LITERATURE REVIEW: EMERGING HUMAN FACTORS TRENDS REGARDING AUTOMATED MINING EQUIPMENT

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1. ABSTRACT

This review of literature explores the emerging human factors trends with automated mining equipment. It begins by defining the term ‘human factors’ and why it is important to consider operators and maintainers when designing and deploying mining automation. Thereafter it briefly focuses on the need to automation in mining and the past problems with automation from a human-element perspective.

To put mining automation into context, automation in other industries is then presented before specific issues in mining automation are discussed; these include ‘degrees of automation’, automation trends and the likely human factors issues that might arise from widespread mining automation.

Finally, conclusions about the human-element impacts of automation are made; these include the likely problems and some potential ways of reducing such problems by means of adopting an operator-centred focus during automation design and deployment.
2. TECHNOLOGY FUTURES PROJECT

The Technology Futures project, being led by the Centre for Social Responsibility in Mining, is one of three streams of research in a broader program of research called the Minerals Futures Collaboration Cluster under CSIRO’s Minerals Downunder Flagship. The Minerals Futures Cluster brings together four University-based research institutions all of which have a strong track record of working in the minerals sector, and CSIRO on addressing the future sustainability challenges of the Australian minerals industry.

The broad aims of CSIRO’s Minerals Downunder 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. More specifically the Technology Futures project fits within the MDU theme; Driving Sustainable Processing through System Innovation. The goal of this MDU theme is to develop “assessment methods and tools to evaluate the impacts of new technologies and the social and environmental cost to Australia.” 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.
3. METHOD

This component of the research project involved conducting a literature review to explore the emerging human factor trends with automated mining equipment. An initial search was undertaken to define the term “human factors” and why operators and maintainers are important considerations when designing and deploying new equipment. To contextualize mining automation and its evolution, automation in other industries was considered. A comprehensive search of the literature available was undertaken using the Scopus and Web of Science databases.

A specific focus was then taken on mining automation. Historical data was obtained using the above databases. Current data was obtained from specific mining company publications such as yearly reports, proceedings from conferences related to automation and new technologies in the mining sector, and web interviews and podcasts with influential figures in areas specific to the emerging trends in automation and new technologies. Finally conclusions about the human-element impacts of automation were made using the above data sources.
4. HUMAN FACTORS AND AUTOMATION

4.1 WHAT IS “HUMAN FACTORS”
Human Factors is the application of behavioural and biological sciences to the design and integration of tasks, machines and human−machine systems. It is concerned with understanding the interactions among people and the other elements of a work system in order to optimize human well being, safety and overall system performance.

With the emphasis on changing work systems to suit people, rather than requiring people to adapt to systems, human factors looks at the world with a focus on the capabilities, limitations, motivations, behaviours and preferences of people. It aims to maximize efficiency, effectiveness, quality, comfort, safety and health by ensuring that systems are designed and implemented based on an operator-centred approach (Horberry et al, 2010).

4.2 WHY CONSIDER THE HUMAN
Optimizing the design of work systems, tasks and new technologies, in particular the human-machine interfaces, so they match the individual operator’s skills, capabilities and limitations, as well as integrating such technologies within the existing work systems are the starting points of a human factors approach. A human factors perspective argues that to be successful, these systems must take into account the human element: for example, interfaces must be ergonomically designed and they must be acceptable to the end-user.

From a purely technical perspective there can be an expectation that the automated control system can perform a function a lower cost than the operator can. This assumption is often false, and that human operators are needed when abnormal events occur, during maintenance/breakdown or when a system designer cannot automate all parts of the systems and the operator is assigned to undertake tasks to fill these gaps (Horberry et al, 2010).

It is also clear that the sometime-held assumption that automation replaces humans is not correct and that rather, it changes the nature of the work that humans do often in ways unintended and unanticipated by the designers of automation. While automation of physical functions has freed humans from various time-consuming and labour intensive activities; however, full automation of mining equipment to include cognitive functions such as decision making, planning and creative thinking is not yet common place.

One of the overall considerations preventing the total removal of humans from these systems has been the knowledge that humans are more flexible, adaptable, and creative than automation and thus better able to respond to changing or unforeseen conditions. While no designer of automation can foresee all possibilities in a complex environment, one approach is to rely on the human operator to exercise their experience and judgement in using automated equipment and usually giving the operator some discretion regarding the use of automation and over-riding authority. Several human factors issues arise from this approach, including:
• consequences of inadequate feedback about the automation’s actions and intentions (Norman, 1990),
• awareness and management of automation modes (Sarter & Woods, 1994), and
• over and under-reliance on automation (Bainbridge, 1987).

Similarly, as found by Horberry et al (2004) for industrial forklift trucks, operators may adapt positively or negatively to new technologies. Positive adaptation occurs when a new technology brings about a positive change in operator behaviour such as when a new speed limiting system saves fuel and increases safety whilst being acceptable and well liked by the operators. Negative adaptation may make the operators engage in more risky behaviours. Technologies that are not accepted by operators are less likely to be used properly and are more likely to be sabotaged or misused; thus any inherent potential for increasing safety or efficiency may not be fully achieved. Unless new technologies are designed effectively, the information presented may create overload, distraction or even confusion to the operator.
5. AUTOMATION ISSUES

5.1 WHAT IS AUTOMATION?

Automation is broadly defined as the intelligent management of a system using appropriate technology so that its operation can occur without direct human involvement (Sheridan, 2002). This is usually realized through computer-based systems and may range between component systems, which may simply involve control of a valve up to complete control systems such as a dragline or a coal preparation plant. Similarly, the associated tasks required range from simple to complex (CSIRO, 2010).

