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Evaluation of human error in workers of an Iranian copper mine during the COVID-19 pandemic using the CREAM

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Abstract.
BACKGROUND: The outbreak of COVID-19 has adversely affected both global economy and public health around the world. These effects have also been observed in many workplaces, including mines.
OBJECTIVE: This study aimed to examine the human error of copper miners during the pandemic.
METHOD: This descriptive-analytical, cross-sectional study was performed on 192 workers of a copper mine in Iran. For this, occupation tasks were firstly analyzed using the Hierarchical Task Analysis (HTA), and then the human error in different subunits was assessed using the basic Cognitive Reliability and Error Analysis Method (CREAM). The prevalence of COVID-19 among miners was determined by assessing positive PCR test records.
RESULTS: The probability of human error in the operational subunits including mining, crushing, processing, and support subunits was estimated to be 0.0056, 0.056, 0.0315, and 0.0177, respectively. All three operational units were found to be in the scrambling control mode. The support unit was determined to be in the tactical control mode. Approximately 50% of all workers had been infected with COVID-19, with the highest prevalence in support units.
CONCLUSION: The results suggest that during the COVID-19 pandemic, copper miners are at higher risk of human error induced by poor working conditions. Therefore, it is recommended to employ some management strategies such as promotion of safety, health monitoring, and adopting supportive measures to control occupational stresses and therefore the probability of human error in the mine's operational units.

Keywords: Human errors, coronavirus, pandemic, miners, CREAM, work

1. Introduction

The outbreak and rapid spread of the COVID-19 infection have adversely affected the global economy, public health, and everyday life since 2020. Workplaces are considered as the primary hotspots for the transmission of this virus [1]. For this reason, health authorities have put much effort into preventing transmission since the beginning of the pandemic [2]. Before the outbreak of COVID-19, it had been proven that working in the illness state can prevent recovery; it also increase the risk sickness absence in the future [3]; negatively effect on productivity; and increase the rate of work errors, accidents, and injuries not only for the person herself/himself but also for her/his colleagues [4, 5]. On the other hand, it is suggested that an increased workload, long working hours, and occupational stressors caused by the COVID-19 pandemic not only can increase the risk of infection but also can pose enormous concerns for the health of employees in the future [6]. The COVID-19 pandemic has also adversely affected the livelihood of employees, job opportunities, and economic stability in many industries, including the mining sector. It has been suggested that COVID-19 can have more severe short-, medium-, and long-term economic, physical, and mental health implications for the mining indus-

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try than for many other sectors [7]. Indeed, poor job security or wage cuts tend to put more stress on low-earning workers [8]. According to statistics, from 2004–2015, a total of 20,731 mine accidents occurred in China, with an average of 1.7 deaths per accident [9]. Many factors, such as stress coping capacity, psychological and physiological performance, and life events can affect the rate of human error and ultimately health-threatening incidents [10]. Regardless of the COVID-19 pandemic, the rate of injury and mortality in the mining industry's harsh work environments has consistently been higher than in other industries [11]. Miners tend to work in fairly dangerous environments almost every day, which explains why this industry still has higher levels of accidents and injuries than the others [12, 13]. In recent years, various studies have been conducted on the causes of human error in occupational environments [14], but many of them lack a proper analysis of external factors that may increase the chance of errors such as life events or psycho-cognitive conditions [15]. Events that affect a worker's everyday life and living conditions (such as the COVID-19 pandemic) can easily provoke emotional disorders, which may affect the worker's mental and even physical health [16]. At the very least, a poor mental state can increase the likelihood of serious non-fatal injuries such as musculoskeletal problems and slipping and falling, which in turn, lead to lost working days [17].

Unfortunately, there is a limited information on the assessment of mining accidents in Iran in terms of human error. Human errors are often the outcomes of human physiological and psychological limitations, such as forgetfulness, negligence, attention deficit, low motivation, carelessness, and recklessness [14, 18]. Unfortunately, the studies conducted on such principles are limited and provide only qualitative descriptions. Miners, especially those who work at control devices, equipment, and systems in various operational units, are exposed to high psychological factors, resulting in augmentation of their error probability [19, 20]. The Cognitive Reliability and Error Analysis Method (CREAM) technique is known as an effective and useful method to determine the cognitive errors with high probability, owning to a detailed theoretical background; focusing on cognitive and psychological, structural, and cognitive contexts of human behavior even in mining. Therefore, this study aimed to identify and assess human error in one of Iran's copper mines during the COVID-19 pandemic in order to adopt effective control strategies to minimize the occurrence of such errors.

