The role of human factors and ergonomics in mining emergency management: three case studies

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Abstract: Mining is a complex and hazardous work domain. This paper presents three related research studies in mining emergency management, highlighting the contribution that human factors and ergonomics are making to this field. The first study investigates the challenges associated with the collection and management of information during underground coal mining emergencies from a human-centred perspective. The second and third case studies build on the first study: the second one focuses on decision making deficiencies in incident management teams and the final one examines organisational issues related to mining control rooms during emergencies. In each of these three research studies, the broad problem is first defined, then the work undertaken and results produced are described, and finally the implications and future work are presented. Following this, the human factors contributions to help create safe and efficient mining emergency management systems are discussed.

Keywords: mining; minerals industry; human factors; ergonomics; emergency management; control rooms; stress; decision making; incident management.

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1 Introduction: mining and the minerals industry

1.1 Size and safety record

The minerals industry is a general name for the exploration, mining, processing and transportation of minerals such as coal, iron, copper and gold. It is a worldwide employer; for example, in Australia it employs approximately 136,000 personnel. Mining and associated industries are in operation across virtually the whole globe, with major zones being in South Africa, North and South America, Australia, Indonesia and much of Europe. The worldwide safety record varies significantly for injuries, ill-health and fatality rates; fatalities range from single figure deaths in Australia (e.g., Safe Work Australia, 2012) to several hundred deaths per annum in third-world mining countries (Simpson et al., 2009). In essence, mining is a major global industry with a variety of hazards that can cause injuries and fatalities unless well managed (Komljenovic and Kecojevic, 2007).

1.2 History of human factors and ergonomics in mining

The application of Human Factors and Ergonomics (HFE) to mining has a rich but irregular history around the world. For example, in the UK the virtual collapse of the coal industry around the 1980's resulted in a major decline in the amount of British work in mining Human Factors (Horberry et al., 2010). Much of the early HFE work is now difficult to access; however, important publications can still be found, such as a US Bureau of Mines funded book about Human Factors in mining by Sanders and Peay (1988) and the British Coal work of Simpson, Mason and colleagues (partly summarised in Simpson et al., 2009 and Horberry et al, 2010). Recent human factors research in the minerals industry has often taken place within a broader risk management framework: this has included physical ergonomics research, mining equipment design and the human element impacts of new mining technologies (Horberry et al, 2010). However, limited human factors research has been made with a specific focus on underground mining emergency management.

1.3 Human element-related components of the mining system

Looking in greater depth at the human-related elements of the minerals industry system, there is no single, 'typical' arrangement that is used at the majority of mine and processing sites (Sanders and Peay, 1988). Instead, it is best described as a complex sociotechnical system where people, procedures, environments and equipment need to interact safely and efficiently. Following Horberry et al. (2010), the main elements in the minerals industry are shown in Table 1.

Table 1 The main elements in the minerals industry, approximately ordered from wider/macro level issues to more micro/physical issues

Varying national laws, regulations, and guidelines
Different equipment developers, manufacturers and suppliers
Worldwide mining companies
Different procedures, rules, practices and cultures at individual mine sites
Varying jobs, tasks and roles
A diverse group of people/operators employed
Differences in the built environment and precise mining method used
Uncertainties in the natural environment (geology, weather and vegetation)

1.4 The importance of emergency management in mining

Mining is a high-hazard industry, with energies (e.g., gravitational, mechanical, and chemical) that need to be controlled. The potential for harm to people at the mine site and in the nearby environment is high unless these hazards are well-managed (Simpson et al., 2009). The current research focus is upon primary safety in terms of preventing the occurrence of incidents or loss of control of energies. However, it is also of key importance to consider secondary safety in terms of minimising the negative consequences of such incidents. An example of secondary safety here would be minimising the severity of a collision between heavy mining vehicles by means of better operator protection in the vehicle's cabin (Horberry et al., 2010).

