

Conceptualization of the Attractive Work Environment and Organizational Activity for Humans in Future Deep Mines

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Abstract—The purpose of this paper is to conceptualize a future-oriented human work environment and organizational activity in deep mines that entails a vision of good and safe workplace. Future-oriented technological challenges and mental images required for modern work organization design were appraised. It is argued that an intelligent-deep-mine covering the entire value chain, including environmental issues and with work organization that supports good working and social conditions towards increased human productivity could be designed. With such intelligent system and work organization in place, the mining industry could be seen as a place where cooperation, skills development and gender equality are key components. By this perspective, both the youth and women might view mining activity as an attractive job and the work environment as a safe, and this could go a long way in breaking the unequal gender balance that exists in most mines today.

Keywords—Mining activity; deep mining; human operators; intelligent deep mine; work environment; organizational activity.

I. INTRODUCTION

THE world's metal mining industry faces a number of challenges covering the whole mining and minerals chain including environmental issues, and which must be addressed with a socio-technical approach [1, 2]. Mining is the extraction of valuable minerals or other geological materials from the earth in the forms of ore body or coal seam, and from which materials such as base metals, precious metals, iron, uranium, coal, diamonds, limestone, rock salt and potash are recovered

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and then processed for industrial consumption globally. In this wise, future mining will be shaped in a context where it will become necessary to produce at costs that are determined by international competition [1]. Based on this perspective, large nations like China, India, Indonesia, Brazil and the whole of Africa will require a larger share of consumption which will lead to the opening of new mines [3]. In this regard, production conditions in mines will be such that the easily accessible ores will be mined first, and new ores will also become more distant or be found in the depths [3, 4]. In the view of Boughen et al [5], large ore reserves are located under the sea and there is hardly any doubt that the mining and off-shore companies will develop new technologies to extract them. Despite the development of such new technologies, the cycle of activity in drilling and blasting operations currently requires human entry and intervention for tasks ranging from geological sampling to the relocation of pumps and electrical supplies [6]. Since it is generally accepted that for safety reasons, humans should be prohibited from entering an automated mining environment; it then becomes important to design the requisite work environment for them to work in.

The purpose of this paper therefore, is to develop a framework for managing the work environment and organizational activity of future deep mines (i.e. the intelligent-deep-mines), entailing a vision of good, healthy and safe mining work without accidents and in un Hazardous environments. The expectation here is to make the mines of the future become a substantially different place to that of today. Yet, there prevails the problem of how to model such intelligent production systems of the future mine for them to become enablers for learning and collaboration across organizational borders. Even if the idea of a holistic perspective on production systems is commonplace in most research areas of today, there is a true challenge in multidisciplinary research that reconnect the research fields and their theories, methods, ideas and results. This observation reinforces the prevailing problem of developing a holistic work organization model to guide the future integration of the deep-mining companies' technical, organizational and human systems. It also reinforces the challenge of developing deep-specialized knowledge in areas associated with each of these systems (i.e. technical, organizational and human) that could contribute towards the attainment of a deep-mine of the future.

II. DEVELOPMENTS IN DEEP MINES AND THEIR WORK ENVIRONMENT

A. *Technological Impact on Fatalities*

According to Moore et al [7], there is a decreasing trend in the number of fatalities in underground mines in the US from as many as 3000 accidents in the early 1900s to 11 accidents in 2003. Similarly, statistics on accidents and sick leave conducted by Metalli showed that the total number of accidents in Finnish metal mines has diminished during the period 1996-2005 from 95 cases to 40 cases and the ration between short term sick leave (70-90%) and long term sick leave (10-30%) has remained relatively constant over the same period [8]. This decreasing trend of accidents and incidents may be due to the fact that technological advances in the form of machinery design, control and operation have provided for a safer work environment and have decreased the number of workers required to perform tasks [7].

Since the mid 1980s, a series of technological advances have greatly changed the working conditions and requirements of deep mine workers. But as Moore et al [7] notes, though the technological advances in the mining industry may have positively affected workers' tasks and the efficiency of extracting coal, they may not have reduced cumulative injuries. Many jobs still expose mine workers to ergonomic risk factors such as awkward postures, exposure to whole body vibration, forceful exertions, and repetitive motions [9, 10]. Thus as technology advances, it is important to consider the effects of these advances on mine workers, to avoid exposing them to cumulative injury risk factors, such as awkward postures, repetitive motions, jarring and jolting and vibration [7]. This is because, as mining depths increase, they bring new stability problems. In this respect, the role of rock mechanics in the design of layouts, cutting sequences, strata stabilization, and roof bolting must be seen as central issues for the future [1]. Improvements in these operations can create significant positive impacts on the subsequent operations.

