Human Factors and Human Error in Mining Industry: A Review and Lessons from Other Industries

Ali Yaghini, Yashar Pourrahimian, and Robert Hall
Mining Optimization Laboratory (MOL)
University of Alberta, Edmonton, Canada

ABSTRACT

Human factors (HFs) play an important role in the mining and mineral industry; affecting operational and maintenance efficiency and safety. It is well-known—even considering the introduction of new technologies and automation in this sector—that a significantly large proportion of total human errors (HEs) occur during the operation and maintenance phase. The aim of this paper is to provide a comprehensive literature review of HF across several industries. From this review, the impact of HF on operation and maintenance will be summarized with a focus on what the mining industry is currently doing and what opportunities for additional efforts in the HF area are. Based on this review, future research directions and themes are identified.

1. Introduction

Over the last decades, the mining industry has focused on improving equipment, machinery and methods that have led to more advanced hardware and software, equipment with higher reliability and productivity, and other technological advancements. These actions have improved both safety and productivity as well as reduced casualties and maintenance workload. Although today's mining equipment and machinery are technologically advanced and highly reliable, the risk of accidents is still relatively high and the key performance indicators have not improved significantly compared to other industries (Sorensen, 2012). A prominent reason could be due to insignificant integration of human factors (HFs) as a part of the planning, operation, and maintenance activities. The current mining system is a people system, and inevitably HF/human error (HE) figure prominently in all aspect of this industry. Even the most advanced technologies and innovations require operators and maintainers with significant knowledge and skills, which could increase the potential for HE.

There are several methods developed for understanding the HF and HE contributing to industrial activities. Their application in operation and maintenance context has been largely advanced, predominantly in aviation and nuclear power industries.

This paper reviews current efforts in the mining, aviation, and nuclear industries for detecting, reporting, and managing HEs and HFs. An assessment of the suitability of approaches used in other industries for the mining industry is given and recommendations for next steps in improving how HFs and HEs are managed in the mining industry is given.

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2. Human Error

Generally, HE is defined as the failure to complete a required task (or execute a forbidden action) that could lead to the interruption of normal scheduled actions, damage to assets or compromise safety (Reason, 1990; Amalberti, 2001; Wiegmann & Shappell, 2003; Dhillon & Liu, 2006). Reason (1990) defined error as "a generic term to encompass all those occasions in which a planned sequence of mental or physical activities fails to achieve its intended out-come." Woods, Dekker, Cook, Johannesen, and Sarter (2010) defined error as "causal attribution of the psychology and sociology of an event." Papic and Kovacevic (2016) defined error as "failure (omission, unsuccessful attempt) to execute a required function, wrong decision in a response to certain problem, performing of function that shouldn't be executed, unsuccessful in recognition (observation, revealing) of a dangerous condition that requires corrective measures, bad timing and bad response to unpredicted circumstances."

HE has only been studied in the last 60 years (Dhillon & Liu, 2006). In general, the literature presents discussions of HE with minimal technical analysis and seems to be an under-researched area and not understood fully (Saward & Stanton, 2015). For the reader interested in a general discussion see Reason (1990), Perrow (1999), Wiegmann and Shappell (2003), Flin, O'Connor, and Crichton (2008), and Woods et al. (2010).

HE has been considered inevitable (Reason 1990; Maurino, Reason, Johnston, & Lee, 1998; Perrow 1999; Wiegmann & Shappell, 2003; Woods et al., 2010); and for instance in the aviation industry, it is associated with 70 to 90% of accidents (Hollnagel, 1993; Adams, 2006; Begur & Ashok Babu, 2016). Civil Aviation Authority (CAA) Safety Regulation Group (2002) stating: "It is an unequivocal fact that whenever men and women are involved in an activity, HE will occur at some point."

The poor condition of the working area (inadequate lighting, high noise levels), insufficient training or skills of operators, improper tools, poor equipment design and poorly written equipment maintenance procedures, and complicated operating processes have been recognized as some of the main reasons for the occurrence of HE (Dhillon & Liu, 2006). Dhillon (1986) classified HE into six categories:

1. Operating errors;
2. Assembly errors;
3. Design errors;
4. Inspection errors;
5. Installation errors; and
6. Maintenance errors.

Additionally, HE consequences are not always immediate and sometimes they may have hidden, undetected consequences which can lead to a latent error condition and delayed undesired outcome(s).

3. Human Error and Human Factor in Mining and Mineral Industry

The 'minerals industry' generally refers to a group of activities related to mining (minerals extraction), their processing and transportation (Horberry, Burgess-Limerick, & Fuller, 2013). The mining and mineral industry is one of the largest worldwide employer and key revenue earner; for example, mining contributed C$56 billion to Canada's Gross Domestic Product in 2015 (Energy and Mines Ministers' Conference, 2016).

Traditionally, mining is considered as an inherently high-risk industry. Nevertheless, the introduction of new technology and an increased concern for safety has helped to reach noticeable decreases in incident and injury rates over the last several years. In an effort to speed up this process, the HFs associated with operation and maintenance need to be addressed (Patterson, 2009). HE is present in mining and mineral industry operation and maintenance. It is an important factor influencing the safety success and effectiveness of operation and maintenance tasks and it can have undesired consequences if errors pass undetected and uncorrected.

The economy has always had a direct influence on the amount of attention which organizations and governments have in mining HF and ergonomic. For example, the 1980s virtual collapse of the coal industry in the UK caused a drop in the amount of British work in mining HF/HE (Simpson, Horberry, & Joy, 2009).

In the literature, with some overlap, HFs and HEs generally fall into the following five categories:

1. Safety and ergonomic related risks
2. Injuries and accidents
3. Mining equipment
4. Automation and new technologies
5. Mineral processing plants.

