Database development

Human interaction with automated mining equipment: the development of an emerging technologies database

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Abstract

Background: In recent years there has been a large increase in the amount of new technology being developed and deployed in the minerals industry. The human element implications of such technologies in mining have not yet been explored in any detail. Aims: The overall focus of this paper is upon operator interaction with automated mining equipment; in particular, it aims to develop a database to capture the emerging technology trends associated with such equipment. Method: A wide variety of data sources were used to create the database, including: personal interviews with technology developers, mine site/ 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, and reviews of mining equipment suppliers guides. To put mining automation into context, specific technologies used in mining automation are grouped in the database by 'degrees of automation', such as fully automated and partially automated systems; assistance devices such as proximity detection/ warning systems; and other relevant technologies. Results: The database, shown in Appendix 1, considers both existing and emerging technologies. A brief product description is also provided, including the technology used, function of the system, and where possible the location of where it is being used. An analysis of the main human element implications of such technology is also provided. Conclusion: Whilst it is a comprehensive database, it is by no means exhaustive of all automated equipment available within the minerals sector. Some technologies are restricted to company/ user-only access with limited or no information publically accessible, and some technologies are still in the research and development stage. It does, however, provide a broad overview of the types of available technologies associated with automated mining practices as well as the emerging trends in new technologies within this sector. By nature, the database represents a changing environment; this paper presents a snapshot of it at one point in time. Further work to keep the information up to date is recommended. It is possible the database could be configured to allow mediated open user access to populate it with up to date information of emerging technologies as this material becomes available. Despite this, the database and associated analysis give an understanding of what is presently available and what are likely to be the human factors issues, such as future skills requirements, associated with such technology.

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Background

Over the last ten years there has been a massive increase in the amount of new technology being developed and deployed in the mining and minerals industries; such technology ranges from simple information systems through to full automation [1]. The introduction of such technology in mining is often for productivity or safety reasons (especially for the removal of operators from hazardous situations). However, there are a large amount of human element considerations that need to be addressed for the technology to be successfully deployed. For instance, new technology is almost certain to change the nature of mining personnel tasks whereby the human often becomes more of a passive supervisor of the process rather than an active operator of equipment [2]. Similarly, human factors issues such as operator acceptance, skilling, user-centred design, human system integration and trust in the technology are of key importance for the technology to be effective [2]. To help this, a better understanding of “what is out there” is necessary; the work described in this paper attempts this by means of creating a “technology watch” database.

The research undertaken was part of a Commonwealth Scientific and Industrial Research Organisation (CSIRO)-sponsored “Technology Futures” project. This was one of three streams of research in a broader program of research called the Minerals Futures Collaboration Cluster under CSIRO’s Minerals Down Under (MDU) Flagship. The broad aims of CSIRO’s MDU Flagship are to unlock Australia’s future mineral wealth through transformational exploration, extraction and processing technologies. The Technology Futures project is a 3-year applied research project to develop technology assessment methods and tools and apply these within the MDU Flagship. The Technology Futures Project aims to reduce the risk that emerging MDU Flagship technologies will result in future conflict through the development of technology assessment approaches.

Database Development Method

This involved developing and establishing a database that was designed to capture as much as possible the available and emerging technologies associated with automated mining practices.

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Source material
Initially a comprehensive internet search was undertaken using various search engines including Google and Google Scholar to locate and become familiar with automated mining equipment used by various mining companies across mostly Australian but also international mine sites. Data were obtained from the following sources:
• specific mining company publications such as yearly reports;
• proceedings from conferences related to automation and new technologies in mining;
• mining equipment supplier’s information guide;
• individual interviews with technology developers, original equipment manufacturer representatives and mine site personnel; and
• downloading of web interviews and podcasts with influential figures in areas specific to the emerging trends in automation and new technologies.

Procedure
A database framework was set up to capture this information. Primarily, attention was given to creating a suitable structure for conveying the information considered most useful across a range of potential users. Following user piloting, it was decided the following information would be most useful:
• the name of the technology system and the manufacturer;
• a brief description of the function of the specific technology indicated;
• the level of automation provided (e.g. warning/information system or automated system) – for example, the specific technologies were grouped in the database by ‘degrees of automation’ based on leading research in the road transport industry [3]. The ‘driver’s locus of control’ taxonomy by Stevens covers technologies that range from informing, to warning, to assisting, through to in-built (i.e. automated) systems [3]; and
• a brief description of the system components and the technology employed.

