LONGWALL AUTOMATION: ARE WE READY FOR SUCCESS?

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The ACARP Landmark initiative has created the opportunity to advance the level of automation in the coal industry by first focusing on the core production area of longwall mining. A proposal for the project has been developed and is currently being considered by the ACR Board. The major outcome of automation using on-face observation has been divided into ten outcome areas that have been fully scoped for the three-year initial project life. A major facilitating technology has been the implementation of inertial navigation system (INS) that can map the shearer position in 3D. A focus of the project is to deliver a system that is at least as productive as the current most productive manually controlled longwall face.

Background

In 2000 the ACR Board elected to set aside 1^c of the 5^c levy per tonne specifically for Landmark projects to enable the ACARP program to target a limited number of key problems and commit greater funding to their resolution. The first landmark project has been committed to the CRC for Coal in a sustainable Development. This paper describes the proposed scope of the second project on Longwall Automation.

The ACARP Research Committee has recognised the importance of increasing the levels of automation in the coal industry. As a first step, last July they invited two key science providers, the CSIRO and the CMTE, in conjunction with the ACARP Longwall Automation Steering Committee, to jointly develop a research proposal to advance longwall automation. Since that time the providers have developed a full proposal for consideration of the ACR Board. This process has included a reviews of past automation attempts, the current level of installed and utilised automation in Australian and overseas mines, the available technology for future automation and extended discussions with OEM groups both in Australia and overseas.

The final proposal has been developed under the guidance of a longwall automation steering committee and an industry expert as well as in consultation with the OEM's.

Project Aim And Outcomes

The aim of the project is to develop longwall automation to the level of on face observation by the end of three years.

The review of previous attempts at longwall automation and the use of current automation technology showed a lack of focus on exception issues from automation attempts and the imperative from operators not to lose productivity from the use of automation. In other words, automation attempts have only worked in ideal conditions. As soon as problems or "exceptions" occur on the face, operators revert to manual operation and the automation technology is disregarded. Even if the automation technology does work in good conditions, unless it produces as much coal as manual operation it will not be used. Operators consistently expressed the view that the longwall was the prime profit centre and that a high level of production consistency

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rather than manning reduction should be the focus of automation. A second focus expressed should be the removal of persons from exposure to respirable dust. Even with advanced dust control techniques, most high production faces were finding statutory standards difficult to achieve.

The achievement of full automation in all conditions requires an advanced development of sensors to replace the input from human sensors. This is in addition to the technical development required for automation under ideal conditions. The initial scope for the landmark project was developed to include both the sensor and technical development for full automation. However the costing for this full scope was larger than the funds available, and a reduced option of on-face observation was the basis of the final proposal for the three year project. Within this scope the face is fully automated, but may need operator input in exception conditions. Typical exceptions would include geotechnical issues on the face such as face guttering and mechanical issues such as broken rams etc. This outcome is significant and in many cases be all that operators require. It is also on the direct path to full automation.

The scope also includes several key sensor developments that will replace or supplement human observations. This includes condition monitoring, collision avoidance for flippers, convergence monitoring in the gateroads and preliminary AFC block-up surveillance.

There are ten key outcome areas that will be delivered by the three-year project. These are:
1. Face alignment
2. Horizon control
3. Open communications
4. OEM involvement/commitment
5. Information System
6. Components to enhance production consistency and reliability to minimise production risks in an automated environment
7. Redefined functions of face operators
8. Implementation at selected sites
9. Acceptable commercialisation plan
10. Implementation plan for progressive automation

These are described in the following section.

Program And Milestones

A work program to deliver results in the ten outcome areas listed above has been produced by the project team and adopted by LASC. The breakdown of the work and the resources through each year of the proposed three-year time frame is included in the budget spreadsheets. The project is summarised in the Gantt chart of **Figure 1**.

	Year 1				Year 2				Year 3			
	3	6	9	12	3	6	9	12	3	6	9	12
Face Alignment												
Real-time shearer position display			♦									
Chock movement controlled by shearer position				♦								
Automated creep control								♦				
Automated face alignment and creep control											♦	
Horizon Control												
Demo enhanced memory cut				♦								
Horizon control with integrated CID											♦	
Communications and Operator Interface												
Develop reliable shearer-gate end data comms				♦								
Construct driver level OEM software interface				♦								
Develop wide-band comms for non-critical data											♦	
Construct and test operator station								♦				
Collision Avoidance												
Implement void monitoring system								♦				
Site testing for collision avoidance system											♦	
Condition Monitoring and Reliability												
Reliability Analysis				♦								
FDI demo on off-line data											♦	
Trend analysis software demo on off-line data											♦	

Figure 1. Project tasks and Milestones

Referring to Figure 1, the proposed work plan under each subheading and milestone descriptions are given in the following paragraphs.