3.1. Safety and ergonomics

Morgan (1988) organized information to provide a step-by-step guide to developing and upgrading a program for safety and technical training for cement plant workers. Mason (1996) described an attitude survey of electricians in a coalfield to improve electricians' safety. Burgess-Limerick and Steiner (2006) presented several possible controlling measures such as hydraulic cable reelers; handrails on continuous miners (CM) platforms; redesign of CM platforms and bolting rigs to reduce reach distances during drilling and bolting; improvements to guarding of bolting controls.

Badri, Nadeau, and Gbodossou (2011) proposed a new concept, called “hazard concentration”, based on the number of hazards and their influence. The method calculates a weight for each category of hazard related to an undesirable event by analytic hierarchy process (AHP) method to integrate of occupational health and safety (OHS) into risk management in an open-pit mining project in Quebec, Canada. The result of their project helped the company to choose a suitable accident prevention strategy for its operational activities. Later, Badri Nadeau, and Gbodossou (2013) developed a new approach based on their “hazard concentration” concept and AHP to risk management in mining projects. They constructed a database of about 250 potential hazards in an underground gold mine in Quebec, Canada. They showed the importance of considering OHS in all operational activities of the mine.

Burgess-Limerick, Joy, Cooke, and Horberry (2012) developed the operability and maintainability analysis technique (OMAT) technique for analyzing risks associated with operation and maintenance tasks, for the purpose of engaging with mining equipment manufacturers to accelerate improvements in the safe design of mining equipment. Horberry, Xiao, Fuller, and Cliff (2013) investigated challenges associated with information collection and management during underground coal mining emergencies from a human-centered perspective. They looked at decision making deficiencies in incident management teams, and organizational issues related to mining control rooms during emergencies to highlight the role of HF in mining emergency management. Nadeau, Badri, Wells, Neumann, Kenny, and Morrison (2013) outlined the challenges faced by deep mining operations for determining how to ensure safe and sustainable working environments. They argued designing new intelligent personal protective equipment that considers HFs could be a solution.

Ergonomics generaly defines as fitting a job to a worker; Torma-Krajewski, Steiner, Lewis, Gust, and Johnson (2007) presented the results from the implementation of an ergonomics process designed to identify and reduce exposures to ergonomic risk factors found in a US surface coal mine. They reported that mechanics and heavy equipment operators had the most concern about ergonomic. Torma-Krajewski and Lehman (2008) presented several examples of task-specific interventions that helped to reduce exposure to risk factors through implementing an ergonomics process to address exposure to risk factors that may result in musculoskeletal disorders or other types of injuries/ illnesses. Their work was a joint research project conducted by the US National Institute for Occupational Safety and Health (NIOSH) and a private mining company. Torma-Krajewski and Burgess-Limerick (2009) presented three case studies describing the steps that three mining companies in the US had taken to apply ergonomics to lower worker exposure to risk factors and musculoskeletal disorders (MSDs) and improve productivity.

3.2. Injuries and accidents

Burgess-Limerick, Straker, Pollock, Dennis, Leveritt, and Johnson (2007) implemented the participative ergonomics for manual tasks (PErforM) program at four Australian underground coal mines to facilitate ongoing miner participation in reducing injury risks associated with manual tasks. They presented several examples of the risk assessments undertaken and resulting potential control suggestions; and discussed the lessons learned. Paul and Maiti (2007) investigated the role of behavioral factors in underground mine's accidents and incidents. By caring out the study in two different coal mines in India they concluded that the group of workers who had experienced an in-jobsite accident were less satisfied with the job and more negatively affected compared to the workers without accidents.

Ruckart and Burgess (2007) analyzed data from the hazardous substances emergency events surveillance (HSEES) system for the period of 1996–2003 and concluded that HE-related events in mining and manufacturing resulted in almost four times as many events with victims and almost three times as many events with evacuations compared with events where HE was not a contributing factor, and also the night shift had no apparent influence on the events attributable to HE. Reardon, Heberger, and Dempsey (2014) reviewed U.S. mining maintenance and repair fatal reports (2002–2011) and developed a classification system to identify patterns and contributing human and non-HFs in fatalities during maintenance and repair operations in mining. They suggested several potential interventions to reduce fatality occurrences for both coal and metal/nonmetal mines. Sanmiquel, Rossell, and Vintró (2015) analyzed 70,000 occupational accidents and fatality reports between 2003 and 2012 in the Spanish mining sector using statistical methods such as Bayesian classifiers, decision trees or contingency tables to identify behavioral patterns. From the identified behavioral patterns, they developed potential prevention policies to decrease injuries and fatalities.

Cloug (2015) presented that there is a relationship between a rise in the fatality rate in the Australian mining industry over the last few years and a fall in commodity prices.

- *Human factor analysis and classification system (HFACS)*

The human factor analysis and classification system (HFACS) is a well-known framework for analyzing and classifying the underlying HFs associated with accidents and incidents. It has been applied in the aviation industry for many years (Wiegmann & Shappell, 2001; Wiegmann, Shappell, Boquet, Detwiler, Holcomb, & Faaborg, 2005; Tvaryanas & Thompson, 2008; Daramola, 2014). The original HFACS, contained 19 categories. These are placed in one of four levels including: unsafe acts, preconditions for unsafe acts, unsafe supervision, and organizational influences. Each tier is dependent on the previous one and factors are assumed to progress from active to latent conditions as they progress up the hierarchy from unsafe acts to organizational influences.