Automation can be characterized by a continuum of levels rather than as an all-or-none concept (Sheridan, 1980 & 2002). Under full manual control, a particular function is controlled by a human with no machine control. At the other extreme, full automation, the machine controls all aspects of the function including monitoring and different levels of automation can be identified between these two extremes. Sheridan (1980) identified 10 levels of automation. Riley (1989) defined automation levels as combinations of particular values along two dimensions: “intelligence” and “autonomy”, where automation with high autonomy can carry out functions only with initiating input from the operator, and at the highest levels, the functions cannot be overridden by the human operator (for example, the flight envelope protection function of aircraft – Parasuraman, 1997).

In the mining domain, Horberry et al (2010) separated 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 and the technology provides a warning or assistance;

- **Mid level automation** which may involve removing operator control at certain times but not others, or having the operator control the equipment from a nearby location. Examples include equipment use during routine operations where the operator is a passive monitor, but takes over if intervention is deemed necessary; and line-of-sight control of underground equipment such as continuous miners, and collision detection technologies that automatically stop equipment when a collision is detected as imminent. In this category 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.

- **Full automation** involves the operator being located remotely from the equipment and using a computer screen, joysticks, and other controls and displays.

Using such taxonomies, researchers have explored approaches that redefine the assignment of human and machine functions in terms of an integrated approach (Endsley & Kaber, 1999;
Langan-Fox et al., 2009). The level of automation (LOA) approach seeks to optimize the assignment of control between the human and the automated system by keeping both involved in system operations (Kaber & Endsley, 2004). Endsley & Kaber (1999) found operator situational awareness under full automation to be less than that observed under intermediate levels. In accordance with this research, other studies have shown that an intermediate LOA may be preferable to keep controller awareness at a higher level and to allow performance of critical functions (Endsley & Kiris, 1995; Kaber & Endsley, 2004).

Adaptive automation refers to the dynamic allocation of system control functions to a human operator and/or computer over time with the purpose of optimizing system performance. It is considered to preserve controller awareness by facilitating a better match between task demands and cognitive resources (Kaber, Riley, Tan, & Endsley 2001). This supports previous research by Kaber & Riley (1994) where they argue operator awareness and preparedness for unexpected system states would be enhanced under such a system.

A special type of automation for mining, teleoperation, requires further elaboration here. Teleoperation, a system with artificial sensors and actuators that allow a human to communicate with it and control it from a distance is increasingly used in mine sites, toxic and other hazardous such as medical radiation. In these situations the operation is generally specialized and specific to particular tasks such as welding or spray painting. Common language and commands are essential with teleremote operation, and often haptic capability is required. Operators have reported that head-mounted displays in combination with force feedback to the controlling hand, creates a sense of telepresence whilst not actually being there (Draper, Kaber, & Usher, 1998; Sheridan 1992a, 1992b), however problems have been reported with teleoperation when the communication channel contains a relatively long time delay (such as 3 seconds round trip delay). Technology advances are seeing teleremote systems playing a significant part in emerging automation trends in the resource industry.

### 5.2. WHY AUTOMATE?

Some of the key drivers for automation (both generally, and for the minerals industry in particular) are shown below:

- Generally automation is thought to perform more effectively, reliably and accurately than a human operator. Also, there is an expectation that the automated control system can perform a function a lower cost than the operator can. As discussed elsewhere in this report, this assumption is often false, and that human operators are needed when abnormal events occur, during maintenance/breakdown or when a system designer cannot automate all parts of the systems and the operator is assigned to undertake tasks to fill these gaps (Horberry et al, 2010).
- Safety – with higher reliability it is often argued that an automated system is safer - however system failures can lead to injuries, loss of containment of
toxic or flammable materials, or catastrophic rupture of equipment resulting in significant damage to the surroundings.

- Time savings and efficiency – it has been argued automation can relieve humans of time-consuming and labour intensive tasks, and can reduce misuse, speed up operation, increase production rates, extend an operation to a longer shift or even continuous production, reduce system inefficiency, ensure physical specifications are maintained and provide consistency (Parasuraman & Riley, 1997). It is also suggested that automation frees up the operator to allow them time and opportunity for long-range planning or decision making.

5.3. WHAT CAN GO WRONG IN AN AUTOMATED SYSTEM?

Automation has a long history marked by many success and equally notable failures. Automation has been defined as a device or system that performs a function previously performed by a human operator (Parasuraman et al., 2000). Sheridan (2006) argues that automation does not simply supplant the person, but enables new activities, creates new roles for the person, and changes activities in unexpected ways. Lee [as quoted by Sheridan, 2006] concludes that as a result, automation often results in surprises at many levels and for automation to achieve its purpose its design must anticipate these changes. One of the ironies in automation design is that as automation increasingly supplants human control, it becomes increasingly important for designers to consider the contribution of the human operator to the system as a whole (Bainbridge, 1987).

When a system fails it is often for more than one reason. In addition to purely technical failures, this often includes the human-machine interface decisions the designer made, the kinds of people operating the system, the amount of training operators received, and the level to which they are physically and mentally able to cope with the system and its changes. Systems failure can be a function of operating procedures provided for the people or the environment in which they are working.

