HARD AUTOMATION TRENDS IN AUSTRALIAN UNDERGROUND COAL MINES

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ABSTRACT

As productivity in coal extraction demands increase in underground coal mines, the industry is faced with finding new ways to support production without jeopardising safety. In modern mines the capacity and scale of longwall coal extraction has steadily increased to a point that support processes are failing to keep pace. In particular, roadway development is continually placed on the critical path of activities which maintain mine production, so any inefficiency in this area is quickly exposed. Original equipment manufacturers are under immense pressure to modify their machines to be more interconnected with each other, with machine communication and logistical sharing of space becoming a known requirement. This paper looks at the changing trends in mining practice, analysing available technology as well as currently emerging research into hard automation and discusses the need to integrate machinery and processes in order to see increases in productivity and safety.

KEY WORDS

Hard automation, roadway development, integrated system, strata support, manipulation.

INTRODUCTION

As part of a cooperative research study involving seven mine companies and the University of Wollongong, an initial six month scoping study was undertaken in 2007 to evaluate the extent of automation in Australian underground coal mining and identify some of the technical risks in automating key processes known to be constraining mine production at that time. Ten mine sites were chosen for the initial analysis to provide a broad cross section of Australian mining conditions as well as the different types of machinery and operational standards used.

The study found that in many instances, there was high variability in mining conditions for the same process. This was mostly the result of geotechnical factors; however, many of the mines having similar geotechnical conditions also had differing machinery, operational standards, consumables, frontline management structure, workforce etc. All of these variables were considered likely to influence the success of any future automation development for the industry. Most importantly, the scoping study highlighted that although there had been advances in 'soft automation', such as digital communications, computer control (Kelly, M., Hainsworth, D., Reid, D., Lever, P., Gurgenci, H., 2003) and condition monitoring (Hill, J., Smelser, T., Signer, S., Miller, G., 1993) the fundamental design of physical machinery (hard automation) and any further opportunities to improve productivity or remove operators from dangerous conditions, had considerable short falls.

Much of the heavy machinery used in underground coal mining is based on the legacy of an evolving design, with the fundamental framework and power systems of machinery achieved through decades of development. A continuous miner is a prime example where its core function of robustly cutting and conveying coal has overshadowed any advancement in some of the other activities, such as manual handling of consumables, strata support and services installation; all of

Figure 1 - A continuous miner with material storage pods and side platforms removed

which require operators on-board the continuous miner platform. The reasons are threefold; Firstly, strata support and consumable storage was previously a secondary operation and has overtime been shoehorned onto an already space constrained miner platform. Secondly, most mine sites use slightly varying processes which result in different frame designs, differing coal haulage and differing types of strata support. Thirdly, other machinery in the immediate area has also been evolving independently and their operation and inefficiencies impact adversely on each other, making the overall process non-continuous.

Figure 1 illustrates the complexity of a continuous miner, and the lack of space available for secondary strata support operations or consumable storage. The figure particularly illustrates the challenge of adapting new physical hardware automation such as consumable manipulators.

Although the continuous miner automation has its own unique challenges, many other processes underground, particularly in roadway development, suffer from similar issues including:

1. A high reliance on manual handling and human operation;
2. The high variation from mine site to mine site including geotechnical and environmental conditions, machinery, types of consumables, logistics, workforce culture and available skills;
3. Confined roadway dimensions and limited access to working areas including conflicting directional flow of conveyed or transported materials;
4. Significant consumable installation using awkward and cumbersome materials;
5. The high quantities of consumables to be transferred, stored and manipulated;
6. Explosive environment which limits the use of standard non-approved automation devices and materials;
7. Continuous moving work stations and limited availability of power sources;
8. Adverse conditions affecting reliability – dust, water ingress, rock falls, vibration, corrosion etc.