HFACS has been modified and applied in several areas. For example, to investigate railway accidents (i.e., HFACS-RR) (Baysari, McIntosh, & Wilson, 2008; Reinach & Viale, 2006; Kim, Baek, & Yoon, 2010), to assess the factors disturbing performance in a hospital operating room

(ElBardissi, Wiegmann, Dearani, Daly, & Sundt, 2007), and to improve patients safety (Milligan, 2007). Patterson and Shappell (2010) used HFACS method to analyze 508 incident and accident cases from across the state of Queensland, Australia to identify HF trends and system deficiencies within mining. They concluded that while the original HFACS method is valid for applying in aviation accidents, the nomenclature and examples within some of the causal category are not compatible with the mining industry. Therefore, they modified the original HFACS framework and developed a new HFACS-Mining Industry (HFACS-MI) framework (Table 1).

Lenné, Salmon, Liu, and Trotter (2012) analyzed 263 significant mining incidents in Australia across 2007–2008 using HFACS. They recommended focusing on HFACS categories at the higher levels such as organizational climate, planned inadequate operations, and inadequate supervision to reduce the number of unsafe acts at operational level. Furthermore, several researches have been done in China, mainly in coal mine section, to investigate mine accidents and safety system deficiencies (Jian-wei & Wen-yu, 2011; Chen, Yin, Zeng, Li, & Li, 2014; Zhao, Li, & Zeng, 2014; Xie, Yang, & Xu, 2015).

3.3. Mining equipment

Burgess-Limerick and Steiner (2006) investigated 959 injuries between 2002 and 2005 associated with CMs, shuttle cars (SCs), load–haul–dump machines and personnel transport vehicles (PT) in New South Wales underground coal mines to determine opportunities for controlling injury risks. They found that the most common work activities that let to injuries were: “strain while handling CM cable (96 injuries); caught between or struck by moving parts while bolting on a CM (86 injuries); strains while bolting on CM (54 injuries); and slipping off a CM during access, egress or other activity (60 injuries)”. Burgess-Limerick (2011) investigated 4,633 injuries occurring in underground coal mines between 2005 to 2008 in New South Wales (Australia) to identify opportunities for controlling equipment related injuries. He concluded that in 46% of injuries, equipment (continuous miner (12%), bolting machines (6%), LHD (8%), longwall (7%), personnel transport (4%), shuttle car (3%), and the rest (6%)) were involved. There were several high potential consequence events reported during the period including: interactions between personnel and mobile equipment; interactions between personnel and longwall shield movements; and transport equipment collisions. He suggested a series of possible short-term control measures for these risks.

Horberry et al. (2012) presented three case studies of HFs, focused on: reducing risks; developing emergency response management systems; and the value of participatory ergonomics in improving the design of mining equipment. They showed that properly dealing with HF is a key part in any sustainability initiative. In another study, Horberry (2012) reviewed the present technologies and the possible HFs issues associated with them and presented a four-stage research and development process to increase the safety and health benefits for operators of new technologies.

Papic and Kovacevic (2016) used a combination of causes-effect diagram, 5 Why? technique and event tree analysis to improve mining machines maintenance effectiveness. They used “Causes-effect diagram” and “5 Why?” technique to detect and categorize HFs/HEs that affect the results of the mining machines maintenance operation. They suggested to (1) use a proactive approach for solving potential HF problems in mining machines maintenance, (2) use the system of error proofing or Poka Yoke (Shingo, 1986) for HE proofing, and (3) providing training in the area of HF to reduce the number of errors in mining machine maintenance.

3.4. Automation and new technologies

Tichon and Burgess-Limerick (2009) reported several experiments on the implementation of virtual reality (VR) as a medium for safety related training in the mining industry and discussed a range of associated issues. They concluded that novice drivers’ hazard perception abilities and maintenance inspection tasks can be improved via training in a VR environment.

Table 1. HFACS and (*HFACS-MI)

Outside factors*	Regulatory Factors		Government regulations and policies effects on the mine's operation, health, and safety.
	Other		Society, economic, and environmental concerns effects on the health and safety of a mine site.
Organizational influences	Organizational climate		Prevailing atmosphere/vision within the organization (e.g., policies and culture).
	Operational process		Formal process by which the vision of an organization is carried out (e.g., operations and procedures).
	Resource management		How human, monetary, and equipment resources necessary to carry out the vision are managed.
Unsafe supervision	Inadequate supervision (leadership*)		Oversight and management of personnel and resources.
	Planned inappropriate operations		Management and work assignment (e.g., aspects of risk management, crew pairing, and operational tempo).
	Failed to correct known problems		Deficiencies related safety areas are ''known'' to the supervisor, and yet are allowed to continue uncorrected.
	Supervisory violations (Leadership Violation*)		The willful disregard for existing rules, regulations, instructions, or standard operating procedures by management during the course of their duties
Preconditions for unsafe acts	Environmental factors	Technological	This category encompasses a variety of issues including the design of equipment and controls, display/interface characteristics, checklist layouts, task factors and automation
		Physical	Included are both the operational setting (e.g., weather, altitude, terrain) and the ambient environment, such as heat, vibration, lighting and toxins
	Condition of operators	Adverse mental states	Acute psychological and/or mental conditions that negatively affect performance such as mental fatigue, pernicious attitudes, and misplaced motivation
		Adverse physiological states	Acute medical and/or physiological conditions that preclude safe operations such as illness, intoxication, and pharmacological and medical abnormalities known to affect performance
		Physical/ mental limitations crew	Permanent physical/mental disabilities that may adversely impact performance such as poor vision, lack of physical strength, mental aptitude, general knowledge, and a variety of other chronic mental illnesses
	Personnel factors	Crew resource management	A variety of communication, coordination, and teamwork issues that affect performance
		Personal readiness	Off-duty activities required to perform optimally on the job such as adhering to crew rest requirements, alcohol restrictions, and other off-duty mandates
Unsafe acts	Errors	Decision errors	These ''thinking'' errors represent conscious, goal-intended behavior that proceeds as designed, yet the plan proves inadequate or inappropriate for the situation.
		Skill-based errors	Highly practiced behavior that occurs with little or no conscious thought.
		Perceptual errors	These errors arise when sensory input is degraded, as is often the case when flying at night, in poor weather, or in otherwise visually impoverished environments.
	Violations	Routine	Often referred to as ''bending the rules''.
		Exceptional	Isolated departures from authority, neither typical of the individual nor condoned by management

