LONGWALL AUTOMATION – A NEW APPROACH

Michael Kelly, David Hainsworth, David Reid, Paul Lever, Hal Gurgenci

Third International Symposium

“High Performance Mine Production”

Aachen, June 11 – 12, 2003

Contact

Mr Michael Kelly

CSIRO Exploration & Mining

P O Box 883

KENMORE QLD AUSTRALIA 4069

Tel: +61 7 3327 4612

Fax: +61 7 3327 4666

Email: mick.kelly@csiro.au

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ABSTRACT

Guidance technology proven in highwall mining applications has enabled a new approach for longwall automation for DERDS faces. This inertial navigation technology has, for the first time, allowed the position of the shearer to be mapped in three dimensions. Following the success of the technology in highwall mining and the successful trials on a longwall face, the Australian Coal Association Research Program (ACARP) commissioned a three year "Landmark" project that will advance longwall automation to the level of "on-face observation" by the end of 2004. The project outcomes have been divided into 10 areas, the first of which, automatic face alignment will progress to an underground demonstration in the first half of 2003, and has the support of the major longwall equipment manufacturers including DBT and Joy Mining Machinery.

AUTOMATION ISSUES

Reviews of previous attempts at longwall automation and industry use of current automation technology revealed that previous automation work suffered from a lack of focus on exception issues and insufficient recognition of the imperative from operators not to lose productivity through the use of automation. 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 discarded. Even if the automation technology does work in good conditions, unless it produces as much coal as manual operation it is not used. Operators consistently expressed the view that the longwall is the prime profit centre and that a high level of production consistency 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.

Moreover, the achievement of sustained full-face automation in all conditions requires the development of new, complex sensors to monitor the face environment before the removal of human operators from the hazardous face area becomes a possibility. This is in addition to the technical development still required for automation of basic coal cutting sequences under the most ideal conditions. Budgetary constraints meant that simultaneous development of all necessary sensors and equipment automation systems was unfeasible in the Landmark project. Consequently, in order to produce short-term project outcomes, a reduced option of 'on-face observation' was adopted as the basis of the final format of the three-year project. Within this scope, face equipment is fully automated, but operator input is available to efficiently manage exception conditions. Typical exceptions include geotechnical issues on the face such as face guttering and mechanical issues such as broken rams etc. However, this outcome is significant and in many cases it may be all that operators require. It is also on the direct path to full automation.

PROJECT AIMS AND OUTCOMES

Based on the principle of automation with on-face monitoring, a number of separate but related research areas were identified in which project effort in the three-year Australian Coal Association Research Program (ACARP) ***Landmark*** project would be concentrated to achieve the goal of longwall automation with on-face monitoring. These areas cover specific technology development, integration of system components and attention to the way automation outcomes are introduced to the industry. The ten specific outcome areas are:

1. Face alignment
2. Horizon control
3. Open communications (between OEM and external systems)
4. Longwall equipment manufacturers (OEM) involvement/commitment
5. Information systems
6. Components to enhance production consistency and reliability to minimise production risks in an automated environment
7. Redefined functions of face operators and training
8. Minesite trials and demonstrations
9. Acceptable commercialisation plan
10. Implementation plan for progressive automation

The paper will briefly summarise all the outcome areas and results obtained in the first eighteen months of the project. Work in this period has concentrated on the outcomes directly leading to automation of basic equipment functions including face alignment, horizon control, open communications, information system and condition monitoring and reliability. Early results in these areas including the real-time mapping of 3D shearer position, on-shearer EtherNet communications, condition monitoring and failure analysis will be reported.

Face Alignment

This area of work concentrates on the geometry of the face within the gate roads. The goal is to automatically maintain face straightness by measuring the 3D position of the shearer (using Inertial Navigation System - INS) in space and using that information to control the movement of the powered supports. This ability has eluded previous researchers. This technology has been applied extensively to highwall mining guidance (Reid 1997) and also in a successful trial implementation on a longwall face at South Bulga (Reid 2001). This outcome area will supply the first deliverables of the project. This is a relatively low-risk outcome. The various technology components, particularly those already present on OEM equipment, are in advanced states of development.