Significant hazards exist with surface/'open cut' mining (e.g., due to the presence of heavy mining vehicles), underground mining (e.g., due to blasting and rock falls) and exploration/drilling (e.g., due to unstable geology). In all of these mining environments, the provision of timely and accurate information is a necessary precursor for effective operator and manager decision making to manage these hazards (Simpson et al., 2009). This paper explicitly focuses on the emergency management challenges related to underground coal mining. The purpose of this paper is to outline the role that HFE can play in helping to manage underground coal mining emergencies. In particular, the paper presents three related case studies, one completed and two ongoing that explore human factors issues related to:

1 the ineffective collection of information during underground coal mine emergencies
2 the decision-making deficiencies of The Incident Management Teams (IMT)
3 the organisational problems in the control room during underground coal mine emergencies.

2 Case study 1: the challenges of collecting and managing information in underground coal mine emergencies

2.1 Background

The collection, display and analysis of information are major problems following an incident in an underground coal mine (Cliff, 2009). These operations are often ineffective and time-consuming as recent events at the Sago, Aracoma, Upper Big Branch and Darby mines in the USA, at the Pike River mine in New Zealand, and the issues identified in the Level 1 emergency preparedness exercises run each year in underground coal mines in Queensland, Australia, all demonstrate (Cliff and Grieves, 2010).

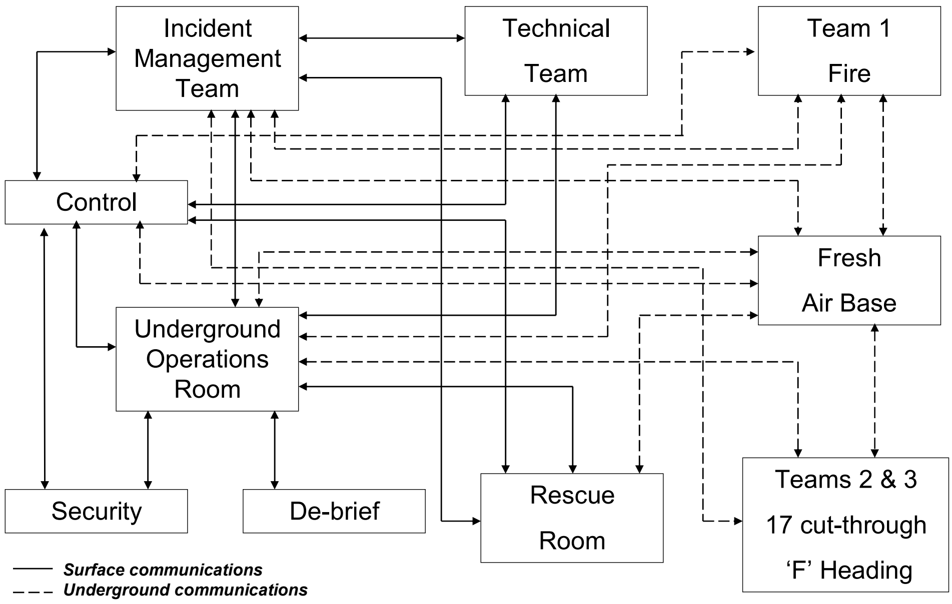
Looking back to the antecedents of the current situation in Australia, one of the recommendations of the inquiry into the 1994 Moura No. 2 underground coal mine disaster, where 11 miners lost their lives, was that emergency response exercises should be conducted at underground coal mines each year to test the mine's internal emergency response system. These exercises have led to significant improvements in the way mines prepare for emergencies and in their abilities to manage the incidents (Cliff and Moreby, 2005).

Despite these successes, we argue that there is still room for improving emergency management, in particular by focusing on human factors issues such as communication, control and organisation (Rasmussen, 1986; Reason, 1997). In general, one of the areas that is dealt with least effectively is the collection, analysis and reporting of information (Cliff, 2009). More specifically, as earlier found by Cliff and Moreby (2005), the information management issues relate to four broad areas.

1 inadequately designed and integrated mine environment monitoring systems
2 poor information flow/record keeping
3 ineffective incident management rooms
4 decision-making deficiencies in IMT.