Also, Tichon et al. (2011) reviewed the evidence for the value of VR as a medium for safety related training in mining. They argued the need of a large scale, systematic, assessment of the results of safety related training via virtual mining environments for future training. Later, Pedram, Perez, and Dowsett (2014) evaluated the impact of VR based training sessions on operators performance, safety standards, and mine productivity and used a cost benefit analysis to investigate the added-value of the VR. In another study, Alem, Huang, and Tecchia (2011), as part of a human system integration project within the CSIRO Minerals Down Under Research Flagship, presented a remote guiding system called HandsOnVideo to support and help a mobile local worker in maintaining complex equipment in mine sites remotely. They tested the usability of the system in a real industry situation.

Lynas and Horberry (2010) presented a literature review and a database of existing and emerging technologies of available automated mining equipment. They used this to explore how new technologies can be developed in ways that take into account HFs to determine the required skills and cognitive capabilities to operate or maintain the new technology for the purpose of developing an optimal interface design to eliminate performance gaps. They concluded deskilling of the operators and maintainer, over-reliance on the technology by operators, poor operator acceptance of new technologies, and poor HFs design of equipment interfaces are real problems. In another study (Lynas & Horberry, 2011a), they discussed lessons related to the impact of HF in automation learned from other industries. They argued several potential problems and their solutions. Also, Lynas and Horberry (2011b) review HFs and ergonomics (HF/E) work in mining and then investigated the emerging trends and HF/E issues associated with automated mining in Australia through a semi-structured interview process. They concluded that there are several issues such as automation, safe design, and workforce skill requirements and organizational issues related to HF/E in the mining industry.

Horberry and Lynas (2012) investigated operator interaction with automated mining equipment by preparing a database that considers both existing and emerging technologies. They used this to analyze the main HF issues for such technology. Recently, Horberry, Burgess-Limerick, and Steiner (2016) introduced the application of human centered design (HCD) in the mining industry and explained the benefits of a HCD approach and several successful examples in this industry.

3.5. Mineral processing plant

Li, McKee, Horberry, and Powell (2011) investigated the current status of control room operators at two different types of Australian mineral processing plants from a HFs perspective to explore the underlying difficulties in their workplace. They concluded developing effective human-machine interfaces (HMI) and alarms, improving operator training, and optimizing organizational factors are key elements to improve integration of operators and technologies. Later, Li, Powell, and Horberry (2012) investigated the status of control room operations in two types of mineral industry in Australia and explored the HF and underlying barriers in the operators' work environment. They concluded that poorly designed HMI and alarms, insufficient operator training, and inappropriate task allocations are among deficiencies in the current information and organizational environments constraining operator control ability.

Figs 1 and 2, illustrate the considered factor and area of study. Table 2 summarizes year of study and country of origin where the study was done.

Table 3 presents a classification of published papers on HF in mining and mineral industry.