Work in the first year has concentrated on:

- The development of a real-time shearer position measurement and display system (SPMDS) to provide accurate measurement of actual shearer position in space in real time for display on the surface. This system also provides for logging of shearer position for later analysis. This is a stand-alone outcome on which the remainder of the automation system will be built.
- The enhanced shearer initiation of chock advance to move chocks to exact geometry determined by the Inertial Navigation System (INS). At this stage of the project, the shearer is controlled manually in the customary fashion.

In the second year of the project:

- Further sensors will be developed to implement automatic creep control and tailgate offset (lead or lag)

- First trials of automatic control of shearer haulage based on the paradigms, models and underground monitoring station developed in outcome 5 (see later) will take place.

In the third year, automation of a suite of extraction methods will be undertaken (uni-di, bi-di, variable web etc).

At the time of writing, an INS has been installed on the shearer at the host mine. Figure 1 shows 3D position data that has been received from the shearer using a wireless EtherNet-based communications system developed as part of outcome 3 of the project. Software applications have been written to enable on-line shearer position to be accessed from within a web browser.

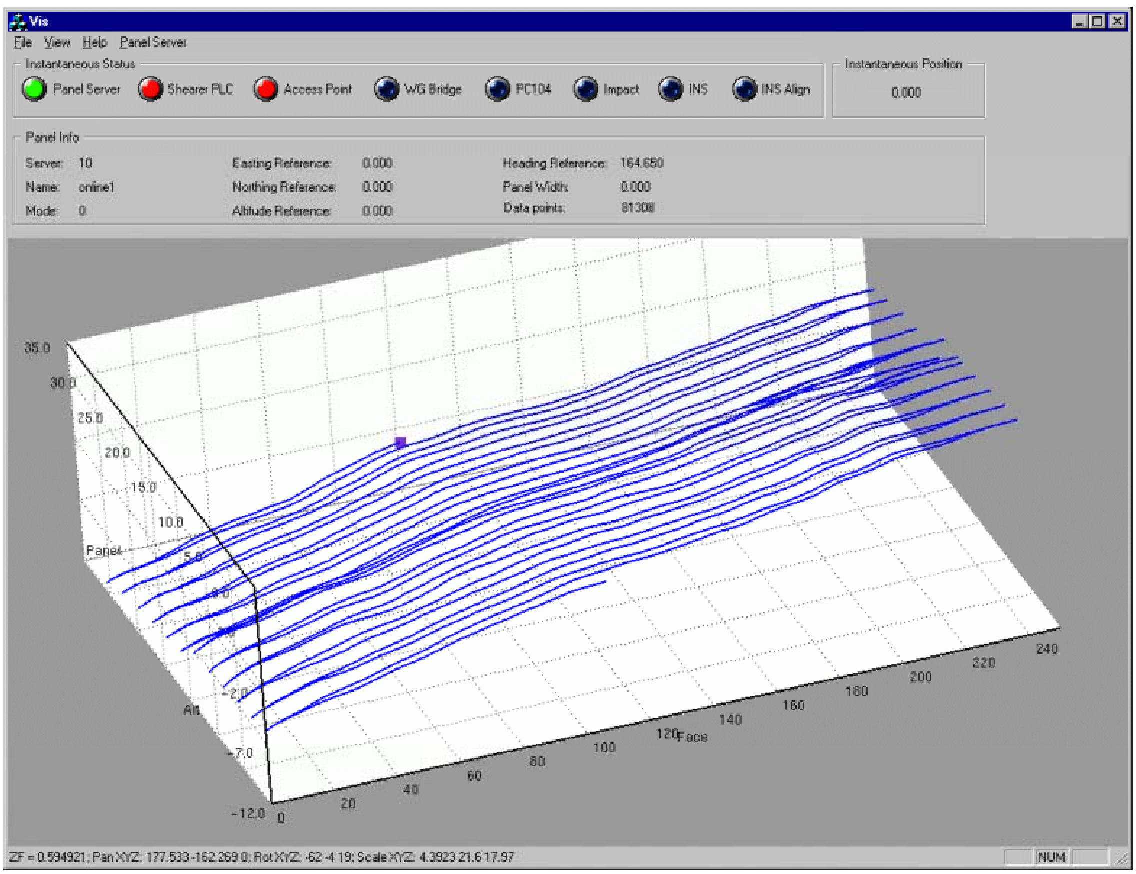

Figure 1 Three dimensional view of actual shearer position

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 will use the vertical position information available from the INS 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.

