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Ergonomic Assessment of Work-Related Musculoskeletal Risks Among Construction Roofers in Central Trinidad

Shane Mungroo and Sang D. Choi

ABSTRACT

Previous studies have shown that laborious work involves tasks that pose ergonomic issues such as work-related musculoskeletal disorders (WMSDs). This study was designed to investigate the risks of WMSDs among construction roofers in Central Trinidad. A total of 61 residential and commercial roofers in the roofing sector participated in this study. A self-administered survey questionnaire and ergonomic observational studies (Rapid Entire Body Assessment and Rapid Upper Limb Assessment) were conducted.

Four roofing stages and their related job tasks common among roofing projects in Central Trinidad were identified. Each roofing stage and job task was investigated for physical risk factors that could result in the development of musculoskeletal disorders or injuries. Results demonstrate that WMSD risks were the greatest during sheet installation followed by the framing stage of roofing. The study also revealed a high risk of WMSD development among construction roofers, especially in their back and shoulders, due to overexertion and motion/position (awkward body postures). The ergonomic assessment tools used in this study provided some valuable insight into the examination of work-related musculoskeletal risks in roofing construction industry.

Keywords: *Musculoskeletal disorders, ergonomic risk, assessment, construction, roofing*

1. Introduction

The construction industry ranks among the major global industries with respect to employment and development (ILO, 2018). In the U.S., construction is one of the largest industries and plays a pivotal economic role. The U.S. construction industry employed over 7 million individuals, and employment of construction occupations is projected to grow 11% from 2016 to 2026 (BLS, 2018a). Although there has been gradual improvement in the industry, the rates of death, serious injury and ill health are among the highest of all industries (HSE, 2012). Construction is consistently ranked among the most hazardous occupations, and it accounts for a disproportionately large percentage of all work-related injuries and illnesses (Choi, Yuan & Borchardt, 2016).

Physical risk factors at work such as high repetition, force, vibration and awkward body posture can lead to musculoskeletal disorders or injuries (NIOSH, 2015). Bernard (1997) conducted a critical review of epidemiologic evidence for work-related musculoskeletal disorders (WMSDs) and highlighted the fact that there is a causal relationship between physical exertion at work and the development of WMSDs. The work-related musculoskeletal risks have been found to characterize construction work and they have been linked to serious and costly health risks (Choi, et al., 2016; Choi, 2012; Choi, 2008; Schneider, 2001).

The prevalence of WMSDs in the U.S. construction industry has been widely reported (CPWR, 2013; Holmstrom & Engholm, 2003). In the U.S., WMSDs in the construction industry were 16% higher than the rate of 32.8 per 10,000 full time equivalent (FTE) for all industries combined (BLS, 2016). In a survey conducted by the Laborers' Health and Safety Fund of North America (LHSFNA, 2016), 40% of construction workers said that working while hurt is a major problem. Working while hurt not only reduces productivity, but continuing to work while hurt can lead to disabling injuries that can end a career in the industry. In the United Kingdom, 64% of cases of self- reported work- related illness in the construction sector were MSDs. A 2011 study among a Dutch population of construction workers found that more than half reported from occasional to frequent musculoskeletal complaints (Oude Hengel, et al., 2012).

The construction industry comprises various trades that utilize different skills and complete different tasks (Choi, et al., 2016). Characteristics of job sites and the work process can expose industry workers such as roofers, carpenters, and iron workers to ergonomic risks which may result in musculoskeletal injuries and disorders. For instance, roofing contractors involve work at elevated levels and sloped surfaces which range

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from nearly flat to almost vertical, and are exposed to very hot conditions. In addition, roofing is a physically demanding job that involves manually lifting, lowering, pushing, pulling, holding and carrying of materials (Choi, et al., 2016) as well as climbing, bending and kneeling (BLS, 2018b). Musculoskeletal conditions among roofers are strongly associated with work limitation, missed work, and reduced physical functioning. Job accommodation or return-to-work programs can be effective in reducing costs and work absence in the roofing trade (Welch, Haile, Boden & Hunting, 2009).

Industrialized countries have developed ergonomic guidelines or regulations to combat WMSDs backed by epidemiological data made available through institutions, systems and research which focus on occupational health (Bao, Winkel & Shahnavaz, 2000). However, a scarcity of epidemiological data in industrially developing countries, such as Trinidad and Tobago, deters the development of ergonomic interventions (Bao, et al., 2000).

To our best knowledge, there is little information regarding the characteristics of the roofing construction industry in Trinidad and Tobago. In Trinidad, most construction roofers are either employed by a small company or self-employed laborers. As a consequence, occupational and health safety cannot be applied in an organizational context, making it difficult to identify or mitigate the ergonomic risk factors associated with the job task. The objective of this study is to identify the occupational ergonomic risk factors that can lead to the development of work-related musculoskeletal injuries and disorders among roofers in the construction sector in Central Trinidad.

2. Methods and Procedures

2.1 Participants and Study Design

Participants for both the survey and observational studies were obtained through requests distributed to roofing contractors in Central Trinidad. A listing of contractors operating in the area was obtained through a major provider of roofing materials in Central Trinidad. All the participants were male, reflecting the demographics of the roofing and construction industry in Trinidad and Tobago. The target sample size for the study was 60 to 80 construction roofers. The authors utilized a mixed methods research design, allowing the combination of both qualitative and quantitative approaches to data collection (Creswell, 2009). Survey research was utilized to collect data on personal and environmental risk factors, work processes, and work-related musculoskeletal injuries and disorders.

A pilot test was conducted to refine the questions and finalize research approaches/instrument before commencing the final survey. The review of multiple sources guided the authors to develop this study's questionnaire sections, particularly based on a previous model by Choi (2012). An observational study of roofers in the field to assess roofing stages and roofing tasks was also conducted. Observational ergonomics assessment tools, Rapid Upper Limb Assessment (RULA) and Rapid Entire Body Assessment (REBA), were administered to assess exposures among roofers. Preliminary studies involved observing roofers at work and reviewing the sick leave records of contractors to identify cases involving WMSD injuries. The preliminary studies assisted in selecting the actual working postures to be evaluated by RULA and REBA.

2.2 Survey Questionnaire

The survey utilized different types of data collection instruments to obtain suitable data for the study. The questionnaire contained an array of closed and open-ended questions to obtain data on personal and environmental factors facing roofers including demographic data, injuries, ergonomic knowledge and employment and work process data. The survey was designed to gather data to best answer the research questions asked, such as the demographics among roofers, injury data and employee perception of WMSD risk factor severity experienced by performing roofing operations.

Additionally, a matrix was designed to allow respondents to rank various WMSD risk factors across the four stages of roofing. WMSD risk factors (e.g., repetition, forceful exertions, awkward posture, vibration, extended task duration) were taken from The Roofing Industry Alliance for Progress (2008). Respondents were instructed to apply a 1 to 4 ranking to each roofing stage for a particular risk factor. A score of "1" indicated that they perceived the roofing stage as presenting the "most severe" risk for the given WMSD risk factor. A score of "4" indicated that they perceived the roofing stage as presenting the 'least severe' risk. This matrix was designed to analyze the severity of WMSD risk factors associated with roofing from the perspective of the roofer in contrast to the observational REBA and RULA tools. A BodyMap was also included in the questionnaire to collect fine-grain data on the symptoms of WMSDs. The final survey questionnaire is provided in the appendix (p. 330).

2.3 Assessment Tools

The BodyMap is an easily administered, subjective musculoskeletal assessment tool that was found to be predictive of a worker seeking treatment for their discomfort, and it is a simple and economical tool for identifying the musculoskeletal risks (Marley & Kumar, 1996). The BodyMap instrument is used to assess both frequency and intensity level of discomfort associated with musculoskeletal disorders. The pictograph recording cells were designed to allow for the simultaneous ratings of frequency (0-3, 3 being constantly) and discomfort level (0-10, 10 being extreme discomfort) on 25 different body regions. Based upon a model developed by Marley and Kumar (1996), it is then possible to have a worker's evaluation categorized as: 1) "likely" to seek treatment; 2) "somewhat likely" to seek treatment; and 3) "not likely" to seek treatment.

The REBA is an ergonomic assessment tool which uses a systematic process to evaluate whole body postural musculoskeletal disorders and risk associated with specific job tasks (Hignett & McAttamney, 2000). The tool consists of a single page work sheet which evaluates body posture, forceful exertions, type of movement or action, repetition, and coupling associated with tasks conducted during the work cycle. Upon observation of postures, the evaluator assigns a score for each of the following body regions: wrists, forearms, elbows, shoulders, neck, trunk, back, legs and knees. Body region scores and provided tables are used to compute risk factor variables and score which represents the level of WMSD risk.

RULA is similar to REBA. It was developed to evaluate the exposure of individual workers to ergonomic risk factors associated with upper extremity musculoskeletal disorders (McAtamney & Corlett, 1993). Again, as with REBA, the worksheet is used to score body regions and compute a score representative of the level of WMSD risk. RULA is used to evaluate WMSD risk factors—awkward posture, forceful exertions and repetition.

2.4 Roofing Stage Classification

During preliminary studies roofing work was classified into four stages: framing, sheeting installation, trims and gutter installation, and soffit installation. Framing involves the erection of the metal trusses and the accompanying metal rafters that act as the substrate for the sheeting to be fastened to. Sheet installation involves the process of fastening the metal sheet panels unto the rafters. Trims are the periphery items of roofing that include the metal fascia and ridge capping. The gutter is classified alongside trims in this study because it is customary in Trinidad and Tobago to install metal fascia and gutter simultaneously. Soffit installation adds the finishing touch to roof works locally and this usually involves securing areas between the walls of buildings and the metal fascia of the roof. This area is called the eave and it is the part of the roof which overhangs the walls of a building.

2.5 Roofing Task Selection

Roofing tasks/activities were appraised during preliminary studies for inclusion into the list of common job tasks that were further investigated in the paper. Table 1 provides the listing of roofing tasks associated with roofing construction stage and the ergonomic assessment tools.

Care was taken to ensure that selected roofing tasks/activities were sufficiently unique from each other in the postures exhibited so as to avoid redundant analysis. Roofing tasks chosen for RULA exhibited upper extremity postures along with awkward or extreme postures. The tasks evaluated were mainly from the trims and gutter and soffit installation stages of roofing because of the repetition and extreme postures involved. Roofing tasks chosen using REBA exhibited very awkward or extreme trunk/back postures such as bending over, etc. The REBA was utilized for five tasks. Two from the framing stage and three from the sheeting stage because these tasks were had the most extreme postures involving the trunk area.

2.6 Data Analysis Procedures

Descriptive statistical analyses were performed on data collected from the survey and observational studies. The rankings collected in the risk factor-roofing stage matrix were mapped to ratings of the same order and tallied and averaged to identify the leading occupational risk factors associated with each roofing stage.

3. Results

3.1 Demographics and Employment Conditions

Of the 61 respondents of the survey, the average age, height and weight was 34 years (*SD:* 8.5 years), 172 cm (*SD:* 7.8 cm) and 75 kg (*SD:* 13.6 kg), respectively. Seventy-seven percent of the participants (47 of 61) were right handed. In regard to roofing experience, the most common amount of work experience was 6 to 10 years. The average team size among roofers was four to five individuals. Roofers who participated worked an average of 8 hours per day for 6 days a week. The majority of the respondents were

Assessment tool	Roofing stage	Roofing task
REBA	Sheeting	Securing panel in place
		Lifting panels
		Fastening panels with screws
	Framing	Purlin installation
		Lifting I-Beam
RULA	Trims and gutter	Gutter bracket installation
		Rainwater downpipe installation
		Trim installation
		Cutting sheet metal with shears
		Ridge capping installation
	Soffit	Soffit panel installation
		Wall angle installation

Table 1. Selected roofing tasks associated with roofing stage and the assessment tools.

Demographics	Mean	Standard Deviation (SD)	Range
Age (years)	34	8.5	20 - 60
Height (cm)	172	7.8	152 - 188
Body weight (kg)	75	13.6	50 - 111
Employment Conditions			
Team size	4.8	1.4	2 - 10
Daily work hours	8.3	1.1	7 - 12
Weekly work days	5.9	0.6	5 - 7

Table 2. Summary of demographic and work conditions.

