and to improve objectivity, reliability, and internal validity (Miles and Huberman, 1994). As a third safeguard, the researchers employed triangulation of the interview data with MSHA injury data. The presence of similarities and consistencies between the interview data collected for this study and the MSHA injury data related to STFs indicates reliability and internal validity of the conclusions drawn from the interview data (Miles and Huberman, 1994).

6. Conclusion

Mobile mining equipment can pose slip, trip, and fall risks to mobile equipment operators when not designed or maintained for safe ingress and egress. Mobile equipment operators identified egress as being more dangerous than ingress due to the lack of visibility associated with descending a ladder and the unknown condition of the ladder and ground. Mobile equipment operators expressed concerns with the use of ladder systems and also with the condition of the provided ladders. The flexible rails, high lower rung heights, and inadequate traction provided on ladder systems result in the perception of increased risk for slips, trips, and falls. Moreover, the nature of routine maintenance may not allow for three points of contact when ascending and descending ladders and may expose operators to awkward postures. Mobile equipment should be routinely inspected to ensure the ingress/egress systems are not worn, bent, or damaged and provide adequate traction, and to ensure the cab doors do not close unintentionally onto the operator. Mobile equipment parking areas should be constructed such that operators are not exposed to hazardous ground conditions, have adequate lighting around and directed towards the ingress and egress system of the equipment, are equipped with tools for contaminant removal, and have access systems to improve the safety of required routine maintenance activities. Where possible, ladders should be replaced with stairs to reduce the slip, trip, and fall risks associated with ingress and egress from mobile mining equipment.

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Appendix A.: Research questions, associated themes, subthemes, definitions, and exemplar quotes from the thematic analysis

Research Question	Theme	Subtheme	Exemplar Quote/s
What portion of the ingress or egress process	**Egress more dangerous than ingress** - Egress from equipment poses	*Backward vs. forward* - Ingress is forward movement, egress is backward movement.	*"I was getting out of the track hoe and you always turn around and step down backwards. If you walk down forwards you have to hang on to hang to it. When I*

Research Question	Theme	Subtheme	Exemplar Quote/s
leads to STF injuries?	greater risk for STF than ingress.		*stepped back, I thought I look back but I stepped down on a rock."*
	Getting in and out of the cab - Getting in and out of the cab can lead to STFs.	Carrying items - Carrying items in the hand while ingress or egressing	*"What you're carrying with you. If you're trying to carry a magazine, a water bottle, and lunch box and something like that all at the same time. You know you're not having good contacts. You're not watching where you're putting everything … if you're trying to carry a bunch of stuff on and off, that's the quickest way to hurt yourself."*
		Opening doors - Opening the door to enter the cab of the equipment.	*"If you're getting in, a lot of times you're pushing the door open. You get halfway in and you're bending over and it comes around and catches you in the tail or you know. Same way when you're climbing out. You back out of the cab when you're coming out so you're so you know the door comes shut it could get you in the shoulder, the arm or something like that."*
What features or conditions of the ingress and egress system contribute to STF?	**Ladder design and condition** - The design and condition of the ladder contributes to STF	Flexible rails - Rails of mobile equipment that are constructed from flexible materials such as rubber or cable	*"Yeah those old trucks had cables as … Yeah they flexed around quite a bit. You could damn near swing."* *"So the rubber that the steps are on is nice and rigid yet, it don't flex a lot. Now, as the things get older, it gets more play in it or whatever."*
		Distance from ground - Height of the ladder rung from the ground	*"Going from the ground up to the first step because it's normally higher."*
		Traction - Slip resistance provided by the walking surface	*"[I] don't like the flat painted surfaces that you're getting in and out of the cab of the tire loaders. Simply because it's a flat painted surface so like I said dust makes it very slick and water makes it very slick and then it looks pretty but I'd like to see something more stable, more grippy, more footing."*
		Bent/damaged - Damaged and not in original condition	*"I have noticed a lot of 'em [ladders] will get bent up."* *"And then on the haul truck itself, once you get up to the fixed ladder basically the metaling has worn down just because the machines are ten years old. There's not a real grip contact anymore. You just got a greater chance of slipping there."*
	Contaminants - Presence of contaminants	On ladders and platforms - Presence of contaminants on the ladder itself or the platform/deck area used for ingress and egress	*"When we're running the track hoe, when you're getting on you can clean the steps and getting off, after you've ran it and traveled it gets clogged back up with mud. So when you're getting off, you don't always have a good clean piece of metal to sit your foot on when stepping off."*
		On hand rails - Presence of contaminants on the handrails of the ladder system or the platform/deck area used for ingress and egress	*"Yeah sometimes you get loaded you know though if it's wet stuff you know and they put it on, it sloshes out and gets on the hand rails. It happens a lot. So you just have to watch that."*
What features of differing ingress and egress systems are considered superior?	**Ladder design and condition** - Design of the ladder on some systems are superior to others.	Rigid ladder > flex ladder (Less flexible > more flexible) – Rigid ladder rails are preferred over flexible ladder rails	*"Make it a little stiffer. It has to move obviously for rocks, but I would make it a little stiffer material so it wouldn't swing as bad, cause it does swing when you step on it. You really have to hold to hold on to your hand rail."*

