ARTICLE IN PRESS

International Journal of Mining Science and Technology xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

International Journal of Mining Science and Technology

journal homepage: www.elsevier.com/locate/ijmst

Cognitive work analysis to comprehend operations and organizations in the mining industry

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ARTICLE INFO

Article history:
Received 25 December 2016
Received in revised form 18 January 2017
Accepted 9 March 2017
Available online xxxx

Keywords:
Cognitive work analysis
Mining operations
Cognitive awareness
Work domain
Human behavior
Safety

ABSTRACT

Complex industrial systems, including mining, have a prominent challenge in understanding the interrelationship among the cognitive processes, working environment and available equipment. The concept of cognitive work analysis (CWA) transcends the traditional analytic methods of evaluating human tasks solely based on perceptual and physical traits, and rather implements the notions of behavioral and cognitive awareness indispensable for the intricacy of modern technology. In the last few decades, academic and industrial settings employ this type of analysis to set a suitable standard for a system's safety feasibility, and as a result reduce human-based errors. This research paper analyzes current CWA methods and proposes a five-level quantification model portraying the overall cognitive quality of a mining operation.

1. Introduction

A dynamic relationship among human, environment and technology exists in various industries. In this relationship, the unpredictability of human decision raises a wide number of concerns, leaving room for improvement in the coordination of engineering complexes such as mining, nuclear, aerospace and other hazardous systems. In a workplace, being a social organization, supervisory activities and coordination among individuals and teams are implemented through cognitive transactions. Given that cognitive constraints and capabilities determine work efficiency of individuals and work group, analytic investigation of cognitive states and processes in a work place could enhance work conditions. Ergonomic principles of understanding the interactions between humans and other elements of the system could increase the overall system performance, improve human well-being and awareness, and thus reduce safety problems.

Human error factors, as will be seen further in this paper, consequently make the mining industry exceedingly vulnerable to accidents, which are generally related to human factors. To reduce and control safety problems, hazard identification and emergency management approaches are required. In this context, cognitive work analysis (CWA) can be seen as a guide for a complex socio-technical system such as mining and a strong potential for these requirements. A socio-technical system has a special focus in functionality on the social processes in terms of communication and cooperation. This approach focuses on designing systems which personal, social, technological, and organizational aspects in a workplace are considered, and then convert them into system design [1,2]. Therefore, CWA classifies those factors in a thorough structure in which it derives the peculiar design process of a mining system and its uncertainties by concentrating design on the constraints [3]. In engineering context, it detects and analyses complicated work capabilities and constraints such that a functional work atmosphere will be created in a robust manner.

Initially defined as a conceptual framework for analyzing the forces that shape human-information interaction, the CWA faces a perplexing challenge. The psychological aspects of a working individual play a crucial role in the approach of a machinery task, sometimes beyond the formal training [4]. The cognitive awareness could be described in this context as a decisive procedure of both conscious (perceptions, logical reasoning, and training knowledge) and unconscious (emotional health, social conditioning, and thoughts) nature, and the singularity of each human cognitive process may easily induce biases. Combined with the complexity of technological design and the entanglement of environmental factors, the necessary question to ask is what strategy should specifically be used to assess the interconnectedness between those three prevailing forces (Fig. 1).

To solve this problem having dilemmatic nature, it is required that a rectification of those three forces into multiple and precise

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http://dx.doi.org/10.1016/j.ijmst.2017.05.008
2095-2686/

Please cite this article in press as: Demir S et al. Cognitive work analysis to comprehend operations and organizations in the mining industry. Int J Min Sci Technol (2017), http://dx.doi.org/10.1016/j.ijmst.2017.05.008

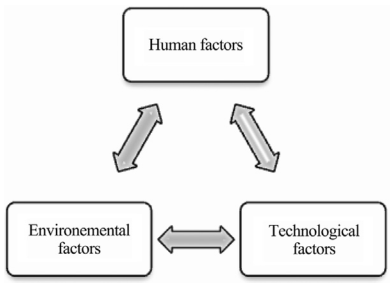

Fig. 1. Interconnectedness between the three prevailing forces in the CWA.

factors, and then forming an elaborated quantitative model, be made. The CWA is divided into a five-step analysis, each of which linearly focuses on a more detailed aspect of the general mining system. Extensive data collection, through observation, documentation and direct communication with working individuals, is usually conducted by a handful of experts in the field, which could paradoxically result in biased results due to their own set of cognitive thoughts. However, given the interaction between the proposed 11 factors, and considering each factor itself as composed of many characteristics, adding up to 35 in total, the model shows a fair representation on the cognitive quality of the mine and its safety feasibility, as shown in Table 1.