In the second year, absolute shearer position information will be used to enhance the performance of existing memory cut systems. The Landmark automation system process controller builds up a database of the extracted seam profile by adding actual floor measurements at each shear. This information can be added as extra information to the existing OEM memory cut horizon control systems. Figure 1 also shows the as-mined seam profile extracted from actual shearer position information. Later in the project, other data (3D seismic, radio imaging etc) will be incorporated into the model used to predict optimal horizons.

Work has also commenced on investigation and development of automated CID systems. This is an area of research and development that has attracted significant research effort since the 1970's (Hainsworth 1997) but with few operational outcomes. The only commercial CID systems are based on sensing of natural gamma emission from roof and/or floor strata. Current CID developments will be monitored and Australian mines surveyed to gather information on existing horizon control techniques, concentrating on the features of the environment comprising the coal seam and surrounding host rock currently used as cues for human operator in seam following. A CID sensor development program will be commenced in the second year of the project, culminating in its incorporation in the automated longwall system in the third year.

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.

The first requirement is for a reliable shearer-main gate end communications method for the transfer initially of 3D shearer position data. Future applications will involve other broadband services such as video and intelligent sensor data, and then as part of a redundant link for shearer control. As the level of automation of face systems increases during the project, the number of operators in the immediate face area will reduce. Sensor systems will be developed to replace the observation functions of on-face personnel. Some of the observation functions will be carried out remotely at the monitoring station using video cameras placed on-face equipment. These systems will require supporting wideband links which will be developed in years two and three.

A wireless EtherNet (IEEE Standard 803.11b) link has been established to the shearer used as the test platform for the INS referred to earlier. Tests have shown that performance of the link is very suitable for transmission of shearer position data. Initially, a simple point-to-point link between the shearer and main gate was implemented as an economical way to enable the performance of the link to be measured. On the basis of these initial tests, the system was extended to give full face coverage by providing a single additional wireless EtherNet node part way along the 250m test longwall face.

The wireless EtherNet is based on commercial products which have been appropriately packaged for the mine environment. This ensures that technology developments which occur at a fast pace in communications and networking can be easily implemented in the system. Similar technology will be used to transport the wideband communications necessary for observation and monitoring functions required in later project stages.

One of the issues facing this aspect of the project is the development of a commonly accepted, industry-wide data communications protocol to permit information flow between longwall equipment from various vendors. Data transfer between Landmark hardware and shearer and powered support systems is of critical importance. Establishment of an appropriate protocol was also a goal of the first year of the project. EtherNet/IP, a recently developed industrial automation communications protocol has been agreed by at least two major equipment manufacturers as the data interchange standard to be used for the Landmark Project. Using an open system such as this is beneficial during the Landmark

Project equipment development stage where negligible access to OEM intellectual property is required by researchers during product development.

This outcome also has wider implications for open connection between equipment in the coal mining industry. Mine operators and equipment specifiers are able to synthesize a system confidently using products from various suppliers.

Work is also progressing on the definition of higher-level communications requirements for transfer of shearer and support motion control.

OEM Involvement

This is a key outcome for the success of the project. Manufacturers of longwall equipment 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 assists transfer of project results to the mining industry at best practice. In order to achieve this, clear communication of project goals to OEMs is necessary, key contacts within their organisations must be made and mutual R&D linkages need to be established.

Good response to the project has been achieved from the OEMs involved in the manufacture of longwall equipment. This is demonstrated particularly in the technical outcomes of the project where progress has been made in several areas.

A complex issue confronted by the project and by OEMs in general is that of safety, where suppliers of equipment have legal obligations regarding the safe operation of their products. When products from several vendors are interconnected in an operation that may be required to operate in an automatic, semiautomatic or manual fashion, depending on the level of automation at a particular installed site, predictable performance is necessary in all cases.