In this respect therefore, the mining industry needs a new mental image of itself based on new technologies with a modern work organization that supports both high productivity and good working conditions [1, 2]. According to Abrahamsson and Johansson [2], there is a need for a new holistic vision for the "mine of the future". By implication, any future mining activity must not endanger the health and welfare of local inhabitants.

B. *Technological Advancement and the Changing Work Environment*

A modern mine is so technically advanced that the proportion of unskilled labour will decrease significantly or disappear, and hence there will be fewer workers with higher wage costs [1]. By implication, the mines of the future will have a smaller staffing with a different kind of model for work organization, since it is expected that automation will provide improvements in terms of work environment and job safety. Production centers will therefore be creating new professional

roles [1]. Yet, there is the concern that despite many promising production concepts, organizational models and development of new technologies during the last decades, the mining industry faces a large gap between expectations and real implementation [1, 2]. There is also the realization that increased automation, combined with an ever tougher global competition, will lead large industrial companies to rely on a lean organization with multi-skilled workers capable of managing multiple areas of the business, with technology and work built around 'autonomation', where people and machines cooperate [11]. In this respect therefore, process automation and remote operation technologies in the mines will enable smarter, and more integrated production systems [11]. In these wise, significant efforts to develop communication systems for increased security have been made [12]. In the view of Abrahamsson et al [1], even though such system is for verbal communication, it should have positive effects on productivity, quality of work, and cooperation. It will also be interesting to see if the system can also support image information and communication, especially based on the perspective that miners equipped with mini cameras could, for everyday and emergency situations, provide their colleagues and senior management with information that is difficult to convey verbally [1]. In this regard, Bassan et al [11] predicted an increasing degree of remote control from production centers and collaborative visualization rooms where the operators have monitoring and coordinating activities across the value chain from distant locations (i.e. in the community or elsewhere). In this case, the remote operators will be supported by intelligent and automated decision systems, and will also use the Web 2.0-system of global communication, information and learning. By implication, the jobs of the operators will change in character towards service work and their new tasks will require different kinds of skills. In addition to dealing with advanced information technology the miners will have to interact with different specialist teams located all over the world. In this regard, mining companies will gradually turn to a flat and lean organization with multi-skilled workers who can operate in several areas and functions within the company [11]. This therefore calls for a work organization that supports high productivity as well as good working and social conditions [1].

Since an important component of good working conditions is a safe environment, deeper mining will add to the complexity of the work environment, possibly increasing the risks for accidents due to rock bursts. Thus, while the mining industry is progressively developing ground support systems for static and dynamic load cases, development of mining methods and equipment could be arranged to reduce the human exposure to the risks, especially, by going from mechanization to automation) [1]. As such, the issues of health and safety are very high on the future mine agenda, and are also strong driving forces behind the ideas of automation [13, 14, 15, 16, 17]. Safety issues primarily concern underground work and the prescribed solutions are wise and

conscious choices of different levels of automation and remote control [18]. Portable video communication systems are today developed in the German coal mines [19]. Virtual Reality (VR) technologies, such as design and production tools have great potential, especially the use of VR in real time to visualize and control the production processes. According to Abrahamsson et al [1], the extended business and open collaboration are two concepts where VR technology can be used to link production functions such as planning, mining, maintenance, logistics, purchasing and for coordination of external contractors, suppliers, and customers all connected to a production flow, a value adding chain, where all share the same goal and everyone sees the same whole. Common visualization of problems and opportunities in the system allows for all to optimize the whole chain rather than sub-optimizing parts [11].