Status of the equipment use, that is whether in use or being tested/developed. Data were further categorized into three broad areas: automated equipment systems (encompassing all levels of automation); collision avoidance/detection systems; and additional systems associated with mining applications (control room management and robotic systems, digital terrain mapping (Table 1).

Table 1: Sample of populated database

<table>
<thead>
<tr>
<th>Name</th>
<th>Function</th>
<th>Automation Level</th>
<th>Description</th>
<th>Status</th>
<th>Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRC mining &amp; P&amp;H</td>
<td>Trackshield collision</td>
<td>Warning/information system</td>
<td>Trackshield is a control system to prevent a shovel operator inadvertently colliding the shovel's bucket with the machine’s tracks.</td>
<td>Tested - Bracalba Quarry, Caboolture, Qld. Currently in pilot production with P&amp;H/ MinePro</td>
<td>The Trackshield system comprises computer hardware that is mounted on the shovel, computer software that runs the hardware and a suite of sensors to determine where the bucket is in relation to the tracks.</td>
</tr>
</tbody>
</table>

As much as was possible, current and accurate information was obtained from extensive searches, however the database is not exhaustive in nature as some technologies are held in commercial confidence, and some technologies are under trial and therefore current information on them is not available.

This database represents a changing environment and it is possible that it could be set up in the future to allow updating of technology information and population of new and emerging technologies as information becomes available.

One way to achieve this is via an open contribution database, where users and visitors can add records of new technologies that are becoming available.

Database Results
At the time of writing, the database contains 48 entries 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). The database is shown in Appendix 1.

Current developments in mining automation
As can be seen from the populated database, it would appear much of the technology to date has been focussed on improving the “manned mining system”. As indicated by database entries, a large percentage of the current automation focus is on surface mining operations, and in particular warning equipment, such as collision avoidance/detection systems. Similar systems for underground mining have been developed but some are yet to receive safety certification. Again, this database has been populated from available information but some technologies remain in commercial confidence, and some technologies are under trial and therefore current information on them is not available.

Opinion remains somewhat divided within the mining sector as to whether the future of mine automation will be directed by current surface mining technologies – for example in the next decade it is anticipated large scale open pit automation trials will gain momentum [4], or underground mining which is not seen to be burdened by the legacy of open pit solutions and appears to some to be better positioned for the uptake of new mining technologies [5].

The overall automation technology trend may be supported by looking at the key issues driving the development of automated systems which are usually cited as safety and
economic improvement. However, while mining companies are constantly looking at productivity and utilisation, health and safety has now come to the forefront with today’s mining company Chief Executive Officers (CEOs) judging on the mines’ safety performance [6] and soon to be held legislatively responsible for the health and safety of site employees.

Recently Cunningham [7] commented on what he saw were the main challenges to the introduction of automated equipment, predicting significant change would not occur over the next few years as change is a long term process. Instead, he predicted an incremental and increased uptake of the currently available technologies and equipment. However, automation specialist Durrant-Whyte [8] believes that the true benefits of automation will only be fully realized through an integrated system. Similarly, it is argued:

“mining company employees no longer talk about the unreliability of the technologies associated with automation, mines will come to depend upon automation in profound and unspoken ways, and they can because automation works reliably, is flexible, safe and can be maintained” (Dudley et al [9]).

As an example, Rio Tinto has embarked on an extensive implementation of automation technology in the Western Australian Pilbara region “Mine of the Future” leading a full-scale trial of autonomous and remotely operated equipment. This system utilises key automation technologies, such as the Komatsu “FrontRunner” autonomous truck dump system. Additionally, driverless trains will transport ore from the mine to the shipping port, and equipment will be managed by Rio Tinto’s Remote Operations Centre 1,300km away in Perth [10].

Future trends in mining automation

Based on review of the current developments in mining automation, Dudley et al [9] consider the following future trends will emerge:

- a growth in the scale of automation – the current concentration on the component or subsystem level providing semi-autonomous operation will become more integrated. Increased focus on automation at the equipment level will provide a gradual shift of focus to the automation of unit operations with the integration of multiple pieces of equipment leading to fully autonomous operations cycles such as dig, load, haul and dump;
- over next 15 years focus will be on six main technology fields: communication, sensing, computing, actuators, electronics, and safety systems;
- an increase in distribution and scale of automation; and
- the rate of automation uptake is likely to be greatest over the next 15 years.