Problems can arise if a control system from another vendor directly commands motion of a particular system. In the Landmark project, all motion commands, whether from an automation controller or operator are filtered by the internal safety mechanisms. Such commands are referred to as motion *recommendations* rather than *commands*. If motion inputs received by a system cannot be implemented because they are outside the safe working envelope, the system does not actuate and reports that the motion cannot be achieved. Consequently, safety is maintained.

Information Systems

There are three separate work areas under this heading.

- The development of a monitoring station. Given the concept of automation applying to this project, a monitoring 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 monitoring station can be further withdrawn outbye.
- 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. As a first step, process maps to characterise current longwall mining extraction methods have been established. In the second year, scripts and sequences to transfer current best practice to the automated system will be developed and trialled. In addition, front-end software to incorporate further geological inputs to seam modelling for horizon control will be installed in the process control software suite.
- The development of display systems to efficiently report system operation and conditions existing on the longwall. Visualisation software to produce high quality representations of the state of the longwall system on the underground monitoring station user interface is currently under development. Preliminary visualisation models, an example of which is depicted in Figure 2, have been created.

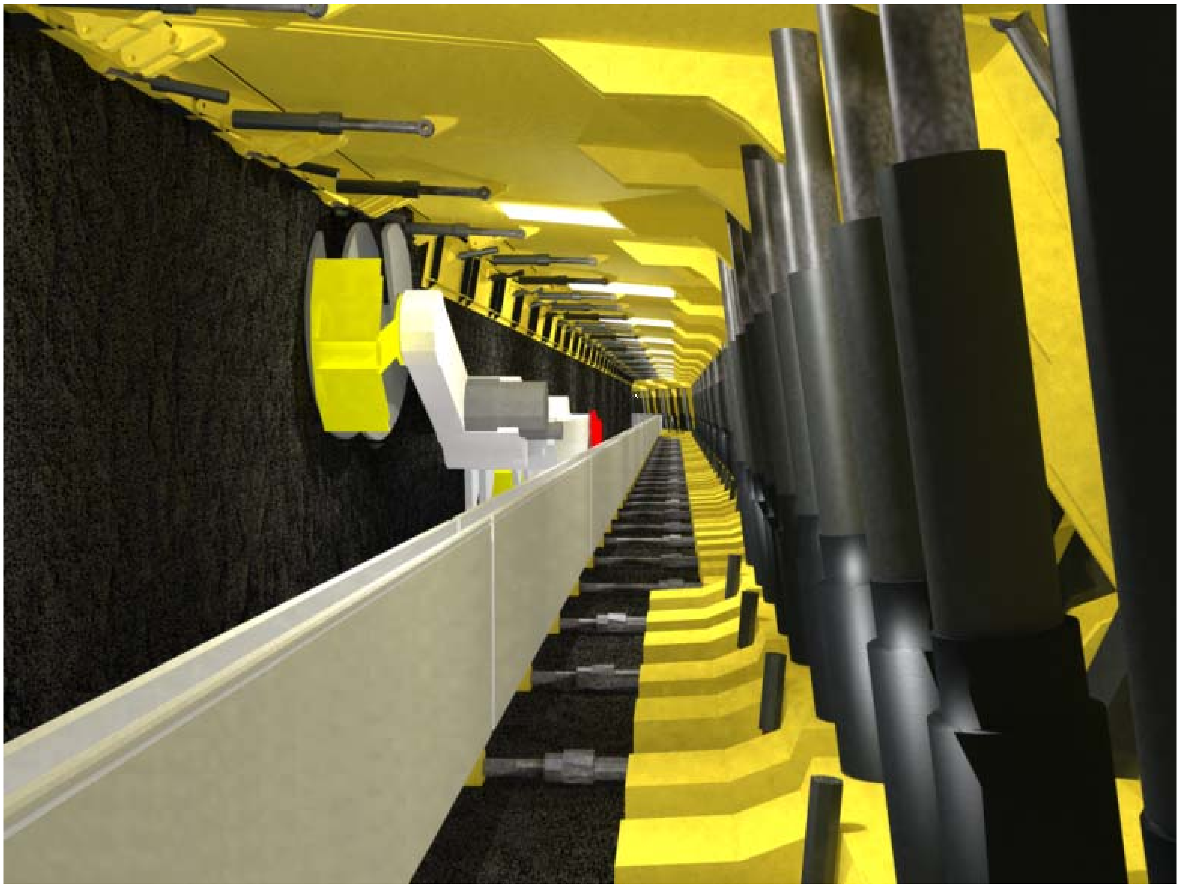

Figure 2 Longwall visualisation

In the second and third years, an exception reporting system to utilise existing OEM-derived condition monitoring and operational data as well as extra information from Landmark sensors will be produced and will interface to the automation system user interface.