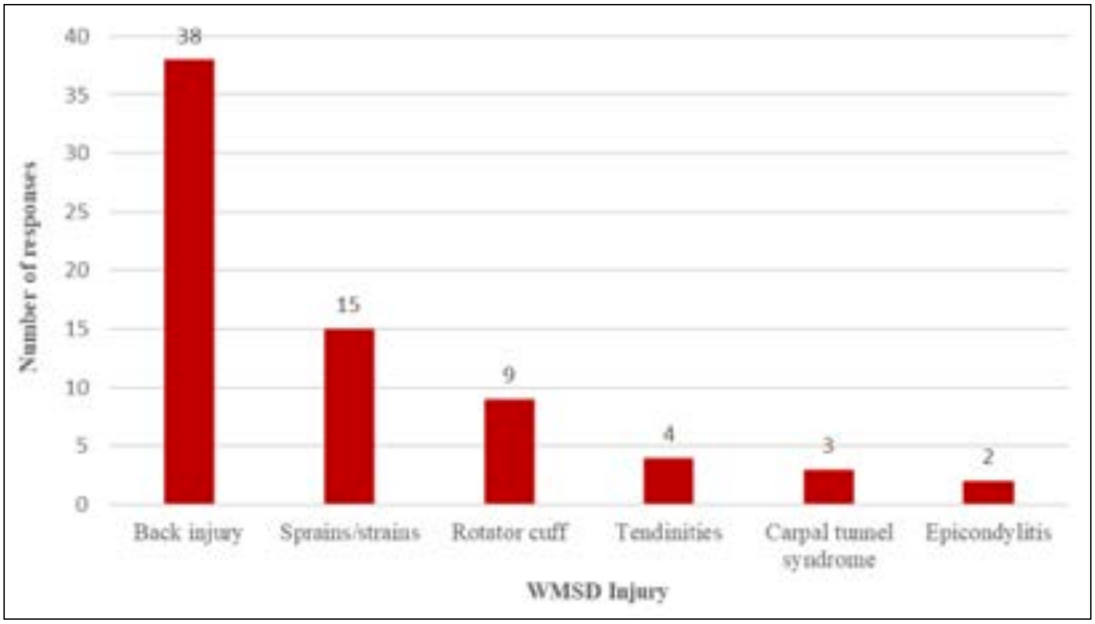

Figure 1. Survey results related to WMSDs experienced by the roofers.

involved in all stages of roofing. Seventy percent of the participants were working as private contractors and only 30% worked for a company. The average division of work among commercial/industrial and residential roofing sub-industries was reported by survey respondents. On average, roofers spent 76% of their work hours on residential roofing. More than 40% of roofers reported a neutral pace of work, whilst approximately 56% reported that they worked at either fast or very fast paced. The summary of demographic and work condtions is provided in Table 2.

3.2 WMSDs

Only 28% of respondents (17 of 61) reported that their employer maintained a written safety program. Twenty-five percent (15 of 61) reported familiarity with the term "ergonomics". Only 2% (1 of 61) of respondents reported that their employer had implemented an ergonomics program. Figure 1 shows the various WMSDs experienced by the respondents. Approximately 54% (38 of 71 total) reported back injury, followed by sprains/strains (21%), rotator cuff injury (13%), tendinitis (6%), carpal tunnel syndrome (4%), and epicondylitis (3%).

Figure 2 depicts the typical causes of WMSDs reported by the respondents. More than one third (33 of 98 total) was the motion/position, followed by overexertion (28%), tools/machinery (24%), slip/trip/fall (15%), and chemicals or others (0%).

3.3 Work Process

In terms of work process, the most common method used to raise materials to roof was manually, followed by crane, pulley, hoist and rope. The commonly used hand tools were drills and shears, followed by hammer, saw, and grinder. Fifty-two percent of respondents (30 of 58) reported lifting 31 to 50 lb per manual lift, while 31% lifted more 51 lb per manual lift. Only 17% reported lifts under 30 lb per manual lift. Sixty-two percent (38 of 61) spent 3 to 4 hours per day lifting, and 24% (15 of 61) stated that they lifted in excess of 4 hours per day and 13% (8 of 61) lifted less than 3 hours per day. For distance traveled during each manual carry, 11 to 30 ft accounted for 64% (39 of 61), followed by 30 ft for each manual carry (32%). Only 3% stated that each manual carry was fewer than 10 ft.

3.4 WMSD Risk Factors

This section contains data regarding the WMSD risk factors (i.e., repetition, forceful exertions, awkward posture, vibration, extended task duration) among the four stages of roofing investigated (i.e., framing, trims/gutter, sheeting, soffit). Respondents were asked to rank the various musculoskeletal risk factors across the stages of roofing with a rank of "1" being the "most severe" and "4" being the "least severe." Extended task duration and forceful exertions proved to be "very severe" during the framing stage of roofing whilst repetition and awkward posture

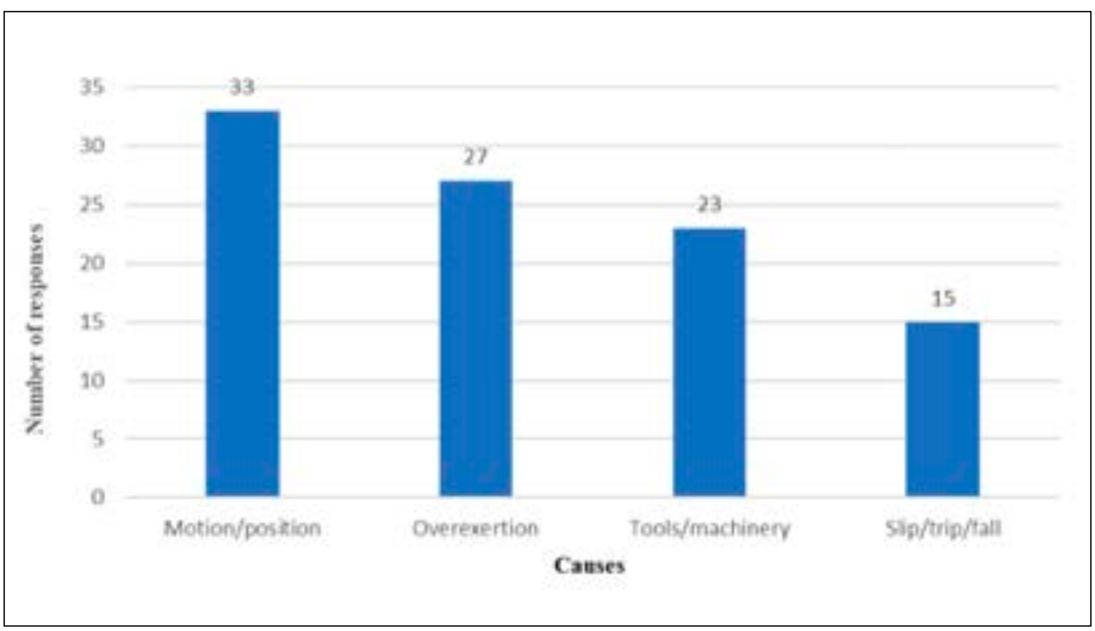

Figure 2. Survey results on typical causes of WMSD injuries.

were not considered too severe. Unlike the framing phase, the severity of risk factors in the sheeting phase was more even with all risk factors in this phase considered either "very severe" or "severe."

Repetition and awkward postures are considered "very severe" during the soffit panels of roofing while forceful exertion, extended task duration and vibration are considered less severe. In regards to the severity of the risk factors during the installation of trims and gutter, all of the other risks factors during this phase of roofing are of "low severity," with the exception of awkward body postures. Also, the average rank of each risk factor was added together for each roofing stage to determine which of the four stages of roofing presented the most severe WMSDs risk factors to roofers. The sheeting phase narrowly surpasses the framing stage as being the stage of roofing that presents the most work-related musculoskeletal risk factors. The trims and gutter and soffit stages of roofing are considered less severe for musculoskeletal risks than those of the framing and sheeting phases.

Roofing stage	Roofing task	REBA score	Wrist & Arm Score	Neck, Trunk, Leg Score
Sheeting	Securing panel in place	12	8	9
	Lifting panels	11	7	8
	Fastening panels with screws	9	5	6
Framing	Purlin installation	12	4	10
	Lifting I-Beam	10	5	7

Table 3. REBA results for five roofing tasks with working postures.

3.5 Findings of Observational Ergonomic Assessment

Table 3 shows that three of the five roofing tasks evaluated by REBA received the REBA final scores of 11 and higher. These scores suggest that these tasks presented very high risks to the workers and that change should be implemented to modify the postures to make them safer. The two tasks (i.e., fastening panels and lifting I-Beam) that received REBA scores of 9 and 10 are considered high risk, and change should also be implemented to reduce the severity of the postures.

Table 4 shows that all postures evaluated by RULA received the RULA final scores of 7, which is the high risks, and that changes need to be implemented to reduce or eliminate WMSD risks.

4. Discussion

This study identified the occupational ergonomic risk factors that could lead to the development of work-related musculoskeletal injuries and disorders among roofers in the construction industry. The findings from this study suggested that overexertion and motion/position were mainly contributed to the increased risks of WMSDs among construction roofers in Trinidad.

Forceful exertions. Roofers were asked to rank the various WMSDs risk factors across four stages of roofing: framing, sheet installation, installation of gutter and trims, and soffit installation. When compared to the other stages, the framing stage was perceived as demanding the highest amount of forceful exertions and was ranked number one for demanding the most severe forceful exertions. The sheeting phase was ranked second while the trims and gutter and soffit phases were ranked third and fourth respectively.

The framing stage involved the use of the heaviest materials and tools (e.g., erection of steel trusses, called I-Beams, and rafters, called Purlins). While a length of Purlin is relatively lightweight, the problem with overexertion in roof framing occurs with the installation of the I-Beam trusses. A standard 20 ft long I-Beam can weigh 180 to 200 lb depending on the density being utilized. Moving a 20-ft, 200-lb beam at ground level can be strenuous especially if it is being done manually. The task of getting that same beam from ground level to roof height manually can prove to be a very difficult task involving great physical exertion on the part of the individuals involved. Sheeting was ranked second for overexertion because the open arm posture involved in lifting bulky sheeting material hastens the tiring of muscles (EU-OSHA, 2004). The trims and gutter and soffit materials weigh much less in relation to those used in the framing and sheet installation stages.

Repetition. In this study, repetition was ranked as the second most severe risk factor for three out of the four stages of roofing investigated. The three stages (sheet installation, trims and gutter installation, and soffit installation) involved high intensity tasks such as drilling and fastening panels to various substrates with screws or nails. Performing work tasks, such as soffit and trims and gutter installation, which involve motor activity of the upper limbs, are a major cause of upper extremity WMSDs especially when the tasks are repetitive (Kedzior and Roman-Lui, 2003). In addition, tasks such as soffit installation engage only the hand; with the shoulder and forearm immobile, selected parts of the body become stressed and there is a static overload of the forearm and shoulder (Kedzior & Roman-Lui, 2003).

Awkward body posture. Compared amongst the four stages of roofing in this study, awkward body posture proved to be the greatest risk factor of WMSDs in two of the stages. The stages include the soffit installation and trims and gutter instal-

Roofing stage	Roofing task	RULA score	Wrist & Arm Score	Neck, Trunk, Leg Score
Trims/gutter	Gutter bracket installation	7	10	8
	Rainwater downpipe installation	7	5	6
	Trim installation	7	9	4
	Cutting sheet metal with shears	7	6	7
	Ridge capping installation	7	8	6
Soffit	Soffit panel installation	7	10	6
	Wall angle installation	7	10	6

Table 4. RULA results for seven roofing tasks with working postures.

lation. For the soffit stage, the average rank calculated for the respondents was approximately 1.5 (1= perceived as the "most severe"' 4 = perceived as "least severe"). This rank suggests that the majority of roofers considered awkward posture to be very severe or severe during the soffit installation. It is hand-intensive work above the head that requires the worker to operate a drill/ screw gun in one hand and manipulate the sheet metal material with the other hand. It is a tedious task due to the fact that the metal panels need to be aligned perfectly and at the same level to provide a perfect finish. It is widely believed that one's quality of work is determined by one's perfection of soffit installation since the task itself is usually the last phase of roof work in Trinidad.