Such issues highlight the organisational and communication challenges that exist at a mine site. To give an example of these organisational challenges, Figure 1 illustrates the complexity of the real communications paths at an underground mine during a simulated incident (adapted from Cliff, 2009). In particular, it shows that on several occasions during past Level 1 exercises, communications have occurred between groups bypassing the formal recognised channels leading to problems when formal communications give different information to that already obtained through other informal channels: this breeds distrust and can lead to panic amongst operators. It is therefore vital to be able to share information effectively so that all operators involved have the same information and situation awareness (Cliff, 2009).

Figure 1 The actual communication paths observed during a simulated mining incident



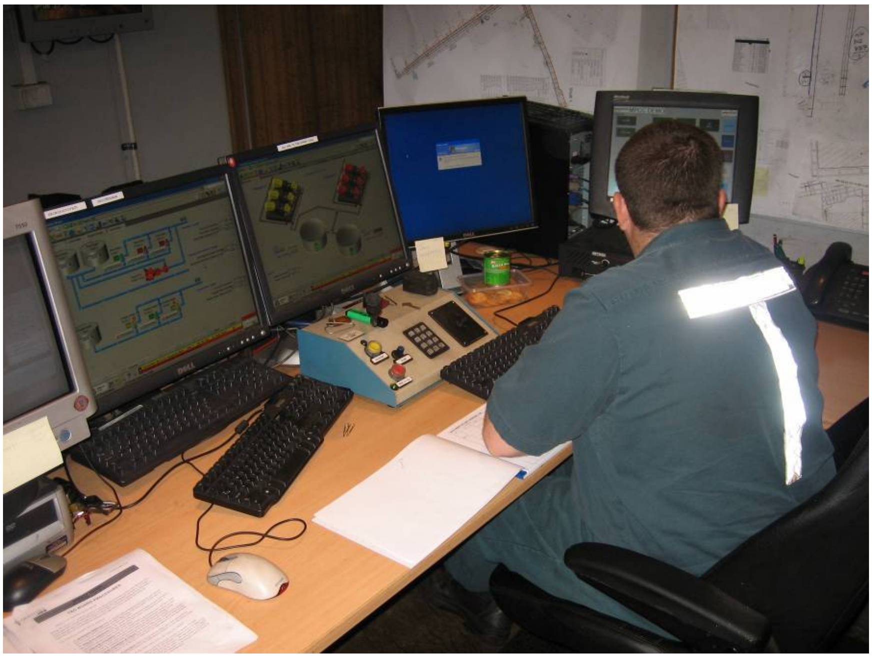
Source: adapted from Cliff (2009)

2.2 Work undertaken

Given the above background, the aim of this research project was to identify ways of improving the information collection and reporting processes used in emergencies in underground coal mines to ensure rapid and effective response, thus minimising the risk to life and other safety/health issues. This was to be achieved through evaluating the current emergency management systems at mines, identifying good practice and also areas that needed improvement. The areas of focus for the project were on three key areas: the control room, senior mine officials at the mine site and the incident management area. Comprehensive details of the research can be found in the original project report of Cliff (2009).

The control room in particular is a key area where accurate information is required during an incident, especially in the early stages until a senior mine official can take charge. The control room remains the first point of contact during an incident for most personnel. Speedy evacuation and in-seam (i.e., where the coal is cut) response is predicated upon knowing what is happening and where all the mine operators are located. It is therefore imperative that there are good communications with the underground, easy access to the location of underground personnel and a mine environment monitoring system that delivers accurate relevant information. Figure 2 shows a typical control room: given the large number of monitors and other visual displays, it is conceivable that an operator could become overloaded during an incident unless the information presented is accurate, prioritised and relevant.

Figure 2 A typical mining control room (see online version for colours)



The research objectives were:

- To identify how information relating to the location of personnel and equipment is accessed and utilised during an emergency by key personnel, in particular by the control room operator(s), the senior mine official on site and the IMT.
- To identify what improvements were necessary for effective information and management during an emergency at an underground coal mine, especially during the first few hours of an incident.