In a variety of domains, the development and introduction of automated systems has been successfully integrated into daily operation. At the same time, however, a considerable number of unanticipated problems and failures have been observed (Sarter et al, 1997), and these new and sometimes serious problems are related for the most part to breakdowns in the interaction between human operators and automated systems. When automation is introduced to eliminate human error, the result is sometimes new and often more catastrophic errors (Sarter & Woods, 1995). Automation often fails to provide expected benefits because it does not simply replace the human in performing a new task, but also transforms the job and introduces a new set of tasks. Operators often then receive inadequate feedback and support in performing these new tasks. Automation also often fails because the role of the person performing the task is often underestimated, particularly the ability to compensate for the unexpected. Additionally, Sheridan (2002) argues automated systems often lack the flexibility of humans needed to handle unanticipated situations; these issues are explored further in Section 4 below.
6. LESSONS LEARNT FROM AUTOMATION IN THE NON-MINING SECTORS

Some of the lessons learnt about new technologies from industries where automation and teleremote operation have already been used on a large scale show that operators’ jobs and tasks do change (often to a more passive role of monitoring the process rather than an active role of controller or driver of it).

6.1. THE “PASSIVE OPERATOR” PROBLEM

There is a trend for the technology being interacted with to become increasingly more complex (Sheridan, 2002). Problems are created in that if a “passive operator” of an automated system loses situational awareness and /or over time becomes deskillled then they may be unable to take appropriate corrective action in the event of equipment malfunction or abnormal space.

Other industry experiences indicate that human factors issues such as how information about the status of the equipment is displayed (for operators and maintainers, especially during equipment malfunction), how it is controlled and how acceptable it is to personnel are key issues. Neglecting these issues will often result in equipment safety and performance problems, such as improper use or even sabotage, or employee distrust (Horberry et al, 2010). Equipment testing and calibration, setup, routine and emergency maintenance, and equipment control during emergencies or abnormal situations all present significant human factors concerns, which can be worsened by the “passive operator” issue (Bainbridge, 1987; Horberry et al, 2010).

6.2. SPECIFIC HUMAN FACTORS CONCERNS

In addition, there are the concerns of acceptability of automation to operators, loss of situation awareness, boredom associated with what has become a vigilance task, deskillling, and operator behavioural changes with regard to different levels of automated systems and how this impacts upon risk – which is particularly important for full automation where the degree of system control by the operator is less. An extensive list of human factor concerns associated with cockpit automation was compiled by Funk, Lyall, and Riley (2009). Horberry et al (2010) continue this theme, confirming significant human factor issues remain with mining equipment automation, albeit with a slightly different focus from traditional concerns about the subject. With less of a focus on manual tasks and environmental ergonomics there is now more of a focus on interface design, acceptance of new technologies, and the changing skill requirements for those who operate and maintain the new equipment. They argue there is the potential for automated systems to overload, confuse and distract, rather than support, or assist the operator, and highlight approaches like standardization, appropriate training and risk assessments, alarm integration, operator and manager consultation and feedback, as vital components of system success.
6.3. OPERATOR SAFETY AND THE BENEFITS OF A USER-CENTRED DESIGN APPROACH

Paramount among the human factor concerns of vehicle automation are driver/operator safety (Sheridan, 1992), workload, the trade off between high workload and high fatigue versus boredom and complacency. Similar concerns were found with highway transportation (Barfield & Dingus (1998), Korunka & Carayon (1999) and Carayon & Haims (2001), demonstrating the importance of end-user involvement in the implementation of technology to the health and well-being of end users. Of course, it should be noted that the implementation of technology in an organization can have both positive and negative effects on job characteristics that ultimately affect individual outcomes (quality of working life, such as job satisfaction and stress; and perceived quality of care delivered or self-rated performance).

Acceptance of new technologies and systems by operators is becoming seen as increasingly important, especially technologies which have potential to significantly enhance safety (Regan, 2011). To be acceptable, these technologies must be among other things useful and satisfying to use. As seen in road transport, if such technologies are unacceptable to operators, they will not demand to have them, in which case they will not have the intended safety benefit. Even if they have them, operators may not use them if they are deemed unacceptable, or may use not them in the manner intended by the designer. A user-centred design approach can have significant benefits in improving technology acceptance by operators and drivers (Regan, 2011).
7. AUTOMATION IN OTHER INDUSTRIES

The economic benefits automation can provide tends to focus on its technical capabilities, and these have been well documented in such diverse domains as aviation (Spitzer, 1987), automobiles (IVHS America, 1992), manufacturing (Bessant, Levy, Smith, & Tranfield, 1992), medicine (Thompson, 1994), robotics (Sheridan, 1992) and shipping (Grabowske & Wallace, 1993). While humans work with and are integral to these systems; however, in comparison with technical capabilities, the human factors issues in automated systems are still less well understood.

7.1. AVIATION

Poor interface design, workload regulation, skill degradation, and automation –induced complacency are some of the issues that human factors professionals have reacted to in aviation automation. Compared with other human-machine systems, aviation exhibits perhaps the most extensive degree of automation. Flight deck automation has generally been well-received by pilots yet with the advent of advanced-technology aircraft and the transfer of safety-critical functions away from human awareness and control, pilots, scientists, and aviation safety experts have expressed concerns about flight deck automation. These concerns concur with literature from other areas of automation and highlight the possibility that automation may increase pilot work-load, the user may lack an understanding of automation, and that automation may be unduly complex (Funk et al, 2009).