A further challenge is to break the unequal gender balance that exists in most mines. In the view of Abrahamsson and Johansson [2], the issue here is not just about recruiting more women in the mines, but rather to challenge the prevailing macho culture in order to create a safer and more productive work environment. This therefore calls for the need to illustrate a possible way forward for the mining industry rationalization by focusing on work organization where cooperation, skills development and gender equality are key components [2]. Such need is derived from the challenges posed by the prevailing thinking among industrial firms that by replacing humans with machines at all levels in the value chain (as a means of meeting the critical issue of effective operation and maintenance of production systems), a rapid increase of automation and integration of various processes and unit operations can occur to enhance the firm becoming economic viable and competitive. In this regards, there is the need to create a vision of the good and safe mining work (i.e. mining work without accidents and in unhazardous environments), because in deep mining, the safety aspects are critical.

III. FUTURE TECHNOLOGY ORIENTED DEEP MINING ACTIVITY

The gap between the understanding of what people are expected to do and what they actually do has given rise to the 'practice' approach in management literature focusing upon the way that actors interact with the social and physical features of context in the everyday activities that constitute practice [20]. The term 'practice' is explained by Jazarbskowski [20] to imply the repetitiveness of performance in order to attain recurrent, habitual or routinised accomplishment of particular actions (i.e. for the actions to become practiced. As such, practice occurs not only in macro contexts that provide commonalities of action, but also in micro contexts in which action is highly localized, and the interaction between these contexts provides an opportunity for adaptive practice [20].

Practice is therefore viewed to be an evolving process of social order arising from the interplay between external and

internal social structure building. In this context, external structure is the wider societal context, in which there is a current of social movement, and change is carried out within the internal context in interaction with the external context. Thus in order to be able to develop a functional innovative work organization model for the intelligent deep mine, there is the need for the development of knowledge to facilitate the integration of technological, organizational and human systems. The sense here is that the developmental approach for the intelligent deep mining should not be viewed only from the perspective of designing systems/automation adaptable to humans. Humans should rather be considered as integral resources whose integration can enhance the possibility of designing better systems (i.e. intelligent automation).

Therefore, in the process of developing new work practices in an organization, the key actors in the exercise also double up as learners of their new activities. When employees are not actively involved throughout the planning and implementation processes, the result is often a poorly designed work system and a lack of employee commitment [21, 22]. In the task interpretation process, the worker has to be able to involve his personal prerequisites such as experience, skills and physical constitution, as well as his/her context as part of social systems inside and outside the organization [23]. Additionally, the worker has to solve all the problems that were not taken care of, or were misinterpreted when management designed the task. As such, employees even frequently display overt or passive-aggressive resistance to the changes [21].

A. Designing Work Organization for Future Deep Mines

Based on the thinking that a production system in deep mining consists of technical components, information, materials and humans, there is the need for holistic perspectives to be included in the design of the system's work organization. In this respect, macroergonomics knowledge becomes relevant. Conceptually, macroergonomics may be defined as a top-down sociotechnical systems approach to the design of the work systems, and the carry-through of the overall work system design to the design of the human-job, human-machine, and human-software interfaces [24, 21]. Macroergonomics is concerned with human-organization interface technology. The empirical science supporting it is concerned with factors in the organization's technological subsystem, personnel subsystem, external environment, and the interactions of these factors as they impact on work system design [25]. Thus, for the future deep mining activities where hazard preventive planning, risk reduction/elimination planning, as well as technological and behavioral change processes are key components, the design of the work organization system is of great concern. This is because, the mining industry is an energy-intensive industry with high carbon dioxide emission, and improvements in energy efficiency will increase the industry's economic profitability as well as reduce its environmental impact [1]. This also necessitates the development of technology for process

management, organizational design, and learning for the deep mines, and which requires the creation of a harmony between the technical and the social system, and which creation can be facilitated by taking a holistic view of the system's functions. The significance of such harmony creation is defined by the realization that in order to enhance the development of intelligent automation systems for industrial firms, there is a need for the creation of knowledge on the harmonious integration of technological, organizational and human systems. This is because such integration will stand to provide the basis for the evolution of a community of practice in the deep mine work environment. In a 'community of practice' individual thought is essentially social and is developed in interaction with the practical activities of a community, through living and participating in its experiences over time [26]. Thus, to understand the practice of deep mining, it is important to move beyond the prevailing institutionalized approaches and knowledge by penetrating the situated and localized nature of deep mining activities in particular contexts. This is because practice should be seen as local and situated, arising from the moment-by-moment interactions between actors, on one hand, and between actors and the environments of their action, on the other hand [20].