2. Materials and method

This descriptive/analytical cross-sectional study was conducted on the copper miners working in one of Iran's biggest copper mines. The cases were selected by means of complete enumeration sampling with at least one-year work experience. The subjects who were not interested in participating or completing the questionnaires were excluded. A total of 192 questionnaire was collected, from which the COVID-19 infections-related data were extracted by mine's health, safety, and environment (HSE) unit. Upon observing and interviewing the unit heads as well as the safety experts, the tasks related to the units of mining, crushing, processing, and support wherein more accident are occurred were included in the study. Regarding the complexity of occupational tasks, heavy workload, and high stress of working in a mine, the analysis was carried out using the CREAM by the following steps:

1. Hierarchical Task Analysis (HTA): CREAM starts with the analysis of work activities using HTA [21]. Inspired from human factors, HTA is a structured, objective method to describe users' performance especially cognitive tasks. This approach offers an understanding of the tasks users need to perform to reach the desired goals determined by operational plans or guidelines. In this approach, the tasks can also be divided into several sub-groups to facilitate the analysis describing the interactions of users and therefore, focusing on goals and plans [22]. In this study, three operational units of mining, crushing, processing, and support units were analyzed using HTA. For this, the operators' tasks were divided into sub-tasks. Figure 1 illustrates the analysis of the fire load operator in the mining unit as an example. Similarly, the crushing and processing units were analyzed [23].
2. Assessment of Common Performance Conditions (CPCs): After task analysis, the general characteristics of each task along with the working conditions affecting performance was assessed using the CPC table (Table 1). The condition effect is described as terms of improved, reduced, or no significant (NS). Afterwards, the total number of these conditions is determined for each specified task. CPC is still a basic comprehensive structure of the

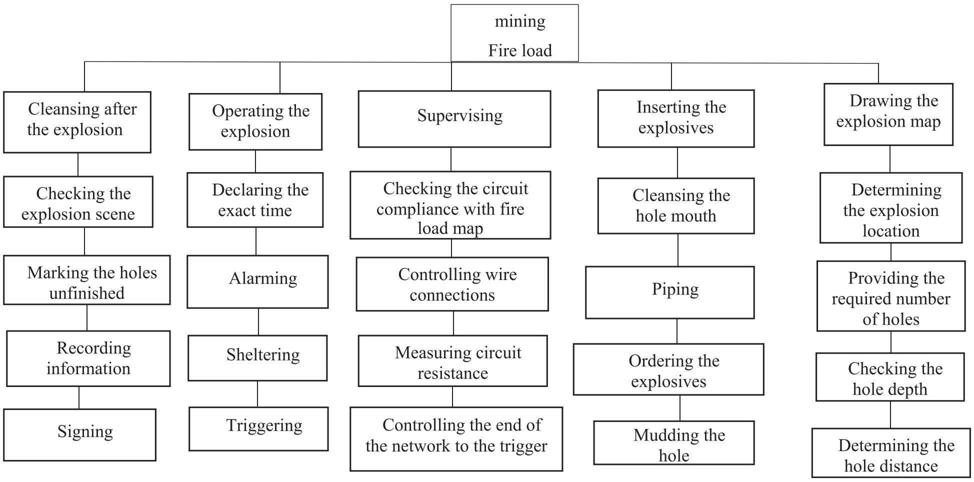

Fig. 1. Analysis of the cognitive tasks of mining (fire load) operator.

Table 1
Context influence index for CPCs

Expected effect	Level	CPC name
Adequacy of organization	Very efficient	Improved
	Efficient	NS
	Inefficient	Reduced
	Deficient	Reduced
Working conditions	Advantageous	Improved
	Compatible	NS
	Incompatible	Reduced
Adequacy of human-machine interaction and operational support	Supportive	Improved
	Adequate	NS
	Tolerable	NS
	Inappropriate	Reduced
Availability of procedures/plans	Appropriate	NS
	Acceptable	NS
	Inappropriate	Reduced
Number of simultaneous goals	Fewer than capacity	Improved
	Matching current capacity	NS
	More than capacity	Reduced
Available time	Adequate	Improved
	Normal	NS
	Temporarily inadequate	NS
	Continuously inadequate	Reduced
Time of day	Day-time (adjusted)	NS
	Night-time (unadjusted)	Reduced
Adequacy of training and preparation	Adequate, high experience	Improved
	Adequate, low experience	NS
	A little inadequate	Reduced
	Inadequate	Reduced
Crew collaboration quality	Very efficient	Improved
	Efficient	NS
	Inefficient	Reduced
	Deficient	Reduced

features for working conditions, indicating the quality of tasks' performance as well as the related probability of error [24].