Following a report from the U.S. Federal Aviation Administration (FAA Human Factors Team, 1996), which acknowledged the existence of significant issues surrounding the safety of flight deck automation, Funk et al (2009) examined source documents and classified them into 114 issues. The top five issues with the greatest supportive evidence and in their opinion requiring more immediate solutions were:

(i) pilot understanding of automation may be inadequate,
(ii) behaviour of automation may not be apparent,
(iii) pilots may be overconfident in automation,
(iv) displays (visual and aural) may be poorly designed, and
(v) training may be inadequate.

However, it should be noted that contradictory evidence exists as to whether attentional demands of pilot-automation interaction interfered with performance of safety-critical tasks. (http://flightdeck.ie.orst.edu/).

Research generally supports the notion that high levels of automation increase difficulty for controllers to maintain awareness of system and environmental dynamics (Kaber et al., 2009; Kirwan 2001; Sanders et.al, 1987). Willems & Truitt’s (1999) research showed that controller situational awareness was lower under monitoring conditions and decreased further with an increase in task load despite the perception that situational awareness did not change.
between active control and passive monitoring. In addition, automation related issues of trust, complacency and over reliance (Felici, 2007- cited in Langer Fox 2009; Gordon, Kirwin, & Perrin, 2007; Sheridan 2002; Sharpies et al., 2007) will become increasingly important as the air traffic controller role changes from active (“hands-on”) controller to relatively passive monitor. Other human factors issues such as boredom, vigilance, monotony, motivation, and stress may also become higher (Hitchcock et al., 2003; Straussberger & Shafer, 2007).

Communication and coordination between operator and system are critical, especially in situations where the operator and the automated systems share control, such as in complex flight systems. This potential problem was evident when Eastern Airlines flight 401 crashed in the Florida Everglades in the early 1970’s. The pilot failed to recognize that the autopilot became disengaged while they were distracted by a faulty indicator light. While the indicator light problem was dealt with the plane was placed on autopilot and the autopilot system accidently disengaged. No one recognized it (the alarm was obscured by cockpit discussion) and the plane continued to fly on manual control without human input but with disastrous consequences (Molloy & Parasuraman; 1996).

7.2. TRANSPORTATION - LAND AND MARITIME

Automation has formed a large part of “Intelligent” Transport Systems (ITS) and Intelligent Vehicle Highway Systems (IVHS) involving the application of sensors, communication systems, and advanced computational and control technologies have been applied to the design of highways and vehicles to improve traffic flow and safety. The European Community countries were among the first to undertake a major development project utilizing these technologies and similar national projects have followed in both Japan and the US. Similar technologies have been applied in other transportation systems such as aviation and air-traffic control, and shipping.

While systems such as these have proven efficient and have significantly increased performance capabilities, several concerns have been raised in the area of human factors. For example the ability to intervene effectively when an automated subsystem fails was found to be one of the key issues in automated cockpits (Weiner, 1988). Other difficulties operators of automated systems face include loss of system awareness and manual skills degradation (Norman et al., 1988) and several studies (Horberry et al 2010; Parasuraman et al., 1992; Wickens, 1994;) support these complex arguments and concur with literature findings from other areas of automation.

It is likely that the development of an automated highway system will be gradual, and any automated vehicle control scheme used initially must be capable of operating in an environment of mixed traffic, with human drivers and automated vehicles co-existing. Technology developed by Huang et al (2000) allowed manually controlled and automatically controlled vehicles to co-exist and tested it in a simulated environment. Using information from vehicle sensors which eliminated the requirement for vehicles to communicate with each other, the format of the system allowed gradual implementation and considered advanced traffic management systems. While technology has largely focussed on navigation and collision avoidance systems and more recently intelligent cruise control, the question remains of how
vehicles without automation should or could interact with those that are automated. This brings additional concerns about driver distraction such as that caused by increased use of cell phones and their many applications while driving. Vehicle integration is a significant area of interest with regard to the presence of automated and non automated vehicles at mine site level (Horberry et al, 2010).

Rail control systems similar to aviation control systems exist, and the glass cockpit idea has been borrowed from the aviation sector and other advanced in-cab displays have been trialled. Locomotives have begun to use fly -by -wire technologies, GPS and sensing technologies to measure critical variables from a maintenance perspective, however the most ambitious rail automation project to date would most likely be the Rio Tinto ‘Mine of the Future” operation in the Pilbara region of Western Australia where an advanced fully automated rail system transports ore from the mine to the shipping port, and the equipment is managed by the Remote Operations Centre 1300km away in Perth.

Surface and undersea vessels have also undergone extensive automation. Modern cruise ships and bulk carrier ships as well as naval vessels have automatic roll stabilization, sonar has provided increased reliability in tracking both depth and potential obstacles, and GPS has provided more accurate position localization. Significant automation advances have occurred in the area of containerization and port facility operation. Automated container ports exist at Rotterdam in the Netherlands, and Brisbane, Australia where automated loading and unloading is accomplished by programmed robotic cranes and driverless vehicles carrying the containers shuttle between ship and loading area. However, an example of where automation can go wrong is the case of the Royal Majesty which ran aground en route from Bermuda to Boston in 1995. The ship had an integrated bridge system including a navigational and command system with GPS and autopilot. During the voyage the GPS antenna became detached and the ship went off course. The autonomous system onboard continued to provide information however it appeared the officers’ on board had limited knowledge of and training for the systems in place and multiple failures occurred with interpretation of the information provided (Grech et al, 2008).

