

# Mining automation human-systems integration – CMOC-Northparkes case study

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## ABSTRACT

Automation offers the mining industry great potential for improvements in productivity and safety. However, the experience of introducing automation in other industries has been that the full potential of new technology is not always realised. Designers are surprised, for example, to find that automation does not eliminate human errors. Unwanted and unexpected consequences also arise if the introduction of automation fails to consider how people will adapt to the new technology. A focus on the technical aspects of automation is necessary but not sufficient for success. The potential for improvements in productivity and safety promised by automation will only be achieved if the joint cognitive system that emerges from the combination of humans and automation is designed to perform the functions required for system success. This case study describes the human factors issues associated with the introduction of automation generally, and describes a case study of the successful implementation of loader automation at Northparkes mine.

Information obtained through a site visit and interviews with operators, safety staff and the project manager revealed the following strategies for successful design and implementation of the automation system:

- involve the people who will be impacted
- encourage constant communication between operators and designers
- provide operators with essential information
- avoid providing non-essential information
- provide the operators with flexibility
- empower operators to take action
- take advantage of the new possibilities automation provides.

## INTRODUCTION

Automation can be defined as technology that performs a function previously carried out by a person (Parasuraman and Riley, 1997). It has the potential to allow the joint human-automation system to achieve levels of performance and safety which are otherwise impossible. For example, the introduction of mechanical cutting of coal to replace manual labour was an early form of mining automation. Examples of automation introduced to mining more recently include: software for mine planning and enterprise optimisation; pedestrian proximity detection systems interlocked with underground continuous mining machines; automatic face alignment and horizon control of underground coal longwall equipment; automatic cutting cycles of continuous mining machines; automation of swing, dump and return phases of the shovel loading cycle; automated drilling systems and automated haul trucks at surface mines; and automated haulage in underground metal mines, an example of which

is the subject of this case study. Human-systems integration is the process by which human characteristics, abilities and limitations are incorporated within the design life cycle of such systems to optimise performance and minimise costs (Booher, 2003; Burgess-Limerick *et al*, 2011).

## HUMAN SYSTEMS INTEGRATION ISSUES IN AUTOMATION

The addition of automation does not eliminate people from the system. Rather, the roles of people are changed and new tasks are introduced. The importance of these new tasks are frequently underestimated, particularly the need for people in the system to respond to unanticipated situations which may include malfunction or failure of an automated component of the system.

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## Changing roles of people in the system

Automation sometimes changes the role people play in the system from continuous active control of a system component to passive supervision or monitoring. One consequence of this change can be degradation of the manual control skills of operators. Introducing automation can also change the type and extent of information available to equipment or plant operators by removing them from direct contact with the process being controlled. This reduces the sources of information (visual, auditory, haptic, olfactory), which may be used to monitor the system, and in particular, to detect and diagnose the causes of departures from normal operation. Both the change from manual control, and the reduced information directly available to the operator, potentially leads to loss of situation awareness and response delays in the event that a human operator is required to take action in response to the system being perturbed beyond its normal operating range.

## Maintaining situation awareness

A challenge for the designer is to ensure the operator maintains situation awareness by determining what information is required by the operator and how this may be provided without overwhelming the operator with data. The design of the interfaces by which information is conveyed becomes a critical concern. Combining data into meaningful information through the creation of visual displays with emergent properties which correspond to system relevant parameters is one approach which may be helpful, as is placing information in a meaningful context (indicate allowable ranges, for example), and/or integrating automation-related information with traditional displays (see for example Flach *et al*, 1998). Displays should avoid the need for the operator to undertake mental transformations to gain meaning from the information. Other options are to create interfaces which predict future states of the system, and/or provide information through multiple sensory channels.

## Avoiding 'clumsy automation'

A potential trap associated with the design of automation is so called 'clumsy automation' (Wiener, 1989) in which easy tasks are automated while complex tasks are left for a human operator, sometimes because they are too difficult to automate. This can exacerbate the loss of situation awareness issue noted above. It can also mean that workload is reduced during already low-workload phases of work, while remaining unchanged, or even increased, during high-workload operations because of the cognitive overhead associated with engaging and disengaging automation (Kirluk, 1993). The choice of which of the functions currently performed by humans should be automated is a non-trivial question which deserves careful consideration. People are good at perceiving patterns. They adapt, improvise and accommodate quickly to unexpected variability. People are not good at precise repetition of actions, or vigilance tasks. However, designing the system requires more than allocating functions to person and machine – rather the challenge is to identify how the operator and automation can jointly perform the functions required for system success.

## New types of errors

The potential for new types of errors, such as configuration errors or errors arising from mode confusion, may be introduced by adding automated components to a system. At the same time, the span of control of an individual operator

is likely to be increased. Delays in the operator receiving feedback resulting from actions, including errors, may be increased. If a reduction in crewing occurs as a consequence of the introduction of automation then there is also reduced redundancy which reduces the probability of error detection and correction. Catastrophic outcomes can result from this combination of automation consequences.