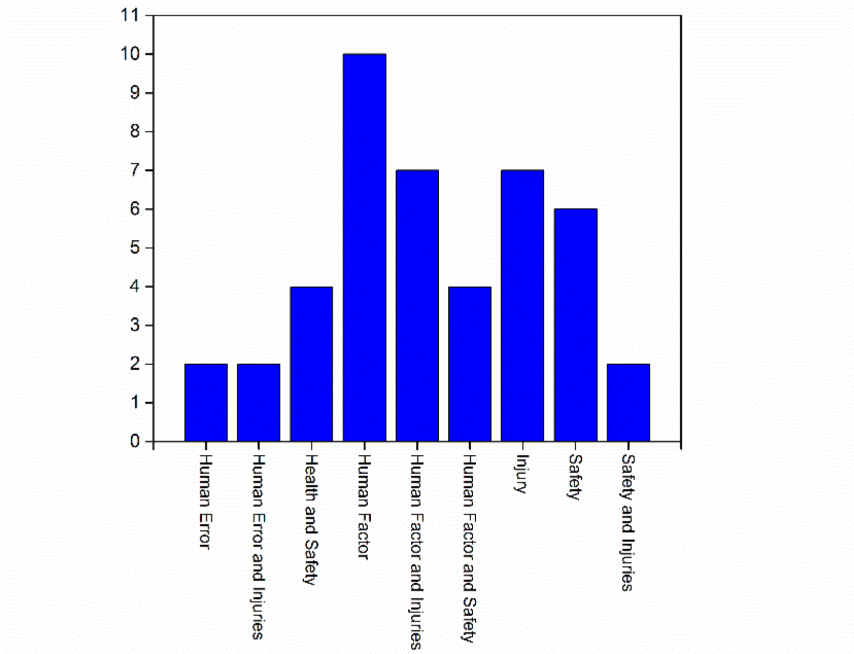

Fig 1. Published papers corresponding to considered factor in mining industry

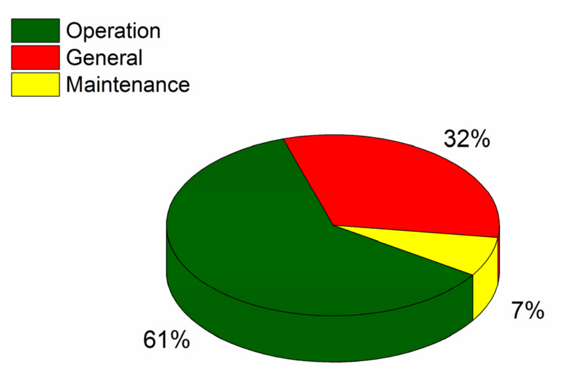

Fig 2. Published papers corresponding to the area of study in mining industry

Table 2. Number of the published papers and country of origin

Year	Australia	China	USA	Canada	UK	India	South Africa	Turkey	Spain	Serbia
1974			1							
1998	1									
2006	1									
2007	1		3		1	1				
2008			1							
2010	3	1					1			
2011	6	2		1						
2012	6	1	1							
2013	1			2				1		
2014	1	2	1							
2015		2							1	
2016	1									1
Total	**21**	**8**	**7**	**3**	**1**	**1**	**1**	**1**	**1**	**1**

Table 3. Summary of published papers about the effect of HF and HE in the mining and mineral industry

Reference	Scope	HF	HE	Safety/health	Accidents/ injuries	Country	Mining method	Operation/ maintenance
Lawrence (1974)	Injury data analysis		Accident causes		HE	USA	Underground mining	General
Mitchell, Driscoll, and Harrison (1998)	Injury data analysis				Work-related fatalities	Australia	General	General
Burgess-Limerick and Steiner (2006)	Injury data analysis				Injuries associated with mining equipment	Australia	Underground mining	Operation
Burgess-Limerick et al. (2007)	Reduce operation injury				Participative ergonomics for manual tasks (PErforM)	Australia	Underground mining	Operation
Ruckart and Burgess (2007)	Accident data analysis		Time of occurrence			USA	General	General
Torma-Krajewski et al. (2007)	Reduce exposure to risk			Implementation of an ergonomics process		USA	Surface Mining	Operation
Coleman and Kerkering (2007)	Injury data analysis	Safety, injuries, and lost workdays		Defining lost workdays as indicators of risk		USA	General	Operation
Paul and Maiti (2007)	Safety management			The role of behavioral factors		India	Underground mining	Operation
Torma-Krajewski and Lehman (2008)	Reduce exposure to risk			Ergonomic interventions		USA	Surface mining	Operation

Table 3. Continued

Reference	Scope	HF	HE	Safety/health		Accidents/ injuries	Country	Mining method
Burgess-Limerick, Krupenia, Zupanc, Wallis, and Steiner (2010)	Equipment design		Reducing control selection errors			Australia	Underground mining	Operation
Lynas and Horberry (2010)	Automation	HF challenges of automated mining equipment				Australia	General	Operation
Patterson and Shappell (2010)	Accident data analysis				HFACS	Australia	General	General
Green, Bosscha, Candy, Hlophe, Coetzee, and Brink (2010)	Automation			Improving safety using robots		South Africa	General	Operation
Lan and Qiao (2010)	Accident data analysis		HEs reliability using gray relational theory			China	Underground mining	General
Alem et al. (2011)	Automation	Remote collaboration				Australia	General	Maintenance
Badri et al. (2011)	Reduce exposure to risk			Integration of OHS into risk management		Canada	Surface mining	Operation
Burgess-Limerick and Steiner (2006)	Accident data analysis				Equipment associated injuries	Australia	Underground mining	Operation

Table 3. Continued

Reference	Scope	HF	HE	Safety/health	Accidents/ injuries	Country	Mining method	Reference
Li et al. (2011)	Mineral process control room operation	Human machine interface				Australia	Mineral processing	Operation
Lynas and Horberry (2011a)	Automation	HF issues with automated mining equipment				Australia	General	General
Lynas and Horberry (2011b)	Automation	Review of Australian HF research and stakeholder opinions				Australia	General	Operation
Tichon and Burgess-Limerick (2011)	Reduce exposure to risk Related to training in mining			A review of virtual reality as a medium		Australia	General	Operation
Jian-wei and Wen-yu (2011)	Safety analysis			HFACS, coal mine safety system deficiencies and unsafe acts		China	Underground Mining	Operation
Wu, Jiang, Cheng, Zuo, Lv, and Yao (2011)	Accident data analysis				Accident data analysis	China	Underground Mining	General
Burgess-Limerick et al. (2012)	Safety management			Safety improvement and injury prevention, OMAT		Australia	General	Operation

Table 3. Continued

Reference	Scope	HF	HE	Safety/health	Accidents/ injuries	Country	Mining method	Reference
Horberry (2012)	Automation			Review of benefits of new technologies in mining		Australia	General	Operation
Horberry et al. (2012)	Sustainability	The role of HF in a sustainable mineral industry				Australia	General	Operation
Lenné et al. (2012)	Accident data analysis				HFACS	Australia	General	Operation
Xilin Li et al. (2012)	Mineral process control room operation	Human-system integration				Australia	Mineral Processing	Operation
Drury, Porter, and Dempsey (2012)	Accident data analysis				Patterns in mining haul truck accidents	US	General	Operation
Chen, Qi, Long, and Zhang (2012)	Accident data analysis				Characteristics of HFs	china	General	Operation
Badri et al. (2013)	Risk management			AHP, OHS		Canada	Underground mining	Operation
Horberry et al. (2013)	Mining emergency management	The role of HF and ergonomics				Australia	Underground mining	Operation
Onder (2013)	Accidents data analysis				Logistic regression models	turkey	Surface mining	Operation
Reardon et al. (2014)	Accidents data analysis				Hazard classification	US	General	Maintenance