Awkward body posture was also determined to be severe for trims and gutter installation. The positioning of the trims and gutter on the roof mean that the arm is always angled upwards at the shoulder and bent downwards at the elbow so that the hands and wrists can operate a drill/ screw gun and hold materials in place. Awkward body posture in sheet installation received an average rank of approximately 2.5 among respondents. This suggests that while the posture involved in sheet installation is not as physically demanding as those needed for trims and gutter and soffit installation, it was widely considered among respondents as being severe for the most part. The fact that awkward posture was ranked least severe among WMSDs risk factors for sheeting with an average rank of 2.5, highlights the fact that sheet installation can be a very strenuous phase of roofing operations since all risk factors were considered "very severe" or "severe."

Vibration. In this study, the main vibrating tools used by respondents were drills/screw guns. This was confirmed in (Choi, 2012) which found that excessive hand arm vibration was a serious concern for contractors due to the extensive use of power tools on a daily basis. Exposure to vibration was found to be the most severe at the sheeting stage and severe in the framing stage. The sheeting stage of roofing requires the extensive use of hand drills or screw guns because this phase involves fastening the metal sheet panels unto the roof substrate. The sheeting material ranges in thickness from 0.5mm to 0.63mm, and the rafters that act as the substrate, that is the Purlin material, is usually between 1.2mm to 1.5mm in thickness. This, along with the frequency of drilling in the roof sheeting phase, can account for the high perceived severity of vibration in the sheeting phase.

A high force and acceleration level in the drill is required when drilling through sheet metal and purlin as compared to the soffit and trims and gutter installation, which usually involves the installation of thinner material, and so it will require less force applied to the drill/screw gun. Vibration was considered severe in the framing stage although the material involved at this stage is thicker than that which is used at the sheeting stage. The speculated reason for this involves the frequency of repetitive actions, such as drilling, involved at this stage of roofing. From the bar graphs on both sheeting and framing WMSDs severity, one can understand why vibration is considered more severe at the sheeting stage than at the framing stage although the materials utilized at the framing stage are thicker. From the graphs, the level of repetitive actions in the framing stage is considered as least severe; however, repetition is ranked as the second most severe WMSDs risk factor at the sheeting phase. Therefore, the high repetition of drilling at the sheeting stage is responsible for the vibration being ranked as the most severe WMSDs risk factor at this phase. This alludes to the synergistic effects among WMSDs risk factors since the exposure to many can increase the risk of developing WMSDs.

Symptoms of WMSDs among roofers. Data collected in this study are in alignment with previous studies (Bao, Winkel & Shahnavaz, 2000; Welch, Haile, Boden & Hunting, 2009) regarding the risks of work related musculoskeletal disorders among the roofers. Based on the study by Welch, et al. (2009), musculoskeletal conditions among the U.S. roofers are strongly associated with work limitation, missed work, and reduced physical functioning. Also, the WMSD levels in Sweden accounted for about 74% of all occupational diseases in 1995 (Bao, et al., 2000). Back injuries were the most common type of WMSD reported among roofers, followed by sprains/strains, rotator cuff injuries, tendinitis and carpal tunnel syndrome. Overexertion and prolonged awkward postures that involve extensive use of the shoulder muscles usually contribute to MSD injuries.

In Trinidad, roofing tasks characterized by activities which lead to rotator cuff injuries include the installation of soffit panels, trims and gutters as they require roofers to work overhead or extend the entire arm for large periods of time. Another MSD injury reported among approximately 10% of respondent was tendinitis. Less than 5% of roofers that participated in the survey complained of carpal tunnel syndrome (CTS).

Severity of WMSD risk factors among roofing stages. One of the main tasks involved at each stage is getting the materials from ground level to the area on the roof that it is needed. Other than the skillset required in the field of roofing that includes balance and working comfortably at height, roofers need to be physically strong and flexible to complete the various job tasks. Strength is needed due to the high level of manual material handling involved, and flexibility is needed for the awkward postures that roof work exposes workers to.

This study found that most MSD risk factors were considered either "most severe" or "severe" for the sheeting phase. This could be due to the tasks involved in sheeting which require manual lifting of the heavy, bulky metal sheet panels, awkward postures and repetition that is characteristic of bending repeatedly to screw/fasten the metal sheet panels to the roof framing. The roof framing stage was considered second in accumulated severity of MSD risks. The soffit stage was ranked third in accumulated severity of risk factors.

The soffit stage got reverse risk factor ranks that the framing stage got. The awkward postures and high repetitive actions involved in soffit work were ranked as "very severe." This was expected because this stage involves working overhead for extended periods with the entire arm inclusive of shoulders, upper arm, lower arm and hands raised. In addition to the shoulders and arms, tremendous pressure is placed on both the neck and back to maintain such postures for extended periods. Also, soffit installation involves a lot of hand and wrist dexterity for repetitive motions involved in fastening the panels to the wall angle substrate. However, forceful exertions and extended task duration were ranked as not that severe. This was expected because the sheet materials involved at this stage is relatively light compared to the solid steel trusses (I-Beam) utilized in the framing stage.

Trims and gutter installation is considered the least severe stage of roofing according to the data collected. Awkward posture was ranked the lowest among the other risk factors in this stage of roofing. This is attributable to the light weight and relatively small sizes of the materials utilized at this stage and the short installation times compared to the other stages.

The other method that was utilized to determine which stage of roofing presented the most severe WMSD risk factors involved the use of the RULA and the REBA. All the tasks were assigned a RULA score of 7. This suggests that the level of MSD risk for the tasks evaluated were very high and that a change in the work process or the implementation engineering controls is needed to reduce or eliminate the WMSD risk factors. The RULA score is a function of the wrist arm score and the neck trunk and leg score. Five out of the seven tasks evaluated received wrist arm scores of 8 or greater. This suggests that the demands of the studied tasks on the upper extremities are great and may contribute to the level of WMSDs that were found among roofers that participated.

MSDs that were found among roofers involved back injuries, sprains and strains, and upper extremity injuries. Although the majority of these MSDs were back injuries and sprains and strains, approximately 30% were upper extremity WMSDs such as Rotator cuff syndrome and tendinitis. Kedzior and Roman-Liu (2003) found that activities such as those evaluated in the RULA tend to contribute to the "static posture of the spine and lower limbs which persists for an extended time, and becomes particularly manifested in the form of lumbar and cervical spine discomfort."

Therefore, even tasks that are demanding for the upper extremities can also contribute to the high prevalence of back injuries among roofers. Both trims and gutter and soffit installation present severe risk factors for upper extremity WMSDs, but soffit and wall angle installation of the soffit stage of roofing received wrist arm scores of 10 while the trims and gutter stage tasks received only one wrist arm score of 10 while all other scores were less. Therefore, the risk factors for upper extremity MSDs are slightly more severe in the soffit stage than in the trims and gutter stage. Two tasks, one from each stage, were deemed to be high risk and so needed to change the work process or implement engineering controls to reduce or eliminate MSD risk. These two tasks were lifting off the metal trusses in the framing stage and fastening/screwing sheet metal to roof substrate in the sheeting phase.

The three other tasks which included Purlin installation of the framing stage, and lifting of panels to roof level and positioning of panels of the sheeting stage, received REBA scores indicative of very high risk and the urgent need to implement change. The REBA scores were 12 for purlin installation and 11 and 12 for lifting of panels and positioning of panels respectively. All five tasks can be responsible for the high number of back injuries and strains and sprains experienced among roofers that participated in the study. Both overexertion as well as excessive and repeated bending involved at these stages of roof installation can account for the WMSDs. From the REBA, the sheeting phase also proved to be slightly more severe than the framing stage for risk factors such as overexertion and motion position with three job tasks whilst the framing stage consisted of two job tasks.

5. Conclusions

The current study established that of the four stages of roofing investigated (i.e., sheeting, framing, trims/gutter, soffit), and the sheeting stage proved to present the greatest work-related musculoskeletal risks in roofing construction in Central Trinidad. The sheeting stage is closely followed by the framing stage. The installation of soffit panels was third and trims and gutter installation proved to be the least frequently reported for the presence of WMSDs risk factors. The REBA and RULA conducted for various postures across the four stages of roofing confirmed the findings of previous studies that roofing tasks exposes employees to extreme and awkward body postures. The BodyMap also revealed that work-related musculoskeletal concerns were to the back and shoulders among roofers in the construction industry. The main WMSDs reported in this study were back injuries, sprains and strains, and rotator cuff syndrome. These findings complemented existing literature on the prevalence of the various types of WMSDs within specific construction trades (e.g., roofing). Also, overexertion and motion/position were perceived as the main causes of work-related musculoskeletal injuries and disorders among construction roofers participated in this study.

Although the study proved to be insightful into WMSDs and their risk factors among roofers in construction in Central Trinidad, it is warranted to conduct further studies among larger populations of roofers to eliminate any exaggerations that may have occurred due to the relatively small sample size. The wide plethora of ergonomics exposure assessment tools provides the platform for further investigation of WMSDs using different variables than the ones used in this study. Similar studies involving roofers in other areas of Trinidad or countries should be conducted to determine a more reliable extent of WMSDs. Subsequent studies should be able to use the information presented in research such as this to develop ergonomic programs and policies to protect construction workers not only in the roofing sector, but also in other occupations/trades in the construction industry. ■

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Appendix: Survey Questionnaire Instrument

Your Age: ______ years Your Height: ______ cm
Your Body Weight: ______ kg

Are you: (1) Left handed ☐ (2) Right handed ☐
(3) Ambidextrous ☐

How many employees including you form your installation team? ______ persons

What are the usual working hours per day?
____

How many days per week are you required to work?
______ days per week

Are you allowed any sick/vacation/personal days off from work?
(1) Yes ☐ (2) No ☐

While at work, are there allotted periods for breaks or rest?
(1) Yes ☐ (2) No ☐

How long have you been employed in the roofing sector?
______ years

Do you work for a company or a private contractor?
(1) Company ☐ (2) Private Contractor ☐

What is the type of work that you do?
Commercial/Industrial Roofing ______ %
Residential Roofing ______ %

At what stage of roofing are you usually involved? (Please check all the boxes that are applicable to you):
(1) Framing ☐ (2) Trim and gutter installation ☐
(3) Sheeting ☐ (4) Soffit ☐ (5) All ☐

What would you say is your average pace of work on a daily basis?
(1) Leisurely ☐ (2) Relaxed ☐ (3) Neutral ☐
(4) Fast ☐ (5) Very fast ☐

How often are you required to work overtime to complete a particular job?
(1) Never ☐ (2) Sometimes ☐ (3) Regular ☐ (4) Always ☐

Does the company/contractor have a written safety program?
(1) Yes ☐ (2) No ☐

Are you familiar with the term "Ergonomics"?
(1) Yes ☐ (2) No ☐ (3) Somewhat ☐

If "Yes," does the company/private contractor you are employed with have an ergonomics program?
(1)Yes ☐ (2) No ☐ (3) Don't know ☐

Have you ever had any work-related musculoskeletal disorder (WMSD)?
(1)Yes ☐ (2) No ☐ (3) Don't know ☐

Please check all the boxes that are applicable to you below:
Sprains/strains ☐ Tendinitis ☐ Rotator cuff injury ☐
Carpal tunnel syndrome (CTS) ☐
Epicondylitis/Tennis elbow ☐ Back injury ☐

What are the most common types of injury or illness in your line of work? Please check all the boxes that are applicable to you:
Sprain/strain ☐ Back injury ☐ Fractures ☐ Burns ☐
Cuts/lacerations ☐ CTS ☐
Other (Please state): ______________________

How do these injuries or illnesses typically happen? Please check all the boxes that are applicable to you:
Overexertion ☐ Motion/Position ☐ Slip/trip/fall ☐
Tools/machinery ☐ Chemicals ☐
Other (Please state): ______________________

Did any of these injuries occur within the last year?
(1) Yes ☐ (2) No ☐

Did you seek any professional advice and/or treatment for the work-related musculoskeletal injury/discomfort?
(1) Yes ☐ (2) No ☐

How are materials usually moved from ground level to the roof?
(1) Manually ☐ (2) Pulley ☐ (3) Hoist/Hi-ab ☐
(4) Crane ☐ (5) Ladders ☐
(6) Other (Please state): ______________________
____

List the most common types of hand tools that you use during work: ______________________

Circle the value in each row that best represents your typical work day:

Accumulated time for manual lifting/carrying during a normal day's work	<1 hr	1-2 hrs	3-4 hrs	5-6 hrs	7-8 hrs
Approximate distance traveled for each manual carry	<10 ft	11-30 ft	31-50 ft	51-70 ft	>70 ft
Approximate weight of the load an individual lifts/carries manually	<10 lb	11-20 lb	21-30 lb	31-50 lb	>51 lb

Steel Manufacturing Incident Analysis and Prediction

Siyuan Song, Qingchen Lyu, Eric Marks and Alexander Hainen

ABSTRACT

Employees of the U.S. steel manufacturing industry encounter dangerous working environments often resulting from limited visibility, hazardous proximity situations between heavy equipment and pedestrian workers and the dynamic nature of manufacturing tasks. Working conditions typical of steel manufacturing environments include increased amounts of repetitive work tasks, elevated temperature, noisy surroundings and an overall rugged work environment. These conditions tend to cultivate conditional and behavioral hazards that increase the probability of employees experiencing an incident in the form of an injury, illness or fatality. In an attempt to proactively identify hazardous situations and conditions, details from safety incident data can be analyzed to identify predictor variables of future of incidents in steel manufacturing environments.

