



A taxonomy of surface mining slip, trip, and fall hazards as a guide to research and practice

Mahiyar F. Nasarwanji^{*}, Patrick G. Dempsey, Jonisha Pollard, Ashley Whitson, Lydia Kocher

Pittsburgh Mining Research Division, National Institute for Occupational Safety and Health, 626 Cochrans Mill Road, Pittsburgh, PA 15236, USA

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ABSTRACT

Slips, trips, and falls (STFs) are the second leading cause of non-fatal injuries and can lead to fatal incidents in the mining industry. Hazard identification is an essential first step in remediating STF hazards and creating a safer work environment. Previous research has identified industry-specific risk factors for STFs, evaluated exposures to those risk factors, and developed taxonomies of the hazards for the construction and farming sectors. In comparison, ErgoMine—a mobile device application-based ergonomics audit tool—is the only systematic evaluation tool that covers STF hazards in the mining industry. However, ErgoMine was not specifically developed to address STF hazards. This paper describes the development of a taxonomy that helps identify STF hazards at surface mining sites and provides recommendations to address these hazards to inform future evaluation tools. The objective was to develop a taxonomy that was self-explanatory, observable, repeatable, and solution oriented. In addition to current regulations, standards and guidelines were used to develop the taxonomy to ensure the focus was beyond basic compliance. A detailed description of how the STF hazard taxonomy was created for walkways, stairways, and fixed ladders is provided, along with two specific applications of its use. The STF hazard taxonomy can be used to develop tools like checklists and ergonomics audits to identify and remediate slip, trip, and fall hazards at surface mining facilities, thereby improving worker safety.

1. Introduction

Slips, trips, and falls (STFs) pose a significant burden to the U.S. mining industry leading to both fatal and non-fatal incidents. STFs were the second leading cause, at approximately 22 %, of non-fatal incidents reported to the U.S. Mine Safety and Health Administration (MSHA) from 2015 through 2018 (Mine Safety and Health Administration, 2015–2018). Analyses of mining fatal and non-fatal STF incidents conducted over several decades highlight the need to reduce STF incidents, some over 35 years old (Buck and Coleman, 1985; Nasarwanji and Sun, 2019; Radomsky et al., 2001). A recent analysis of surface stone, sand, and gravel mining operations found that STF incidents occur at a rate of 6.2 per 1000 full-time equivalent employees per year, leading to approximately 23,800 total days lost per year, and having an estimated cost of \$17.5 million per year to the U.S. mining industry (Nasarwanji and Sun, 2019). In addition, approximately 10 % of surface mining fatalities are related to STFs (Nasarwanji, 2016).

The importance of reducing STF incidents in the mining industry has been recognized, with several surveillance studies providing insight into

the most common activities and equipment associated with non-fatal events. Based on MSHA non-fatal injury data (2015–2018), walking or running (35.4 %) and getting on and off equipment (24 %) were the two main activities at the time of the STF event (Mine Safety and Health Administration, 2015–2018). Non-fatal injuries related to getting on and off equipment have been previously investigated (Moore et al., 2009; Nasarwanji et al., 2018; Pollard et al., 2019; Santos et al., 2010). In comparison, the activities of walking and running have not received as much attention, with only one observational field study investigating STF risk factors on walkways, stairs, and ladders (Nasarwanji et al., 2019). Surfaces commonly used for walking and running at mines include walkways and stairways and hence are the focus of this work. Walkways could include both marked designated paths of travel as well as other surfaces traversed commonly. Falls from stairs and ladders also pose a burden in the mining industry (Nasarwanji and Sun, 2019). Walkways, stairs, and fixed ladders are infrastructure components of mine sites, and ergonomics and safety deficiencies can be addressed through engineering controls. Other research has investigated portable and extension ladder safety (e.g. (Simeonov, 2017)), and were not a

^{*} Corresponding author.

E-mail address: MNasarwanji@cdc.gov (M.F. Nasarwanji).

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focus areas of this research.