Sarter and Woods (1995) noted automation creates new kinds of knowledge demands making it particularly difficult to keep track of an evolving situation when several people are simultaneously using an automated system (as in an aircraft), or consecutively as the watch keeping officers on a ship. Lutxhof and Dekker (2002) argue automation creates new human weaknesses, amplifies existing ones, and human error does not vanish but its nature is changed by automation. They argue the more autonomous the machine, the more the consequences of error get displaced into the future, further compromising opportunities to recover, and what designers really need is guidance on how to support the co-ordination between people and automation. From their perspective, the key to a successful future of these systems appears to lie in how the system supports co-operation with the human operators, not only in foreseeable standard situations, but also during unexpected circumstances. The more powerful (i.e more automated and complex) automated systems become the more feedback needs to be supplied to make technical system behaviour observable, and human operators must be allowed to preserve their strategic role in
managing system resources as they see fit given the circumstances of a situation (Christoffersen & Woods, 2000).

### 7.3. MEDICAL

Parts of the health care system are highly automated and many are tightly coupled systems with a high degree of complexity. In complex systems, disturbances are ever present and unanticipated events are not unusual. Operating theatres, radiotherapy, surgical pathology and anaesthesics are good examples of complex systems reliant on automated systems that provide connection between information from imaging devices and treatment devices. Uncertainty is a significant component of complex systems and in health care much of the interaction is mediated by devices and technologies which highlight the need for cognitive ergonomic considerations.

Technologies are often seen as an important solution to improving quality of care and reduction or elimination of errors (Bates & Gawande, 2003) and new digital technologies such as surgical navigation are changing clinical working systems. However, the manner in which new technology is implemented is as critical to its success as its technological capabilities (Eason 1982; Smith & Carayon, 1995) and a significant characteristic of the technologies is the usability of the device essentially by means of end user involvement in design and implementation of new technologies to ensure user acceptance and successful outcomes.

Significant challenges are faced by medical practitioners learning complex technical procedures such as colonoscopy, endoscopy, or cholecystectomy, and many of the skills required for these procedures are now learned through simulation processes. However, problems arise when the simulation processes have been developed without human factor analyses of the motor and perceptual tasks involved in performance of the procedure (Zupanc et al., 2009).

A rapidly expanding area of health care is in the area of telemedicine where delivery of services is via various communications and data channels allowing access to specialist consultation in remote geographical areas. Again, human factors issues arise with technology component compatibility, feedback and real time information processing. Similar technology has been introduced into the resource industry with capabilities for problem diagnosis/maintenance of remotely located automated equipment.

### 7.4. MATERIALS HANDLING

Generally, automation in this area has been developed to remove or minimise the requirement for operators to perform manual tasks, including human handling, therefore typical tasks for automation include the movement and stacking of containers, and clearing of debris following natural disasters. The autonomous machine must be capable of mapping a changing terrain and localizing itself within that environment, recognizing and tracking objects, localizing objects to enable accurate pick-up and placement of load, able to perform short and long term planning, and able to react to external changes to the environment.
Examples of this technology include the Hot Metal Carrier (HMC) utilized at smelters, and the AutoStrad container automation system at the Patricks Wharf facility at the Port of Brisbane. Durrant-Whyte (2010) was responsible for a technological revolution in Australian container terminals has developed an autonomous robot straddle carrier for automated movement of shipping containers in port. Using a combination of machine automation and remote control to enhance productivity and reduce wear and tear on the equipment, the system features motion control and navigation systems enabling it to move and stack containers either into a holding yard or onto waiting vehicles. Whilst the system operates in Brisbane, the control room is located in Sydney.

7.5. AERIAL ROBOTICS, AEROSPACE SYSTEMS AND UNDERWATER ROBOTICS

Deep-space probes and communication specific satellites are fairly commonplace now. These devices have provided much information for human remote supervision of computer-intelligent devices with their own sensors and actuators (Sheridan, 2002). Robotic automated systems have been developed for intelligent surveillance machines used for the detection and classification of vegetation, as well as information driven actions for improving classification and mapping of remote marine environments (the Warren Centre Report, 2010). The ability of these systems to conduct geo-referenced, high resolution, repeatable surveys of remote marine habitats, in particular those beyond diver depths, represents one of the key contributions of recent advances in AUV (Automated Underwater Vehicle) systems. Similar technology is likely to be employed in systems associated with remote mining operations.

7.6. NUCLEAR POWER PLANTS AND PROCESS CONTROL

Process plants are increasingly run by automation, and were among the first large-scale systems to be controlled in this way. However, when malfunction occurs that threatens safety, there is a tendency to try to improve safety by simply adding more automation. Sheridan (2002) stated that with one nuclear plant malfunction simulation he counted 500 displays that changed in the first minute and 800 in the next. Often additional technology may correct the original problem, but produce other problems, not the least of which is greater complexity and less predictability and understanding by the human operators.

As an example, the Three Mile Island disaster core meltdown partly occurred because operators were confused about what was happening. This in part was due to the complexity of operating the plant and illustrates that the operators could not effectively handle the various and voluminous information from the alarms, indicators, and control devices activated during emergency conditions.