The challenges for adapting further automation to existing machines and processes are immense and so Original Equipment Manufacturers (OEMs) have tended to toward soft automation if any improvements are made. In these instances the automation has been relatively easily applied to existing mechanised components rather than using hard automation where new automated manipulators and other moving machinery are needed to replace the human elements, often requiring high levels of innovation and possibly overall process change.

Although the challenges are great, the Australian underground coal industry, researchers and OEM's are realising that hard automation in the form of innovative mechatronic devices are needed if improved process efficiency and operator safety is to be achieved. This paper discusses some of the research and development in this area seen thus far and how collaboration is working towards solving some of these challenges.

MANUAL HANDLING

Manual handling is mostly used in the transfer, loading and manipulation of strata support consumables, but other activities include services extension, monorail installation and panel extension. All of these activities fit within the roadway development process, where other heavy machinery is operating.

In a 2009 ACARP study "Reducing Injury Risks Associated with Development Equipment" Robin Burgess Limerick (2011) found that the number of injuries reported by underground mines in New South Wales, Australia for the period July 2005 to June 2008 was 4,633 (excluding surface injuries at underground mines and well as hearing loss claims) of which 46% (2,149) were involved with equipment. Of these, 812 injuries were directly associated with continuous miners and bolting equipment on those miners, as shown in Figure 2.

Burgess-Limerick (2011) subsequently reported that consideration of the data presented in Figure 2 "... reveals that injuries most frequently occurred whilst miners were drilling and bolting, and handling bolting supplies such as drill steels, bolts and mesh. Common injury mechanisms associated with drilling and bolting included: striking part of the equipment, or being struck by falling objects such as steels, bolts, plates, or material from the roof and rib, or hydraulic fluid; strain; and some part of the person caught between moving parts of the equipment. Handling a variety of objects including bolting supplies, and especially cable, was associated with strain to various body parts ...".

Manual handling activities overwhelmingly provide the biggest opportunity to increase efficiency and reduce lost time and fatal injuries if automation was employed. In a report commissioned by Gibson (2005) and the Australian Coal Association Research Program for the "Current Status and Improvement Strategy for Roadway Development", one of the major constraints to roadway development rates was noted as being the installation of roof and rib support. When surveying 35 Australian underground mines on how they would describe the effectiveness of current face roof bolting equipment and systems, almost half of the respondents (42%) rated them as being low. When asked what they considered to be the biggest constraint to improving the continuous cutting rate, 56% of the respondents ranked roof and rib support activities as the most limiting factor.

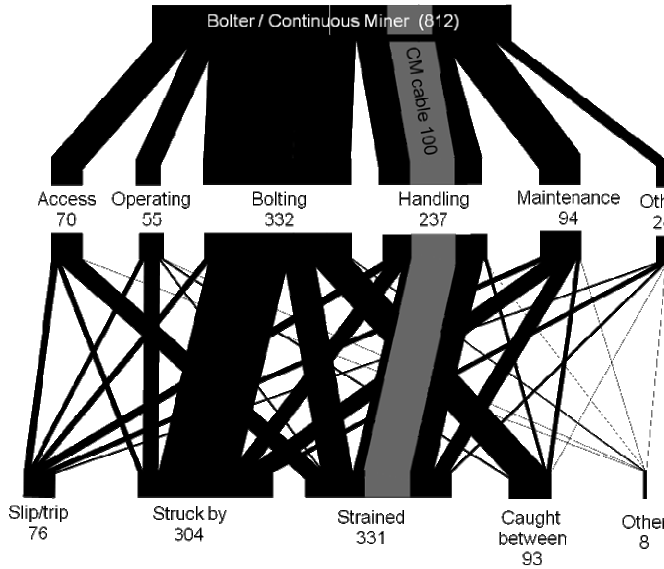


Figure 2 - Underground injury frequency by activity and mechanism for continuous miners and bolting machines for NSW mines during the 3 years to 30 June 2008 (Burgess-Limerick, 2011)

Further to this finding, the report identified that the logistics supply, transportation, distribution and handling of roof and rib support consumables are issues at older, extensive mines now, while the achievement of higher development rates being achieved will compound this issue at most mines in the future (Gibson, 2008, 2010).