The objective of this research is to utilize statistical modeling to identify specific variables that have high correlations of an unsafe event or condition within a steel manufacturing facility. Safety lagging indicator data (injuries, illnesses and fatalities) from an active steel manufacturing facility were input into multiple statistical predictive models to better understand how individual safety metrics can predict incidents. Results indicate weather, task performance, moving equipment, location, defective equipment, and personal responsibility all greatly increase the probability of an injury, illness or fatality occurring within a steel manufacturing environment. The contribution of this research lies in the presented framework for predicting variables that significantly impact lagging indicators as well as scientific evaluation of the framework.

Keywords: *Lagging indicators, safety performance metrics, steel manufacturing safety*

1. Introduction

Members of the U.S. steel manufacturing industry continue to experience a significant number of injuries, illnesses and fatalities (Reimink, 2016). The combination of intricate technology and physical labor create a complicated challenge for safety managers in steel manufacturing (Verma, et al. 2014). Like other larger industrial sectors, steel manufacturing has implemented pro-active safety program elements to improve safety performance of employees (Cambraia, et al. 2010; Lander, et al., 2011). For example, many steel manufacturing companies implement hazard identification programs in an attempt to identify and mitigate hazards before an injury, illness or fatality occurs (Basso, et al., 2004). Based on results of the identified hazards, mitigation strategies are created and implemented (Mohammadfam, et al., 2011). Although these pro-active safety programs are successful, a knowledge gap exists between analyzing incident data and understanding high impact variables for incidents, injuries and illnesses.

The objective of this research is to find elements from near miss reports that have a significant correlation with injuries, illnesses and fatalities in an active steel manufacturing environment. Statistical prediction models are implemented to identify correlations of multiple variables derived from safety data from a steel manufacturing facility collected over eight months. The Binary Logistic Regression Method was implemented for this study. The dataset contained approximately 2,300 incidents and was divided into 63 variables. The goal of this research is to provide insight into elements that are common to injuries, illnesses and fatalities in steel manufacturing in an effort to enhance safety performance in this type of work environment.

2. Literature Review

The following section reviews the steel manufacturing industry and associated hazards, the current state of safety

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in steel manufacturing and statistical predictive models. A research needs statement is derived from results of the review.

2.1 U.S. Steel Manufacturing Industry

The U.S. steel manufacturing industry produced 6,382,000 tons of steel in October 2016 (TE, 2016). The U.S. steel industry operators more than 100 steel producing facilities which produce 87 million tons of steel valued at $75 billion in 2014 (AISI, 2016). This industry is a segment of primary metals manufacturing which employed approximately 372,800 people in August 2016 (BLS, 2016) and accounted for 1.4% of primary energy consumption in 2006 in the U.S. (U.S. EIA, 2012; Zhang, et al., 2010). Almost 69% of all steel manufactured in North America is recycled each year (AISI, 2016). After production, steel manufacturing companies ship 42% of their product to construction sites and 27% to automotive manufacturing facilities (AISI, 2016).

2.2 Steel Manufacturing Incidents and Hazards

The U.S. steel manufacturing industry is one of the most dangerous when compared to other industrial sectors in the U.S. Statistics show that Steel foundries has an incident rate of 9.1% of total nonfatal occupational injury and illness cases (BSL, 2015b). The primary metal manufacturing industry experienced 28 workplace fatalities in 2014 which increased from the 17 fatalities experienced in 2013 (BLS, 2015b). The main cause of these fatalities was fires, explosions and contact with equipment or objects (BLS, 2015a). The primary metal manufacturing industry also experiences a significant number of non-fatal injuries. The industry recorded 20,000 non-fatal injuries in 2014 and 19,900 in 2013 (BLS, 2015b). 20,540 illnesses resulting from workplace hazards were experienced by primary metal manufacturing personnel in 2014 (BLS, 2015b). This number was slightly lower from the 21,320 illnesses experienced by this industrial sectors in 2013 (BLS, 2015b). For both years, the main contributing cause to the illnesses was exposure to noise (BLS, 2015b). These injury, illness and fatality statistics indicate that much improvement is required in steel manufacturing safety performance.

Steel manufacturing employees experience multiple hazards including exposure to high temperatures (Dhar et al. 2006), exposure to chemicals (Safty, et al., 2008), ergonomic problems (Han, et al., 2007) and noise exposure (Ologe, et al., 2006). The implementation of specific measures for preventing workplace injury and illness in the steel manufacturing industry depends largely on the recognition of principle hazards (ILO, 2005). One study identified several risks that steel manufacturing workers accept as part of workplace conditions including noise and heat exposure (Nordlof, et al., 2015). Several safety climate surveys of steel manufacturing have revealed the major underlying problems were inadequate health and safety procedures, pressures for production and employee experience (Adl, et al., 2011; Baek, et al., 2008). Furthermore, management commitment, organizational industrial relations and the political environment impact safety hazard awareness through the implementation of safety policy (Karkoszka & Szewieczek, 2007). Although hazard identification provides a useful method for mitigating hazards, the impact of specific hazards categories on injuries, illnesses and fatalities has not been quantified.

2.3 Predicting Safety Performance

Due to the perceived value in safety performance prediction, researchers have attempted to estimate safety performance of steel manufacturing employees from various perspectives. Correlations between incident causes and specific types of incidents were identified for a steel manufacturing facility (Verma, et al., 2014). For example, the study found that unsafe acts done by subcontractors are more frequent than injury cases (Verma, et al., 2014). One steel manufacturing safety study claimed that patterns of employee norms predicted perceptions of work environment safety and at-risk behavior (Watson, et al., 2005). The study also found an employee group's belief in management's safety values predicted at risk behaviors for steel manufacturing workers (Watson, et al., 2005). Safety hazards, safety culture and production pressure were found to significantly influence employee's attitudes with regard to safety in a steel manufacturing facility (Brown, et al., 2000). Minimal research has been conducted to quantify specific variables that contribute to injuries, illnesses and fatalities in the steel manufacturing industry.

2.4 Research Needs Statement

The steel manufacturing industry needs a scientific approach to identify and predict specific variables that increase the probability of an unsafe event or condition within a steel manufacturing facility. This approach can be achieved through statistical analysis and prediction modeling of historical steel manufacturing incidents. By understanding the impact variables of steel manufacturing incidents, critical elements to each event can be identified. This information can equip industry leaders to recognize critical causation attributes and mitigate before an injury, illness or fatality occurs.

3. Methodology

The purpose of this research is to identify and analyze variables from safety incident reports that significantly impact the probability of an unsafe event or condition within a steel manufacturing facility. The safety incidents used were from an active steel manufacturing facility in the U.S. that specializes in carbon coil and plate markets. Approximately 2,300 reported incidents from employees at the steel manufacturing facility between January 2010 and August 2016 were input into statistical predictive models.

3.1 Variable Description

A large steel manufacturing company in the U.S. provided researchers access to a safety incident database reported by employees and analyzed by safety managers at the company. Variables retrieved from employee safety incident logs were organized by safety managers into company-specific safety categories. To perform predictive statistical models, variable categorizes were defined as either independent or dependent variables. The dependent variables included all metrics associated with the outcome of a reported incident such as an injury, illness or fatality. These incident types were referred to as response variables because they were hypothesized to result from the independent variables. Nine groups of incident types were extracted from the original dataset and divided into the following two categories: 1) safety lagging indicators and 2) safety leading indicators. Unlike lagging indicators, safety leading indicators are safety metrics that occur before an injury, illness or fatality occurs and are generally a measure of performance processes and work activities (Hallowell, et al., 2013).

For this research, incident type was the selected dependent variable. The dependent variable included nine categories which are defined in Table 1.

Category	Description
Lagging Indicators	
OSHA Recordable	An injury or illness that results in death, days away from work, restricted work, medical treatment beyond first aid or loss of consciousness (OSHA, 2001).
Lost time	A specific type of OSHA recordable in which an employee is unable to return to work or is assigned restricted work on the day or shift following the incident (OSHA, 2011).
First aid	Any incident that requires stopping work but does not require a trained medical professional for assistance (OSHA, 2016).
Property damage	An incident that results in destruction to real or personal property.
Environmental Incident	Incident resulting in unsafe working conditions or hazardous environmental conditions.
Fire	Incident resulting in explosion and/or fires.
Leading Indicators	
Restricted duty/ modified work	Occurs when an employer keeps the employee from performing one or more of the routine functions of his/her job (OSHA, 2006).
Policy violation	Incident caused by an employee failing to follow an OSHA regulation or company specific safety policy (Hallowell, et al., 2013).
Near miss	An unplanned event or unsafe condition that has the potential for injury or illness to people, or damage to property, or the environment (Hallowell, et al., 2013).

Table 1. Description of dependent (response) variables.

Due to the limitation of Binary Logit Model, the dependent variable has to be dichotomous. The variable incident types were changed into two new dichotomous variables named "lagging indicator" and "leading indicator." The lagging indicator was selected as the dependent variable in the model in attempt to identify what variables impact these events. These dependent, or response variables can be statistically explained by the combination of independent variables. All dependent variables are quantitative and are calculated through counting individual events. Although the categorization system is susceptible to human error, categorizes were assigned by one individual safety manager within the company following a consistent decision criteria. Figure 1 shows a screenshot of some of the variables recorded when incidents occurred in the steel manufacturing facility.

The independent variables implemented included aspects of the reported incident not including the incident type. Table 2 provides a definition of all 16 independent variables assessed. It is hypothesized that these independent, or predictor variables can statistically explain the occurrence of dependent variables or incident types for a steel manufacturing facility. Each of the variables listed in Table 2 is a binary variable.

Category	Description
Summer Indicator	Incident occurred in June, July or August
Task Performed Indicator 1	Incident occurred during operating
Task Performed Indicator 2	Incident occurred during driving
Moving Equipment Indicator 1	Incident occurred during operating crane
Moving Equipment Indicator 2	Incident occurred during operating truck
Moving Equipment Indicator 3	Incident occurred during operating forklift
Moving Equipment Indicator 4	Incident occurred during operating trailer
Mobile Equipment Indicator	Incident involved mobile equipment
Location Indicator 1	Incident occurred in Roll Shop
Location Indicator 2	Incident occurred in Coil Yard or Disposition
Location Indicator 3	Incident occurred in Cut to Length (CTL) shop
Location Indicator 4	Incident occurred in West Gate
Location Indicator 5	Incident occurred in Water System
Location Indicator 6	Incident occurred in Melt Shop
Preliminary Cause Indicator 1	Incident caused by defective equipment
Preliminary Cause Indicator 2	Incident caused by personal responsibility

Table 2. Description of independent (predictor) variables.

Based on the information of the original dataset, the dataset was categorized into 62 independent variables. Variables can be divided into the following six categories: 1) incident time of day indicator; 2) month of incident indicator; 3) incident details indicator; 4) task performed indicator; 5) mobile equipment indicator; and 6) location indicator. Both incident details indicator and task performed indicator were categorized by key word search from the original text description of the incident reporter. The incident details category includes descriptions in which a specific task was performed when incident occurred. These variables were categorized into the following five independent variables: 1) operating; 2) removing; 3) loading; 4) driving; and 5) dumping. The task performed indicator category represents moving equipment that was operated when incident occurred. These incidents were further categorized as: 1) crane; 2) truck; 3) ladle; 4) forklift; and 5) trailer. Finally, 16 independent variables were selected to test the model.