Checklists and audits have been designed and applied in multiple industrial sectors to identify human factors and ergonomics issues (Drury and Dempsey, 2012). For the mining industry, ErgoMine is a mobile-device application-based audit tool, developed by researchers from the National Institute for Occupational Safety and Health (NIOSH), to identify ergonomics and safety hazards and provide remedial actions in three types of mining operations (Dempsey et al., 2016). The audits were developed based on previously recommended requirements, including being self-explanatory, observable, repeatable, and solution oriented (Dempsey et al., 2017). The ErgoMine tool provides three primary audit sections—maintenance and repair activities, bagging operations, and haul truck activities. STF hazards are briefly covered in several of the maintenance and repair and haul truck modules of the audit. Since the audits were not developed to specifically address STF hazards, there was a need for more detail to comprehensively address STF hazards in mining environments. The development of the taxonomy described herein was a foundational component of a project designed to more comprehensively address STF hazards in mining.

Previous research studies provided significant insight into some aspects of the task, equipment, and environmental characteristics associated with STF incidents in mining. However, there was a need to systematically identify, categorize, and create a framework of mining system features associated with STFs to facilitate the development of relevant research and practical solutions and tools that allow mine workers to efficiently identify and remediate STF risks. The primary advantage of a taxonomy that identifies STF hazards at surface mining sites is the ability to provide a structured approach to communicating the scope of STF hazards to researchers, safety and health practitioners, and miners. As more systematic research efforts are undertaken, the taxonomy can be expanded to include a sociotechnical systems approach that considers broader factors such as organizational and economic influences.

1.1. Slip, trip, and fall hazard taxonomy

Previous taxonomies of STF hazards developed for mail delivery, residential construction, and farming have largely focused on macro-level factors that contribute to STFs, such as environmental, individual, and organizational factors, with little detail on specific hazards themselves (Bentley and Haslam, 2001; Bentley et al., 2005, 2006). These macro-level factors are a good first step at highlighting the various aspects that need to be considered when looking at STFs but may not provide adequate detail to evaluate the workspace. Industries such as healthcare, mail delivery, construction, dairy, and food service have reactively identified STF risk factors through exposure information, and some of these industries (healthcare and food service) have developed proactive context-specific tools to identify the STF hazards (Bell et al., 2008; Bell et al., 2010; Bell et al., 2000; Bentley, 1998; Bentley and Haslam, 2001; Bentley et al., 2006; Bentley et al., 2005; Courtney et al., 2013; Courtney et al., 2010; Lipscomb et al., 2006; Verma et al., 2011a, b, 2012). Most of these evaluations rely on observing and assessing STF hazards in the environment, which can pose a significant data collection burden and may miss uncommonly encountered hazards based on the need to employ sampling strategies.

In order to develop this comprehensive taxonomy, the approach implemented by the authors of this paper was to use applicable MSHA regulations as well as relevant consensus standards and guidelines (hereafter, collectively referred to as “standards”). The use of published standards to help develop checklists and audits is not novel but can help meet the minimum requirements for safety (Drury and Dempsey, 2012). This approach was adopted as it meets the minimum regulatory requirement and captures uncommon hazards that pose a high risk (e.g. working around floor openings, which has been shown to lead to fatal falls (Nasarwanji, 2016)). Although this approach can be less of a burden than field STF exposure assessments, the importance of the exposure

assessment cannot be overlooked, especially for prioritizing interventions.

1.2. Information sources

Initially, mining-specific regulations under MSHA’s jurisdiction (30 CFR) were considered related to walkways, stairs, and fixed ladders at surface operations. In addition, the U.S. Occupational Safety and Health Administration (OSHA) regulations (29 CFR) were added to accommodate mine sites that may have oversight from both agencies. However, a preliminary evaluation of the regulations indicated that they may not capture all STF hazards. Hence, other voluntary standards and guidelines were included, such as those set by the American Society for Testing and Materials (ASTM), the American National Standards Institute (ANSI), and the International Organization for Standardization (ISO). These voluntary standards and guidelines provide additional details that would help identify STF hazards and may also be more detailed than MSHA/OSHA standards. This allows the remedial actions within the taxonomy to go beyond the minimum requirements. Table 1 contains a list of regulations, standards, and guidelines used to develop the STF hazard taxonomy for walkways, stairways, and fixed ladders.

Table 1
Published guidelines used for developing the STF hazard taxonomy.