The introduction of automatic machinery often prevents operators from safely working in the immediate area, and so a knock-on effect begins whereby the complete automation of the process may be required. This is difficult when the operation of equipment relies heavily on human sensory control to provide operations like tramming and steering, horizon control or drill rig positioning. It is therefore often necessary to provide new soft automation solutions, and Australia's Commonwealth Scientific Industry Research Organisation (CSIRO) are currently developing a continuous miner navigation system to provide real time position and operational information intended to assist bolting and mesh installation (Reid, D. C., Ralston, J. C., Dunn, M. T., and Hargrave, C. O., 2011). Real time sensing of the continuous miner's position relative to roof and rib support materials can greatly assist hard automation tasks in the automatic control and placement of proceeding support.

CURRENT STATE-OF-THE-ART

The recently released and yet to be commissioned Joy 12EDM (entry development miner) perhaps reflects state of the art in Australian roadway development as it incorporates electro-hydraulic roof and rib bolting rigs and a roof mesh handling system which racks forward individual roof mesh sheets to the bolter platform area where operators manually rotate and position the roof mesh sheet for subsequent installation to the roof. Even though the machine is fitted with electro-hydraulic bolters with semi-automated functions, operators are still required to insert and change-out drill steels, install roof and rib bolts in the drill chuck, and insert the chemical anchor cartridges in the bolt-hole prior to inserting the bolts. Furthermore, operators are required to handle and install the rib mesh sheets, and to rotate and position the roof mesh modules.

Joy have demonstrated an eight position roof bolting carousel system which holds four conventional resin anchored bolts and their associated resin cartridges (or potentially eight self drilling bolts). The system was developed in conjunction with their electro-hydraulic bolter, and essentially automates the conventional resin anchored bolting process albeit the carousel needs to be manually reloaded. Joy has since chosen to focus their efforts on development of the electro-hydraulic bolter and its fitment to the 12EDM miner platform rather than continue development of the bolting carousel system. It is noted that Sandvik has similarly developed a semi-automated electro-hydraulic bolter while Down Under Control recently demonstrated a hydraulically actuated semi-automated bolter control system.

The recent introduction of Hilti Onestep self drilling bolts (Bayerl, M., Danzebrink, B., Thyrock, K., Opolony, K., Gollnick, I., 2009) or the Novobolt (formerly Peter Gray or GSS self drilling bolt currently under trial) (Gray, P., Hawker, R., Sykes, A., Tadolini, S., 2009) has shown that the drill steel/bolt changeover process and chemical anchor cartridge insertion can be eliminated from the bolting cycle thereby improving operator safety and bolting cycle times. It is understood that Hilti are currently working with Sandvik and Joy to adapt the respective electro-hydraulic bolter drives and controls to accept the Onestep bolt, while Joy are involved in underground trials of the Novobolt on their new electro-hydraulic bolters. Both self-drilling bolts remove a number of steps in the installation process and therefore are well suited to fully automated installation.

Fletcher produces a mobile bolter which incorporates a winching mechanism that allows a mesh module to be drawn onto the back of the machine to assist mesh installation during place change bolting operations. Mesh is manually handled into a bolting position and no automatic manipulation is known to exist. Sandvik similarly have a winching mechanism to load mesh modules into the roof mesh magazine although like the Joy 12EDM system still requires operators to manually rotate and fully position the roof mesh. To our knowledge, there are no continuous miner mounted automatic mesh manipulators which mechanically handle and position steel roof or rib mesh prior to bolting.

A recent development in rib confinement has been the use of rolls of light weight polymeric mesh which are rolled out in front of the rib bolting station and kept in place by the rib crash barrier until rib bolts are installed. It is understood that conceptual handling and dispensing systems using these rolls have been considered at individual mines although they have not yet been developed. Again, the concept of using rolls of mesh for roof support has been considered by individuals/mines but not progressed to fruition.