IncidentID	IncidentDate	AreaDesc	DeptDesc	SpecificLocation	IncidentDetails
1	9/13/08 9:30 PM	EAF	Melt Shop	Old Carbon Silo	Driver stepped out of his truck and rolled his ankle over on
2	9/14/08 8:00 AM	Melt Shop	Melt Shop	Scrap inspection stand	The driver parked his truck and went to get his paper work
3	12/2/08 12:00 PM	Mobile Maint	Maintenance	Northport Auto Supply picking u	Incident Description
4	12/6/08 7:45 AM	EAF/LMF/Refi	Melt Shop	Behind Flood Wall, West side of	He was operating the Genie 135 man lift. He was in the proc
5	12/11/08 12:15 PM	NULL	NULL	Refueling Station-Rolling Mill	He was moving the manlift to the refueling station by the Ro
6	12/11/08 11:32 AM	EAF	Melt Shop	ER#13	Incident Description Install electric box at ER#13, both cont
7	12/14/08 1:30 PM	Caster	Melt Shop	Tundish Lifting Jig Stand	He was in the process of picking up the tundish lifting jig wi

Figure 1. Sample database screenshot.

3.2 Binary Logit Analysis

Multi-level models are especially useful when individual variables are subcategories within larger units and it is thought that both individual-level and group-level elements impact the dependent variable (Lau, 2007). Mixed-effects regression models have become increasing popular for clustered datasets (Goldstein, 1995). Due to the organization and metrics recorded for the steel manufacturing safety incident database analyzed in this research, the Binary Logit Model was one statistical prediction model selected for analysis. The probability, denoted Pr(Y), is assumed to be determined by a set of independent variables (X1, X2, … , Xj), and a corresponding set of parameters (β0, β1, β2, … , βj). It is specified as a linear function of the independent variables by the following equation (Hainen 2016):

$$Y_i = \beta X_i + \varepsilon_i \qquad i = 1, 2, \dots, n$$ ***Equation 1***

where, Xi is the independent variables (lagging indicators). β is a vector of estimable parameters and ε_i is an error term. The logit distribution constrains the estimated probabilities between zero and one. The estimated probability is:

$$\Pr(Y) = \frac{e^{\beta}}{1 + e^{\beta}}$$ ***Equation 2***

In the logit model, the logistic cumulative density function is (Young & Liesman, 2007):

$$\beta = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_j X_j$$ ***Equation 3***

If Y is the binary response variable, then the following statements are valid:

1) $Y_i = 1$ if the trait is present in observation (lagging indicator) *i*

2) $Y_i = 0$ if the trait is not present in observation *i*

Additionally, Y = 1 meaning that x_i equals one if the trait is present in the observation (i.e., summer indicator is true) and y_i = zero otherwise. The statistical software program Nlogit with the logistic procedure was used to estimate the maximum likelihood probability function. The Binary Model was executed with the safety incident dataset from the active steel manufacturing facility. Results of the model are provided in the subsequent section.

4. Results

Results from the completed Binary Logit Model are presented in this section. Detailed outcomes of each model and potential impacts to safety in the steel manufacturing environment are discussed.

4.1 Results of Binary Logit Model

For this research, all independent variables that entered the model were considered at the significant level of 0.05. No other independent variable met the correlation coefficient value of 0.10 for entry into the model. The log-likelihood of this model is -734 and all parameters were included if their *t*-statistic was greater than 1.96. The total number of observations included in the model was 1,153. Numeric outputs of the Binary Logit Model concerning the potential probability of an incident occurrence are provided in Table 3 and corresponding marginal effects are presented in Table 4.

Variable Description	Estimated Parameter	*t*-statistics
Summer Indicator	0.415	2.78***
Incident Details Indicator 1	0.470	2.46***
Incident Details Indicator 2	1.130	2.39***
Task Performed Indicator 1	-0.457	-1.94***
Task Performed Indicator 2	0.813	2.00***
Task Performed Indicator 3	1.158	2.28***
Task Performed Indicator 4	0.729	1.74**
Mobile Equipment Indicator	0.001	3.93***
Location Indicator 1	1.279	1.87**
Location Indicator 2	1.315	2.63***
Location Indicator 3	1.492	5.15***
Location Indicator 4	-2.243	-2.55***
Location Indicator 5	-1.222	-2.39***
Location Indicator 6	-0.619	-1.88**
Preliminary Cause Indicator 1	0.247	3.41***
Preliminary Cause Indicator 2	-0.247	-3.42***
Sample size, n	2,300	
Log-likelihood	-734	

***0.01, **0.05, *0.10

Table 3. Binary Logit estimation for potential probability of an incident occurrence.

Variable Description	Marginal effect
Summer Indicator	0.0918
Incident Details Indicator 1	0.1024
Incident Details Indicator 2	0.2216
Task Performed Indicator 1	-0.1039
Task Performed Indicator 2	0.1677
Task Performed Indicator 3	0.2260
Task Performed Indicator 4	0.1519
Mobile Equipment Indicator	0.0002
Location Indicator 1	0.2856
Location Indicator 2	0.2938
Location Indicator 3	0.3332
Location Indicator 4	-0.5011
Location Indicator 5	-0.2730
Location Indicator 6	-0.1383
Preliminary Cause Indicator 1	0.0551
Preliminary Cause Indicator 2	-0.0553

Table 4. Marginal effect of the potential probability of an incident occurrence.

Outputs from the Binary Logit Model identified injuries were associated with employees of the steel manufacturing company working in the summer (include June, July or August) with *t*-statistics of 2.78 and marginal effect of 0.0918. This steel manufacturing firm is located in Southeastern region of U.S. which experiences elevated temperatures during the summer. One possible explanation for this higher possibility is that severe weather is potentially more impactful to employees than normally weather. Employee may be distracted and fatigued due to the high temperature. According to the outputs of the Binary Logit Model, incident details indicators related to operating and driving with *t*-statistics of 2.46 and 2.39 represent a large correlation of having an incident. This statistic verifies the current proximity problem in the manufacturing environment between pieces of equipment and pedestrian employees.

The output parameter of task performed indicators which includes cranes provided a t-statistic of -1.94 which indicates cranes have a negative correlations of having incidents. One can hypothesize that recent increased safety attention of cranes can project an increased awareness of activities involving cranes in steel manufacturing environments. Other outputs of the Binary Logit Model show that workers who operator trucks, trucks and trailers and forklifts have a relatively large correlations of having an incident with a *t*-statistic of 2.00, 2.28 and 1.74, respectively. These pieces of equipment are typical violators of hazardous proximity situations between pieces of equipment and pedestrian employees. Each of these pieces of equipment have limited visibility around the equipment footprint which adds to the overall proximity hazard. It is also important to note that employees who are required to be near mobile equipment have a high *t*-statistic of 3.93 demonstrating that pedestrian employees near mobile equipment have a high positive correlations to injuries. This finding is consistent with past research which identified hazardous proximity situations for pedestrian employees in manufacturing environments (Horberry, et al., 2004).

The location indicators analysis found that employees working at the west gate, water system or melt shop have negative correlation to have an incident with *t*-statistics of -2.55, -2.39 and -1.88, respectively. The west gate was the main entrance used for shipping products and receiving materials from transportation delivery trucks (the marginal effects of location indicator in Table 4 show that the west gate had the largest impact). The area denoted as water system or melt shop is an environment where scrap metal is melted into liquid steel and placed into molds for creating structural steel elements. These work environments are clearly marked as no pedestrian areas which has helped eliminate risk and safety problems in these areas. On the contrary, employees located in the roll shop, coil yard or cut-to-length shop have positive correlations to have an incidents with *t*-statistics of 1.87, 2.63 and 5.15 respectively. These areas require pedestrian workers and thus are subject to hazardous proximity situations between equipment and workers-on-foot. These specific findings for this data set are useful for this specific steel manufacturing plant, but this same approach can be applied to other steel manufacturing plants as well as manufacturing plants in general. This system provides a custom-tailored analysis to understand risky locations at other manufacturing environments.

After assessing the preliminary cause indicator, defective equipment with a *t*-statistic of 3.41 has a positive correlation of resulting in an incident. This analysis suggests that defective equipment in the steel manufacturing facility were more likely to result in an incident. Because newer equipment typically includes more safety features, one can understand the reason for this high probability. Furthermore, this may help provide feedback for upgrades to equipment and then post-upgrade review.

Lastly, the personal responsibility indicator projected a *t*-statistic of -3.42 which indicates a negative correlation of resulting in an incident. For this specific facility, it seems unsafe employee behavior was not common and thus did not result in many incidents. This indicates the observed personal safety behaviors had a negative correlation of an incident. Although subjective, an inverse correlation can be hypothesized between the less injuries and a higher quality safety culture within this steel manufacturing company.

5. Conclusion

This research implemented the Binary Logit Model to analyze the correlations of lagging indicators within a steel manufacturing facility as well as identified specific impact variables for incidents. The model was selected to analyze the factors that may have the correlations of potentially having an incident occurring from a reported incidents. Findings from the regression suggest that a positive correlations between incidents and summer months. Results also suggest that injuries has a positive correlations with pedestrian employees are near pieces of moving equipment. Mobile equipment including trucks, forklifts and truck and trailer combinations have a positive correlation of causing an incident. Overall, employees of the steel manufacturing company experience greater success with mitigating hazards from crane operation than other moving equipment operations.

Location indicators showing that employees who worked at locations with a high population of moving equipment were positive correlated with having an incident. Consequently, employees that work in environments free of moving heavy equipment have inverse correlations with incidents. For this specific steel manufacturing environment, defective equipment have high positive correlations between an incident and unsafe worker behavior was not prevalent in incidents.

Results of this research identify meaningful correlations between lagging indicators and incidents report elements. These findings provide insight into weather, task performance, moving equipment, location, defective equipment, and personal responsibility indicators. The contribution of this research lies in the presented framework for predicting variables that significantly impact lagging indicators as well as scientific evaluation of the framework. By identifying these impact variables and their connections to lagging indicators, safety managers can optimally direct mitigation efforts of their safety program. ■

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An Examination of Mining Companies' Online Health and Safety Policies: Implications for Improving Risk Management

Emily J. Haas, Margaret Ryan and Dana R. Willmer

ABSTRACT

Health and safety management system (HSMS) document reviews show occupational health and safety policies as a primary system element. One way that companies operationalize tasks and communicate expectations to their employees is through their health and safety policies. As a result, policies should be visible and clearly promote desired practices. However, limited research exists on the quantity and scope of health and safety practices within company policies.

In response, this study analyzed the publicly available health and safety policies of 26 mining companies to determine the quantity of health and safety practices that mining companies encourage in relation to the plan-do-check-act cycle. A thematic content analysis of the policies identified elements and practices within the text. On average, companies communicated information on about seven elements (range 1 to 14, SD = 3.49) and discussed 15 practices (range 2–34, SD = 9.13).

The elements in which companies highlighted the most practices were risk management, emergency management, leadership development, and occupational health. A discussion of the policy trends shows areas that mine sites can improve upon within their plan-do-check-act cycle, in addition to encouraging the use of both leading and lagging indicators when checking and acting to manage health and safety performance.

Keywords: *Health and safety policy, mining, qualitative content analysis, plan, do, check, act cycle, risk management*

1. Introduction

Mining companies and their employees are expected to identify and manage risks at their worksites to ensure the health and safety of everyone at the site. The primary mechanism in place to control these risks is a company's health and safety management system (HSMS) (Boyle, 2012). Broadly, an HSMS is a set of standard, interrelated, and interacting elements used to promote and achieve occupational Health and safety goals (ANSI, 2005; BS OHSAS, 2007). Many HSMS documents (e.g., Health and Safety Executive, 1997; International Labour Office, 2001) attribute the source of their basic management system to Deming's plan-do-check-act (PDCA) model of continuous quality improvement and organize their practices within this cycle (Johnson, 2002). The PDCA cycle is a well-adopted approach in health and safety management and promotes continuous learning and adaptability (Robson, et al., 2007). Consequently, the practices conveyed within an HSMS are expected to minimize incidents, injuries, illnesses, and even save worker lives (Alsop & LeCouteur, 1999; Arocena & Núñez, 2010). In the U.S., both OSHA and MSHA regulate and encourage aspects of an HSMS (*Federal Register,* 2010, 2011).