Area	Regulation/Standard/ Guideline	Name
Walkways	CFR 30 §56	Safety and Health Standards – Surface Metal and Nonmetal mines
	CFR 29 §1910	Occupational Safety and Health Standards
	CFR 29 §1926	Safety and Health Regulations for Construction
	ASTM F1637-13	Standard Practice for Safe Walking Surfaces
	ANSI A117.1–2009	Accessible and Useable Buildings and Facilities
Stairways	ANSI A1264.2 2012	Standard for the Provision of Slip Resistance on Walking/Working Surfaces
	IBC-2015 Chapter 10	Means of Egress
	CFR 30 §56	Safety and Health Standards – Surface Metal and Nonmetal Mines
	CFR 29 §1910	Occupational Safety and Health Standards
	CFR 29 §1926	Safety and Health Regulations for Construction
Fixed Ladders	ANSI A1264.1–2017	Safety Requirements for Workplace Walking/Working Surfaces and Their Access; Workplace, Floor, Wall and Roof Openings; Stairs and Guardrails Systems
	ANSI A117.1–2009	Accessible and Useable Buildings and Facilities
	ASTM F1637-10	Standard Practice for Safe Walking Surfaces
	ISO 14122–3:2001	Safety of machinery — Permanent Means of Access to Machinery — Part 3: Stairs, Stepladders and Guard-rails
	IBC-2015 Chapter 10	Means of Egress
Fixed Ladders	ASABE S412.1	Ladders, Cages, Walkways and Stairs
	MARI990 (R2014)	
	CFR 30 §56	Safety and Health Standards – Surface Metal and Nonmetal Mines
	CFR 29 §1910	Occupational Safety and Health Standards
	CFR 29 §1926	Safety and Health Regulations for Construction
Fixed Ladders	ANSI-ASC A14.3–2008	American National Standards for Ladders
	ASABE S412.1	Ladders, Cages, Walkways and Stairs
	MARI990 (R2014)	

CFR: Code of Federal Regulations.

ASTM: American Society for Testing and Materials.

ANSI: American National Standards Institute.

IBC: International Building Code.

ISO: International Organization for Standardization.

ASABE: The American Society of Agricultural and Biological Engineers.

1.3. Development of the STF hazard taxonomy

The objective of the STF hazard taxonomy was to serve as a list of categorized STF hazards based on available standards. Six characteristics were considered in the development, like those adopted by Dempsey et al. (2017), including: 1) modularity, achieved by categorizing and classifying the hazards, 2) self-explanatory nature, achieved by simplifying language of the observable or measurable hazards for non-experts, 3) content validity, achieved by using published standards, 4) observability, achieved by ensuring the hazards were described so they were immediately identifiable or easily measurable, 5) applicability, achieved by providing generic hazards for commonly found walkways, fixed ladders, and stairways, and 6) solution-oriented nature. Although not the primary goal of the taxonomy, remedial recommendations were included to meet the solution-oriented characteristic, allowing the taxonomy to be used for audits and hazard evaluations. A five-step process was adopted for developing the final STF hazard taxonomy for walkways, stairways, and fixed ladders as described in detail below (Fig. 1).

Step 1

An initial list of hazards that could lead to STFs were created by reading each standard from Table 1. The initial list was made by one researcher (MN) who had 3 years of expertise focusing on slip, trip, and fall prevention research and 6 years of expertise in conducting occupational safety and health research within the mining industry. Attempts were made to capture the primary hazard as part of the standard; however, some liberties were taken when simplifying the wording. As an example, CFR 29 §1910.22(a) (2) indicates that “when wet processes are used, drainage must be maintained and, to the extent feasible, dry standing places, such as false floors, platforms, and mats must be provided,” which was then documented as the hazard “for wet processes, false floors, platforms, mats, or other dry standing places not provided where practicable.” This initial list of hazards included 169, 79, and 62 hazards respectively for walkways, stairways, and fixed ladders.

The various hazards were then categorized and segregated by one researcher (MN) based on specific areas of interest and/or features, e.g. rise, tread, handrails, illumination, etc. for stairways; or pitch, platforms and landings, rungs, clearances, etc. for fixed ladders. Table 2, Table 3, and Table 4 show the initial taxonomy of hazards and the number of hazards identified for each category (columns labeled Step 1). After the initial categorization, another researcher (JP) with more than 10 years of experience conducting occupational safety and health research,

Table 2

Taxonomy of hazards on walkways along with the number of hazards identified for each category through the five steps of taxonomy development.