Research by Gilmore, Gertman and Blackman (1989) into human factor issues and automation in process control further supports this explanation of the Three Mile Island events. In a review by Chang et al (1999) of a new nuclear plant developed under strong safety principles rather than production principles from inception - largely because of the potential consequences arising from the accidental release of radioactive materials, they found human factors considerations had been significantly incorporated into the design of the control room.
layout and information presentation, however concerns with design issues frequently associated with human factors in advanced control rooms were identified within the initial design. Their findings support other research findings including increased operator cognitive workload associated with managing the interface, difficulty navigating through and finding important information presented in the visual display unit, difficulty understanding how the advanced systems worked, greater shifts in operator workload in the event of a computer failure, and loss of operator vigilance, pattern recognition, ability, and skill proficiency.

7.7. MANUFACTURING

Manufacturing industries have long obtained the key benefits of automation with individual robots previously developed specifically for assembly, handling, machine tending, packing, palletizing, painting and welding. However, automation in the manufacturing industry is not without problems (aside from the potential for defective parts), as in other domains significant human factor issues arise with managing the many variables in the system including monitoring, scheduling and intervention in the case of machine failure (Sheridan, 2002).

Research by Co et al. (1998) indicated that advanced manufacturing technology changed both the way management viewed its work, and the morale and performance of the workers. This they argued translated to a necessary shift in management style from didactic to participative as managers were required to interact with higher-educated and higher skilled workers. The resultant impact on the workforce included changes in the technical complexity of the job and skill level required, and the fear of being made redundant. The rapid technological changes associated with automation in the minerals industry are bringing similar challenges and these will likely impact heavily on the skill levels and educational requirements of the mining workforce of the future (McAree and Lever, 2010).
8. AUTOMATION IN THE MINING SECTOR

8.1. EARLY MINING AUTOMATION WORK

In mining, progress in automation began during the 1960’s. Three stages of automation were identified by Konyukh (2002). The first unmanned underground mining rail carriages came into production at General Blumenthal mine in Germany in 1967, and this driverless technology was rolled out through the 1970’s in Europe and the United States. Automated drills were being developed in the US at this time also. The second stage of automation involved introduction of remote-control underground ore-extraction machines in the mid-1970’s. These machines were controlled by operators on the surface with the aid of two cameras. The third stage came in the mid-1990s when hard rock mines adapted some technologies developed by the coal industry. They used remote control from the surface of their load and haul machines or “boggers”. Additionally, automatic shotcreting machines and rock-bolting devices became remotely controlled, however these machines were still reliant on a human operator to guide the machine.

8.2. SYSTEM VS COMPONENT LEVEL AUTOMATION

Currently most automation effort is concentrated on the component or subsystem level providing semi-autonomous operation, and is engaged on a small scale relative to the number of mines, processing plants and export facilities in Australia. It is often very difficult to retrofit automated technology to existing equipment. However, in the next five years, it is likely the integration of semi-autonomous subsystems will allow for increasing focus on automation at the system level.

As the reliability of autonomous equipment is enhanced there will be a gradual shift of focus to the automation of unit operations. Today, various degrees of automation exist across mine sites – minimal (remote operated machinery on the ground), partial (control room/subsystem–wash plant maintained by a central control room), and fully autonomous or integrated (truck, digger, rail fleet operated autonomously from a remote location off site). Researchers envisage integration of multiple pieces of equipment will eventually lead to fully autonomous operation cycles such as dig, load, haul then dump (McAree, 2009), and new automated equipment will be sourced as a “plug in” to the existing mine operation system.

8.3. THE USE OF SCANNERS AND ROBOTS

Automation in mining now uses scanners and robots extensively. Designed to function in place of humans and carry out a variety of tasks automatically or with a minimum of external control, utilizing integrated sensors and control systems fitted onto existing and new mining equipment theoretically enables a machine to perform a particular task or tasks without human control (CSIRO Earth Matters, April 2010).

Autonomous machines need sensors to locate and orientate themselves, requiring navigation and guidance technology including lasers, mm-wave radar and computer vision for monitoring mine geometry, and stand-alone safety systems for various semi-automated activities.
Mining robots differ from those used in manufacturing processes, where components are conveyed to the robot, assembled and the product conveyed away from the robot. In mining the robot needs to move to and around the work areas to perform its task. Examples of these types of robotics are the automated Load-Haul-Dump, automated dragline swings, rope-shovels and hydraulic excavators, autonomous blast–hole drilling equipment.

Concrete examples of this technology include the system developed for underground coal mining where cutter location is determined and design pillar dimensions are maintained while ensuring maximum coal recovery, the 3D navigational control system for the long-wall process, and also the automated roof bolting systems. In hard rock mining a navigational system has been developed for the autonomous Load-Haul-Dump.

8.4. UPTAKE OF MINING AUTOMATION

There is a general view that the mining industry is slow to adopt new technologies (Tilton, as quoted by Bellamy & Pravica, 2010), however research indicates a substantial increase in the uptake of automated and semi-automated technologies.

McAree (2009) summarized what he sees as the emerging trends for mining automation in the CRC Mining Annual Report 2009. For surface mines, he believes key activities will focus on excavation and loading, and producing outputs that incrementally deliver autonomous rock loading. For underground applications he sees key activities will be directed to enhance situational awareness – from which the output will be an operator decision support tool that improves energy efficiency and mine vehicle safety. He indicates research and development will be undertaken with major equipment manufacturers to deliver these in a form ready for the industry to use.

8.5. CURRENT TRENDS IN MINING AUTOMATION

A current CRC Mining Automation Program has identified and addresses four gap areas they believe must be bridged for successful automation uptake (McAree and Lever, 2010):

(i) Control strategies must be developed to enable automated machines to operate interdependently with other equipment;

(ii) Situational awareness capabilities must evolve to the point where they can replace the many and varied functions performed by human operators;

(iii) Technologies are required that enable effective integration of automated machinery into mine systems; and

(iv) Workforce skills must be enhanced to support deployment of high-end automation technologies.