Recent research has made some headway in trying to understand the roles of external factors in the work environment and how management practices conveyed within an HSMS can support aspects of risk mitigation and management (Barling, Kelloway & Iverson, 2003; Nordlöf, Wiitavaara, Högberg & Westerling, 2017; Parker, Axtell & Turner, 2001). However, research also needs to understand what practices are commonly included in writing and how these inclusions may inform the standardization and execution of an HSMS to enhance the response to site-wide risks. In addition, more updated HSMS consensus standards by OHSAS 18001, ANSI Z10 and the Health and Safety Executive (HSE) note that incorporating the PDCA into policies can help individual workers convert intent into

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actions on the job (HSE, 2013; BS OHSAS 18001, 2007). To that end, this study attempted to characterize the scope and depth of HSMS practices as described in a sample of company Health and safety policies, and subsequently any strengths or weaknesses as the policy practices relate to the common PDCA cycle.

1.1 Barriers to Effective HSMSs

An HSMS is a set of interacting strategic practices used to achieve occupational safety and health goals (e.g., ANSI/ASSP Z10; BS OHSAS 18001) and reduce inadequacies in risk management (Frick, et al., 2000). More specifically, health and safety practices contained within such a system consist of meaningful actions, such as observations, decisions or rules that can enhance workplace perceptions and performance and, thus, help prevent incidents (BS OHSAS 18001, 2007; Brassell-Cicchini, 2003). Despite the various resources available about Health and safety management, companies differ in their ability to effectively execute such practices within a systematic HSMS (Duijm, et al., 2008; Nordlöf, Wijk & Westergren, 2015a). Research cites various contributors to struggling HSMSs, including a lack of knowledge (Salminen, 1998), finances (Larsson, Mather & Dell, 2006) and productivity priorities (Nordlöf, et al., 2015b). Additional research argues that a lack of commitment to formalizing a system—including developing and executing a routine set of practices—can also impact the interpretation and execution of an HSMS (Arocena & Núñez, 2010; Biggs, Banks, Davey & Freeman, 2013).

Specifically, the mere existence of many different systems, elements and practices can make developing, formalizing, and sustaining efforts difficult. Although it can be beneficial for organizations to have the flexibility to develop their own customized plans, for smaller companies in particular, this can be overwhelming. To illustrate, the National Mining Association (NMA) compared common management systems for what they include [i.e., CORESafety, OHSAS 18001, ANSI Z10 and OSHA's Voluntary Protection Programs (VPP)]. A snapshot of this comparison is provided in Table 1. It should be noted that this paper uses the CORESafety framework developed by NMA in 2011 as a framework for the current study, given the mining-specific nature of the research. As can be seen in Table 1, the 20-element CORESafety system is consistent with ANSI Z10 and OHSAS 18001 consensus standards and only goes into slightly more detail in breaking out certain things.

In tandem with a lack of system consistency and subsequently commitment, another problem is that an HSMS requires sustained efforts and actions throughout the continuous PDCA cycle. Although it may seem like doing would be more desirable than other aspects of the cycle, regular execution of practices aligned with one phase of the cycle at the expense of another can impede the system's success (Haas & Yorio, 2016). Along these same lines, little theoretical work has been postulated to help understand the process by which health, safety, and risk practices are communicated throughout the PDCA cycle (Kirsch, Hine & Maybury, 2015; Robson, et al., 2007). The lack of lining up common elements and practices to the PDCA is a critical gap in current HSMS research,

Elements of comparison	CORESafety	OHSAS 18001	ANSI Z10	OSHA VPP
Leadership development	X			X
Responsibility and accountability	X	X	X	
Risk management	X	X	X	X
Emergency management	X	X	X	Partial
Training	X	X	X	Partial
Culture enhancement	X			
Communication and collaboration	X	X	X	
Reinforcement and recognition	X	Intervals	Intervals	Annually
Change management	X	X		X
Resources and planning	X	X		
Work procedures and permits	X	X	X	X
Occupational health	X	X	X	X
Incident investigation	X	X	X	X
Behavior optimization	X			
Engineering and construction	X	X	X	
Contractor management	X	X	X	
Assurance	X	X	X	X
Documentation and information management	X	X	X	

Table 1. Comparison of common HSMS program elements (adapted from NMA, 2013).

considering that the revised ANSI Z10 standard, among other systems, state that the PDCA should serve as the blueprint for better health and safety management (Toy, 2012). This lack of communication and coordination within a company can negatively impact how an HSMS is interpreted on the job (Guidotti, 2013). Therefore, it is important to recognize how messages and processes can impact outcomes in the workplace and what may help improve system coordination. A potential way to enhance communication of expectations is to improve the breadth and depth of company Health and safety policies.

1.2 Health and Safety Policies as Standardized Communication About the HSMS

One way that companies operationalize tasks and communicate expectations to their employees is through their health and safety policies. Policies solidify how companies prioritize respective health and safety responsibilities, and their commitment to providing knowledge, training, and advice to employees (Lin & Mills, 2001). Additionally, adequate policies provide clear direction which enhances the health and safety investment and benefits for companies (Bianchini, Donini, Pellegrini & Saccani, 2017). As a result, policies should be visible and clearly promote desired practices.

HSMS document reviews show occupational health and safety policies as a primary system element (Robson, et al., 2007). Meta-analyses of companies' HSMS practices also confirm strong health and safety policies as a common denominator that can function as a leading performance indicator (Lin & Mills, 2001; Mearns, Whitaker & Flin, 2003; Robson, et al., 2007). To date, limited research exists on the quantity and scope of health and safety practices within company policies. However, the off-shore industry prescribes a health, safety, and environmental policy as a primary benchmark document, arguing that a strong public policy that is monitored demonstrates commitment to safety and headway toward zero helath and safety incidents (Sykes, Pazman & Thoem, 1997).

Most companies are expected to establish Health and safety policies to communicate their expectations. For example, the International Organization for Standardization (ISO) (2003) argues that healtyh and safety policies do not merely become another document, but serve as an integral part of the company culture, values, and performance expectations that function as a mechanism to avoid incidents. Assurance of policy compliance in terms of annual self-assessments is also a critical aspect in showing commitment and progress (Mearns, et al., 2003). Additional guidelines encourage the adoption of "a comprehensive and integrated health and safety policy and the governance structures to support it via active leadership" (State of Queensland, 2013, p. 3).

As noted, policies as a form of communication messaging should help workers attend to and organize risk-based information, and then execute desired activities. Therefore, a clear policy must foster well-understood values and associated practices among workers (Bowen & Ostroff, 2004; Davis & Tomason, 1999). In contrast, vague policy practices could influence what hazards workers choose to pay attention to and how they interpret and respond to risks. To date, little research has collected information about company health and safety policies to determine general HSMS performance in regards to the PDCA cycle. Understanding where policy language is more focused could provide insight into organizational performance and potential areas in need of more emphasis to help prevent lagging indicators. Specifically, ASSE (2017) advocated for developing risk-based rather than compliance frameworks which they stated would be "the most impactful policy shift" (p. 2).

1.3. Study Objectives

Risk management as a part of overall organizational performance is associated with health and safety practices as they are interpreted and then executed in the workplace (Larsson, et al., 2006). This case study sought to initially understand the former by assessing the frequency and descriptive nature of health and safety practices within a sample of mine company policies. Additionally, we wanted to know what health and safety practices are emphasized the most and in what stage of the common PDCA cycle they are discussed. To that end, we used publicly available health and safety policies for 26 companies to answer the following questions:

- Research Question 1: Which HSMS elements and complementary practices are most discussed across mine company health and safety policies?
- Research Question 2: Where do companies focus their health and safety practices within the PDCA cycle, as described in health and safety policies?

2. Methods

NMA stresses that every mine should conduct, employ, and evaluate a risk-analysis process to prevent incidents (Grayson, 2006). To support these efforts, NMA worked with industry partners to develop an HSMS program called CORESafety (nd). CORESafety boasts a 20-element HSMS framework specific to mining. Believing that more companies affiliated with NMA would have health and safety policies, researchers used the publicly available NMA member list (N = 243) as the initial sample pool. In addition, the application of the CORESafety framework in the current study rather than other consensus was important because this framework was developed in collaboration with mining stakeholders for use at the site-level. Therefore, the content within each element and respective practice was deemed important and applicable within mining.

2.1 Online Health and Safety Policy Retrieval

For each of the 243 NMA-member companies, online searches to find and include each company's health and safety policy occurred in several steps:

- The organization's name was entered into Google search to locate the company's website.

•Organizations that did not have an official website were eliminated (n = 10).

•A search for each company's health and safety policy was completed on the home page or sub-tab, using the internal search bar to type: "health and safety." If the site did not have an internal search bar, then an external search for the organization's Health and safety policy was conducted via google. If this search also turned up with no results, the organization was eliminated from the sample (n = 195).

In general, the policies found were retrieved from a health/safety subtab on the company website. It was found that 38 of the 243 NMA companies had a health and safety policy that could be publicly accessed on their website.

2.2 Sample

Of these 38 companies, 26 could also be retrieved using MSHA's (2017) online retrieval database. The other 12 were members of NMA but not active mining companies that could be located in MSHA's online retrieval system. For example, there are member companies that specialize in consulting to help provide assistance in health and safety performance and assessment. Other companies specialize in developing and selling engineering, hazard protection, or firefighting products to the mining industry. For the purposes of this study, we limited the sample to those that are affiliated with MSHA, assuming they all have similar compliance issues that a policy would help address. So, the 26 remaining mining companies made up the sample for the current study.

Of these 26 companies, 12 (46%) mined coal; 11 (43%) mined some type of metal; and 3 (11%) mined some type of non-metal aggregate. In addition, 8 (31%) of the companies primarily ran underground operations; 7 (27%) surface; and 11 (42%) had both surface and underground operations. The 26 companies were responsible for several mine sites throughout the domestic U.S. and some internationally as well. The range of active mine sites for the sample was 1 to 16 (M = 5.65, *SD* = 4.549).

2.3 Content and Thematic Analysis of Health and Safety Policies

Researchers copied each available policy into a Word document for analysis. Policies ranged from 1 to 12 pages. Thematic coding (Saldaña, 2015) was used to identify HSMS elements and complementary practices within the text. In order to consistently assign and code each identified health and safety practice to a corresponding element, researchers developed a guidance document using definitions of HSMS elements and example practices as outlined in the CORESafety handbook. Detailed information about the 20 elements allowed strict and clear guidelines to help researchers determine inclusion and code assignment. Although many HSMS programs exist, the current study only used CORESafety because the mining-specific terminology and practices helped minimize the chances of coding error. Specifically, the CORESafety handbook details the 20 elements and a total of 133 complementing practices, providing an exhaustive list for researches to consult.

Two researchers discussed each policy line by line and collectively coded each identified practice, referring back to the guidance document of the elements, practices and definitions. This method reduced the chances of excluding or miscoding a practice (Armstrong, Gosling, Weinman & Marteau, 1997). When assigning identified practices to elements and transferring the codes for subsequent reporting, researchers used a "1" to show "yes" and a "0" to show "no." For example, if researchers identified a practice that they deemed to be part of an HSMS element such as Leadership Development, they put "1" under that element for the company. If researchers identified no practices that corresponded to Leadership Development within a company policy, they entered "0" for that element. This assignment allowed for the quantification of company practices within each element.

After assigning each health and safety practice to a corresponding HSMS element, all practices were grouped under their respective elements, creating a 20-tab coding document used to identify themes, or patterns in the data. The primary researcher initially worked independently, adhering to theoretical coding guidelines in the sense that the PDCA cycle was used to identify similar types of practices for each element (Boyatzis, 1998). The PDCA phases functioned as umbrella areas that accounted for codes that emerged within each policy, with practices eventually informing the research questions (Corbin & Strauss, 2008; Saldaña, 2015). This framework was particularly helpful in identifying where policies were weak (e.g., evaluating) and strong (e.g., planning, training). After the primary researcher initially developed themes, definitions, and examples to create a codebook, three researchers provided inter-rater reliability coding of the data to confirm the validity of the results (Landis & Koch, 1977).