1. Face Alignment

This area of work concentrates on the geometry of the face within the gateroads. The goal is to automatically maintain face straightness by measuring the three dimensional position of the shearer in space and using that information to control the movement of the powered supports. This ability has eluded previous researchers. Shearer position measurement is performed using inertial navigation techniques, already developed to a high level by the project team. This technology has been applied extensively to highwall mining guidance and also in a successful trial implementation on a longwall face at South Bulga.

This outcome area will supply the first deliverables of the project:

Outcome	Description	Year 1	Year 2	Year 3
1.1 Realtime shearer position display (3D*shearer)	Allows accurate measurement of actual shearer position in space in real time for display on the surface. Also provides for logging for later analysis. This is a stand-alone outcome on which the remainder of the automation system will be built.	• Complete real-time shearer position measurement system (based on ACARP Project). • Develop real-time position display software.	•	
1.2 Shearer position-controlled chock movement	Second pre-automation deliverable. Enhanced shearer initiation of chock advance to move chocks to exact geometry determined by INS navigation system. Assumes availability of OEM read-rod sensors. Face system manually controlled.	Install and test chock motion system (in-kind contrib.. from mine).		
1.3 Automated creep control operational	Longwall equipment automatically steers along desired track between gateroads. First trials of automatic haulage control of shearer from remote operator station.		• Develop longwall-gateroad distance sensor. • Construct creep-control / auto hualgae software. • Field test longwall creep control / auto-haulage system.	
1.4 Sustained automatic face alignment and creep control	Automation of extraction methods e.g. bi-di, uni-di, half web etc.			Field test various cutting modes developed in 5.2

This is a relatively low-risk outcome. The various technology components, particularly those already present on OEM equipment are in advanced states of development.

2. Horizon Control

This outcome involves maintenance of the cutting operation between desired roof and floor horizons. The goal is to provide automatic horizon control responding to actual changes in seam profile. Two approaches will be used. One is to use the vertical position information available from the inertial navigation system employed in the face alignment system to greatly improve vertical control achieved in current memory cut systems. The second is to pursue sensor development for real-time coal interface detection (CID) systems

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<table>
<tr><th>Outcome</th><th>Description</th><th>Year 1</th><th>Year 2</th><th>Year 3</th></tr>
<tr><td>2.1Demon-strate enhanced memory cut</td><td>Enhanced memory cut utilises absolute position of the shearer as feedback to the existing open-loop OEM memory cut methods.</td><td rowspan="3">• Develop horizon control software based on shearer.
• Evaluate coal interface detection sensing methods.
• Survey mines for CID applicability.
• Commence development of CID sensor.
• Optical marker band detection. Pick force / vibration.</td><td rowspan="3"></td><td rowspan="3"></td></tr>
<tr><td>2.2 Site dependent interface detection</td><td>Extra information (3D seismic) added to input to horizon controller.</td></tr>
<tr><td rowspan="3">2.3 Horizon control with integrated CID</td><td rowspan="3">Coal interface detection allows fine-tuning of the cutting horizon to closer tolerances than achievable with other methods.</td></tr>
<tr><td></td><td>• Site dependant data integrated to process controller.
• Continue CID sensor development,
• Commence CID software development. Purchase NGR sensor.</td><td></td></tr>
<tr><td></td><td></td><td>• Manufacture and install CID sensor.
• Test CID horizon control.</td></tr>
</table>

Outcome 2.2 is low risk being built on components which themselves represent low technical risk.

Outcome 2.3 is higher-risk. Considerable work has been done on CID system development in the past without producing a general solution because horizon characteristics are highly site-specific. However this project will address two of the most promising areas, natural gamma and pick vibration and will examine a third principle which has not received much research attention in the past, optical following of marker bands.

3. Communications and Operator Interface

This outcome area is a vital part of the overall project, providing the physical linkage between all the equipment and system-oriented outcomes. Face alignment, horizon control, information systems and production consistency and reliability all require communication links between each other and information display to operators situated remote from the face.

Outcome	Description	Year 1	Year 2	Year 3
3. Open Communi-cations		• Develop reliable shearer / gate end communications for monitoring data transfer. • Develop mineral robust data comms system for critical real-time OEM control. • Negotiate data protocols with OEM's. • Construct driver-level OEM software interface. (In-kind OEN contribution assumed).		
			Develop wide-band comms. system for non-critical data transfer.	
				Continue wide-band comms system development.

This outcome has low technical risk. The highest component of risk is in securing the cooperation of the OEMs to contribute to an industry-wide common communications protocol. This aspect is addressed specifically in the next outcome area.