3. Determination of Total Cognitive Failure Probability (CFPt): This step starts with computing a score of control mode (called β) by subtract-

Table 2
Relations between the context influence index and the control mode

Control mode	CFPt	Context influence index
Strategic	$0.00005 < P < 0.01$	–7 to –4
Tactic	$0.001 < P < 0.1$	–3 to 1
Opportunistic	$0.01 < P < 0.5$	2–5
Scrambled	$0.1 < P < 1.0$	6–9

ing the total number of conditions that improve performance from the total number of conditions that reduce performance. This score is then substituted into the following equations to estimate the total human error probability using the CREAM matrix [25, 26].

$$\beta = X - Y = \sum R - \sum I \qquad (1)$$

Where, β refers to control mode index, X and Y are the number of reduced and improved influence indexes, respectively, and K is the constant coefficient.

$$CFP = CFP_{max}/10^{K\beta_{max}}$$

$$\beta_{max} = 9, \beta_{min} = -7$$

$$CFP_{max} = 1.0, CFP_{min} = 0.0001,$$

K = 0.25, CFP = 0.0056,

$$CFP = CFP. \times 10^{0.25\beta}$$

$$CFP = 0.0056 \times 10^{0.25\beta} \qquad (2)$$

4. Regarding the β scores (the highest and lowest values of 9 and -7 for reducing and improving of the performance, respectively) that reduce and improve performance (9 and -7). CFPt values were obtained and the control modes were determined accordingly (Table 2 and Fig. 2).

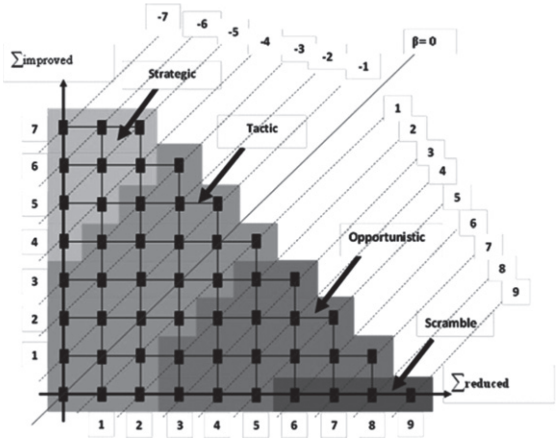

Fig. 2. Context influence index and control modes.

Table 3
Percentage of COVID-19 among miners

Task name	Number	COVID-19	%
Processing	45	15	16.6
Mining	35	12	13.4
Crushing	35	16	17.7
Support units	77	48	53.3
Total	192	90	47

3. Results

The demographic analysis of the population showed that 100% of the participants were male (71% married and 29% single). The workers' mean age was found to be 35 ± 8 years, of which about 50% had been infected with COVID-19, with the highest prevalence in support units (53.3%) (Table 3).

The results of the nine CPCs in the four subunits of mining, crushing, processing, and support (Table 4) showed a negative impact of the working condition on the performance in three former units. Nevertheless, no significant impact was found on the performance of the workers in the support subunit.

The results of the basic CREAM method are presented in Table 5. According to the results shown in Table 4, for example the crushing unit total number of CPCs that will reduce performance (ΣR) is equal to 5 and the total CPCs that will improve performance (ΣI) is equal to 1. The control mode index (β), according to Equation 1, would be 4. According to Fig. 2 the opportunistic control mode is selected for control mode type. As well as, based on Equation 2, the CFPt would be 0.056. As shown in Table 2, this number is in opportunistic control mode area. A similar calculation has been performed for the processing, mining and support units and the CFPt in these cases would be 0.0177, 0.0315, and 0.0056, respectively. Also the control modes processing and mining units fall into opportunistic control and support units in tactical control, based on CFPt values.

According to the basic CREAM analysis, among four mining subunits, crushing and support were found to be the highest and lowest probability for

Table 4
Context influence index for CPCs

CPC name	Mining	Crushing	Processing	Support units
Adequacy of organization	NS	NS	Reduced	NS
Working conditions	Reduced	Reduced	Reduced	NS
Adequacy of human-machine interaction and operational support	Reduced	Reduced	NS	NS
Availability of procedures/plans	NS	Reduced	NS	NS
Number of simultaneous goals	Reduced	NS	Reduced	NS
Available time	Reduced	NS	NS	NS
Time of day	Improved	Improved	Improved	Improved
Adequacy of training and preparation	NS	Reduced	Reduced	NS
Crew collaboration quality	NS	Reduced	Improved	Reduced

Table 5
CREAM basic method results

Task name	Control mode	Value of β	CFPt
Processing	Opportunistic	2	0.0177
Mining	Opportunistic	3	0.0315
Crushing	Opportunistic	4	0.056
Support units	Tactic	0	0.0056

human error, respectively. In the β diagram, the crushing subunit was specified on the border between scrambling and opportunistic control modes and all other subunits fell in the scrambling control mode (Table 5).