Research Question	Theme	Subtheme	Exemplar Quote/s
		Stairs > ladder - Stairs are preferred over ladders	*"I think that everything should have a more or less a set of steps instead of a fixed ladder."*
	Traction - Slip resistance provided by the walking surface.		*"I've seen some of them that are just very aggressive and would almost snag your foot getting on to it cause they just have so much bite and they're excellent. Plus they just have more of a gapping so material wouldn't build up on them like say mud, dirt. It would just fall right through. So yes, I've seen better ones."*
	Lighting – Equipment-mounted lighting that illuminates the ingress and egress system and surrounding areas.		*"You could turn the master key on from the ground level and then you'll have lights on your stairs and everything. So you can see early in the mornings or late at night getting on and off. And then once you're on the ground you can set them off and go to your pick up, you know."*
What tasks other than ingress and egress lead to STFs?	**Maintenance and repair tasks** - Maintenance and repair tasks lead to STF on mobile equipment.		*"Change oil filters or something like that you have to carry oil up or filters or something. That might make you more liable. … something that'd cause you to fall unless you wasn't just paying attention"*
			"I would say when you're greasing it simply because of all the grease [fittings] are not in very ideal locations. So sometimes you're like in a … you're just in different positions. Sometimes you might be in a kneeling position. Sometimes you might be down on your knees looking up trying to find the grease fitting just to do regular maintenance too."
			"Now some of these smaller machines does not have that [platform for cleaning windows]. And they're out there hanging onto the rail trying to wipe their window or something, you know."
			"On the haul trucks, changing out the cabin air filters because you're basically standing on the bumper to change out the cabin air filters but you don't have a work platform and you're not able to keep three points of contact by changing out a cabin air filter."
What conditions not directly related to ingress and egress systems contribute to STFs during ingress and egress?	**Ground conditions** - Condition of the ground or walking surface	Weather - Rain, snow, ice accumulations resulting in slippery and/or muddy conditions	*"You know getting off onto the ground if it's frozen or snowed since you been driving. That there, you got to watch it you know. Be real careful."*
		Uneven/unlevel ground - Ruts, slopes, holes, rocks, etc. on the ground or inclined roadways	*"I mean if you're out in the quarry, I mean the grounds a lot more unlevel. Yeah, when you're stepping down, I mean, you don't really know how level the ground really is or if there's a rock there, you might step on a rock or whatever."*
			"You got to watch if you're parked on an angle cause you'll be a couple feet higher than where you've started"
	Disrepair of unrelated parts - Other parts on equipment (not ingress/egress system) are not maintained in good working order.		*"And also the cab doors themselves. They've got like a little gas cord shock cover that hold the door open. Sometimes they don't stay open all the way so you get halfway in and it comes swinging shut and knocks you a good one."*

Research Question	Theme	Subtheme	Exemplar Quote/s
	Footwear - Design and condition of footwear contributes to STF	Metatarsal boots - Wearing metatarsal boots	*"We've had issues now over the past few years of having to wear metatarsal boots. So, depending on which brand that you wear, makes it a little bit different because they're more bulky. And so you can get your toes hung and depending on you know, on some of the equipment steps may be a little closer together and then like in the cab going back to operating, you know, for they're more bulky and not as flexible, the pedals will be sometimes aggravating."*
		Traction - Wearing of the outsole	*"If you don't have a good pair of shoes. A lot of time the real comfortable shoe that somebody will wear there's not much traction on the bottom of it and it makes it slippery too."*
		Muddy boots - Mud accumulates on outsole of boots	*"Well, it's, you know if it's raining or you know muddy at all, of course we got it on our feet. There's no way of cleaning feet off getting in. We could knock 'em off, but it's you know, doesn't do that much. And then getting back out, you know, unless you've sat there long enough and your feet had time to dry, you know they're wet coming back out too.* *Well, the rain itself and walking to the equipment through the mud you get it on your boots, and you … Makes it a little slippery."*

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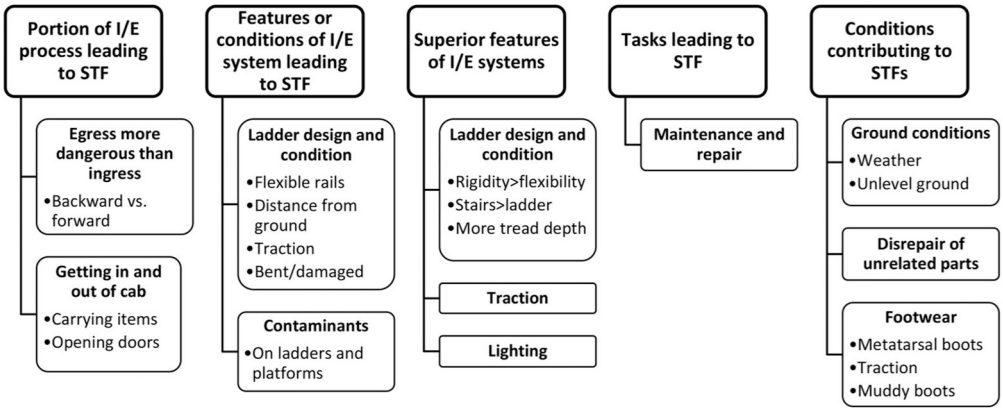

Fig. 1.

Thematic map indicating the research questions with their associated themes (in bold text) and subthemes (in bulleted lists).