4. **OEM Involvement**

This is a key outcome for the success of the project. OEM's need to be committed to the landmark project process to enable technical outcomes to be incorporated into future machine specifications. In addition, their direct involvement in the project will assist commencing and continuing the Project at best practice.

Outcome	Description	Year 1	Year 2	Year 3
4 OEM involvement / commitment	This is a key outcome for the success of the project. OEM's need to be committed to the landmark project process to enable technical outcomes to be incorporated into future machine specifications. In addition, their direct involvement in the project will assist commencing and continuing the Project at best practice.	• Establish key contacts. • Establish IP Agreements. • Establish mutual R&D linkages.	• Maintain R&D linkages.	• Maintain R&D linkages.

5. Information Systems

There are three separate work areas under this heading. The first is the development of the operator station. Given the concept of automation applying to this project, an operator station is required close to the face to facilitate both on-face monitoring and the development, testing and commissioning of automation systems. As the automation process matures, the operator station can be further withdrawn outbye. The second is the development and implementation of the automatic longwall process comprising the design of the automatic operation sequences to be input to the control systems and the modelling of simple geotechnical inputs required for horizon control and face alignment. The third is the development of display systems to efficiently report system operation and conditions existing on the longwall.

Outcome	Description	Year 1	Year 2	Year 3
5.1 Information Systems		5.1.1. Operator station hardware implementation. 5.1.2 Stage 1 – Communications with LM and OEM hardware. **(Part of Outcomes 1&2)** • Construct operator station cabin. • Install hardware.		

		• Develop Landmark process control software. Part of 5.1 & 5.2.		
5.2 Automation sequence development / process design		Develop process maps for each cutting system.		
			Design scripts and sequences for 1.3, 1.4, etc.	
5.2.1 Seam Horizon Modelling				
Seam horizon modelling system designed	*Design a system that autonomously models a seam horizon based on sensory data from the face and equipment, and known geological and geophysical data sets. The system will be capable of intelligently comparing these data and outputting control information to guide the longwall.*		*Design an autonomous seam horizon modelling and control system.*	
System development resources procured and installed.			*Purchase and install all software/hard-ware required to develop the system.*	
System software developed.	*Build and unit test each system module as it is developed. Unit testing will be conducted according to the testing strategy.*		*Build and Test system.*	
System tested offsite.	*Testing will be performed with simulated inputs.*		*Perform offsite testing.*	
5.3 Exception Reporting			Provide information interface to basic display.	
				Maintain / enhance interface to basic display.

6. Production consistency

Initial project planning revealed that to achieve full longwall face automation, a major effort requiring of the order of half the total project budget would be required to automate the functions carried out by on-face personnel which are not concerned with actual on-line control of mining equipment operation. These functions involve sensing and observation activities that are challenging to automate completely. Consequently, in view of the priorities of LASC the concept of on-face monitoring by personnel either on or close to the face was adopted for the duration of the current project. In this mode of operation, video systems are used to relay face and gateroad geotechnical conditions to the operator station. It was decided to conduct survey projects in the area of convergence and void monitoring and automated gate road monitoring and a full-scale project to develop systems to avoid collisions between shearer and supports.

Outcome	Description	Year 1	Year 2	Year 3
6.1 Coal Flow Optimisation.				• Visual lump / void / blockup / environment sensor. (cameras attached to comms system). • Radar lump / void/ blockup / environment sensor study.
6.2 Geotechnical Characterisation				
6.2.1 Improved Convergence Monitoring	*Development and trialling of a new generation convergence monitoring instrument*			Survey convergence monitoring methods.
6.2.2 Software Development for Chock Pressure Analysis	*Developing software for an already proven "non live" analysis method and site trialling as a live system. Will give the ability to view chock pressure information over any time scale. Also determine actual periodic weightings and assist in the prediction of these weightings and their effect with reference to other geophysical data.*			Software development for chock pressure analysis.

6.2.3 Void monitoring and development of response to detected voids	*Determining the most effective system to detect roof voids across the L/Wall face. Once system is determined, analyse / interpret system output with the intention of developing a suitable response system and field trialling unit.*			Survey voice monitoring systems.
6.2.4 Collision Avoidance	*Develop a GUI system for "bolting on" to the OEM based collision avoidance system and field trial (part of outcome 1). Develop a GUI system based on sensing, analyse / interpret output with intention of developing a suitable response and field trialling.*	OEM collision avoidance (part of outcome 1).		
			Develop collision avoidance sensing system.	
				Continue development and implement collision avoidance.
6.2.5 Gateroad monitoring	*Determine most effective system to monitor gateroa d deformation. Develop GUI system to interpret / analyse data and give suitable response and field trial system.*		• Hardware design (laser and extensometer equipment). • Communication / processing hardware. • Software development. • Hardware purchase (laser and extensometer). • Field tests	
			.	Site installations and trials.

