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Review

The Health and Safety Benefits of New Technologies in Mining: A Review and Strategy for Designing and Deploying Effective User-Centred Systems

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Abstract: Mining is currently experiencing a rapid growth in the development and uptake of automation and other new technologies (such as collision detection systems); however, they are often developed from a technology-centred perspective that does not explicitly consider the end-user. This paper first presents a review of the technologies currently available (or near-market) and the likely human factors issues associated with them. The second part of the paper presents a potential long term strategy for research and development that aims to maximise the safety and health benefits for operators of such new technologies. The strategy includes a four stage research and development process, this covers: better understanding the needs for technology, user requirements and risk/cost analysis; human element design, procurement and deployment processes; evaluation and verification of the strategy; and dissemination of it to relevant stakeholders (including equipment manufacturers, mine site purchasers and regulators). The paper concludes by stressing the importance of considering the human element with respect to new mining technologies and the likely benefits of adopting the type of strategy proposed here. The overall vision is for mining to become safer and healthier through effective user-centred design and deployment of new technologies that serve both operator needs and the demands of the workplace.

Keywords: ergonomics; new technologies; human element; user-centred; automation; safe design; mining occupational health; human factors

1. New Technologies in Mining

1.1. The Need for New Technologies and Automation in Mining

The ongoing imperative for safe and healthy workplaces has been one of the major drivers for the introduction of new technologies into mining [1]. Examples of such technologies include full automation of mining processes (e.g., blasting), proximity warning systems for mobile mining equipment, operator fatigue detection technologies or fire detection systems [2]. However, similar to many other industrial and transport domains, the rapid development and growth in such new systems has often seen them being deployed as the technology becomes available, without them being systematically designed, integrated into work environments and evaluated from a user-centred perspective [1]. As seen in domains where considerable research and development work has been performed to achieve good human system integration (e.g., aviation or defence), to be successful, new technologies must take into account the human element [3]. For example, they must meet the requirements of the job or task, work in emergency or abnormal operational states, support operators, and be acceptable to the eventual end-users [4]. Human factors issues with new technologies are thus of key importance, but are often not considered in sufficient detail.

1.2. Definitions of Automation and New Technologies

'Automation' or 'new technology' are not unitary terms: instead they cover a wide range of devices, components and systems [5]. There are different levels of technologies operating in most industries, although the uptake of them in the minerals industry has generally been slower than in some domains (e.g. aviation) they still can be categorized in roughly similar ways [3]. To simplify greatly, automated systems and new technologies in mining can generally be separated into broad categories related to system control, ranging from technologies that simply warn or inform users, through to full automation in which no operator is physically present at the work location [1].

A database of current and emerging technologies in mining was published in 2012 [2]. A wide variety of data sources were used to create it, including:

- personal interviews with technology developers, mine site or corporate personnel and regulators;
- attendance at relevant mine site automation conferences;
- podcasts by leading mining personnel;
- desktop reviews of relevant articles;
- original equipment manufacturer product lists and websites;
- reviews of mining equipment suppliers guides [2].

Specific technologies identified in the database were grouped by 'degrees of automation', such as fully automated and partially automated systems; assistance devices such as proximity detection or warning systems; and other relevant technologies. At time of publication, the database contained 48 records comprising 17 entries relating to autonomous or semi-autonomous mining systems; 26 entries relating to warning or detection systems; and 5 entries relating to other systems that support the automation functions (such as control room management, digital terrain mapping, driverless trains and port facility operation) [2]. In terms of trends to be distilled from the database, in addition to the general growth of new technologies being introduced into this field (especially at the wider system level, rather than piecemeal technologies), the authors noted that there was a lack of user-centred design with approximately only one third of the database entries explicitly mention how the technologies might impact upon the operator [2]. As such, either human operators and maintainers are no longer important, or they have been simply been largely overlooked by the engineering-focused developers of these technologies. As will be argued in the first part of this paper, the human element cannot be overlooked, and the second part of the paper therefore proposes a method to help bring the equipment design focus to explicitly include operational and maintenance personnel.

There has been much recent discussion of the ‘Mine of the Future’ concept, where full automation will supposedly replace (or at least reduce) the need for human presence at mine sites. Whilst such concepts and visions are attractive to engineers and managers, it seems unlikely that full automation could be used on a wide scale across the entire industry in the near future as it must be remembered that prototype technology to automate some of the major tasks on a mine site (e.g., haul truck operation) have been available since the 1970s but have only recently been successfully implemented [6]. So, like road transport, it seems likely that there will be an incremental uptake of new technologies and automation in the minerals industry (largely based on safety, profit or operational criteria) rather than a sudden changeover to fully automated mines [6]. Despite this, the strategy presented in the second part of the paper has been designed to work for all technology levels: from operator information and assistance systems through to more fully automated ones.