## Human responses to automation can have unanticipated consequences

The response of humans to the introduction of automation can also lead to unanticipated consequences. One dimension of the human responses relates to the trust the human operator has in the automation technology. Operators may come to be complacent and over-trust the automation, either failing to note and respond to automation failures (particularly when such failures are rare) or altering behaviour in ways which reduce the intended safety benefits of automation. For example, the proposed introduction of pedestrian proximity detection technology interlocked with the braking systems of underground coal haulage equipment could potentially lead to operators and pedestrians taking less care to avoid interactions, with potentially fatal consequences. Conversely, lack of trust in automation may lead to operators disengaging, disabling, or ignoring the technology. A high rate of false-alarms is a threat to the introduction of any proximity detection technology, and in general the failure of technology to improve short-term productivity is a threat to the adoption of the technology.

The change in operator roles associated with the introduction of automation can also be problematic if the operator's job satisfaction is reduced. The key here is to allow operators to leverage old skills into new ones, as well as involving operators in the automation design and implementation process and empowering them to have an ongoing role in improving the system.

## LOADER AUTOMATION AT CMOC NORTH PARKES MINES

The aim of this case study is to investigate the successful implementation of loader automation at China Molybdenum Co Ltd (CMOC) Northparkes mines through presenting information gained through observation and interviews with operators and CMOC Northparkes mines staff. CMOC Northparkes mines is a copper/gold block caving operation in central New South Wales, Australia, which commenced mining in 1994. The mine is owned by CMOC (80 per cent) and Sumitomo Group. The mine was previously owned by a Rio Tinto subsidiary. Teleoperation, and subsequently automation, of the underground loaders has been trialled in various forms at the mine since 1998. Implementation of the Sandvik Automine system currently in use began in 2010.

Operators located in a surface control room load ore at drawpoint using manual teleoperated control (Figure 1). The loader is then switched to automated mode to travel to the run-of-mine bin where the ore is dumped autonomously. The loader then autonomously returns to the next drawpoint selected by the operator. Each of three operators is typically responsible for three loaders. The operators' interface with the system is via three screens, keyboard and mouse, as well as joysticks and pedals, which mimic the controls found in a manually driven loader (Figure 2). Audio from the loader is available to the operators, and the operators communicate with other crew members underground via radio. One screen (Autonomous Control System) provides the operators with



FIG 1 – Surface control room layout with two autonomous loader operators located at the front of the room.



FIG 2 – Autonomous loader workstation.

information and control over the overall system, while a second (Mission Control System) allows the operator to monitor the location of loaders, select loaders for manual control, and modify the drawpoints to which a loader will travel autonomously. A third screen provides a video feed from the loader (switchable between front and rear) and a schematic 'teleoperation assist' window, which provides an indication of the location of the loader being controlled or monitored relative to the laser scanned surroundings (Figure 3).

As well as undertaking manual teleoperated loading at the drawpoint, the operators are also responsible for monitoring the overall system status and making decisions in response to events such as loader breakdowns, typically modifying the planned sequence of drawpoints. The operator can also modify the behaviour of the loader during autonomous phases. For example, if a section of roadway has deteriorated, an operator can highlight the roadway section via the Mission Control Interface and set a reduced maximum

speed for the loader during the autonomous travel in that section of roadway.

Implementation of the autonomous loaders has reduced the exposure of operators to a range of injury risks, particularly whole-body vibration and musculoskeletal injury risks. Productivity benefits include the ability to continue to mine through shift changes and blasting, resulting in a 23 per cent improvement in daily tonnes produced. Information obtained through a site visit and interviews with operators, safety staff and the project manager revealed the following strategies for successful design and implementation of the automation system.

### Involve the people who will be impacted

Involving the people who will be impacted by the change was seen as critical. An initial step in the implementation of the current automation system was for representatives of all stakeholders to spend three days mapping out the consequences of the proposed automation for all tasks undertaken across the mine. It became clear during this process that all underground tasks would be affected. For example, at shift change the impact of the introduction of surface control of loaders enables production to continue. This removes time pressure to execute the change, allowing greater time to be spent in shift handover and planning for the new shift. However, it was noted that access to, or through, sections of the mine where autonomous loading was in operation would be prevented, which impacted on the performance of a range of other tasks.

### Constant communication between operators and designers

Constant communication between operators and designers throughout the implementation and subsequent operation of the autonomous system has been critical in developing and refining the user interface. The continuous presence of manufacturer expertise on-site allowed a rapid feedback loop with designers.



FIG 3 – Video feed and ‘teleoperation assist’ window provided to operators.

### Provide operators with essential information

Providing operators with opportunities to suggest modifications to the system has been a key feature in the success of the automation implementation. Operators continually update a list of issues, and a ‘wish list’ of improvements, which are fed back to the system designers, and many changes to the system have resulted. For example, equipment damage was occurring because the loader was hitting the walls of the drawpoint while under manual control. A suggestion made was to use the laser scanners already in place for autonomous navigation to detect the proximity of the walls during manual operation and to convey this information to the operators through changes in colour of the scanning information provided on the teleoperation assist window. This information was also used to automatically apply the loader’s brakes prior to the loader hitting the walls.