Primary hazard categories for walkways	Step 1	Step 2	Step 3	Step 4	Step 5
Secondary hazard categories for walkways					
Carpet	6	6	6	5	3
Change in level/transition	5	5	5	3	1
Contaminants	5	5	5	4	2
Crossovers	2	2	2	2	1
Elevated walkways	26	26	26	12	12
General characteristics	6	6	6	3	2
Conveyer walkways	3	3	3	1	0
Ramps/inclined walkways and ramp landings	17	17	17	11	5
Floor walkway surface	6	6	6	6	4
General	9	9	9	4	0
Gratings	2	2	2	1	0
Handrails	21	16	15	14	9
Housekeeping	9	9	9	0	0
Mats	16	16	16	13	6
Openings	23	23	23	18	9
Floor opening covers	4	4	4	3	1
Floor openings	6	6	6	4	2
Hatchways and chutes	3	3	3	3	2
Holes for passage of materials	5	5	5	4	2
Other openings/skylights	1	1	1	1	1
Wall openings/hoisting areas	4	4	4	3	1
Slip resistance	7	7	7	7	3
General characteristics	0	0	4	4	0
Inherently slippery environments	0	0	3	3	0
Guardrail	18	18	18	11	8
General characteristics	12	12	12	0	0
Pipe railing	1	1	1	0	0
Structural steel railing	1	1	1	0	0
Wood railing	4	4	4	0	0
Toe boards	0	4	4	2	2
Vertical clearance	3	3	3	3	2
Warnings and markings	0	0	0	0	2
Wheel stops & parking bollards/posts	11	11	11	0	0
Total	169	168	167	108	59

several of which included slip, trip and fall research, and who did not create the initial list of hazards, verified that the hazard matched the standards. This was done by re-reading the standard and verifying that the primary hazard matched the standard. In the few cases where discrepancies, primarily editorial, were identified the primary hazard was

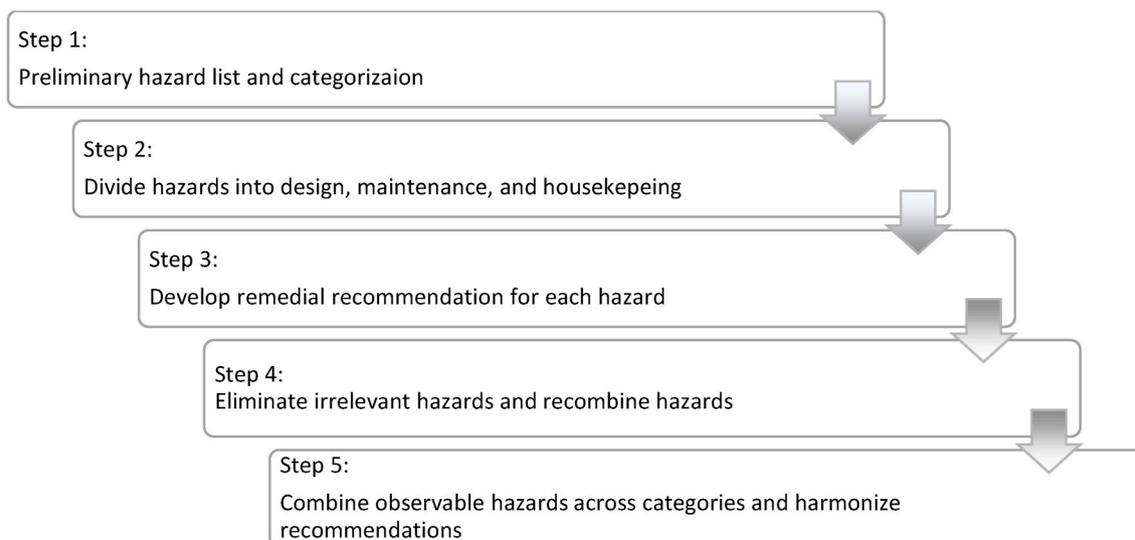


Fig. 1. Five-step process to develop slip, trip, and fall hazard taxonomy for walkways, stairways, and fixed ladders.

Table 3

Taxonomy of hazards on stairways along with number of hazards identified for each category through the five steps of taxonomy development.