1.3. The Benefits and Pitfalls of New Technologies

Theoretically, new technologies offer great potential to improve operator safety and health. Fit for purpose devices can form another layer of protection to add to any physical and organisational measures already employed. In addition to potentially removing operators from hazardous situations, they could also present innovative ways of addressing long-standing safety issues, such as lessening the severity of an injury by means of better incident detection and response systems [7].

Safety and health concerns are, of course, not the only reason to introduce new technologies in this domain. As previously noted [1], other factors are:

- **Lower cost of production**. Examples include more ore transported, or more efficient process control operations.
- **Requirements for enhanced precision**. An example of this is automated blast hole drilling, where not only is there a potential safety benefit, but the correct location of the blast holes can theoretically be more accurately achieved through automated systems.
- **Less environmental impact**. In theory, they can be more sustainable, minimize the need for land reclamation (for example, by using keyhole mining methods, rather than open-cut operations) and require less energy to extract and process the commodity.
- **Being able to mine areas previously inaccessible**. For example, being able to mine in hard to reach locations that previously could not be mined economically.
- **More data**. The capacity to collect more data, often in real time, on the performance and state of equipment can be of considerable advantage for issues such as equipment maintenance scheduling and appropriate responses in emergency situations.

- **Reduced manning.** Although it is a myth that automation fully removes the need for all human involvement, in some cases it may reduce the need the humans, at least those on the front line (for example, automated haul trucks requiring less direct control).

But generally these devices in mining have been designed from a technology-centred perspective, rather than first seeing what are the needs and what safety benefits they might bring [1]. The non-mining literature is replete with cases of new technology failures [5]. These range from devices being badly integrated, not coping with excursions from normality, irrelevant for tasks, displaying unnecessary information, not accepted by operators or overly relied on [8–10]. As such, most of these issues are in some ways related to a failure to take into account the human element in the design or deployment of the new technology.

1.4. The Importance of the Human Element

It is argued here that improving the design of new mining equipment and automated systems (especially their interfaces) so that they match the operator's skills, motivations, capabilities and limitations, as well as better integrating those technologies within the systems of work, are key issues to consider for their benefits to be fully obtained [4]. Key human factors information includes how user requirements are captured, how human element information is provided in an accessible form for designers to use (e.g., regarding human capabilities), how appropriate human-centred methods are used to evaluate designs (e.g., user trials to examine actual usage or acceptance) and how the equipment is integrated into the work system (for example, looking at issues of possible resistance to changes, procedural modifications, use in emergency or abnormal states or where equipment retrofits are needed) [1].

Lynas and Horberry [2] identified the following human element problems that might emerge without proper consideration of the human element with new mining equipment:

- Poor operator acceptance of new technologies or automation after they are introduced.
- Lack of technology standardization.
- Problems with integration and overload from multiple warnings or alarms.
- Inadequate operator and maintainer training and support.
- Over-reliance on the technology by operators (especially a problem for safety critical systems).
- Organisational issues—introducing new technology can change the nature of the tasks to be performed.
- Being outside of the system control loop.
- Behavioural adaptation or risk homeostasis—the introduction of automation and new technologies can result in operators engaging in more risky behaviours.
- Deskilling or wrong skills held by operators and maintainers.

Quite clearly, as seen in other industries where automation and other new technologies have been introduced, there are considerable hazards with not fully considering the human element. The systems can fail, not work optimally or lead to harm to those people charged with running and maintaining them. The strategy proposed below helps to address these issues by providing a means to better consider the human element in automated mining.

2. A Strategy to Better Consider the Human Element

2.1. Objectives

The strategy presented and advocated here would develop and evaluate an overall approach for maximising the safety and health benefits of new technologies, and then to apply this to the design and deployment of such technologies in mining.

The objective is to maximise the safety and health benefits of new technologies that may be introduced into such high-hazard mining workplaces. No formal methodology has previously been applied to systematically consider the design and deployment of new technologies in mining from a user-centred perspective [1]. Following Haddon [11], the strategy should consider how such systems can be used with different categories (person, equipment or vehicle and physical or social environments) and phases of injury (pre-event, event or post-event, e.g. emergency communication systems). Therefore, new technologies can be used for primary, secondary and tertiary safety (and health events), and not just be restricted to devices fitted to vehicles or equipment in mining.