For the deep mines of the future, the issue here is not only about designing systems/automation as well as work environment that are adaptable to the mine-workers underground, but rather to consider the workers who are engaged in the different facets of future mining activities as key resources whose understanding of the deep mine practice could be utilized towards enhancing creativity in designing better systems (intelligent automation). The argument here is that a work organization system for the future deep mine should be seen to consist of humans/people and technology (i.e. it must be seen to consist of technology-driven production processes, improved infrastructure and application of digital signals, assessable and accessible information, safe material, low energy and waste products, as well as friendly human work environment and an atmosphere for learning). In such system, there will always be a sense of ongoing process of social becoming that is realizable through a chain of social events, or practice and all of these aspects must be in tune [20]. Therefore overall knowledge is needed in the deep mine's work system design and its parts, especially on how to harmoniously integrate the human and the other systems in the value chain (i.e. to be able to see the human as an integral part of the system, and an asset). By implication, the future deep mine can be theorized as organizational activity system. But as Aldrich [27] argues, the theorization of organizations as activity systems have the tendency to bias thinking towards a concern for processes. According to Aldrich, many of these processes are goal-directed and boundary-maintaining, and these characteristics, in turn are central to the open-system or neutral-system model of organizations identified by Thompson [28] as the emerging focus of organizational sociology. Focusing on processes also makes salient the dialectical tension between members' behaviors, which

threaten to push an organization into ultimately contradictory activities, and leaders' efforts at pulling members' contributions together into a coordinated whole [27].

Since organizations possess technologies (i.e. techniques for processing raw materials and/or people) for accomplishing work, organizational activity then emphasizes a work system design in which technology affects social relations in organizations by structuring transactions between roles that are building blocks of an organization. Based on this understanding, the characteristics of the overall work system design for the future deep mine could be carried down to the design of individual jobs, as well as human-machine and human-software interfaces in order to ensure a fully harmonized work system. When this goal is achieved, the results should be dramatic improvements in various aspects of organizational performance and effectiveness [25].

B. Designing Organizational Activity System for Future Deep Mines

In future deep mining activity, Bardram's [29] characterization of an activity as consisting of several actions, and each action also consisting of several operations attains a sense of significance. By this, the organizational activity of deep mining could be categorized into three levels. These are the activity level, the action level and the operation level. Based on this categorization, an organizational activity is viewed to consist of actions or chains of actions, which in turn consist of operations. Therefore, organizational activities are not static or rigid entities, and are under continuous change and development which is neither linear nor straightforward, but rather uneven and discontinuous [30]. By implication, each organizational activity has a history of its own and a systemic-structural activity synthesis [31] entailing the cultural-historical and systems-structural as well as the human factors/ergonomics and cognitive psychology understanding of this development is needed in order to understand the current developmental situation of the organizational activity. This characterization of an organizational activity is illustrated in figure 1 below.

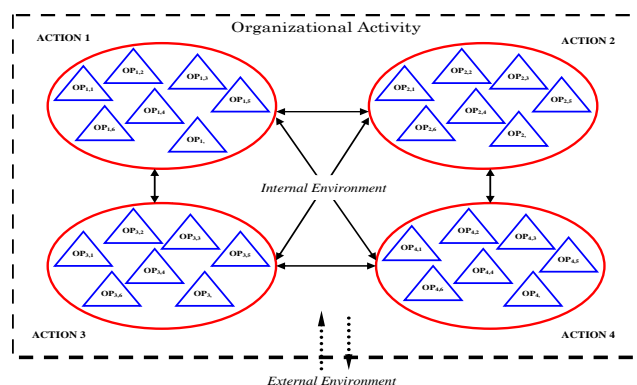


Fig. 1 Simplified illustration of an organizational activity in a future mine (where OP stands for operation)

Figure 1 above provides an idea of the complexity inherent in organizations relative to the functional dynamics of work practices and management. Such complexity is relative to the number of different operations (OP) entailed in each action, and also the number of different actions to be required of the organizational activity. This visualization of organizational activity (OA) can be summarized mathematically as follows;

$$\text{Org. Activity} \approx \sum (\text{Action 1} + \text{Action 2} + \text{Action 3} + \text{Action 4} + \dots + \text{Action N}) + \sum \text{Internal Constraints} + \sum \text{External Constraints},$$

$$\text{Action N} = \sum (\text{OPN},1 + \text{OPN},2 + \text{OPN},3 + \dots + \text{OPN},n) \\ N = 1, 2, 3, 4, 5, 6, 7, \dots, n$$