6.3. Condition Monitoring and Reliability

A proper understanding of the reliability of the existing system is essential. We will start with the reliability block diagram of the longwall system including a hierarchical tree structure for the longwall system and its parts and appropriate representations for environmental characteristics and operator's actions.

Past failure data will be reviewed for nominated sites and a Pareto analysis will be performed to identify the critical failure modes. Root cause failure analysis may have to carried out for some of the failure types to identify the exact nature of the failure and its root cause. This is important because in a series system like longwall machinery, the failure of one item will lead a chain of failures and sometimes it is difficult to identify the original failure that starts the chain. The results of this work will lead to engineering design change recommendations to fix the problem or redundancy options to circumvent it. Present maintainability of critical items and maintainability under an automation regime will be evaluated. Another result of this work will lead to identification of limitations that will need to be placed on the automation system.

A Failure Modes, Effects and Criticality Analysis will be performed on the entire longwall machine system. This is standard practice to help identify reliability "sinks" in the system and to understand their cause-effect relationships. A review of the OEM-supplied or planned condition monitoring systems will be carried out and their implications for a successful implementation of automation will be assessed.

The deliverable at the end of the work-package will be a comprehensive Report that describes the results of the above work. This Report will also produce specifications for the ongoing tasks of fault detection and machine condition monitoring.

Outcome	Description	Year 1	Year 2	Year 3
6.3 Condition Monitoring and Reliability				
6.3.1 Reliability Analysis	*Review of present machine reliability; Threats to automation regarding reliability; Proposals for engineering design changes and redundancy options to remove these threats.*	• Review maintenance logs and monitoring data; carry out a FMCE analysis. • Produce reliability analysis report.		
6.3.2 Fault Detection & Trend Analysis	*FDI (Fault Detection & Isolation) Software for timely detection and classification of machine failures and other external or internal discrete events that may be threatening production.*	Analysis and pre-processing of on-line maintenance log data.	Statistical analysis of data; software to generate remote monitoring displays.	Develop FID software & demonstrate on off-line data.

6.3.3 Trend Analysis & Sensor Self-test	*Software that primarily will use the machine data to detect events like slabbing off the face, piling, pick wear and coal seam conditions; Software modules for sensor self-test and on-line assessment of sensor data reliability.*		Identify external trends that need to be monitored; collate training data for trend analysis.	
				Develop trend analysis software and demonstrate off-line.

7. Training: Redefined Functions of face operators

One of the keys to the successful implementation of longwall automation systems is recognition that the skills required in an operator of an automated system will be different to those at present required on the face. Attention must be paid to staff selection and training.

Outcome	Descripton	Year 1	Year 2	Year 3
7. Training				
Online training system designed.	The training system will include displays of documentation, operation check lists etc.		Design online training system using remote operators station .	
Online training system developed.			• Build and test training system. • Develop content for on-line training / simulator system (competency based).	
				• Seek industry feedback for training system (iterative approach). • Modify design of training system (iterative approach).

8. Implementation Plan

This activity has no allocated budget. The implementation plan allows for the necessity to establish field sites at more than one location. Costs for duplication of equipment which cannot be provided for reliably in the initial project budget will be dependent on in-kind support form sites and OEM’s.

9. Commercialisation

This activity will facilitate the technical transfer and presentation of project outcomes to the industry. Models for manufacture of automation system components and intellectual property arrangements will be developed and put in place as outcomes are delivered.

10. Implementation Plan for Progressive Automation

This activity will benchmark all longwall mines in Australia and will provide them with detailed information regarding their current automation status and a roadmap outlining steps necessary to achieve various levels of automation utilising Landmark project outcomes.

Conclusions

The ACARP landmark process has afforded the underground coal industry with a tremendous opportunity to develop and implement cutting edge technologies into a package that will provide an automation capability for our longwall operations. Key new technologies of INS and IT improvements from other industries will assist this process. The benefit for the industry will a potentially higher, more consistent production rate and the removal of face workers from more hazardous areas.

Although the task remains complex, the risks are relatively low as most of the technologies have been proven in other areas. The focus on productivity and designing the system for exception issues will also ensure a lower risk and provide an incentive for progressive operations to uptake the automation technology. The onus will be on the project team to communicate these outcomes progressively so that companies may include “landmark compliant” longwall specifications into future orders and upgrades.

The question remains, are we ready as an industry to take advantage of this technology?