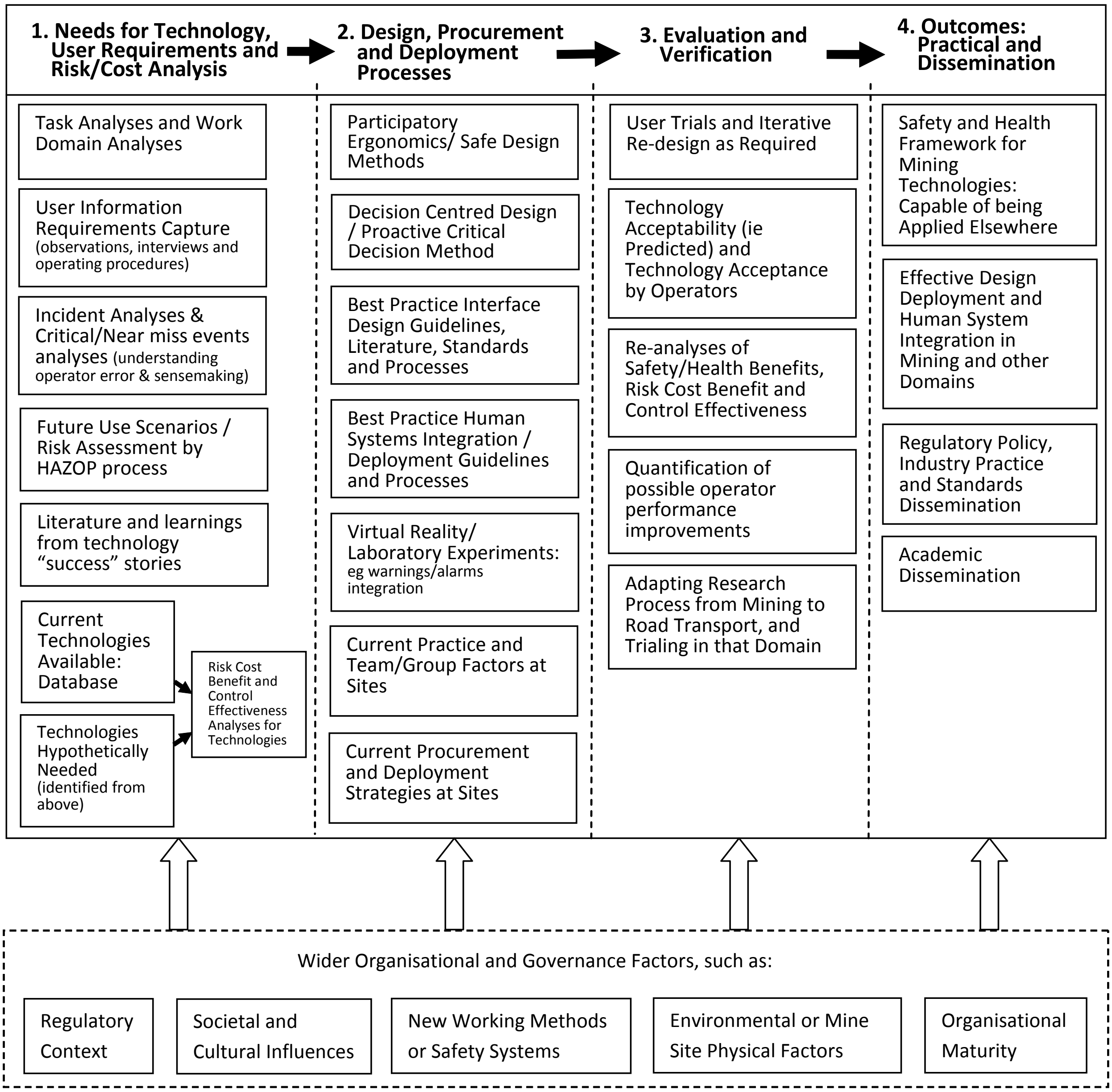
2.2. Methodology

A four stage integrated methodology is proposed to meet these research objectives. Figure 1 shows the methodology. In summary, Stage 1 focuses on identifying the technology needs, what users require from potential technology and analysing the risks and costs associated with it; this includes analysing the work domain and tasks, capturing user information requirements and examining previous incidents to help identify effective technological controls. How these technologies are designed from a user-centred perspective and then deployed in the workplace is the focus of Stage 2. From Stages 1 and 2, a framework to determine which technologies should be developed and how they would be designed and deployed would be created. Stage 3 is an iterative evaluation and verification of these processes and methods in mining (and comparing it to similar initiatives in other industries, such as road transport). Finally, the outcomes of it would be disseminated in Stage 4. This dissemination would target three stakeholders: the designers and manufacturers who are creating such new technologies, the regulators who oversee the industry and the industry purchasing and deploying it (e.g., mine sites).

It should also be noted from Figure 1 that the strategy should also be cognisant of the broader context in which work takes place. For the minerals industry this includes:

- the regulatory context (e.g., who are currently advocating the use of new technologies such as collision detection systems to mobile mining equipment);
- wider societal and cultural influences (e.g., the societal trade-off of safety against production);
- other working methods and safety systems (e.g., quality improvements);
- specific environmental and mine site factors (such as mining method: at the crudest level between underground and open-cut mining);
- new safety systems being appropriate to an organisation’s maturity. Technology changes more quickly than organisational culture, so the culture must be mature enough to be capable of supporting technology changes [12].