3. Results

3.1 Research Question 1

On average, company policies shared information for about seven HSMS elements (range 1 to 14, *SD* = 3.49) and discussed 15 practices (range 2 to 34, *SD* = 9.13). The results tend to highlight practices for elements that are consistently cited as critical to a well-balanced and functional HSMS including risk management, leadership development, assurance, and occupational health (OSHA, 2012; Yorio & Willmer, 2015), which was an encouraging finding.

The elements that companies highlighted the most, including practices around leading and lagging indicators and interventions, included risk management (51 unique practices); emergency management (38); occupational health (30); culture enhancement (27); leadership development (24); HSMS assurance (20); and management systems coordination (18). Alternatively, some elements were not mentioned at all (i.e., change management) and others rarely, including resources and planning (2 unique practices); reinforcement and recognition (7); contractor management and purchasing (10); and communication and collaboration (11).

It is worth mentioning that some of the practices listed were requirements of the company, especially when referring

HSMS element	% companies discussed element	# practices within element	Example practices found within policies
Fatality Prevention /Risk Management	62%	51	• Use proactive risk program to improve competency of workers to identify, understand, and manage risks. • Conduct fatality prevention audits regularly. • Perform systematic evaluation for common hazard identification inputs, including near misses.
Emergency Management	42%	38	• Maintain emergency response teams and training. • Perform emergency preparedness audits every 2 years. • Ensure that internal and external communications plans are in place.
Occupational Health	42%	30	• Systematic approach for estimating exposures to chemical and physical agents for all materials, processes, and employees. • Compliant with the BS OHSAS 18001:2007 standard. • Qualitative assessments define air and noise monitoring and validation plans for each facility and are analyzed to determine if exposure management programs are required.
Culture Enhancement	62%	27	• Safety is a core value and is the foundation for how we manage every aspect of our business. • Provide a working environment that is conducive to personal health, mental alertness, and awareness.
Leadership Development	42%	24	• Leadership program emphasizes improving frontline supervisors' ability to engage constructively with their teams. • Leaders on site help design the methods to effectively measure safety performance.
Safety & Health Management Assurance	42%	21	• Policies, strategies, and performance indicators to manage risks and improve performance are approved by corporate. • Compliance with regulations are managed in part through joining the NMA CORESafety mining program. • Follow OSHA recordkeeping rules to record incidents.
Management Systems Coordination	46%	18	• System identifies twelve elements for building a safe workplace and creating a sustainable safety culture. • Safety and Health Policy applies to all operations worldwide, including new acquisitions. • Develop management systems that meet and implement the expectations and requirements specified.
Responsibility & Accountability	35%	18	• Identify personal and group responsibilities for all personnel and ensure each person is aware of his/her role. • Periodically assess performance against target for each person and provide feedback.
Documentation & Information Management	35%	16	• Use industry standards of all incident frequency rate and the lost time injury frequency rate. • Report safety performance in Annual Sustainability Report.

Table 2. Example HSMS elements and practices identified within NMA company policies, Part 1.

to MSHA or OSHA rules. However, many practices were not listed in response to any regulatory requirement. For the purposes of this study, we were interested in first, the frequency of practices listed, and second, how they aligned with the PDCA cycle—not necessarily their adherence to existing rules or requirements. Table 2 shows the top six elements mentioned throughout the policies, including the number of companies that specifically mentioned the element and how many practices in total were identified throughout the policies. Finally, (paraphrased) example practices are shown in the table to demonstrate what type of language was used to communicate support and action for health and safety.

This table shows where current company policies place priorities for day-to-day activities. Considering recent changes to consensus guidelines that have explicitly promoted the value of policy development and constant checking of the policy throughout the PDCA cycle (e.g., ASSE, 2012; HSE, 2013) the researchers felt it was important to align these results to the stages of the PDCA, as organized by CORESafety.

3.2 Research Question 2

Themes were identified within each phase of the PDCA cycle to help pinpoint potential strengths and weaknesses of company Health and safety systems. Figure 1 shows where the CORESafe-

Behavior Optimization	27%	15	• Educate regarding the causes of safe and unsafe behavior. • Develop a workplace observation and feedback process.
Training & Competence	37%	13	• Provide site-based H&S orientation for all new or transferred employees, visitors, contractors, and vendors. • Conduct initial, ongoing and periodic refresher training.
Engineering & Construction	27%	13	• Collaborate with academic institutions, federal and state agencies to test new concepts and H&S technologies. • Design and maintain facilities.
Incident Reporting & Investigation	31%	12	• Ensure all personnel are trained and understand the company's and regulatory authority's definition of a recordable incident and their obligation to comply. • Investigate all incidents, including near misses.
Collaboration & Communication	27%	11	• Involve employees in continuous improvement activities to enhance H&S performance.
Assurance	27%	10	• Develop a process to measure H&S performance through the use of leading and lagging indicators. • Senior management participate assurance to optimize transparency and ensure there are adequate resources.
Contractor Management & Purchasing	27%	10	• Ensure all employees and contractors are trained and competent to safety perform their work. • Support employee-led discussions about safety experiences and lessons learned pre and post shift.
Work Procedures & Permits	19%	8	• Standard operating procedures (SOPs) are developed for routine and repeated non-routine work based on outcomes of systematic job and task (SJT) analyses. • Use SOPs as the basis for on-the-job training and audits by front line supervisors and managers.
Reinforcement & Recognition	19%	7	• Establish a formal process to reinforce and recognize employee performance, involvement in proactive activities.
Resources & Planning	8%	2	• Hire a local workforce. • Develop indoctrination of new/transferred employee plan.
Change Management	0%	0	• N/A

Table 2. Example HSMS elements and practices identified within NMA company policies, Part 2.

ty elements fit into the phases of the PDCA cycle. Not surprisingly, if the CORESafety elements are aligned within the PDCA cycle, it is visually apparent that a majority of system elements are focused on the "do" within the cycle. It can be assumed that, since more elements are aligned with the do phase of the cycle, policies would heavily emphasize what they are doing and promoting on their respective sites to manage health and safety. As Figure 1 also shows, the plan portion of the cycle is a focus on fatality prevention and risk management. Although this element could span across all phases of the cycle, CORESafety contains several elements that focus on aspects of risk management, such as work procedures, training, and engineering, which are all a part of the risk management process that are established in early planning and development.

Now that an organization of results have been provided within both the PDCA cycle as well as the prevalence of practices and elements within the policies, a more in-depth look at the practices can be discussed.

3.2.1. Writing the plan. The results showed that the sample of companies spend a lot of time communicating interventions developed for health, safety, and risk management (e.g., an inventory of hazards, behavior-based decisions, and exposures to hazards). Such practices, synonymous with the planning phase of an HSMS, were among the most prevalent within the policies. These results show that companies establish fairly routine, standard workplace rules and processes. Examples of these identified planning practices were grouped into themes for each element, including the following example for risk management: "Tools, rules, and procedures developed to promote adequate execution of risk management and assessment."

The practices within these themes contained intervention activities that focused on identifying leading indicators through assessment programs, tools, or software (Haas & Yorio, 2016). Example practices that fell into planning included activities such as: fatality management programs to identify and review critical incident scenarios; life-saving rules to be used in relation to key risks; safety leadership coaching programs that emphasize frontline supervisors' ability to engage constructively with teams; and industrial hygienists conducting risk assessments of potential health issues.

3.2.2. Executing the plan. Fewer companies highlighted the implementation of practices that were discussed in the planning phase. Those companies that did describe their doing practices often detailed how they executed risk-based activities, specifically through other specific elements within their HSMS. Policies most often discussed practices within risk management that help workers to perceive risk; identify high-hazard situations that have the potential to result in injury; perform active assessments on noise, air, and other exposure monitoring; and use various behavioral programs to identify and share risky scenarios, what behaviors could prevent incidents, and ways to discourage risky behavior. Several of these practices fell into themes that focused on executing specific programs to prevent future incidents.

Nonetheless, a consistent trend across policies was a lack

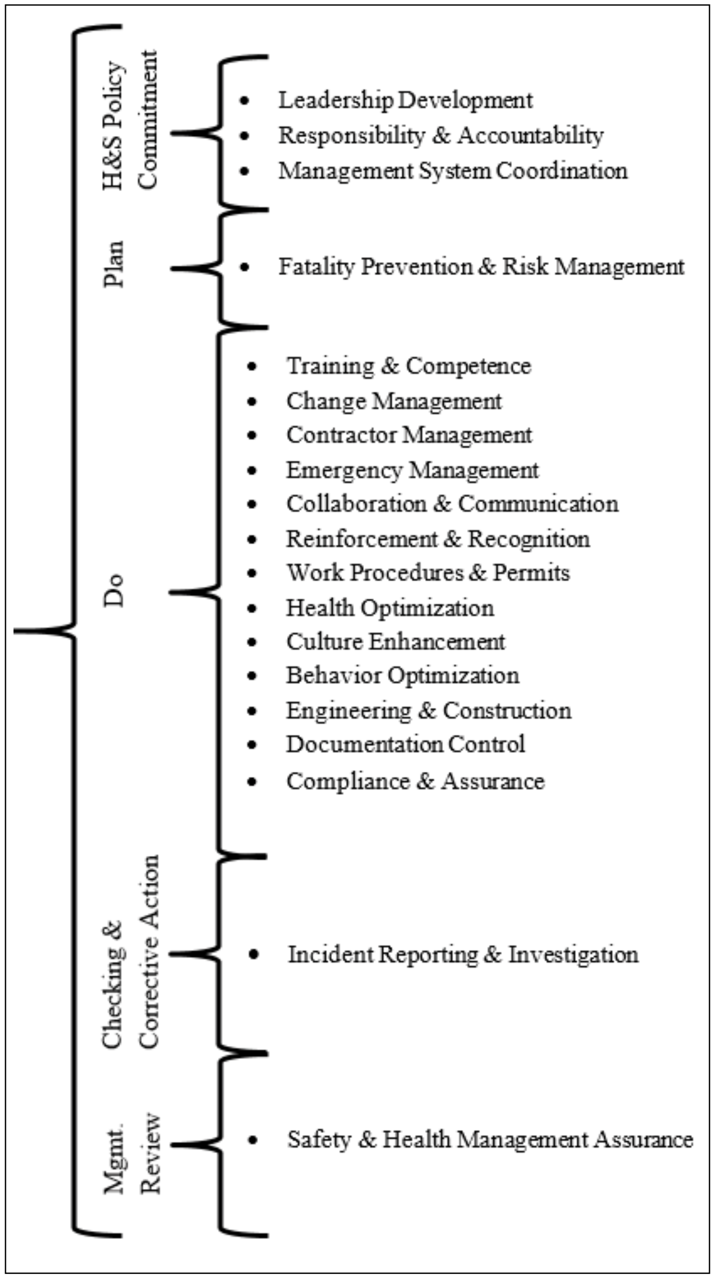

Figure 1. Organization of CORESafety's elements within the generalized PDCA cycle (adapted from CORESafety, 2011; Haas & Yorio, 2016).

of reference about what happens after hazards are identified—including some type of process that should be utilized by employees. Rather, companies more often highlighted activities in place at operational levels higher up in the organization about how and what strategies and tools are reviewed. However, policies did not go into strategic detail about how employees should respond on the ground to use the programs and tools identified to mitigate risks. This gap should be addressed because Health and safety policies exist as a communication mechanism for employees throughout the entire company and can be a good daily reference point for the hourly workforce. This is especially important since HSMS consensus guidelines note that, based on evaluation and corrective actions, policies should be updated (HSE, 2013).

3.2.3. Lack of checking and acting practices in policies. In comparison to the first half of the PDCA cycle, companies discussed fewer practices, and in less detail, about how employees are expected to check and respond to site-wide risks. This finding correlates with previous research asserting that traditional HSMS programs often have less activity corresponding to the check and act domains of the Deming Model (Robson, et al., 2007). For example, there was no category of practices identified within the Leadership Development element about how companies evaluate their leaders on site and how they respond if certain competencies need to be improved. Obviously, this does not mean that companies do not have a mechanism to evaluate their managers on site. However, without a formal practice documented for employees to reference, it is difficult for the workforce to know steps in place for improving identified problems. For example, one company simply stated, "We use NMA's CoreSafety initiative that focuses on preventing accidents before they happen using leadership and assurance."