To achieve these objectives, the work programme was in four main stages:

1 *Identify current routine information collection and reporting processes in use on mine sites*. By surveying underground coal mines (in Australia) and creating information flow maps (similar to Figure 1) for three purposes:
   - identify location of persons and equipment at the mine
   - monitor and analyse the mine environment
   - understand who has access to this information, in particular in the control room, the senior mine official on site and if an IMT was convened.

2 *Emergency response plans, duty cards and other relevant information*. Reviewed information patterns from approximately ten Level 1 emergency response exercises completed since 1998:

- characterise information requirements
- compare the requirements with the actual processes uses
- collate any previously-identified gaps or problem areas.

3 *Based on the broad understanding of current practice obtained from stages 1 and 2, a subset of four mines was then selected and researched in more depth*. The four mines had differing emergency response systems that, taken together, were broadly typical of how the process is managed across all of Australian coal mining. Each site was visited to gain detailed knowledge and understanding of the information management processes in use for routine operation and those required to manage significant incidents, including information paths, decision making and emergency response requirements. Time was spent observing control room operators, and interviewing senior mine officials.

4 *Identify mechanisms to improve these processes*. In particular this focused on:

- Identifying required characteristics. This was partly based on regulations, mine management interviews and mining best practice (identified from literature reviews).
- Identifying current processes. This was based on the broad understanding obtained in stages 1 and 2, and the in-depth reviews of four mine sites in stage 3.
- Identifying information gaps and problem areas. Essentially this was an examination of the gaps between what should happen and what actually happens at mine sites. The operator and management interviews and observations in stage 3, and reviews of recent mine site incidents, where key data sources.
- Consulting relevant research. This included past coal mining projects reported in the open and industry literature worldwide.
- Identifying practical solutions and improvements. This analysis used the above information gaps, problem area and literature reviews to develop potential solutions. A participatory approach was employed whereby possible improvements were commented upon by senior coal mining industry.

This final phase also included identifying the barriers that have prevented past research from being implemented successfully at mines and where possible solutions to overcome these barriers. Again, a participatory approach was used that involved discussions of previous and possible future barriers with both mine site and corporate mining managers.

2.3 Findings and next steps

The aims of this project were the improvement in quality of information collection, analysis and dissemination at underground coal mines, the reduction in time taken to acquire the information and make decisions, and the associated improvement in emergency response capacity (Cliff, 2009). In terms of improving the collection of information for effective use in underground coal mine emergencies, the main findings of this HFE research project were:

- As revealed by the in-depth review at four mine sites and the interviews with both operators and management, the emergency management system at mines often seemed to be no more than a paper document that had not been properly tested.
- The incident reviews, observations and interviews revealed that most mines had not formally identified what information would be necessary in an emergency, particularly what would be required to ensure rapid re-entry for rescue purposes.
- Similarly, the incident reviews, observations and interviews revealed that there was an urgent need to define the minimum information requirements.
- Observations of actual work practice and subsequent interviews with managers identified that there was a need to define an industry wide competency standard for control room operators.
- Finally, incident reviews, observations and interviews (with operators and managers) revealed that mines need to significantly increase the training carried out in emergency preparedness and response especially in the management of incidents.

Although the success of recommendations derived from the above findings have not yet been formally evaluated in terms of their long-term improvements, the outcomes from this project are currently being used by the principal providers of emergency preparedness training for Australian underground coal mines (the Mines Rescue Services of New South Wales and Queensland) to include in both their emergency management training and design of emergency management software. The authors have visited these Mines Rescue Services to support information uptake and the implementation of any training of software materials derived by the research. Finally, the information is currently being fed back to participating mines to enable them to improve their emergency management systems, and it is anticipated that further work to evaluate the resultant changes will then be conducted.

In summary, while this case study focused on technical information requirements (e.g., design of emergency management software), in the next sections, we describe two ongoing research studies aimed at getting a better understanding of the psychological and organisational issues related to the IMT and control room.

3 Case study 2: incident management team investigations

As outlined earlier, findings from the Level 1 emergency preparedness exercises run annually in Queensland, Australia, consistently bring up decision-making and other human element issues relating to the IMT (Cliff, 2009). Therefore, the second case study explores the decision-making deficiencies of the IMT and how the development of non-technical skills training might improve the effectiveness of the IMT.