Table 3. Continued

Reference	Scope	HF	HE	Safety/health	Accidents/ injuries	Country	Mining method	Reference
Horberry (2014)	Equipment design	Safety in design				Australia	General	General
Zhao et al. (2014)	Accident data analysis				HFACS	China	Underground mining	Operation
Chen et al. (2014)	Accident data analysis				HFACS, Bayesian network	China	Underground mining	Operation
Sanmiquel et al. (2015)	Accident data analysis				Bayesian network, data mining	Spain	General	Operation
Xie et al. (2015)	Safety analysis			HFACS, SPA set pair analysis		China	General	Operation
Gui and Chun (2015)	Accident data analysis				Research on responsible person	China	Underground Mining	Operation
Papic and Kovacevic (2016)	Equipment maintenance	Cause-effect diagram and event tree analysis				Serbia	General	Maintenance
Horberry et al. (2016)	Equipment design	Human-centered design				Australia	General	General

4. Aviation, Nuclear, and other industries

Aviation and nuclear industries have done a significant amount of research to investigate the impacts of HF/HE in their maintenance activities (B.S. Dhillon & Liu, 2006), and still continue their efforts to overcome many remaining and newly introduced HF/HE related challenges (Begur & Ashok Babu, 2016).

To demonstrate the progression of methodologies and theories, in the rest of this section, the contributing HF and HE in maintenance and operation activities are reviewed separately.

4.1. Maintenance

Because of the complex nature of the procedures, including removal and replacement of different components, detecting faults which in many cases are uncommon and difficult to spot and require high levels of attention and expertise, tough working conditions, difficult ergonomic body positions, and regularly under time pressure, maintenance tasks are vulnerable to HE (Pennie, Brook-Carter, & Gibson, 2007).

HEs in maintenance has been a contributory factor in several high-profile accidents across different industries (Pennie et al., 2007). HE in aircraft maintenance is cited for 15% to 20% of aviation misshapes (Manwaring, Conway, & Garrett, 1998; Patankar & Taylor, 2004; Rashid, Place, & Braithwaite, 2013; Begur & Ashok Babu, 2016) and at least 70% of naval aviation safety occurrences in UK (Saward & Stanton, 2015).

4.1.1. Aviation

Drury (1991) offered a taxonomy and means of eliminating maintenance errors in the aviation industry, and later, Graeber and Marx (1993) showed the economic aspect of maintenance error.

Shepherd and Johnson (1995) described several research products that are currently improving safety and efficiency in maintenance applications worldwide. Hobbs and Williamson (1995) investigated the type of errors made by maintainers in corporations with an air carrier in the Asia-pacific region. Havard (1996) presented British Airways' initiatives regarding HFs. Kania (1996) investigated casual factors contributing to HE. O'Connor and Bacchi (1997) presented an error taxonomy to classifying HE in maintenance and dispatch operations. Witts (1997) discussed the impact of HF on aircraft maintenance in Air UK Engineering. Reason (1997) claimed that maintenance-related error is one of the largest single HFs problems in modern aircraft systems. Ford (1997) discussed the impact of HE in airline maintenance on safety and discussed what is required to lessen the safety inadequacies. Shepherd and Kraus (1997) investigated the effect of several factors such as technician teaming and advanced technology, and evaluation of simplified English on the performance of maintainers. Amalberti and Wioland (1997) argued the relationship between aviation accidents and errors and the systemic safety approach for large socio-technical systems. Nelson, Haney, Ostrom, and Richards (1997) presented a structured method to identify, assess and prevent HE in space operation which can be applied. Koli, Chervak, and Drury (1998) developed two HF audit methods in aircraft inspection and maintenance process tasks to detect the human-system mismatches that can lead to errors, they are inspection audit and maintenance audit which can be used either in paper version or on a portable computer. McGrath (1999) with regard to airworthiness and safety, discussed aviation management imperatives to improve the professionalism of the field personnel's culture. Latorella and Prabhu (2000) reviewed current trends in dealing with HE in aviation maintenance and inspection. Wenner and Drury (2000) presented a methodology for analyzing the HEs' reports. Reason (2000) presented a job-oriented approach to determine the human performance problem in aviation. Shepherd (2002) explained actions regarding aircraft maintenance and inspection HFs.

Strauch and Sandler (1984) article discuss the important role of the aviation maintenance technician (AMT) in the safe operation of an aviation system. Hibit and Marx (1994) anticipated that using maintenance error decision aid (MEDA) can improve safety and maintenance system reliability. Allen and Rankin (1995) evaluated MEDA through a field test. Rankin, Hibit, Allen, and Sargent (2000) also evaluated the development and implication of MEDA to determine and eliminate the factors that contribute to maintenance error. Bao and Ding (2014) used MEDA and correspondence analysis methods to analysis maintenance error in 3,783 Aviation Safety Reporting System incident reports submitted during the period of January 1, 2008 to

December 31, 2008. They argued that a large proportion of maintenance errors has been initiated by both maintenance personnel and non-maintenance personnel, and individual-related factors and management-related factors are the most common reasons for maintenance error.