In this paper, a five-level quantification approach is presented to assess the overall cognitive quality of a mining operation in such a way as to put a specific emphasis on safety issues. Given that human errors is a significant source of mining accident, the proposed approach has potential to reach to zero harm objective of mining operations [26,27].

2. Related work

Significant progress has been made in comprehending human behavior such as the process of decision-making under uncertainty and the effect of cognitive and motivational biases on the output of risk analysis [5,6]. Engineering fields recognize the human mind as a complex network having an assertive role in the completion of a project, but much confusion arise regarding the factors affecting human performance and potential ways to improve it [7]. As an example, the equipment design or the working environment might seem as influential factors, however, without the subjective awareness of each working individual, these external objective forces cannot be defined as correlating effects, but merely as independent units.

Until the half of the 20th century, tasks were mostly physical and repetitive, and human-factor engineering introduced an elementary form of task analysis, which simply examines the only and most efficient way of performing a task [8]. The role of cognitive processes and external components in early industrial domains appeared extraneous in assessing the probability of unanticipated events. Subsequently, the need for an applicable tool arose in industries integrating logical process and automation as part of their systems, and therefore the concept of cognitive analysis became an emerging research area. Rasmussen et al. developed the CWA framework as a general approach of investigating the task itself, the work domain, the strategies and the cognitive processes. Initially, this approach was implemented in nuclear power plants, known for their extensive systems, and their precarious management of accidents by operators [9,10]. The CWA has paved the way towards different frameworks such as ecological interface design, which is designing the interfaces in complex socio-technical systems as a primary focus and resolving small and medium-scale issues in petrochemical, nuclear and other process control systems [11]. Overall, the methodological framework of the CWA could benefit from overcoming the uncertainties arising from the interactive mining system, as seen in the discussed model in the following section.

CWA has been used in many engineering areas. For example, Salmon et al. applied CWA to rail level crossing systems such that a range of situations where systems thinking could be modified or re-designed to improve behavior, and safety was determined [12]. Hilliard and Jamieson utilized the CWA to monitor and target energy efficiency. In the mining industry, CWA started to attract interest [13]. Xiao et al. applied work domain analysis, which is the first step of CWA, to an Australian underground coal mine considering the investigation of the mine emergency management requirements of control room operators [14].

3. Cognitive work analysis levels

The initial aim of the CWA research is to meticulously analyze all the components of an industrial complex system (e.g. mining), and then arrange them into five different categories, with their own specific level of details: work domain, control task, strategy, social organization and cooperation, and Worker's competencies. In turn, each level has its own methodology of interpreting and collecting the available data with a qualitative acquisition tool used by experts in the field [10,15,16,20,24].

3.1. Level 1: Work domain analysis

This level highlights the general characteristics of the system. In mining context, the objective is to unfold the mining system and its constraints that all stakeholders expose. Overall productivity of consecutive operations such as rock fragmentation, materials handling, mineral processing or equipment reliability, requires an indispensable comprehension of the environmental force and its constraints. Accordingly, the expert tools such as abstraction hierarchy and abstraction decomposition space probe classified documents, operation manuals and interviews with working individuals to reveal those constraints and the preeminent objective of the mine rather than its detailed functionalities. Abstraction hierarchy includes system goals along with its external restrictions on operation, organizational structure with a measured functional criterion, general criteria that functional criteria is built on, and functional capabilities of mining equipment. The outcome of this stage will detail the mining system on the basis of the constrains affecting equipment and human behavior.

3.2. Level 2: Control task analysis

The second level, control task analysis, evaluates the essence of the tasks, relevant to the functional purposes determined in the level above. Hence, every aspect of the technological design, such as its compatibility and its efficiency to the assigned role can be identified, as well as the degree of simplicity in implementing roles for each working individual. The specific tasks are listed to accomplish the goals within a work domain. In a mining operation, there are many tasks regarding analyzing, controlling, implementing, assisting, coaching, coordinating, developing, inspecting, maintaining, evaluating, motivating, making decision, monitoring, predicting, computing and communicating. For example, tasks in bench drilling include clearing bench, borehole examination, making holes, equipment inspection and maintenance, hole bottom cleaning, bit replacement, determination of spacing, burden and inclination. It also involves communication between mine foreman, drill operator and the engineer; coordinating priming, loading, and stemming holes; and safety measures. The acquisition