Much of the development work to date has been on technologies to improve the “manned mining system” but the focus now is on building the “autonomous mining system”. This is largely driven by mining companies looking to increase productivity and utilization as well as safety, however as mentioned previously, other reasons to look to autonomous mining are the
ability to reduce infrastructure costs, achieve process consistency and a counter measure to critical labour shortages. 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, McAree & Lever, 2010).

In general, while developed mainly for safety or efficiency reasons, automated and new technologies have been summarized into the following broad categories Horberry et al (2010):

- removal of operators from hazardous situations;
- lower costs of production;
- requirements for enhanced precision (as with automated blast hole drilling); less environmental impact;
- ability to mine previously inaccessible areas;
- more data and information available and
- reduced manning of equipment (although as discussed previously, automation does not fully remove the human)

Opinion is somewhat divided within the mining sector as to whether the future of mine automation will be directed by current surface mining technologies for application above ground – for example in the next decade it is anticipated large scale open pit automation trials will gain momentum (Bellamy & Pravica, 2010), or underground mining which is not seen to be burdened by the legacy of open pit solutions and appears by some to be better positioned for the uptake of new mining technologies (Goddard, 2011).

The key issues leading to the development of automated systems are usually cited as safety and economic improvement and while mining companies are constantly looking at productivity and utilisation, safety has now come to the forefront with today’s mining company CEOs judged on the mines’ safety performance like never before (Murphy, 2010). Other good reasons to automate within the mining sector are to reduce infrastructure costs, to achieve process consistency and to counter labour shortages which are expected to become critical in the not too distant future.

Recently Cunningham (2010) commented on what he saw were the main challenges to introduction of automated equipment in the mining sector. He commented that successful implementation varied depending on the level of infrastructure installed to cater for the equipment and mine management commitment and “buy in” across all management and staff levels. He discussed the problems with the changing expectations on the workforce, how the work of the future would be undertaken, and the challenges with introducing automation into a production environment and the acceptance of that technology within the work environment. He predicted there would not be significant changes over the next few years as changes take a long time to occur, but that there would be increased uptake of the currently available technologies and equipment, and more interest from mine management in change in perception of what might be possible within individual mines.
An additional factor that may influence the uptake of new technologies is the lead time to develop and commercialize new equipment. In the mining sector this is often between 7 and 10 years. Many companies have a short term financial quarter focus, and more often now mines operate for less than 10 years (Bartos, 2007).

In a different vein, Durrant-Whyte (2010) believes that drawing parallels from changes in other areas such as the aerospace sector over the past decade indicates that the true benefits of automation will only be fully realized through an integrated system. He believes automation will change mining in the following ways:

1. Effective use of real time information will change the mining process to a more precise and predictable operation.
2. Automation will minimize the human operator being located on site, especially in repetitive and potentially hazardous activities such as truck driving and drilling. Skilled operators, geologists and mine planners will increasingly be located remote from the site itself.
3. Mining in areas which would otherwise not be viable will become possible and mined more selectively with lower environmental impact than currently possible.

Similarly, Rio Tinto has embarked on perhaps the most extensive implementation of automation technology seen in the resource industry so far. The “Mine of the Future” program has already led to the establishment of a full-scale trial of autonomous and remotely operated equipment in the Pilbara region of Western Australia. Key automation technologies include the Komatsu “FrontRunner” autonomous truck dump system and the autonomous blast-hole system. Driverless trains will transport ore from the mine to the shipping port, and equipment will be managed by RioTinto’s Remote Operations Centre 1300km away in Perth.

Much has been written about time and cost saving aspects of the operation – absence of driver fatigue, increased safety, the ability to use the equipment in potentially unstable areas, better operations in a challenging work environment, the ability to overcome some of the lost time of blasting practices, and enhanced energy efficiency by reducing variability in the operation of the equipment. However, a major consideration in the overall success of automation in the mining sector is ensuring that those responsible for operating and supporting the technology have the knowledge, skills and ability to do so.

The overall skills and knowledge requirements of the workforce of the future is outside the scope of this review, however the recent report by the Mining Industry Skills Centre’s Automation for Success Report has brought to the forefront many of the issues threatening the sustainability of increased automation implementation (McAree & Lever, 2010). The research is the outcome of a study undertaken by the Cooperative Research Centre for Mining (CRCMining) to identify the impacts of emerging automation technologies on skill requirements for workers and maintainers of the equipment. In brief, these findings indicate a skills gap associated with automation that is expected to widen with time, that the skills and knowledge required is distinctive and not catered for by an existing framework, and that a
systematic framework is required to bridge this gap. The difficulty lies in ascertaining exactly what constitutes the skills and knowledge that will be required to operate and maintain the automated equipment given the rapid technological changes in both the equipment used and the systems required to operate it.