Primary hazard categories for stairways	Step 1	Step 2	Step 3	Step 4	Step 5
Secondary hazard categories for stairways					
General	6	6	6	3	2
Handrails (hand holds) & guardrails/stair rails (barrier)	32	31	30	30	19
General characteristics	15	6	6	5	4
Handrail clearance	1	1	1	1	1
Handrails (hand holds) & guardrails/stair rails (barrier) placement	0	8	8	9	4
Handrails at landings	4	4	4	5	3
Height	6	6	5	4	3
Mid-rails/knee-rails and baluster/post	6	6	6	6	3
Illumination on stairs	2	2	2	2	1
Landing/platform	7	7	7	8	7
Nosing	3	3	3	3	3
Rise	6	6	6	6	3
Short flight of stairs	2	2	2	2	1
Spiral stairs	6	6	6	5	5
Stair use	1	1	1	1	0
Surface and finish	4	4	4	2	2
Temporary stairs (during construction)	3	3	3	0	0
Tread	5	5	5	4	4
Vertical clearance	2	2	2	2	2
Total	79	78	77	68	48

Table 4

Taxonomy of hazards on fixed ladders along with number of hazards identified for each category through the five steps of taxonomy development.

Primary hazard categories for fixed ladders	Step 1	Step 2	Step 3	Step 4	Step 5
Clearances	8	8	7	6	3
General	5	5	5	5	5
Inspection and maintenance	6	6	6	0	0
Long ladders (multiple sections, cages, and wells)	7	7	8	8	6
Pitch	1	1	1	1	1
Platforms & landings	6	6	6	5	4
Rungs	13	13	13	13	11
Side rails & grab bars	8	8	8	5	5
Use of ladder	8	8	8	8	8
Total	62	62	62	51	43

re-worded to better represent the standard.

Step 2

To identify the cause of the hazard and to develop remedial recommendations, three primary areas for each hazard were explored: 1) the design of the walkway, stairway, or fixed ladder, such as the tread depth on stairs or rung spacing on ladder, 2) maintenance issues that were not fixed or issues that could be fixed through maintenance, such as bent ladder rungs, or a missing section of guardrail, and 3) housekeeping issues which could be eliminated through regular cleaning, such as debris or material accumulation on stairways and walkways. Each hazard from the taxonomy in Step 1 was re-coded to identify design, maintenance, and housekeeping issues that could cause the hazard. Three researchers (MN, JP, and WP [acknowledged]) independently re-coded the hazards into the three categories. Multiple researchers with diverse expertise were used to explore all possible hazard alternates instead of focusing on similarities. Hazards identified by all three researchers were combined after discussing the various alternatives. In most cases, the hazard could be categorized into one or two of the three

categories of design, maintenance, or housekeeping. In a few cases, the hazard could be categorized into all three. One example is “the clear width across treads is less than 22 inches for stairways” where the stairway may have not been designed appropriately or may be limited due to bent or deformed support structures, or due to accumulation of debris or material which reduced the useable width.

Some hazards initially identified could not be categorized into the three areas and were instead marked as policy, organizational, administrative, behavioral, or not applicable/too stringent for mining. For example, the hazard “the carpet is not periodically inspected and re-stretched” on walkways was marked as policy/organizational/administrative. The hazard “individual not facing ladder when using it” for fixed ladders was marked as a behavioral issue. Hazards on temporary stairways, commonly used in construction and not in mining, such as “traffic is not prohibited on stairs where treads are not installed,” were marked as not applicable to mining. Refer to [Table 2](#), [Table 3](#), and [Table 4](#) (columns labeled Step 2) for the updated taxonomy of hazards and how many hazards were retained in each category.

Step 3

In Step 3, remedial recommendations were added for each design, maintenance, and housekeeping hazard. Again, three researchers (AW, LK (with 2 years of expertise focusing on slip, trip, and fall prevention research in the mining industry each), and JP) independently provided recommendations for hazards in the three categories. Again, researchers with diverse expertise were used to explore all possible alternates. The best recommendation, which were often a combination of the various alternatives was selected though discussion with a fourth researcher (MN). Based on the previous tread width example, the recommendations were: “design stairs such that the width across any tread is at least 22 inches” for design and “routinely inspect and maintain stairs to ensure no obstructions are present which would reduce the width across any tread to less than 22 inches” for maintenance and housekeeping. Hazards marked as policy, organizational, administrative, behavioral, or not applicable/too stringent for mining were eliminated in the next step. The core concept of using administrative and policy changes to mitigate hazards, such as periodically inspecting and maintaining items or encouraging positive behaviors like using three points of contact when climbing ladders were retained and included as part of the recommendations where appropriate. As an additional check, one researcher (KS [acknowledged], more than 4 years of experience conducting mining safety and health research) verified that the hazard matched the standards as in Step 1. In the very few cases where minor discrepancies, primarily editorial, were identified, changes were made to the hazard and recommendation to better represent the standard.