Production Consistency

Many of the functions carried out by on-face personnel 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 the concept of on-face monitoring of the operation of automation systems 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 gate road geotechnical conditions to the monitoring station. However a number of project activities are concerned with development of automation systems to carry out key monitoring functions.

Collision avoidance: In the second and third years of the project a sensing system will be developed to measure the separation distance between the shearer and roof support components. It is likely that this will be based on a scanning laser rangefinder.

Coal flow optimisation: A visual monitoring system to detect face and production anomalies such as oversize coal lumps, conveying blockages, and development of face and roof voids will be implemented. This will be achieved through video monitoring systems displayed in the monitoring station, where changes to the operation can be made.

Convergence monitoring: The latest developments in support leg convergence monitoring methods will be analysed, and software will be developed to monitor and analyse leg pressures on line to assist in predicting chock weightings along with the fusion of other geophysical data.

Void monitoring and response: As well as the use of visual monitoring methods, a survey will be conducted of other sensing methods that are applicable to detection of voids.

Gateroad monitoring: In the second and third years a monitoring system for gateroad deformation will be built and field trialled. This will use laser and extensometer-based measurement systems.

Condition Monitoring and Reliability

The production delay records for the past three years were analysed in detail for one of the project sponsors. Mining delays as well as interruptions to the production due to equipment failures (recorded as planned and unplanned maintenance) were included in this analysis.

On average, about 50% of all downtime was found to have been attributed to planned and unplanned maintenance. This is a substantial number. A Pareto analysis showed that 30% of failure categories account for over 90% of total equipment-related downtime and the top 10 failure categories account for well over 50%.

While Pareto analysis is useful in identifying the top failure categories, a more discriminating analysis is offered by using scatter-plot representation.

A scatter plot is basically a logarithmic plot of mean time to repair against the number of failures. Since the total downtime associated with each equipment failure is the product of the two, constant downtime curves appear as lines on logarithmic axes.

The scatter plot for the period under consideration is presented in Figure 3.