In the late 1990's CSIRO (Hainsworth, D., W., Reid, D. C., McPhee, R. J., Ralston, J.C., Corke P. I., and Winstanely, G., 2001, Kelly, M., Hainsworth, D., Reid, D., Lever, P., Gurgenci, H., 2003) attempted to fully automate the primary strata support activities at the face. CSIRO collaboratively designed a dedicated platform, the Autonomous Conveyor and Bolting Module (ACBM) which consists of three major hard automation systems:

1. A prototype autonomous feed and bolting system. The feed system was designed and constructed by IHI in Japan and demonstrated in October 1999. The feed mechanism is a mechanical underfeed system used for bolt selection.

2. A prototype auto roof bolting system was further developed by Hydramatic Engineering. Development in this area was subsequently stalled during the project.
3. A self drilling bolt with a new bulk chemical system which is described as a complete hands-off bolt installation process. The two systems were combined to form a fully autonomous feed and bolting unit that are mounted on the ACBM platform

The ACBM was designed to operate behind the continuous miner, the rationale being that a separate module machine was needed to mount the drilling units and contend with space issues. The distance from the face of the ACBM means it can only be used in a limited number of mines having the geotechnical capability to have several metres of unsupported roof before bolts and mesh are installed. At this stage, there are no plans by the CSRIO to redesign or further develop the ACBM concept.

As can be seen from the above state-of-the-art, operators are still required to be positioned at the immediate face in a confined working environment in close proximity to rotating and moving equipment. OEMs and operators alike are still reliant on engineering and administrative controls (MDG 35.1, 2010) to reduce operator exposure to entrapment in rotating equipment rather than designing out the hazard through full automation.

In 2008, the University of Wollongong (UOW) embarked on a research project of fully automating the manual handling activities on the continuous miner (van Duin, S., Meers, L., Donnelly, P., Oxley, I., 2013). The technologies developed and demonstrated in UOW's fully integrated and automated roof and rib bolt and roof and mesh handling system are, albeit at a laboratory stage, considered break-through technologies. The challenge is to bring these technologies through to industrial application. Figure 3 shows the laboratory test frame which simulates one side of a continuous miner Joy 12CM30. Figure 4 shows two examples of innovative compact hard automation devices.

The project demonstrated the ability to automate and integrate a number of disparate strata support related functions. It has also highlighted the challenge posed attempting to retrofit new technologies onto existing continuous miners within a tightly restricted mining environment. The imposed limitations of a Joy 12CM30 miner and a 2.8 m high roadway clearly limit the ability to fit any major materials storage capacity on the mining platform and therefore necessitate close examination of the materials resupply function. The automation system operates at virtual advance rate of 10 metres per operating hour and requires 1.6 tone of materials to be supplied and interfaced at the rear of the machine. This requirement exposes a complete new set of challenges outbye of the miner and potentially all the way back to the supplier, with attention to material delivery, specification and timing. As a result, Meers, L., van Duin, S., Ryan, M. (2013) are currently conducting an extended research program in an attempt to solve these issues.

INTEGRATED AUTOMATION SYSTEMS

Possibly the best example of an integrated system in a mining setting is a tunnel boring machine used in civil construction. These machines operate in conditions not too dissimilar to coal mining and similarly manage conflicting directional flow of support consumables and mined rock. Each of the individual sub-processes is highly dependant on each other, and a stoppage at one end of the process is likely to effect the entire advancement of the machine.