With the predicted emerging focus on technology integration and a shift of focus to the automation of unit operations (and in particular the technology fields listed above), it is clear consistent monitoring of these technologies is required to achieve a database that provides information relevant to the user. While every attempt has been made to create an up-to-date database the information contained is limited somewhat by the availability of current and accurate information. To maintain a database that is current and able to provide useful and timely information consideration needs to be given to how this database will be maintained and operated in the future.

Analysis: Human Factors Insights from the Database

New technologies and system control

In the mining domain, and used here in the database classification, Horberry et al [12] separate automation and new technologies into three broad categories based on system control:

- **Lower level automation**, which includes warning systems, such as proximity detection systems, and technologies that signal maintenance of equipment. In this category, the operator is in full control of the system at all times, with the technology providing warnings or assistance. Roughly half of all the entries in the database are from this category: partially this high proportion might be explained by these systems being simpler to develop compared to large-scale fully automated systems. Of this category, the majority are various collision detection/proximity warning systems to alert an operator of mobile equipment that another vehicle (or pedestrian worker) is nearby: most of the interfaces are simple visual or auditory warnings;

- **Mid level/partial automation** (also including semi-automated and remote control systems), which may involve temporarily removing operator control, or having the operator control the equipment from a nearby location. Approximately a quarter of the database entries are in this category. Database entries here include collision detection technologies that automatically stop equipment when a collision is detected as imminent. The operator is in control of the equipment at most times, but certain functions are automatically controlled by the system and overseen by the operator. A specific example here is the ongoing shovel automation work by Cooperative Research Centre for Mining (CRCMining/ P&H) that aims to automate the most routine part of the task (the ‘swing’ part after an electric shovel’s bucket has been loaded with ore/coal by an operator, then the operator regains control to subsequently dump the bucket’s contents). From a human factors perspective, how the process is affected by this temporary removal of control, and how the operator then regains system control from the technology, are key issues to research.

- **Full automation**, which involves the operator being physically located away from the equipment. Interaction is by computer screen, joysticks, sensors, and other controls and displays. Approximately a quarter of the database entries are in this category: these include full control of mobile mining vehicles or fully automated cutting of coal by a ‘longwall’ process. Using the longwall automation by companies, such as Inbye Automation, as the example, human-element issues here might include setting up the cutting process in a coal seam initially, ongoing supervision of it, and remedial maintenance if/when the system malfunctions.
In more general terms, as seen described by Lynas and Horberry [1] each level has slightly different human factors issues associated with them. For example, operator de-skilling might be less of an issue for lower level automation, whereas warning design for the proximity detection systems, or operator acceptance of new assistance systems are key priorities. Conversely, loss of situation awareness, boredom associated with what has become a vigilance task, de-skilling, are particularly important for full automation where the degree of system control by the operator is less [1,11].

**The importance of user-centred design**

One issue very clear from the database was the surprisingly lack of focus on the operator. Only approximately one-third of the database entries explicitly mention how the technologies might impact upon the operator. It is unclear how many of the systems were developed from a user-centred perspective; however, mining has been an industry slow to embrace a human-centred approach [11,12], so it is unlikely that operator needs, characteristics or limitations have been formally considered in the design process to improve the “fit” between end-users and the equipment/ technologies being interacted with. As noted elsewhere, the design of new mining technologies and equipment plays a critical part in the safety and efficiency of work tasks that are conducted by operators who are using it; however, the design of such systems is still heavily technology-centred rather than user-centred [13].

With the introduction of these new technologies in mining (especially the more automated ones), the role of the operator in the overall system will change, but it is still a central part of the mining system rather than an optional extra [11]. Thus, developing operator-centred approaches for the design and integration of new/ automated mining technologies is a key priority area for the technology to be successful [13]. In the specific context of mining automation, a four-stage user-centred design process was recently advocated by Horberry and colleagues [14]. From this, the four-stage iterative plan to better incorporate the human element into the design of new mining technologies was developed, this encompasses:

i. a task analysis of manual operation;
ii. using a participatory design process;
iii. employing best practice HF/E data and guidelines; and
iv. undertaking user-testing.

As seen in other domains that have successfully introduced automation (e.g. aviation), this work argued that unless new technology in mining takes into account the human element that would ultimately operate or maintain the systems by means of a user-centred design approach, then it is unlikely that such technology would be successful [14].

**Skills requirements**

Whilst the actual design of technologies to achieve a good fit with the operator is perhaps of central importance from a human factors perspective, the skills and training required by operators also cannot be overlooked [11, 14]. However, due to the evolving nature of the mining technology being developed and deployed, the exact skills and capabilities requirements cannot be fully specified at this stage.