3.1 Background

Within the IMT, the overarching problem identified is that decision making is not optimal (Fuller et al., 2012). The reasons for this include the issues of information flow, access to information, information accuracy, multiple handling of information, poor communications, poor preparedness and limited facilities within the IMT room (Cliff, 2009). In response to this, the Queensland Mines Rescue Service (QMRS) have developed an incident control system and training programme, similar to that used by the emergency services (Queensland Mines Rescue Service, 2009). It is a command and control structure that defines the roles, responsibilities and communication flow during an emergency response (Queensland Mines Rescue Service, 2009). However, despite its implementation in 2005, Level 1 emergency exercise reports still call for additional training to improve decision making (Fuller et al, 2012). This indicates that a technical systems approach alone, without considering the psychological factors associated with an emergency response, is insufficient to maximise performance.

Human factors research reveals that poor decisions made during an emergency situation have been a significant contributory factor in the occurrence and severity of major disasters (for a summary see Flin et al., 2008). The evidence suggests that humans are especially vulnerable to impaired decision making when tired, emotional and stressed (Canon-Bowers and Salas, 1998; Douglas and Flin, 1999; Kowalski-Trakofler et al., 2003; Paton, 2003; Schwarz, 2000). Aspects of fatigue, emotion and stress were all present during the Pike River Coal Mine rescue operation (Royal Commission on the Pike River Coal Mine Tragedy, 2012). A mining emergency response can involve long work hours and reluctance to rest (Simpson et al., 2009). Unaccounted for miners (potentially killed or injured) are colleagues, friends and possibly even family of those executing the response. The situation often involves incomplete information; the situation is dynamic and the decisions that need to be made have the potential for catastrophic consequences, not only in terms of injury and loss of life but also legal ramifications for the individual with statutory responsibility for the mine (i.e., the mine manager). Some mines are trialling technological solutions (radio frequency identification tags), however, experience in their use indicates that there are significant operational issues to be resolved before they can be relied upon to identify where people are in an emergency (Pang and Zhang, 2011). Further, there are time pressures on decisions. A decision made too slowly could endanger those underground who may be running out of respirable air, while a decision made too quickly without a full evaluation of the facts could endanger the rescuers.

It is proposed that if an IMT are to make optimal decisions in an emergency, they need to prepare for the effects that emotion, stress and fatigue may have on themselves, their colleagues and the overall success of the response, in addition to applying the incident control system.

3.2 Work undertaken

Our first step was to conduct an analysis of the Queensland Level 1 Emergency Exercise reports. In terms of the IMT, the aim was to gain a better appreciation of what aspects of the decision making process are problematic. It should be noted that it was sometimes difficult to determine if a decision was right or wrong simply from the outcome. Outcomes are not necessarily directly related to a decision and there are stages within the decision making process where errors can occur such as faulty or incomplete data, poor communication, or a misunderstanding of the situation. A study of the literature pertaining to emergency response within high reliability industries was conducted to determine if any lessons learned could be applicable to the mining context (Fuller et al, 2012). Finally, we conducted site visits, observations of emergency exercises, participation in emergency management training and over 29 interviews with key stakeholders (e.g., Queensland Mines Rescue Service personnel) to better understand the decision making issues.

3.3 Findings and next steps

The emergency management literature in other high reliability organisations indicates that there are a number of 'non-technical' skills that are critical for effective emergency response. Communication, situational awareness, leadership, teamwork, stress and fatigue influence emergency performance within several industries including aviation, the military, nuclear power, maritime, rail, health, fire services, and offshore oil and gas (Flin et al., 2008). Further, these skills have been targeted by Crew Resource Management (CRM) training in the aviation industry. Today, most of the major international airlines include CRM as part of their training. It is recommended by both European and American aviation regulators and is a mandatory component of training for UK pilots (Flin et al., 2008; ICAO, 1991; Sexton et al., 2000).