The same gap emerged regarding Health and safety practices associated with acting. As an example, under risk management, where several companies outlined risk assessment processes, the practice that could be associated with acting was "use risk assessments to respond to incidents." Although both of these practices include key buzzwords, employees cannot take anything tangible from this policy practice and execute appropriate proactive decisions.

4. Discussion

The qualitative analysis of available policies showed the range of companies in terms of having more or less in-depth Health and safety practices and whether or not practices were distributed throughout the PDCA cycle. These results provide implications for future research and practical considerations for mine practitioners. These results and possibilities for improvement are especially timely and relevant in the light of impactful policy shifts being viewed as moving from a compliance model to an integrated risk-based approach, including identifying, assessing, and mitigating risks (American Society of Safety Engineers, 2017).

4.1 Carrying Health and Safety Practices Through the PDCA Cycle

Recent research shows that many mine company policies continue to be vague and have poorly established rules and procedures (Bourrier, 2017). Likewise, the current study showed that company policies did not document the quantity and scope of Health and safety practices that might be expected throughout the PDCA cycle. Specifically, the check and act practices almost exclusively responded to lagging indicators rather than proactively following through on the leading indicators outlined in the policy planning phase. In addition, because fewer elements are associated with checking and acting, companies may have to be extra diligent about ensuring they have content about reporting, investigating, and assurance. Specifically, although assurance was discussed a little more frequently, only 31% of the companies in the current study discussed practices that were associated with incident reporting and investigation—the primary element associated with checking.

Absence of documented procedures can be problematic in terms of workers executing desired behaviors. Specifically, lack of policy characteristics found to inhibit worker Health and safety performance include: 1) vague work tasks; 2) limited information on performance; 3) lack of guidance on activity measurement and success; 4) no assigned job roles; and 5) little consideration for range of task performance and compliance (McLeod, et al., 2016). We argue that, in order to enhance effective decision-making, all practices within Health and safety policies should serve as a specific function to clarify, manage, or prevent risks rather than be placeholders for subsequent reference if an incident occurs on site.

4.2 Balance Leading/Lagging Indicators and Interventions Within Policy Practices

As noted, there was a lack of policy practices synonymous with checking and acting in response to leading indicators identified within company policies. Because practices and programs to identify leading indicators were given ample attention in the planning and doing phases, the absence of their evaluation was surprising. Additionally, whenever responses to leading indicators were mentioned within policies, the text was vague, so employees may be left wondering what their decisive role in risk prevention is on the job. For example, one policy practice within a highly discussed element, HSMS assurance, was "We have been monitoring, measuring and working toward improving leading indicators of performance while simultaneously increasing the growth of the company. As a result of our efforts, lagging indicators such as worldwide recordable and lost time rates have continued to decrease." Again, this practice provides buzzwords and offers efforts that are occurring at the operational level, but provides little guidance to the hourly workforce on their roles in HSMS implementation.

Further, when policy practices proceeded to state that evaluation activities were in place, it was not to check how any activity was functioning. Rather, evaluation practices were more often in response to incidents. Similarly, research shows that acting and checking tend to be in response to workplace accidents, legislation, or enforcement, rather than acting as proactive measures (Robson, et al., 2007). Therefore, it is possible that workers' decisions and actions are, in part, due to the priority that company policies place on responding to incidents rather than focusing on their prevention. For example, a common company practice within the Risk Management element was, "Recording, reporting, and investigation protocols are in place for all accidents, incidents, losses and near misses."

Despite the above gaps, the results also showed that some companies do publicly document more practices within their policies that complete the PDCA cycle, with a focus on both leading and lagging indicators. An example of one company that took these practices through the cycle is reflected in this

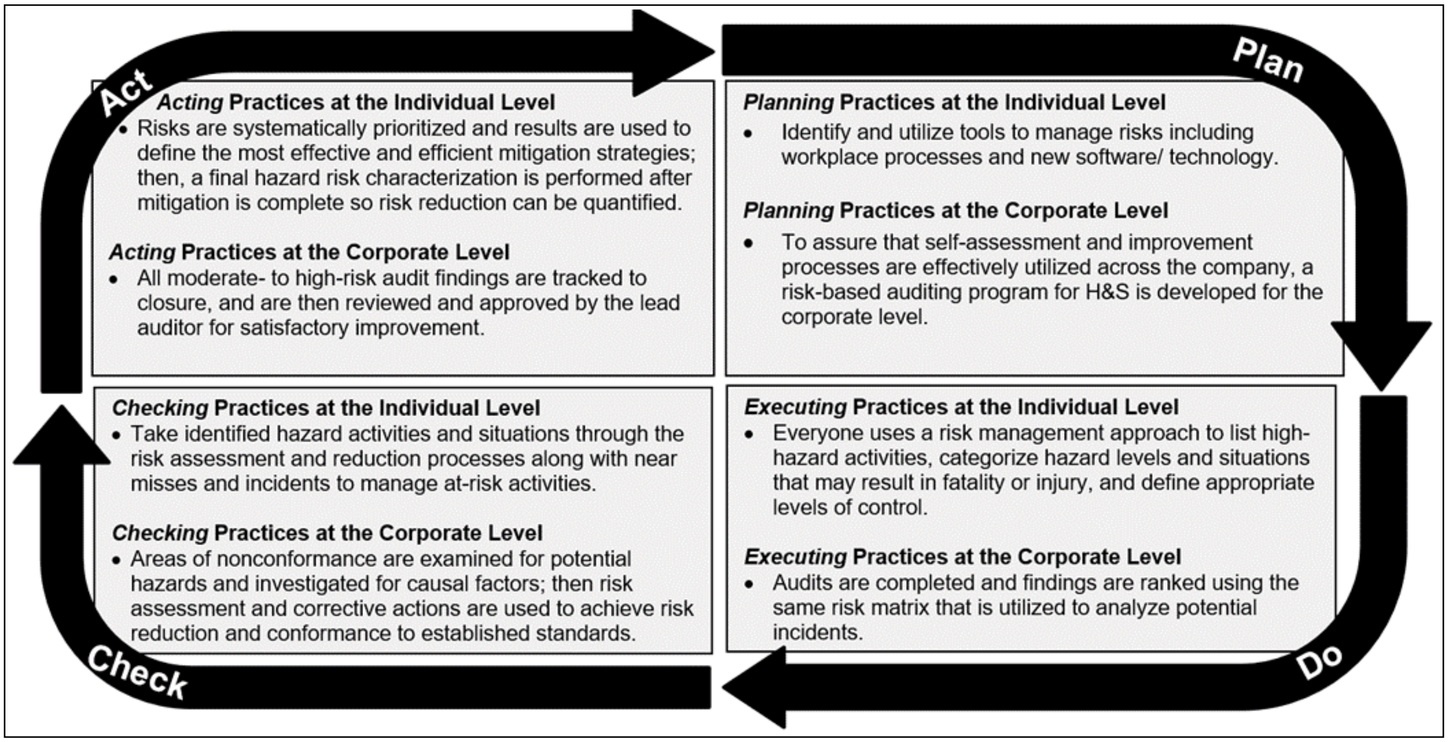

Figure 2. Example policy that displayed health and safety practices throughout the PDCA cycle.

statement: "We have implemented Safety Violation Reduction Plans at each mine site. These plans focus on the top five most frequently cited categories at each location, and form corrective action plans. These plans are reviewed quarterly and appropriate adjustments are made." In this example, the lagging indicator is not an incident or illness, but a near miss, with an opportunity to correct before something more serious occurs on site. An example of policy health and safety practices that proceeded throughout the PDCA cycle in detail from both an individual worker and organizational level is provided in Figure 2 in order to provide greater clarity on the subtle differences among the phases of the PDCA.

These examples help illustrate how some companies showed policy depth and breadth. Additionally, the figure shows how some companies strategize and communicate the expectations of their hourly-level workforce and corporate-level employees. Thorough practices including the examples in Figure 1 were rarely found to be in place throughout the sample of companies in the current case study. Research supports the importance of managing risks by engaging in consistent dialogue between employees and managers and engaging employees in ongoing risk response and monitoring (Coombs, 2014; McComas, 2005). Through the process of documenting checking and acting practices within policies, companies can improve the context and opportunity to build the knowledge, skills, abilities, awareness, and motivation of workers.

4.3 Communicate and Coordinate the System

Finally, results show that companies have an opportunity to foster stability in their workforce through not only having clear, consistent practices within their policies, but also posting their policies on company websites for everyone to easily access. Research suggests that system practices must exhibit consistency between what they intend to do and what they actually do in order to continually improve safety (Bowen & Ostroff, 2004; Delery & Doty, 1996). However, these mandated and recommended Health and safety behaviors must be explicitly visible by the workforce so that workers can identify relevant risks presented throughout the day and execute the necessary responses. If workers are not able to read policy practices and make a cognitive connection between a given Health and safety practice they are expected to perform and the outcomes promised by the organization, then the message to workers is potentially left unnoticed or inconsistent with the purpose of the practice. Involving everyone in conversations around policy practices and subsequently making these practices available to everyone may help workers take more ownership of their workplace risks and enact safer choices (Battles, et al., 2006).

5. Conclusion

Possessing a strong policy that loops the PDCA cycle has been linked to an effective, low-cost approach to prevent incidents (Walker & Tait, 2004). This study provides initial insights into these aspects of mining policies. Specifically, the analysis showed how 26 companies prioritize and communicate their Health and safety objectives, through the quantity and scope of their policy practices. The qualitative analysis showed that practices can be enhanced to have more depth and clarity about what is expected of employees to prevent incidents.

5.1 Limitations

This study, although providing implications for communicating and coordinating Health and safety management practices within mining, is not without methodological limitations. First, the sample is small and the results cannot be generalized to all NMA companies and other high-risk industries. Along these lines, it is quite possible that a majority of these NMA companies do indeed have Health and safety policies but they are not publicly available and rather, posted on an internal website that can only be accessed via their company intranet. A similar limitation exists within each company, since individual mine sites could have their own organizational-level policy that covers practices in more detail. However, it can also be assumed that site-level policies would derive specific HSMS elements and practices from the values communicated in their parent company policy.

Also, the researchers who coded the policy practices did so through their own interpretation of the CORESafety elements and practices. A guidance document with definitions and examples was used throughout the coding process but it is possible that other researchers would have identified and selected different quantities and assignment of practices. Although the analysis revealed instances where the execution of safety behaviors might be enhanced, there is still much speculation about how the implementation of an HSMS looks at these sites, not to mention other factors, including company longevity, worker experience, etc, that was not available but should be considered with the results.

Finally, the purpose of this analysis was to inform and perhaps persuade mining companies to improve their policies, particularly in lieu of recent research suggesting that policies are vague and have poorly established rules (Bourrier, 2017). The efforts within this small-scale study were designed to provide results in a way that undergirds company policy efforts by pinpointing specific content and gaps that, if addressed, could improve miner knowledge and decision making on the job. Although CORESafety was the chosen framework used to analysis the policy content, other HSMS frameworks could be adhered to more closely throughout the study as well. However, using other frameworks may not have provided the clear gaps in certain elements, such as change management, that need addressed in company policies.

5.2 Future Directions

Despite these limitations, this information can be used to encourage mining companies to consult their website and check: first, the accessibility and visibility of their policies and second, the quantity and scope of their policies. Moving forward, companies have the opportunity to reassess their policy visibility and content to ensure their Health and safety goals and messages are being communicated adequately and better equip the workforce. Additionally, it may behoove upper management to determine if there is a distinct absence of specific HSMS elements and practices as well as an absence of checking and evaluating practices that can be added to improve the consistency of what managers promote and expect in day-to-day operations. Finally, assurance of responsibility and communication is continually promoted in HSMS research (Bianchini et al., 2017) but little guidance about where and how to start making progress in these areas is provided on the company level. This study shows that responsibility, by way of policy practices, should be further studied in order to understand potential impacts on workers' effective implementation and evaluation of decisions, behaviors, and ultimately incidents that occur on site. Future research should work to more explicitly document these links in terms of workplace incidents. ■

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