Figure 1. Strategy Methodology.



The methodologies shown in the four stages of Figure 1 are further explained below.

Stage 1: Obtaining an understanding of the technology needs, user requirements and risk/cost analyses

Effective solutions cannot be developed without first understanding the problem. So, Stage 1 focuses on identifying the technology needs, what users require from potential technology and analysing the risks and costs associated with it. A variety of human element methods are required, ranging from understanding the work domain and the tasks that take place, capturing user requirements, examining where things went wrong or nearly went wrong (e.g., identifying how operators made sense of incidents rather than simply labelling them as 'human error'), understanding future use requirements (including applying the risk assessment process HAZOP to assess deviations from 'normal' working) and undertaking literature reviews (especially regarding technology 'successes'). This stage should also further develop a database of currently available technologies. From all these above methods, the technologies that are hypothetically needed would be analysed.

Finally, the control effectiveness of the technologies should be analysed based on methods successfully used in mining (e.g., Bow Tie analysis for mining hazard control by Kizil *et al.* [13]). Criteria from Horberry *et al.* [7] could also be used, these state that possible new technology should:

- address a problem that was a factor in previous safety or health incidents;
- be technologically feasible and not require overly extensive retrofitting;
- not likely to be strongly opposed by operators;
- be capable of integrating with other equipment, training regimes and safety procedures;
- have no 'low-technology' countermeasure equally capable of cost-effectively performing the same role;
- be reliable, display the required information and produce few false alarms.

Stage 2: Design, procurement and deployment process for user-centred new technologies

How these identified technologies are designed and deployed in the workplace is the focus of Stage 2. It is envisaged that it should use participatory ergonomics and safe design methods (involving end-user input)—Decision Centred Design—to examine the key workplace decision points for effective design [14] and best practice human factors knowledge (e.g. the Federal Aviation Administration's Human Factors Design Standard [15]) for both interface design and human systems integration. It is likely that experiments would need to be undertaken to supplement existing knowledge (e.g. operator responses to multiple alarms in complex mining vehicles). Then, how groups and teams are organised at sites should be studied, together with analyses of mines' current procurement and deployment strategies.

Stage 3: Iterative evaluation and verification of the processes and methods in Stages 1 and 2

From Stages 1 and 2, a process to determine which technologies should be developed and how they should be designed and deployed would be created. This process would be iterative and flexible, based on what technologies are actually being introduced to mine sites (e.g. collision detection systems). It is likely to require user trials of technologies, assessing technology acceptability (i.e. predicted) and acceptance (*i.e.*, actual), a re-analyses of the safety and health benefits proposed in Stage 1 and quantifications of operator performance improvements with the new technologies (e.g. number of critical incidents).

To this point, Stages 1–3 of the strategy would have focused on mining. The final part of Stage 3 would be to compare the draft process to best practice being employed for user-centred design of new technologies in road transport. Road transport does have a slightly different set of constraints, such as varying types of operators or drivers, different technologies and the decision to actually use a technology is usually in the hands of the end-user (*i.e.*, the driver), whereas in mining the use of the technology is usually compulsory. Despite this, many new comparable technologies are also being introduced into road transport from an explicit consideration of the individual driver (e.g., speed limiting, congestion sensing or collision detection systems) [16], so mining could benefit from these user-centred design methods and road transport system findings.

Stage 4: Outcomes: practical application and academic dissemination

Finally, when the strategy has started being implemented, the outcomes of it should be disseminated, especially focusing on the safety and health framework for technologies in high-hazard mining domains. The outcomes should focus on both practical and academic dissemination. To maximise the practical benefits in industry that would result from developing and applying the approach (in terms of safer and healthier new mining technologies) dissemination should target three stakeholders: the designers and manufacturers who are creating such new technologies, the regulators who oversee mining or minerals processing, and the industry purchasing and deploying it (e.g., mine sites). Focusing on who makes the technology, who regulates its use, who buys it and who will ultimately use it is the key to maximise the safety and health benefits of new devices that will be introduced in high-hazard mining workplaces.

3. Conclusions

This review paper has described how new technologies and automation are inexorably being deployed in mining. It seems likely that their rate of deployment will grow in the next 5–10 years [3]. Although many positive outcomes are likely to emerge, lessons from other industries have shown that unless the human element is explicitly considered with respect to new mining technologies then there are also likely to be some negative impacts. Mining can become safer and healthier through effective user-centred design and deployment of new technologies that serve both operator needs and the demands of the workplace. A strategy to achieve this was presented in this paper; what is needed now is for researchers and technology developers to further develop and then apply such a human factors strategy, and for mining companies at both a mine site and corporate level to better appreciate the importance of explicitly considering the human element.

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