A comparison of the non-technical skills found to be critical in other industries, with the observations and recommendations from Level 1 emergency exercises, indicates that these same non-technical skills are relevant to mining and may be the key to addressing the decision making deficiencies (Fuller et al., 2012). These non-technical skills and comments from Level 1 assessors to support their existence in mining are shown in Table 2.

Table 2 Common non-technical skills and relevant Level 1 assessor comments

Non-technical skill	*Evidence from Level 1 exercise assessor comments*
Decision making	*Decisions not being recorded.*
	Not having a clearly defined decision making process.
	Groupthink evident.
	Best with only core IMT members.
Situational awareness	*Taking the initial decision/scenario or response as the only one and not considering all alternatives.*
	Failure to consider all the options available to them.
	Being reluctant or cognitively unable to redefine the scenario to the correct one following an initial misinterpretation of the situation.
Communication	*Poor communications.*
	Better communications between CRO and IMT required.
	Some communications not recorded.
	Vital information for decision making not getting to IMT.
	Electronic communication went well.
	IMT not challenging IC, more input from IMT required.
	Told wrong family next of kin was dead.
	Information to IMT was slow and not of high quality.
	Information flow needs to be improved.
	IMT in the dark.

Table 2 Common non-technical skills and relevant Level 1 assessor comments (continued)

Non-technical skill	*Evidence from Level 1 exercise assessor comments*
Teamwork	*Confusion regarding roles and responsibilities within the Mine Emergency Management System.*
	Rescue team not included in decision making.
Leadership	*Goals not clear.*
	Incident controller trying to set own goals.
	Better objectives need to be set.
	IMT needs to take control of all activities on site once formed.
Stress management	*Decisions are not driven to completion.*
Fatigue management	*Fatigue affecting decision making.*

The next step is to identify which aspects of the non-technical skills are particularly relevant to the mining IMT via surveys and further observations of mine emergency simulations. For instance, the emotions that occur when rescuers know the victims can be more intense than when dealing with strangers. From this, future work will involve the development and evaluation of a non-technical skills training package. This will be included in the QMRS emergency management training programme to ensure that participants not only understand the system that they will be working with, but also how to optimise their own and others performance from a human factors perspective.

4 Case study 3: control room investigations

4.1 Background

As previously mentioned, another key finding from the Queensland Level 1 Emergency Exercise reports was that the control room operators need more efficient and effective systems to help them respond to mining emergencies (Watkinson and Brady, 2008). The control room is the communications centre of an underground coal mine. The control room operator is responsible for monitoring the performance and movement of people, and fixed and mobile plant equipment underground. Because of these responsibilities, the control room operator is usually the first person to identify or be notified of a potential emergency. Therefore, it is critical that control room operators have adequate resources to provide effective immediate response to emergencies.

Despite the importance of the control room operator's role, there has been little research on control room operations in a mining emergency context. Researchers have studied control room operators in process control domains like nuclear power (Liao, 2011); however, with a few exceptions (Li et al., 2011), there is little research on control room operations in the minerals industry. Moreover, to the best of our knowledge, researchers are yet to study the challenges associated with control room operations during mining emergencies. Therefore, we are involved in research to better understand the control room operator's role during mine emergencies and contribute to the development of better support systems so that control room operators can respond more efficiently and effectively to mining emergencies.

4.2 Work undertaken

Our first step was to conduct an analysis of the Queensland Level 1 Emergency Exercise reports. We conducted an inductive content analysis of the emergency exercise reports. Specifically, we analysed the recommendations and issues directly related to control room operations and grouped each finding into similar categories, the result being broader categories that capture the core challenges encountered by control room operators across the all the reports. Subsequent observations and informal interviews at two Australian control rooms supported the challenges identified from the emergency exercise reports. For the purposes of this paper, we provide a general summary of the challenges.

4.3 Findings and next steps

Overall, we found that the challenges involved either technical limitations or broader organisational issues. In terms of technical limitations, two main problems emerged. First, we identified issues related to control room information systems. For example, there were instances where

a important software (e.g., gas analysis information) was not available

b control room operators could not modify software to meet their monitoring needs

c busy interfaces that made it difficult for the control room operator to read and detect important information.