Liang, Lin, Hwang, Wang, and Patterson (2010) developed an on-line maintenance assistance platform (on-line MAP) for technicians to remove HE in performing aviation maintenance and inspection tasks. Chang and Wang (2010) determined nine significant human risk factors out of 77 preliminary and 46 primary risk factors in aircraft maintenance technicians by conduction an empirical study of Taiwan's airlines to improve maintenance operations. Atak and Kingma (2011) presented a case study about the safety culture of an aircraft maintenance organization and analyzed the various roles and the tensions between the quality assurance and maintenance management departments to stress the paradoxical relationship between safety and economic interests. Rashid et al. (2013) investigated the impact of human reliability on aviation maintenance safety and introduced a new model indicating the commencement and spread of critical maintenance HEs within aviation maintenance organizations. Cromie et al. (2013) described an initiative being utilized by a European aviation maintenance company to overcome the challenge of integrating human and organizational factors (HOF) training within a risk management context in a European aviation maintenance company. Chen and Huang (2014) introduced the Bayesian network (BN) approach to perform Human reliability analysis (HRA) in aviation maintenance visual inspection activities. Chen (2014) analyzed the characteristic, cause and mode of the aviation maintenance error to address appropriate management and control method for specific aviation maintenance HEs. Rashid, Place, and Braithwaite (2014) proposed aviation maintenance monitoring process; an integrated process to identify HE causal factors using fuzzy Analytic Network Process theory. Shanmugam and Robert (2015) reviewed and analyzed HFs in aircraft maintenance. They concluded that application of HF principals has created a great impact on the design of aircraft maintenance facilities, task cards and equipment, and these HF principals are applied to enhance the safety behavior in aviation maintenance workstation. Saward and Stanton (2015) described the nature and extend of individual latent situational error in naval aircraft maintenance by combining prospective memory, attentional monitoring, and schemas theories. Begur and Ashok Babu (2016) presented a method to collect and assess the data to analysis and reduce HFs in aircraft maintenance and improve the maintenance practices in order to decrease the number of aviation mishaps they might cause.

4.1.2. Nuclear power

Seminara and Parsons (1985) presented an overview of several HFs research conducted under the sponsorship of the electric power research institute (EPRI). They identified HFs problem areas and future research opportunities rather than provide direct solutions for deficiencies. Jacobsson and Svensson (1991) investigated psychosocial work demands of a maintenance group in a nuclear plant during the annual maintenance outage, based on a stress paradigm. They found that increased work strain, shiftwork including night work and reduced social support would have a negative impact on performance. Gertman (1992) presented a review of a mainframe version of a computer code for simulating maintainer performance. Pyy, Laakso, and Reiman (1997) investigated about 4400 HEs in nuclear power plant (NPP) maintenance between 1992 and 1994 to identify common cause failure mechanisms. He suggested that enhanced coordination and review, post-installation checking and start-up testing programs might decrease number of errors. Kim (1997) described the Korean-version of HPES (human performance enhancement system) program and the current status of CASHPES (computer-aided system for HPES) development to reduce HEs and to enhance human performance in nuclear power plants.

Nakatani, Nakagawa, Terashita, and Umeda (1997) proposed DIAS, a new method to evaluate the human interface design of nuclear power plant equipment from the viewpoint of HE in maintenance activities. Lee, Oh, Lee, and Sim (1997) presented several HFs research including the development of a HFs experimental facility; the development of an operator task simulation analyzer; and analysis of HE cases performed by the Korean Atomic Energy Research Institute. Sola et al. (1997) described an overview of the main activities carried out by CIEMAT (Spain Research Centre for Energy, Environment and Technology) in the nuclear power plant industry regarding HF. Huang and Zhang (1998) analyzed root causes and discussed protective measures with respect to safety for HE events in operating and maintenance activities at the Daya Bay

Nuclear Power Plant, China. Röwekamp and Berg (2000) analyzed the operational behavior of different fire protection features based on the examination of reported results of regular inspection and maintenance programs for German nuclear power plants. Antonovsky, Pollock, and Straker (2014) investigated 38 maintenance-related failures in the petroleum industry using a HF Investigation Tool (HFIT) based on Rasmussen's model of human malfunction to identify the role of HF. They concluded there are three frequent HFs contributing to the maintenance failures: assumption (79% of cases), design and maintenance (71%), and communication (66%).

4.2. Operation

Mogford (1997) introduced the Taxonomy of Unsafe Operations for accident investigation and human casual factor classification, including the condition of operators and supervisory error. Li, Baker, Grabowski, and Rebok (2001) investigated 329 major airline crashes, 1,627 commuter/air taxi crashes, and 27,935 general aviation crashes between 1983 to 1996 to determine the role of pilot error. They also investigated the probable relationship between pilot certificate rating, age, gender, and flight experience as measured in total flight time. Wiegmann and Shappell (2001) used HFACS for the first time to analyze the human causes of commercial aviation accidents between January 1990 and December 1996. They confirmed the viability of HFACS framework for use within the civil aviation arena. Hirotsu, Suzuki, Kojima, and Takano (2001) investigated all incidents in Nuclear power plants (NPPs) during last 31 years using multivariate analysis to find HE occurrence patterns in this industry. They concluded wrong unit/train/ component, slip due to inattentiveness, improper setting value, inappropriate action, misconnection or miswiring of terminals, insufficient tightening or inadequate fitting objects, and insufficient torque management were major HE types during maintenance. Additionally, Wrong unit/train/component, operational slip due to inattentiveness, and operational deviation or disorder were major HE types during operation.

Shorrock and Kirwan (2002) introduced TRACEr, a HE identification (HEI) technique, for the analysis of cognitive errors in air traffic control in the UK. Grech, Horberry, and Smith (2002) analyzed maritime accidents in order to identify the role of HE and Situation Awareness (SA). Their results revealed that loss of SA had a partial role in the majority of investigated maritime accidents. Khan, Amyotte, and DiMattia (2006) developed a new HE probability index (HEPI) for offshore operation based on the SLIM (success likelihood index methodology) to constrain the chances of HE occurrence and reduce the consequences of such errors through changes in training, design, safety systems and procedures, which would lead to a more error-tolerant design and operation.

Bellamy, Geyer, and Wilkinson (2008) analyzed a small sample of major chemical accidents to find logical patterns of associations which can be used in the applied contexts of inspection and auditing. The result of their work helps inspectors and chemical companies understand how HFs and safety management systems fit together.