Similarly, wheel spin causes damage to the loader’s wheels but was hard for operators to detect while loading remotely. A wheel-slip detection sensor was added and an indication of wheel slip provided to the operator through a change in colour of the schematic loader wheels in the teleoperation assist window. In both cases the presentation of relevant information to the operators in a meaningful way ensured the information could be used effectively to reduce equipment damage.

Relevant information is also conveyed inadvertently, rather than by design. One operator explained that it can be difficult to gauge when the bucket has been lowered sufficiently to the ground in preparation for loading. If too much pressure is placed on the ground by the bucket, the loader’s front wheels will raise and wheel slip occurs. The operator noted that the camera shake which could be seen on the video feed when the bucket was lowered was a useful cue.

### Avoid providing non-essential information

Conversely, another change made was to reduce the number of loader fault alarms presented to the operator. Many of these alarms, while relevant to an engineer during commissioning, are not relevant to the day-to-day operation of the loader. As well as being a nuisance to operators because each message required acknowledgement, being habituated to frequent non-essential error messages led on at least one occasion to an operator failing to react to a critical error, with potentially serious consequences. Presenting only essential information is another human-centred design principle.

### Provide the operators with flexibility

Providing flexibility in information provision is another strategy. In this case, the loaders are fitted with a microphone, and the audio is available to the operators, however this information is not wanted by the operators and the audio is not switched on because the nuisance value of the noise outweighs the benefit of any relevant information conveyed. Opportunities for improving the provision of information to the operators are continually being explored, for example, the camera system will be updated to high definition.

Many details of the automation implementation were left to production crews to determine. For example, in the transition to autonomous loading, some crews decided to ensure all crew members were trained for autonomous control, while others chose to have specialist autonomous operators. The number of loaders for which an operator should have responsibility was also determined by the crews. While four loaders can be controlled by one person, the cognitive load was overly fatiguing and three was determined to be optimal. During operation, some crews choose to allocate three loaders to be controlled by each operator, while other crews allowed more flexibility, with all loaders able to be controlled by any of the three operators on shift at any one time.

Allowing crews to choose different strategies provides opportunity to evaluate different options, and comparisons between operator and crew productivity can be used to fine-tune operator strategies and identify aspects of operator behaviour which lead to improved productivity.

Interesting questions remain about the training of future operators, such as whether autonomous loader operators need to necessarily have prior experience of manual loader operation, and how new autonomous loader operators will be trained. The development of an autonomous loader simulator may be a useful technology to use to select and train future operators, who may not necessarily have an underground mining background.

### Empower operators to take action

In some cases, production crews also have taken action without involving the system designers. One issue being encountered was that the cameras and scanners were accumulating dust, which was causing the automation to fail. While the system designers were exploring options for on-board cleaning mechanisms, the crews devised a means of dumping water

on the camera and scanners when required. In another case, the mine's engineering team implemented emergency stop sensor under the loader independently of the manufacturer as an additional safety feature.

Making all aspects of the control system and flexible as possible and giving operators maximum control over the automation increases the degrees of freedom operators have to adapt to new situations. This potentially conflicts with design engineers' natural tendency to constrain the system and restrict operator discretion.

### Take advantage of new possibilities

The implementation of autonomous loading has also had unanticipated consequences for future process improvements. The ability to more flexibly execute different drawpoint extraction patterns, and modify these extraction patterns, has prompted the development of optimisation software to determine in real-time the optimal pattern of extraction. This is itself a form of automation which will provide assistance to the shift-boss in maintaining situation awareness of the extraction and aid in decision-making.

### CONCLUSION

The successful introduction of new technology requires consideration of people who interact with the technology. Introducing increased automation into the mining industry

will only result in improved productivity and safety if the joint system that emerges from the combination of human and automated components is designed to function as a whole system.

### REFERENCES

- Booher**, H, 2003. *Handbook of Human-systems Integration* (Wiley: New York).
- Burgess-Limerick**, R, Cotea, C, Pietrzak, E and Fleming, P, 2011. Human Systems Integration in defence and civilian industries, *Australian Defence Force Journal*, 186:51–60.
- Flach**, J M, Vicente, K J, Tanabe, F, Monta, K and Rasmussen, J, 1998. An ecological approach to interface design, in *Proceedings 42nd Annual Meeting Human Factors and Ergonomics Society*, pp 295–299, (Human Factors and Ergonomics Society: Santa Monica, CA).
- Kirlik**, A, 1993. Modelling strategic behavior in human-automation interaction: why an 'aid' can (and should) go unused, *Human Factors*, 35:221–242.
- Lee**, J D and Seppelt, B D, 2009. Human factors in automation design, in *Springer Handbook of Automation* (ed: S Y Nof), pp 417–436 (Springer-Verlag: Berlin).
- Parasuraman**, R and Riley, V, 1997. Humans and automation: use, misuse, disuse, abuse, *Human Factors*, 39:230–253.
- Wiener**, E L, 1989. Human factors of advanced technology ('glass cockpit') transport aircraft, NASA Contractor Report, 177528, NASA-Ames Research Center, Mountain View, CA.