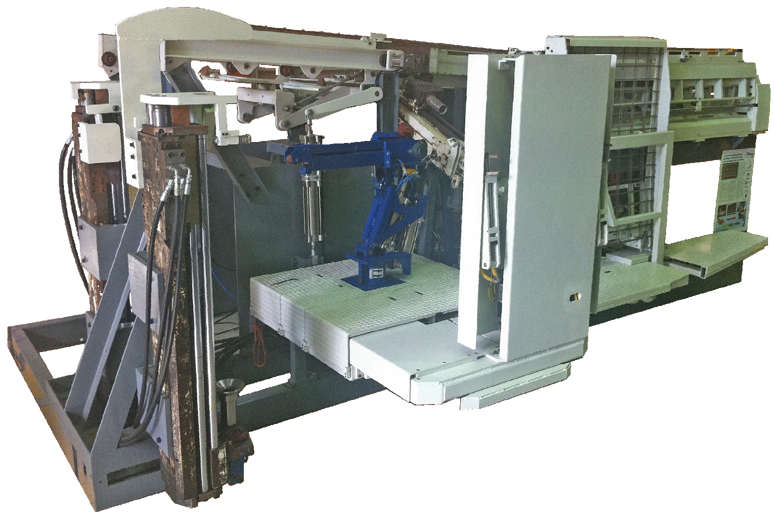
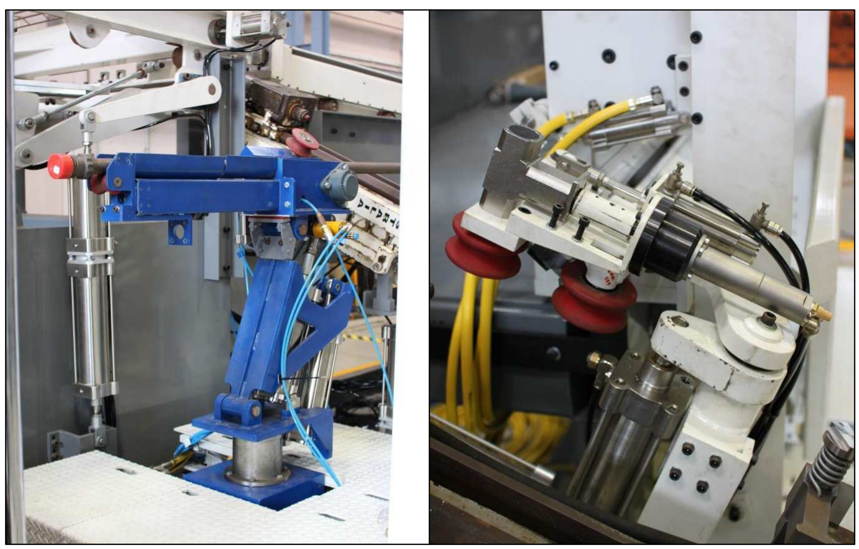


Figure 3 - University of Wollongong's continuous miner automation test frame



(a) (b)

Figure 4 - Examples of hard automation in the form of consumable manipulators: a) roof bolt manipulator; and 2) compact multipurpose bolt transfer and rib bolt manipulator

Tunnel boring machines are designed as a complete integrated system, where each individual process is monitored and coordinated interdependently. Each of the transfer points along the length of a modern borer rely on manipulation devices specifically designed to seamlessly interact, so that when a consumable is loaded at the start of the process, its capture and location is known the entire length until installation.

In contrast, underground coal mining roadway development relies on a series of independent machines, including, fixed conveyors, shuttle cars, flexible conveyor trains, continuous miners and mobile boot ends - as well as support vehicles such as LHD's and other transportation and hauling units. This mismatch of interactive equipment makes it difficult to transfer materials effectively in the required timeframes and volumes. The high level of human interaction further complicates the process, and significantly increases the chances of human error. Likewise, any attempt to introduce new hard or soft automation is limited by the impact it has on up or down stream serial processes. The result is an overall system that transfers its inefficiencies and is susceptible to new bottlenecks and further delays.