Step 4

Most hazards marked as policy, organizational, administrative, behavioral, or not applicable/too stringent for mining were eliminated because they are not easily observable as part of a hazard assessment. Behavioral hazards for ladder use, such as not facing the ladder when using it, not maintaining three points of contact, carrying object or load in hand when ascending or descending ladders, jumps/slides off ladder, etc. were retained due to their importance in preventing ladder fall injuries and because they could be easily observed. Eliminating items reduced the hazards to 108, 58, and 51 hazards for walkways, stairways, and fixed ladders, respectively. Refer to [Table 2](#), [Table 3](#), and [Table 4](#) (columns labeled Step 4) for the updated number of hazards for each category of the taxonomy.

At this stage, the hazards, which were divided into three categories of design, maintenance, and housekeeping, were again re-combined into a single observable hazard. The recommendations were pooled together to form one recommendation when there were multiple remedial recommendations for design, maintenance, and housekeeping.

Step 5

As a final combination, hazards with similar observable details were combined, and the same was done for their remedial recommendations. As an example, walkway hazards from Table 5 that were from different categories in the taxonomy were combined into one observable hazard “pooled water/liquid on the walking/working surface and landings” in the Contaminant Removal category with a remedial recommendation to “install walkway surfaces, such as gratings, that prevent the pooling/accumulation of liquid in wet process areas. Install drains to route liquid away from walking/working surfaces. Routinely inspect and maintain walking surfaces and drains.”

To ensure recommendations were worded similarly, editorial changes were made to harmonize the recommendations. Combining hazards resulted in the overall taxonomy further shrinking to 59, 48, and 43 hazards for walkways, stairways, and fixed ladders, respectively. Refer to Table 2, Table 3, and Table 4 (columns labeled Step 5) for the final number of hazards for each category of the STF hazard taxonomy.

1.4. STF hazard taxonomy for walkways, stairways, and fixed ladders

The final STF hazard taxonomy for walkways, stairways, and fixed ladders is provided as Supplementary data. In most cases, a single (primary) category could accommodate all hazards. In some cases, it was beneficial to further categorize hazards into a second (secondary) category. An example of where a secondary category of hazard was helpful was for handrails/guardrails along stairways and floor openings for walkways. It is noteworthy that although the number of hazards in each category are reported to show how the taxonomy was developed and evolved, the numbers are irrelevant from an auditing or safety perspective. The number of hazards identified are more likely related to additional details with which standards cover a topic or to hazardous areas that need more regulation and not to the severity or risk level of the hazards. Hence, the focus should be on the overall categories of interest and the observable hazards within each category, which are discussed briefly in the following sections.

Table 5
Example of how hazards from different categories were combined into one observable hazard.

Primary Category	Secondary Category	Hazard
Contaminant removal	–	For wet processes, drainage not maintained
Contaminant removal	–	For wet processes, false floors, platforms, mats, or other dry standing places not provided where practicable
Contaminant removal	–	Piled snow blocks drainage, walkways
Elevated walkways	Ramps/inclined walkways and ramp landings	Landings subject to wet conditions shall be designed to prevent accumulation of water
General	–	Drains not kept clear and free flowing
Combined into 1 observable hazard		
Primary Category	Secondary Category	Observable Hazard & Recommendation
Contaminant removal	–	Hazard: Pooled water/liquid on the walking/working surface and landings Recommendation: Install walkway surfaces, such as gratings, that prevent the pooling/accumulation of liquid in wet process areas. Install drains to route liquid away from walking/working surfaces. Routinely inspect and maintain walking surfaces and drains.