Second, there were various technical problems related to unreliable communication systems that made it difficult for the control room operators to monitor and coordinate emergency response activities.

A more important finding is the challenge associated with broader organisational issues related to

a lack of training

b ineffective coordination.

For example, at the moment, control room operator training usually involves being mentored by a more experienced control room operator for a short period of time. There is little to no formal training for control room operators. Therefore, findings from the emergency exercise reports consistently show that control room operators lack skills in the collection and analysis of gas samples. This contributes to major delays in understanding the underground atmospheric conditions, which is critical for deciding if mine rescuers can go underground.

Another key organisational problem is ineffective coordination between the control room operator and the IMT. The IMT is made up of experienced and senior mine managers and technicians who are responsible for planning and managing the emergency response. Findings from the emergency exercise reports consistently show very little direct communication from the IMT back to the control room operator. The result is that the control room operator has a limited understanding of the planned emergency activities which can result in delays to the implementation of emergency procedures as the control room operators tries to make sense of what is happening and what they need to do about it.

Although an ongoing research project, we have already identified important information about control room operator difficulties during mine emergency situations. Overall, our research highlights the importance of considering both technical and organisational factors when developing support systems for control room operators. Our next step is to conduct more detailed field investigations of control room operations during routine and emergency situations to study whether challenges associated with emergency operations might differ from those associated with routine operations.

5 Discussion and conclusions

Although human factors in the minerals industry has had a fairly long history (e.g., Sanders and Peay, 1988), until now, there has been a paucity of work examining mining emergency management from a human element perspective. As noted earlier, mining is a major worldwide industry with a variety of hazards that can cause injuries and fatalities: this is particularly so in underground mining where there are a limited number of escape routes when emergencies occur. Building on a taxonomy of the human element issues in the minerals industry (proposed by Horberry et al., 2010), this paper focused on three related case studies about mining emergency management. The main conclusion arising from the three different studies presented here is that mining emergency management can be made safer and more efficient by taking a human-centred perspective to investigate the challenges during coal mine emergencies (e.g., observations of routine work and emergency exercises, interviews with operators, examinations of previous incident data and analyses of emergency exercise reports) and using this information to inform the design of emergency training, procedures and support systems.

In more detail, the first case study identified key challenges of collecting and managing information during emergencies in underground coal mines. The other two case studies built on this by investigating psychological and organisational issues related to the responses of the IMT and control room operators, respectively. The second case study presented work to show how decision making in the IMT may be improved by means of better non-technical skills. It showed how many of the non-technical skills previously identified in other domains are equally applicable to mining, and outlined an ongoing process to use these identified non-technical skills in future mine emergency training. In contrast to case study 1, case study 2 shows that accurate and timely information is not sufficient in itself: incident management teams also needed to know how to optimise their own and other team members' performance from a human factors perspective. The final case study illustrated how control rooms can be made more efficient and effective in responding to mining emergencies by improving organisational issues such as training and coordination. Case study 3 partly supports the general need for accurate and timely information for mining emergency management that was found in case study 1 (exacerbated by often poor interface design in the control room so the information is not optimally presented to operators). However, case study 3 also expanded the focus and revealed some of the wider organisational problems such as ineffective coordination between the control room operator and the IMT and a general lack of training in key aspects of the control room operators' duties (e.g., their lack of skills in the collection and analysis of gas samples).

In addition to completing these long term programmes of research (e.g., evaluating the effectiveness of non-technical skills training on incident management teams' decision making), another important topic of research in the general area of mining emergency management is the impact of automation. Although mining automation, in theory, promises to reduce the number of mining personnel working underground, for the next 5–10 years, it is likely that only components of the mining system would be automated (e.g., blasting), so operational and maintenance staff would still be required underground (Horberry, 2012). As seen in other industries where automation has been more widely introduced, new technologies are likely to alter the actual work done underground, so emergency management would need to reflect these changes. Despite this uncertain future, taking a human-centred perspective, of first understanding the tasks required to be undertaken underground then using a participatory ergonomics approach to help develop safe emergency management systems, will still be essential.

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