4. Discussion

4.1. Basic method-CREAM

The Cognitive Failure Probability (CFP) and Probable Control Modes (PCM) were determined in the operational units (viz. mining, crushing, and processing) and support units in one of Iran's copper mines during the COVID-19 pandemic, using Cognitive Reliability and Error Analysis Method (CREAM). The final goal of the basic method-CREAM was to identify and assess human error and increase performance reliability and to decrease CFPt. In order to reach proper results, the control mode type should move from opportunistic mode to strategic mode. Mazloumi et al. used CREAM technique to analyze a petrochemical control room in Iran. In this study, CPCs factors were analyzed and demonstrated that "number of simultaneous work", "time of day (circadian rhythm)" and "adequacy of training and experience" are related to reduction of performance reliability. They suggested in order to increase performance reliability, the instructions for emergency situations should be used and the shift work schedule should be noted. Also improved the quality of training courses [27]. In this study, the analysis of the basic CREAM method for the two operational units (mining and crushing) demonstrated that "adequacy of human-machine interaction and operational support" and "working conditions" are related to the reduction of performance reliability (Table 4). Therefore, it is necessary that, in order to increase performance reliability, the workers have sufficient skills for their tasks. Another strategy is to improve working conditions. According to the basic CREAM outcomes (Table 5), although the operational units (i.e. mining, crushing, and processing) were in the opportunistic control mode, taking some measures e.g., moving toward tactical and strategic modes are still needed to achieve the best strategic plan to improve working conditions [28]. Since workplace design plays a significant role in enhancing such conditions, mine officials can take some actions in this setting as well [29].

4.2. COVID-19 pandemic

Because of the relatively high prevalence of COVID-19 disease among miners at the start of the pandemic (about 50% infection; Table 3), this study looked into its impact on employer performance [30]. On the one hand, the analysis of the CPC results in three operational units of mining, crushing, and processing revealed that working conditions could have the most significant effect on an employer's performance, and therefore, on human errors in such facilities, which was consistent with the nature and characteristics of the industry concerned [31]. On the other hand, working during COVID-19 showed a negative effect on working conditions. The results are in close agreement with the previous reports on the increasing stress level under critical COVID-19 conditions [32]. Since work stress can negatively effect on the miners' performance as reported elsewhere [29]. Such psychosocial factor (i.e. stress level) can then induce higher human error probability (HEP) in working settings as reported in several studies [33–35]. In fact, the psychosocial factors have shown a significant effect on safety, HEP, and catastrophic accidents in the mine [19, 36]. Despite these findings, a few studies have focused on the intensified effect of the COVID-19 pandemic in the mining sector. Regarding the importance of the issue; the unreliability of the human element; and the limited research performed on the subject of human error in the mining profession, especially in the time of COVID-19, it seems that mine managers and HSE units need to consider adopting some more and better measures to minimize the risk of error in this harsh occupation.

4.3. Limitations and future research directions

Although this study aimed to identify and assess human error in one of Iran's copper mines during the COVID-19 pandemic using the CREAM method, there are still some limitations regarding time and resource factors. The CREAM method focused on the impact of environmental conditions or Performance Shaping Factors (PSFs) on human errors when calculating the Human Reliability Analysis (HRA) for a given task. However, in addition to the influence of environmental conditions or PSFs, human error was also affected by Human Inherent Factors (HIFs). Therefore, future research can explore this issue in order to discover which factors are most effective on human errors.

5. Conclusion

The results of this study showed that the COVID-19 pandemic has increased the human error risk for a high percentage of copper miners. From the parameters studied, poor working conditions were found to be the main factor influencing the occurrence of human error, which in turn, was influenced by COVID-19. The probability of human error and subsequent accidents, therefore, can be greatly reduced by taking appropriate management strategies such as promotion of safety and health monitoring (as either quantity or quality standpoints), and adopting supportive measures for controlling occupational stresses in such operational units.

Ethical approval

This cross-sectional study was conducted on miners from June to September 2021 at Koomehmine Pars (Nasim Copper), Bardaskan, Iran. The study protocol was approved by the Research Ethics Committee of Tarbiat Modares University (registration code: IR.MODARES. REC.1401.080).

Informed consent

Written informed consent was obtained from all participants.

Conflict of interest

The authors do not have any conflicts of interest.

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