5. Discussion and Conclusion

Years of study has proved that attention to HF and reducing HE is one of the best ways to enhance performance and reduce the risks of accidents and incidents.

Like the aviation industry, the mining industry needs to first identify major HF/HE related to its operation and maintenance activities. The next step is to quantify the economic aspects of them. Although, it seems difficult to address all HFs/HEs and their consequences, the final result would give professionals, researchers, and even managers an exact indicator of the influence of each HF/HE in their job activities. In addition to the possibility of revealing yet unseen HF/HE during this process, finding the magnitude of each HF/HE's economic impact can facilitate improvements by revealing and addressing the most critical factors.

Performance shaping factors (PSFs) are a number of direct or indirect factors and aspects of the task, person or environment that are likely to increase the chance of HE. They have been used in risk analysis in several industries, and are considered the major contributors to HE (Boring & Blackman, 2007; Broberg & Kolaczkowski, 2007). Therefore, to identify and reduce the HEs, it is necessary to further analyze the PSFs involved in mining and mineral operation and maintenance activities. The results of this type of study would help the mining industry to reduce HE and improve PSFs involved in their activities by considering a necessary change(s) to equipment, tools, or process, as well as changes in management approaches.

Additionally, cognitive biases which generally define as systematic patterns of deviation from norm or rationality in judgment (Haselton, Nettle, & Murray 2015) and their role in incidents and disasters, as well as how they alter decision making and lead to undesirable outcomes need to be investigated.

- ***HE probability assessment methods***

HE Probability (HEP) assessment methods for quantification of human reliability are an under researched area in the mining and mineral industry. Further studies to identify a suitable HEP method among the different available methods such as subjective judgment HEP methods [e.g., Absolute Probability Judgment (APJ), Paired Comparisons (PC), Success Likelihood Index Method (SLIM) (Embrey, Humphreys, Rosa, Kirwan, & Rea, 1984)] and AHP-SLIM or HE database methods [e.g., HE Assessment and Reduction Technique (HEART) (Williams, 1986), JEHDI, and THERP (Swain & Guttmann, 1983)] for each individual mining sector and activity can enable researchers and professionals in this industry to properly address the related issues.

- ***HFACS***

Fatalities and major accidents are not acceptable to the mining and mineral industry, and the role of HF and HE can help with the goal of eliminating them. In an effort to reduce the rate of accidents, the HFs associated with them needs to be addressed. Currently, despite a few mining and mineral industry accident analysis studies, there are no reports about the main HF and HE caused accidents and incidents in Europe and North America. More studies are needed to gain a better understanding of the systemic factors contributing to mining accidents, and to evaluate those organizational and supervisory failures that lead to HF and HE. The results would provide the information necessary to reduce mine accidents.

Additionally, despite the fact that HFACS has been approved as a practical method for investigating the role of HF in accidents and incidents, it suffers from some inherent deficiencies. HFACS analysis is based on accident reports. Reporting of an accident often involves subjectivity and filtering and the causal inference may be manipulated by the data collection method. Also, considering the different background, position, and level of education of people writing them, accident reports will differ in both content and format. More study is needed to create a comprehensive reporting form based on the HFACS method to enables people across the industry to writes universal, extensive, and detailed reports of the accidents and incidents. These pre-defined forms approach would prevent the loss of information for some aspect of incidents or accidents and would help ensure consistent analysis of data.

The final reporting system also facilitates analyzing accidents to look for logical patterns of associations. The idea is that once identified, the patterns can be used in the applied contexts of operation and maintenance. If the patterns can be found in practice they can be used to identify weaknesses that could cause major accidents. Similarly, the patterns can be used to understand accident causation during accident investigations.

- ***Automation and new technologies***

Increased interest in using automated mining equipment, ranging from in-vehicle assistance systems (such as collision detection or prevention) through to fully automated and ‘people-less’ equipment (Lynas & Horberry, 2010), has brought to attention the importance of HF. However, current studies show that the human related part of automation (e.g., skill level of staff to support the automation) has not developed at the same pace as the equipment technology, because it is required to provide operators and maintenance crew with new skills to operate and support these technologies (Lynas & Horberry, 2010).

It is shown that simultaneously working with several semi or fully automated machines which need human interaction is a potential environment for HE where the role of HF needs to be investigated. In such an environment, studying risk-taking behavior using risk-taking theories such as risk homeostasis theory (RHT) (Wilde, 1989) could emphasize the importance of motivational factors in interventions to reduce operational risk.

On the other hand, studies in other industries have shown that excessive levels of mental workload or performing physical work concurrently with a cognitive task may have a negative impact on operator performance by impairing mental processing or delaying information processing and it could trigger HEs (DiDomenico & Nussbaum, 2011; Ryu & Myung, 2005). An assessment of the effect of mental workload in modern semi or full automated mining and mineral industry environment can reveal important aspects of the design and evaluation of an occupational task.

Remotely located individuals working on operation and maintenance tasks and using virtual reality as a medium for operation simulation are two fast growing sectors in the mining industry. For instance, several systems have been developed to enable a maintenance expert to remotely guide a technician through repairing a piece of equipment (Alem et al., 2011; Karsenty, 1999). Also, utilizing virtual reality as a medium for operation simulation offers the opportunity to enhance operational skills such as problem-solving, and decision-making under stress, without exposing trainees or others to undesirable risks (Tichon & Burgess-Limerick, 2009). The exact potential of these new technologies for improving efficiency, productivity and safety by removing HE (skill-based errors, violations, inadequate supervision and etc.) during operation or maintenance tasks still needs to be evaluated.

6. References

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