While it is apparent the skills shortage will not be limited to a trade level skill base, it does seem most likely this group will take on the greatest share of support for automation at all the above-mentioned levels of system control [9]. It is anticipated the industry will require 190 new automation support staff each year based on industry skill demands (Dudley et al [9]). The skills and cognitive capabilities required by these automation technicians will depend on the tasks performed and the technologies worked with and the four skills gaps identified in the report (communication, problem solving, planning & organization and technology) have been translated by Dudley et al [9] into a detailed Automation Competency Map. The Dudley et al report stresses a shifting level of engagement between the high knowledge level required to perform tasks independently and lower level of skill required to perform tasks under the detailed direction of experts in the field (or from a centralized control centre). It is likely these changes in technology support and delivery will have widespread implications at the remote or local community level as it is evident there will be a significant change in the skill set required by those remaining on site [9]. This would be particularly acute for technologies in the ‘full automation’ category of the database.

**Other likely human factors issues**

In addition to the design and skills/ training issues mentioned above, there are likely to be many other significant human factors impacts from the deployment of new technologies in mining [11]. These are very similar to those encountered in other industries, in summary these include (adapted and extended from Horberry et al [12]):

- poor operator acceptance of new technologies/automation after they are introduced (this is a possible issue for most of the technologies in the database).
- problems with integration of multiple warnings/ alarms (this issue may occur in different ways for the different levels: for lower level systems it might be possible overload from having another warning system introduced in a mining vehicle’s cab, whereas for more automated systems in might involve designing the interface optimally before deployment).
- lack of technology standardization (the database clearly shows the large number of different companies developing products in this area).
- inadequate operator and maintainer training and support.
- over-reliance on the technology by operators (especially for safety critical systems such as those detecting possible conflicts between several large mining vehicles).
- de-skilling or wrong skills (e.g. skills in manual operation but not in automated operation).
- organisational issues - introducing new technology can change the nature of the tasks to be performed, so a careful analysis of new tasks is a vital early step.
- being outside of the system control loop (this is particularly an issue for technologies in the ‘full automation’ category of the database, or where the technology temporarily removes aspects of control, such as automated the routine aspects of a task, and the operator then needs to resume full control).
• behavioural adaptation/ risk homeostasis - as found in other industries, the introduction of automation and new technologies can result in operators engaging in more risky behaviours. In road transport, this phenomena has been studied more lower level technologies such as advanced braking systems or forward collision warnings: as such, it is a possible human factors issue for the lower level automation entries in the database, such as proximity detection systems, where an operator might modify their behaviour based on ‘knowing’ where the other mining vehicles are located.

Conclusions

As the database shows, it is clear that the worldwide resource industry is being transformed by its increasing use of automated and new technologies. At one end of the scale, this revolution is leveraging off-the shelf technologies to incrementally improve the control of various mining processes, and the other end some strikingly bold initiatives are currently in progress to implement fully autonomous mines. Technology developers are working within this space to provide stand alone and integrated systems that provide solutions for the complexities arising from this massive change of focus within the industry.

A database that captures this information is a valuable tool for those working in this area. However, difficulties lie firstly in sourcing accurate information - some technologies are held in commercial confidence, and some technologies are under trial and therefore current information on them is not available; and secondly in how the database will be monitored and populated with new information as it becomes available.

Despite these caveats, it is argued here that the current database helps to capture the emerging technology trends associated with automated mining equipment. It also provides a broad overview of the types of available technologies within this sector. Further work to expand and maintain the database is strongly recommended. One way to assist with this ‘technology watch’ is for a future version of this database to be configured to allow mediated open user access to populate it with up to date information of new and emerging technologies. To prevent the future database from being filled with irrelevant or purely commercial material from technology manufacturers then full open user access may not be a viable method; instead having it mediated, by users sending possible entries to the database creators for them to approve, might be a possible approach to keeping the information current. Of course, such a process still would require time and funding to maintain it, so additional proposals from the wider human factors and ergonomics community in Australia and elsewhere regarding such maintenance issues are encouraged.

As noted, there are many likely human factors issues arising from such technology, including user-centred design of the systems, skillling/ training issues, operator acceptance and work organisational implications. It is clear from the database that many technologies have been developed purely from a technology-centred perspective that does not specifically consider the needs or abilities of the operator. Experience from other industries has shown that unless such human element issues are considered then the technology is likely to either fail or at least not work optimally. As such, adopting a user-centred design process and involving operators at all stages of the mining technology development and deployment is a central recommendation of this paper.

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