The Australian underground coal industry is now recognising the importance of a continuous integrated system and several mine companies are either using or considering using continuous haulage as alternative to stop/start batch haulage systems. Attempts are also being made to incorporate more services onto the mobile conveyors or supporting monorails as well as integrating the conveyance of consumables within these systems. Furthermore, researchers and OEMs are recognising the importance of providing better control or positional awareness at the interface points of heavy machinery, how these interact and how consumable materials and coal haulage can be effectively transferred. To complement this flow, sensing and continuous real-time state monitoring of machine operations allows complex material transfer systems to be designed and controlled.

CONCLUSIONS

The state-of-the-art of the world's automation technology has advanced so rapidly that many industries, and notably underground coal mining, are struggling to keep pace and find that the methods they still use are out of step with today's productivity expectations and OH&S requirements. To date, soft automation has been used in underground coal mining to make relatively small gains in productivity. The removal of manual handling is the logical next step if substantial gains and safety improvements are to be made.

The challenge for machine and process designers, plant managers and operational staff, is how to adapt new hard automation to old legacy machinery and processes. Although new automation solutions, in the form of manipulators and material transfer systems, have been proven in ideal laboratory environments as standalone independent systems, work still continues on finding ways to integrate automation into the entire process. The recommendations from research findings are gradually been accepted by the industry, however, the success of these systems can only be realised if mine operators are committed to changing the process and possibly consider radical new ways of developing roadways as an integrated system.

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REFERENCES

Bayerl, M., Danzebrink, B., Thyrock, K., Opolony, K., Gollnick, I., Application of Hilti One Step Bolts for roadway support in German deep coal mines, *Proc. 28th International Conference on Ground Control in Mining*, ICGCM, p 59-69, 2009.

Burgess-Limerick, R., Injuries associated with underground coal mining equipment. *The Ergonomics Open Journal*, 4, (Suppl. 2-M1), 2011, 62-73.

Gibson, G., (2005), *Australian Roadway Development – Current status*, (ACARP Report: C15005), Brisbane.

Gibson, G., (2008), Improving Roadway Development in Underground Coal Mines, *In the proceedings for the AusIMM 13th Australian Tunnelling Conference*, V1.3, 978-1-920806-80-4.

Gibson, G, 2010. CM2010 Roadway development research and development strategy, presented at *Mine Site Automation and Communication Conference*, Perth, July 2010.

Gray, P., Hawker, R., Sykes, A., Tadolini, S., New Developments in Self Drilling Rock Bolt Technology, *Proceedings - 28th International Conference on Ground Control in Mining (ICGCM) Morgantown*, WV, USA, 2009, p 161-168.

Hainsworth, D., W., Reid, D. C., McPhee, R. J., Ralston, J.C., Corke P. I., and Winstanely, G., (2001), Automation applied to a rapid roadway development system for underground coal mining, *Proc. Regional Symposium in Computer Applications in the Minerals Industries*, Tampere, Finland, pp. 23 – 32.

Hill, J., Smelser, T., Signer, S., Miller, G., (1993), Intelligent drilling system for geological sensing, *Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems*, Yokohama Japan, 26-30.

Industry and Investment NSW, Mine Safety Standards, (2010), MDG35, Guideline for bolting and drilling plant in mines, 2010, MDG 35 090831.

Kelly, M., Hainsworth, D., Reid, D., Lever, P., (2003), Gurgenci, H., Longwall Automation – A new approach, *Third International Symposium HigH Performance Mine Production*, Aachen.

Meers, L., van Duin, S., Ryan, M., (2013), Rapid Roadway Development, *30th International Symposium on Automation and Robotics*, Montreal QC.

Reid, D. C., Ralston, J. C., Dunn, M. T., and Hargrave, C. O., (2011), A Major Step Forward in Continuous Miner Automation, *Proc. of the 11th Underground Coal Operators' Conference*, University of Wollongong & the Australasian Institute of Mining and Metallurgy, 2011, 165-171.

van Duin, S., Meers, L., Donnelly, P., Oxley, I., (2013), Automated bolting and meshing on a continuous miner for roadway development, *International Journal of Mining Science and Technology*, Feb 2013.