In large firms, such as the deep mines, different phases of organizational (i.e. mining) activities are undertaken to extract the requisite minerals or other geological materials from underground the earth. These activities include the development work, and mining. Each of these mining activities entails series of actions, with each action consisting of several operations undertaken by different persons or groups, and/or mechanization process. For example, in relation to the activity model shown in figure 1 above, the “development” work activity is composed of excavation which is undertaken almost entirely in waste rock in order to gain access to the orebody. Carrying out this activity requires the performance of the following six actions: - drilling rock face; charging explosives; blasting explosives; removing blasted material (i.e. muck out round); scaling (i.e. removing any unstable slabs of rock hanging from the roof and sidewalls to protect workers from injuries and equipment from damage); supporting excavation. Similarly, performing each of the six actions outlined above entails the undertaking of specific operations. For example, the action of “drilling rock face” includes the undertaking of several operations resulting from interaction between one or more persons and the technology as well as equipment being used. As an illustration, one person can use highly sophisticated equipment, such as the Rocket Boomer L1 C-DH, to perform the rock face drilling action by carrying out the following sequential operations: - before starting each drilling task, the operator firstly functions as a trained mechanic by spending some time (up to 15 minutes) to check the Rocket Boomer’s engine, as well as feed its hoses and grease points. The operator then mounts the equipment’s comfortable cabin, and with the aid of computer programming via a screen panel, the operator guides the machines long arms to the appropriate spots on the rock surface, and which spots are then drilled to the required penetration depth. Therefore, for the intelligent deep mine, the interdependent safe activities to be involved can be visualized from the learning made from existing best deep mining practices and other innovative practice ideas.

It is imperative from above that actions are fundamental components of activities and are subordinate to specific goals.

The goal of an action is a conscious mental representation of the outcome to be achieved with its function being the orientation of the action [32]. As such, in deep mining activity, different actions may be undertaken to meet the same goal. This then implies that activities are realized as goal-oriented actions. Operations, which are ways of executing actions, correspond with the ways of goal achievement and are directly determined by the objective conditions in which the goal is given and has to be achieved. Operations may become routinised and unconscious with practice [29]. Thus the first condition for any organizational activity is the presence of a need. In fact, an organizational activity is oriented by the transformation of a need into an objective (or motive). Though such a need can be sufficient to stimulate activities, it is unable to direct the concrete orientation of the stimulated activity.

IV. ATTRACTIVE WORK ENVIRONMENT MODEL FOR FUTURE DEEP MINES

Based on the discussions in section 3 above, a framework for safe work environment for future deep mining, here-in referred to as the Intelligent-Deep-Mine (IDM) could be designed. The necessity for the IDM is based on the realization that deep mining is still a dangerous activity as previously highlighted, but whose transformation (i.e. from dangerous activity) into a developmental safe activity should be seen as attainable. In working towards the realization of the IDM, a concept worth considering is Noorts and McCarthy’s [6] proposition for three consecutive phases of ensuring safe underground mining, due to its critical and constructive perspective towards the automation of underground mines.

The first phase requires that all work is done from vehicles that have safety cabins provided with substantial physical comfort. During this phase, mining activities entailing operations, such as sampling, surveying, maintenance and the like, are to be gradually mechanized and controlled by operators working from vehicles equipped with manipulators and safety cabins. All mine work is to be performed from inside the safety cabin that has a comfortable climate. The cabins would resist falling rocks and prevent injuries to operators. The vehicles would also have systems protecting operators from roll-overs and collisions. Similar safety cabins are to be integrated with other mobile mining operation units, thus protecting all workers from a hostile environment. The second phase requires zero entry to the mines’ development and production areas. In other words, no worker is needed to enter the mines production areas. That is, the workers are to be removed from the mining (i.e. production) areas and stationed in safe and secure control rooms, from where they could monitor and control the different mining operations remotely. The third phase suggests mine production with zero entry for all employees to be based on comprehensive automated systems. In this final phase, a total revision of the mining layouts used in traditional drill and blast mining is required, with the introduction of an overarching automation system.