1.5. Applications of the STF hazard taxonomy

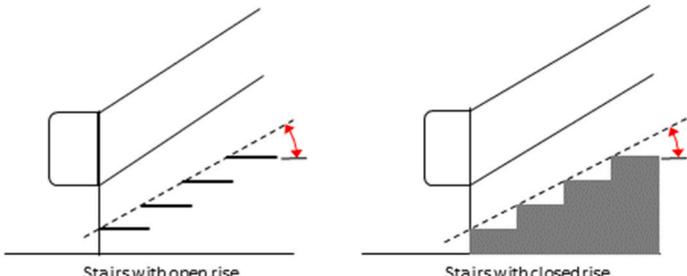
Although this manuscript outlines the development of a STF hazard taxonomy, the overall objective of developing the taxonomy was to inform the development of hazard assessment tools. One such instance where the STF hazard taxonomy helped in this regard was to develop a workplace audit checklist for walkways, stairways, and fixed ladders for the mining industry. As indicated earlier, STF hazards are only briefly covered in ErgoMine (Dempsey et al., 2016). Considering the burden posed by STFs to the mining industry (Nasarwanji and Sun, 2019), it is important to inspect and evaluate working surfaces to ensure they do not pose a significant STF risk that could lead to an incident. As the taxonomy was developed to include hazards that are easily observable and measurable, are categorized based on location and feature, and include remedial recommendations, the entire taxonomy was converted into three detailed checklists for walkways, stairways, and fixed ladders. The checklists include relevant figures and images where necessary and minor editorial changes to the recommendation so that a novice user, without knowledge of technical jargon associated with design, maintenance, and housekeeping, could still inspect the walkway, stairway, or fixed ladder. Fig. 2 (top) shows an example checklist item from the stairway checklist, and Fig. 2 (bottom) shows the corresponding recommendation. Electronic versions of these checklists will be incorporated into the next iteration of ErgoMine (Nasarwanji et al., 2021).

The second application of the taxonomy was for a systematic observational hazard assessment of walkways, stairways, and fixed ladders at surface mines (Nasarwanji et al., 2019). The objective of the hazard assessment was to quantify the frequency of encountering specific hazards at surface mines. As the entire taxonomy could not be utilized due to its breadth and the data collection burden associated with quantifying exposures, only maintenance and housekeeping issues were considered (from Step 4 of the taxonomy development) (Nasarwanji et al., 2019). Researchers were able to further reduce the number of hazards for the assessment by assigning risk priority numbers (RPN) to each hazard based on the perceived likelihood of occurrence, perceived likelihood of detection, and the hazard’s perceived severity of potential injury and eliminating those with low RPN values (Bahr, 2014). Based on the systematic observational hazard assessment, the study identified that solid debris (rocks and stones on unpaved surfaces and material accumulation on paved surfaces) and liquid contaminants (pooled water) were common hazards encountered on walkways. In addition, issues with treads on stairs and with landings on fixed ladders were common.

2. Discussion

Due to a lack of tools to help with proactive STF hazard assessment in the mining industry, this paper highlights the development of a STF hazard taxonomy which informed the development of STF hazard identification and remediation audit tools. A taxonomy of STF hazards was developed based on the recommendations by Drury and Dempsey (2012), which indicated that regulations, standards, and guidelines can be an excellent source of information to identify hazards when developing audits and checklists. Both mining-specific and general industry regulations in the U.S. along with common standards and guidelines were used for the taxonomy development to ensure validity of the hazards identified. It was convenient that hazard categories lined up with specific elements or features of the walkway, stairway, and fixed ladder. This allowed each feature, such as the tread or handrail, to be completely evaluated before moving on to the next feature. The same can be said about features like clearances, illumination, and slip resistance.

Some elements such as rungs on ladders, platforms and handrails along stairways, and handrails and floor openings along walkways and elevated walkways, specifically have a lot more detail in the STF hazard taxonomy. This can be due to additional detail provided in the

Category	Select all conditions present	X = Yes
Design	<p>3.1 Pitch of the stairway is less than 30° or more than 50°.</p> 	

Recommendation

Design

Q 3.1 You indicated that the pitch of the stairs is less than 30° or more than 50°. Install stairs with a pitch between 30° and 50°. Outside of this range it is hard to design stairways with the required tread depth and rise. For a pitch/grade less than 15°, use an inclined walkway. For a pitch/grade between 15° and 30°, use a combination of stairs and level walkways. If the pitch/grade is between 70° and 90°, it is recommended to use ladders.