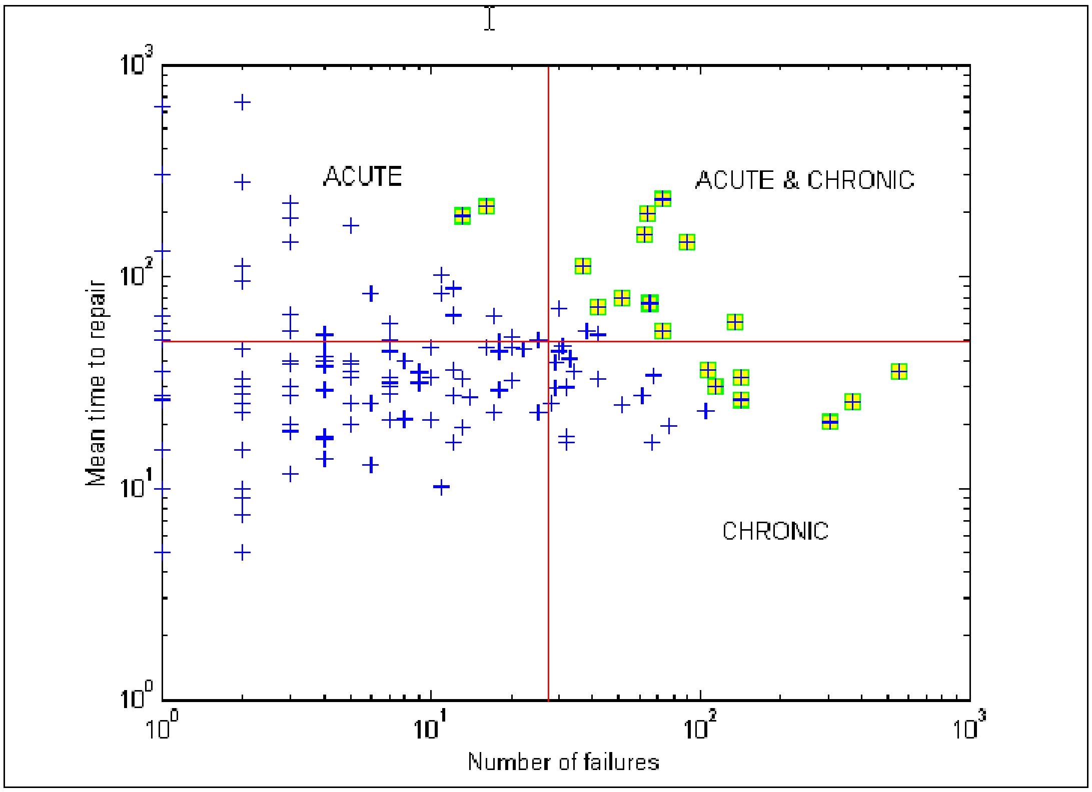

Figure 3. Scatter plot representation of failure histories

Each point on this plot refers to an individual failure category. The identities of these failures are currently under review by the project sponsors and would be released in the final report for the project. In the context of the present paper, it is sufficient to note that the plot area is separated into four quadrants as shown. The lower left quadrant includes those failures that do not appear too often and when they do are easily fixed. The attention should be focussed on the other three quadrants: Acute; Chronic; and Acute & Chronic.

Chronic failures are relatively easy to fix when they occur but they still cause significant amounts of downtime. Acute failures are those that should have been eliminated a long time ago. They are probably caused by a design deficiency.

The most striking result is the number of failure categories that are both and acute and chronic. This indicates serious problems in the original design and/or selection of the equipment.

Our current research area is progressing along two fronts: improved tools for design for reliability; and improved tools for condition monitoring.

Under the heading of computer-aided tools for design and/or selection of longwall equipment, the following suite of software tools is an advanced stage of preparation:

- Prediction of chain speed, dynamic chain tensions, and sprocket tooth loading in armoured-face conveyor chains ─ with capability to simulate systems with different configurations including CST or fluid coupling power transmission.
- Prediction of dynamic forces and vibrations during shearer operation ─ with capability to simulate systems with lacing patterns under different cutting modes.

In the area of condition monitoring, the following products are being targeted:

- Fault detection and isolation software based on a bank of parallel classifiers including neural networks and model-based detectors
- An on-line estimator that will estimate individual pick forces from measured vibrations and motor currents. Such an estimator will have several uses:
    - Health monitoring of the shearer power transmission
    - Monitoring the condition of the individual cutting picks
    - Mapping the cutting effort against the face geometry and use such mapping to identify the locations of discontinuities or hard bands to help with the horizon control of the shearer

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 are different to those presently required on the face. Attention must be paid to staff selection and training.

In the second year an on-line training system will be set up utilising the monitoring station. Additionally, because system operational data will be available over the minesite LAN, off-line training will also be possible on the surface using on-line information. The training process will be refined as mine operational personnel gain more experience with the automation system.

Minesite Trials and Demonstrations

The project provides for field trials and demonstrations of all the developed technologies at one location. This initially will involve three minesites at South Bulga, Moranbah North and Newlands and other minesites may be come involved as the project progresses.

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.

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 longwall operations. Key new developments in inertial navigation and information technology from other industries will assist this process. The benefit for the industry will be a potentially higher, more consistent production rate and the removal of face workers from more hazardous areas.

The project has been running for eighteen months and several important milestones have been achieved:

- On-line 3D shearer position information is now available
- Wireless EtherNet has been shown to be a viable, robust face communications system
- EtherNet/IP has been adopted as the standard for communications between OEM and Landmark control systems.
- Condition monitoring analysis results suggest the feasibility of implementing an on-line trend and condition monitoring system

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.

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