Although the mining industry has managed to automate some of the operations highlighted in the first phase, and to some extent the second phase of Noorts and McCarthy's [6] concept, full automation is still a very distant goal in most underground mines. The reason for this is that technology platforms to improve safety, machine productivity, work productivity have been developed with limited and local goals, instead of aiming to attain total automation as a general goal for underground mining. It is therefore, important to acknowledge the fact that even if it is to be possible to successfully create the IDM as closely as to its portrayal in the mental vision, the reality is that a lot of underground mining work will continue to exist in the nearest future, thus challenging Noort's and McCarthy's [6] suggestion of production with zero entry for all employees based on comprehensive automated system. As such, there will still be concerns about employed operators and maintenance workers whose jobs must be made safe, probably by locating them above ground. This therefore brings to the fore the challenge of developing new mining machines and improving existing ones, but which challenge must be tackled in a systematic way. Such systemic approach consists of a large number of development projects in which risk analysis must be conducted in a systematic way, especially in the early development stages, so that safety and security solutions could be optimized. An issue of relevance here concerns the question of how to identify the risks that might be inherent in mine development projects.

The classical tools for the identification of occupational risks in the existing production environments of deep mines are "safety rounds" and "incident and accident reporting". Because these tools are deemed less suitable for identifying and assessing risks in future mine work environments, other types of methods, such as, preventive work safety analysis, preventive deviation analysis, and preventive energy analysis, are then needed. The purpose of a deviation analysis is to prevent or to predict abnormalities that can cause damage, and to develop proposals to improve security measures. Deviation Analysis is a good method because it takes into account the entire system (i.e. Human-Technology-Organization). Energy analysis focuses more on technology and might be useful when developing new production systems. The three main components in an energy analysis are - (i) energy that can damage, (ii) targets that may be harmed, and (iii) barriers to energy. The energies usually considered are: Gravity, height (including static load); Linear motion; Rotary motion; Stored pressure; Electrical energy; Heating and cooling; Fire and explosion; Chemical effects; Radiation; Miscellaneous (human movement, sharp edges, and points). In most situations, once a risk analysis is completed, systemic measures such as those listed below could be implemented in chronological order to enhance the quality of the work environment.

- Risk and accident prevention in the planning stage by replacing the hazard entirely (for example, through automation to eliminate some underground work).

- Isolation of individual hazards in a risk process (for example, by designing ventilation and layout so that the blasting fumes cannot be spread outside the risk zone).

- Changing process technology and behaviour (for example, drilling with water hydraulics rather than pneumatics to reduce dust emissions).

- Limiting the hazard through enclosures to ensure physical protection (for example, building concrete borders and railings at the shaft openings).

- Isolating personnel from the risk area (for example, by supplying mining vehicles with safety cabins and also with good climate control).

- Reducing risks through instructions, procedures, and training (for example, procedures for safe handling of explosives).

- Reducing risks through personal protective equipment (for example, making available functional working clothes to workers).

- Eliminating fatalities through the provision of leadership, systems and processes for the prevention of fatalities (for example, managers and senior leaders engaging in relentless drive to prevent fatalities through their personal actions, as well as the activities and processes for which it is their responsibilities to ensure that they are in place).

Depending on the complexity and severity of problems, different combinations of the eight measures outlined above may be required, but the best recommendation is to always try to attack the root causes of the problem first since this tends to result in the most cost efficient and result efficient solutions.

Though the challenges and the changes required to attain the future mine status are large and numerous, the discussion in the sections above has pointed out that the creation of good and safe mining work (i.e. mining work without accidents and in unhazardous environments) is a possibility. The indication is that future deep mining activity could be designed in such a way that it makes the working environment a substantially friendly and enabling place to work than that of today. In this wise, intelligent production systems could be modeled to make them become, in the eyes of the human operator, enablers for increased safety, learning and collaboration across organizational borders. Also, a work organization and human organizational activity that supports high productivity as well as good working and social conditions could also be designed. With such intelligent system and work organization in place, the mining industry could be seen as a place where cooperation, skills development and gender equality are key components. By this perspective of the prevalence of an enabling environment, both the youth and women might view mining activity as an attractive job and the work environment as safe, and this could go a long way in breaking the unequal gender balance that exists in most mines today. It is therefore concluded that the conceptualized "intelligent deep mine" is a representation that covers the entire value chain of the future deep mine, including environmental issues, and the systemic measures provide a framework for enhancing the quality of

the work environment.

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