8.6. FUTURE TRENDS IN MINING AUTOMATION

Based on the above review of current trends, the following future trends in mining automation can be hypothesised (based in part on McAree and Lever, 2010):

- An increase in distribution and scale of automation - a wider penetration of automation. Currently automation is engaged on a small scale relative to the number of mines, processing plants and export facilities in Australia.
- The rate of automation uptake is likely to be greatest over the next 15 years
- A growth in the scale of automation – currently most effort is concentrated on the component or subsystem level providing semi-autonomous operation. In five years the integration will likely allow for increasing focus on automation at the equipment level. As reliability of autonomous equipment is enhanced, there will be a gradual shift of focus to the automation of unit operations. The integration of multiple pieces of equipment will lead to fully autonomous operations cycles such as dig, load, haul and dump. Preparation must respond to the subtly changing technology focus that the different scales of automation will bring.
- Over next 5 years currently developing technologies will be on the market. In addition a general advancement in the features and capabilities of existing devices and components.
- Over next 15 years focus will be on 6 main technology fields: communication, sensing, computing, actuators, electronics, and safety systems.

The forces driving automation appear to be coming from the four areas - the corporate area (looking to optimize efficiency); the OEM’s (looking to provide products to resource industries, and product differentiation to increase market share); the site workforce (technicians seeking the most efficient, reliable and least expensive solutions to their problems), and the technology researchers and developers (industry seeking advancement of technologies through research, development and demonstration as well as specific site problems) (Horberry et al, 2010).

Overall, the worldwide resource industry (at least in industrialized countries) is being transformed by its increasing use of automated technologies. At one end of the scale, this revolution is happening organically, leveraging off-the shelf technologies to incrementally improve the control of various mining processes in line with best industry practice, and the other end are some strikingly bold initiatives currently in progress to implement fully autonomous mines. Between these extremes is a spectrum of innovation that stands to profoundly change the industry over the next 15 years. It is argued that now is the critical time to plan for the future skill requirements of an automated industry to avoid a skills shortage of specialized employees and be unable to implement efficient technologies (McAree & Lever, 2010).
The implementation of automation must be accompanied by effort directed at supporting a company’s workplace culture in their acceptance and management of the uptake of automation (Sheridan, 2002). The resource industry has a conservative history, and the implementation of new technology and processes must overcome a well established culture and mindset. This requires strong leadership and influence at senior management level, a need to maintain resilient leadership skills, develop supervisor skills and ensure talent development processes are established as part of the progression to enable industry and sites to be prepared for change management. It is critical for personnel to understand the reasoning behind automation, both the benefits of automation now and the positive impacts this will have on the future of the resource industry. The financial cost involved in automation is substantial, and therefore a significant level of understanding is required to provide a stable platform from which to implement the desired changes.

8.7. LIKELY HUMAN FACTORS ISSUES WITH MINING AUTOMATION

It appears from the literature presented above that the more specific human factors problems and challenges associated with automated equipment are very similar to those encountered in other industries. These especially concern both the design (eg of interfaces) and deployment (e.g. operator acceptance) of technologies.

In terms of addressing these human element concerns, a risk management framework is frequently adopted in contemporary mining using Human Factors to guide the application of the principles and knowledge to any particular technology design problem. Assuming that the outcome of the risk assessment is that action is indicated, the risk control phase incorporates identifying and evaluating potential control options, before implementation and ongoing review. By establishing an understanding of the broader context in which the person–equipment interaction takes place before undertaking hazard identification and risk assessment, from the Human Factors perspective, the emphasis for risk control is on elimination or reduction of risk through design controls rather than focusing excessively on administrative controls such as training, selection or personal protective equipment.

This above process also places emphasis on consultation with the people concerned. The issue is at the heart of ‘participative ergonomics’ approaches, which take as an underlying assumption the notion that the people involved are the ‘experts’ and must be involved at each stage of the risk management cycle if the process is to be executed successfully. Evidence exists to demonstrate the effectiveness of such approaches across industry in general and in mining in particular (described in Horberry, Burgess-Limerick & Steiner, 2010). The challenge for the human factors community will be to adapt this approach to the radically different tasks and ways of working that automated mining brings.

Humans whether operators, maintainers, trainers, supervisors, or managers are a central part of the mining system rather than an optional extra (Billings 1997; Sarter & Woods, 1994; Wiener, 1989). Thus, developing operator-centred approaches for the design and integration of new/automated mining technologies is a key priority area.
9. CONCLUSIONS

As noted above, this literature review suggests that the specific human factors problems and challenges associated with automated mining equipment are very similar to those previously encountered in other industries. In summary, they include (adapted and extended from Horberry et al, 2010):

- Poor operator acceptance of new technologies/automation after they are introduced.
- Poor human factors design of equipment.
- Problems with integration of multiple warnings/alarms.
- Lack of equipment standardization.
- Inadequate operator and maintainer training and support.
- Over-reliance on the technology by operators.
- Organisational issues - introducing new technology often changes the nature of the tasks to be performed, so a careful analysis of the new operational and maintenance tasks is a vital early step in ensuring that organizational issues are addressed.
- Behavioural adaptation / risk homeostasis - as found in other domains, the introduction of automation and new technologies can sometimes result in operators engaging in more risky behaviours in automated systems.
- Operators being outside of the system control loop.

Successful automation is more than just replacing humans with control systems to operate machines. It involves both positive planning and an iterative approach to the redesign aspect of both machines and processes to gain the full benefits of the potential strengths of both people and automation technologies.

The redesign must take into account the environment in which the machine operates and the expectations of people involved in the process. It should be consultative in design with potential operators as well as engineers. It requires system integration and skills in many areas of engineering and communications as well as practical experience with mine operations to ensure requirements for robustness and intrinsic safety, equipment maintenance and operator acceptance are carefully thought through. Adopting a user-centred design process and involving operators at all stages of technology development and deployment is the ultimate recommendation of this report.
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