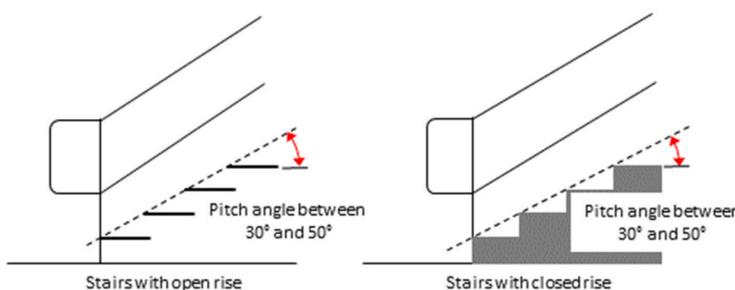


Fig. 2. Example of checklist item (top) and corresponding recommendation (bottom) from a Stairway Audit Checklist developed for ErgoMine based on the STF hazard taxonomy.

standards, potentially due to the risk associated with those elements or the intricacies of design. Appropriate platforms, handrails, and floor openings are key to prevent falls that have already been shown to pose a fatal risk in the mining industry (Nasarwanji, 2016).

The development of the taxonomy could have been simplified if remedial recommendations were not included; however, the utility of the taxonomy would be limited in this case to hazard identification. In addition, its utility as an audit tool, as in the case of the STF hazard checklists developed for the next iteration of ErgoMine (Nasarwanji et al., 2021), would not have met the requirements set forth by Dempsey et al. (2017) that the audit be solution oriented. Hence, the benefits and utility of generating remedial recommendations for each observable hazard outweighed the additional effort to generate the recommendations.

The utility of such a taxonomy for STF hazards has already been described in the earlier section on its application. Although, the systematic hazard assessment was successfully completed, it did involve making significant revisions to the taxonomy to reduce the number of categories for the observational study. The taxonomy’s strengths were more apparent when developing the STF checklists. However, these checklists and their use in the next iteration of ErgoMine (Nasarwanji et al., 2021) still need to be validated through usability testing and an evaluation of inter-rater and test-retest reliability.

The development of the STF taxonomy does have its limitations. The inclusion/exclusion criteria for standards were not specific; however,

attempts were made to include all regulatory standards in the United States and commonly referenced guidelines and standards. Standards are likely to evolve and be revised over time. Hence, the taxonomy should also be updated when significant changes are made to standards and guidelines. Although some of the standards used have more recent versions available, the changes made were not significant enough to update the taxonomy at this time, and the versions included in the taxonomy are still representative of the standards. The taxonomy may not be all inclusive, and specific areas excluded are clearly specified and some STF hazards, not clearly identifiable in the current standards, may have also been excluded. Underground operations were excluded due to unique requirements of the work environment. Mobile equipment and portable and extension ladders were previously investigated and hence excluded (Moore et al., 2009; Nasarwanji et al., 2018; Pollard et al., 2019; Santos et al., 2010). Personal fall arrest systems, fall protection, and ladder fall arrest systems were not considered as part of the taxonomy. The importance of fall protection in preventing fall incidents in the mining industry is not trivial (Hrica et al., 2020; Nasarwanji, 2016), and the NIOSH researchers feel it warrants its own dedicated investigation and analysis. Experts, outside of the National Institute for Occupational Safety and Health (NIOSH), were not included as part of the STF hazard taxonomy development; however, the authors have diverse backgrounds with all having some expertise in slip, trip, and fall prevention in the mining industry. Finally, there is a level of subjectivity to the process of the taxonomy development. However, care was taken at

each step to ensure that the hazards extracted from the taxonomy were checked against the standards at multiple points and input from multiple researchers with expertise in the mining industry, and STF were combined to develop the final observable hazards and recommendations.

3. Conclusions

Hazard identification is a critical step in creating safe work environments. The identification and subsequent remediation of slip, trip, and fall hazards may lead to significant injury reductions in the mining industry. Although a number of regulations and standards were used, the goal was to provide specific recommendations for proactive design and reactive assessment of walkways, stairways, and fixed ladders for use by mines. The STF hazard taxonomy developed under this effort can be directly used to inform the development of tools to improve the identification and remediation of slip, trip, and fall hazards at surface mining facilities, thereby improving safety and preventing occupational injuries.

4. Disclaimer & acknowledgements

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. Mention of any company or product does not constitute endorsement by NIOSH, CDC.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.apergo.2021.103542>.

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