OUTCOMES OF THE LANDMARK LONGWALL AUTOMATION PROJECT WITH REFERENCE TO GROUND CONTROL ISSUES

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Abstract

Inertial navigation technology has, for the first time, allowed the position of a longwall shearer to be mapped in three dimensions. Following the success of the technology in highwall mining and successful trials on a longwall face, the Australian Coal Association Research Program (ACARP) commissioned a three year "Landmark" project that aimed to advance longwall automation to the level of "on-face observation" by the end of 2004. This project has been completed with the following successful technical outcomes:

- Automatic face alignment was achieved, using an inertial navigation-based sensor on the shearer, to accurately measure face geometry and feedback signals used to move OEM (Original Equipment Manufacturer) roof supports.
- Operational on-line measurement of creep with creep information incorporated into face alignment corrections.
- Inertial Navigation System (INS)-based enhanced horizon control was bench-tested.
- Operational broadband communications system to shearer using wireless Ethernet on a commercial-product basis.
- Acquisition of located coal-face features for use in thermal infrared-based horizon control.
- Automated Longwall Information System (LIS) developed which integrates information from multiple systems and sensors and provides high quality visualisation and control interfaces.
- Automatic roadway and face convergence monitoring tools successfully tested.
- Condition monitoring tools developed and demonstrated for improved face reliability.

This paper summarises the outcomes of the project and describes the work being undertaken for the 2 year Landmark Extension project approved in April 2005. Consistent with the conference theme, the paper focuses on the ground control aspects of the project.

Introduction

The Landmark Longwall Automation project was carried out by CSIRO (Commonwealth Scientific and Industrial Research Organisation, Australia) and The Cooperative Research Centre for Mining Technology and Equipment (now CRC Mining) under the direction of the Longwall Automation Steering Committee (LASC), a sub-committee of the ACARP Underground Research Committee. The overall goal was to develop systems that would result in:

"A longwall face that will operate automatically within pre-defined parameters to enhance health and safety and production consistency, to lower operating costs and improve return on capital".

It was recognized that input to a number of aspects of underground operations would be required to achieve longwall automation within the framework defined above. Consequently a number of work areas were identified, and the research program structured around them. These areas were:

- Face Alignment – lateral direction control and face geometry.
- Horizon Control – cutting horizons maintained as required by the mining process.
- Open Communications – open communications architecture between system components (hardware and software).
- OEM involvement/commitment – mechanisms for exchange of information between the project team and equipment manufacturers.
- Information System – Monitoring station, automatic sequence design, and operator displays.

- Production consistency and reliability – Geotechnical monitoring, coal flow optimisation, collision avoidance between components, condition monitoring and reliability.
- Training – redefined functions of face operators.
- Implementation Plan – implementation of automation system components at strategic selected sites. Most of the Trials were completed at Xstrata's Beltana Mine.
- Commercialisation Plan – effective models for transfer of the technology to the industry.
- Implementation Plan for Progressive Automation – provide all longwall mines in Australia with specifications and implementation plans to upgrade to appropriate levels of automation.

After the project was completed in February 2005, an extension was approved to take the prototype outcomes from the initial project to a robust demonstration and commercial stage. This paper lists the goals and achievements in each of the work program outcome areas for the initial project and the scope of the extension with particular emphasis on ground control aspects. The basis of the paper is the initial project report (1).

Outcome 1: Face Alignment and Creep Control

Goal: There were two original project goals:

- To maintain a designed face alignment automatically by measuring the three-dimensional position of the shearer and to use this information to appropriately control the movement of the powered supports.
- To implement creep control by measuring the position of roof support structures in the main gate and use this information to adjust the face geometry to control creep

During the project, a method of longwall retreat measurement was invented and a goal was added:

- To develop a system to directly measure longwall retreat (chainage).

Achievements:

- Automatic measurement of shearer position using the Landmark Shearer Position Measurement System (SPMS) has been achieved on a production basis.
- Accurate shearer position information is now routinely used at Beltana No 1 Mine (Beltana), a collaborating site.
- There have been no failures of either Honeywell or Litton INS hardware at Beltana in three longwall blocks.
- There has been only one computer failure due to flash memory failure. This was not due to the operating environment. The cause of this failure was isolated and controls have been implemented.
- Supervised operation of closed loop face alignment has been realized. Figure 1 shows the general arrangement of the face alignment system.
- Automatic measurement of creep distance has been demonstrated and creep correction information has been manually applied to the face at Beltana.
- A system to automatically measure longwall retreat progress has been prototyped and successfully tested.

A typical instrument rack containing the SPMS is shown in Figure 2

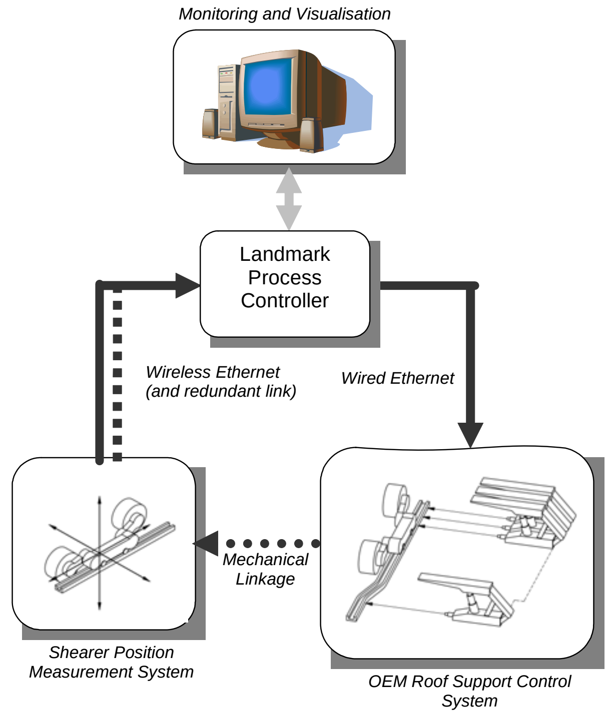

Figure 1: Block diagram of the components and general arrangement of the face alignment system. The primary control loop is indicated by the darker arrows after (1)

Landmark Extension Project Scope:

- Commence program with Northrop Grumman to optimise the LN270 INS performance for the longwall guidance application.
- Continue face alignment production trials to improve functionality and reliability of face alignment control software.
- Commence automatic creep control testing and production trials.
- Implement longwall retreat measurement system on a production basis.

Ground Control Aspects:

Maintaining a straight face has inherent ground control advantages in terms of being able to maintain an even goaf edge and not having to stop and perform straightening cuts. There is also the opportunity of being able to maintain a different face profile purely for ground control reasons. In Australia, under heavy ground conditions, many faces suffer from convergence and face spall in the mid-face area due to the break profile forming a convex curve that is in advance of the mid-face position and in retard over the gateroads. Automatic face alignment will allow operators to choose a convex face shape to match the natural face break profile and still be within manufacturers' tolerance for face curvature.

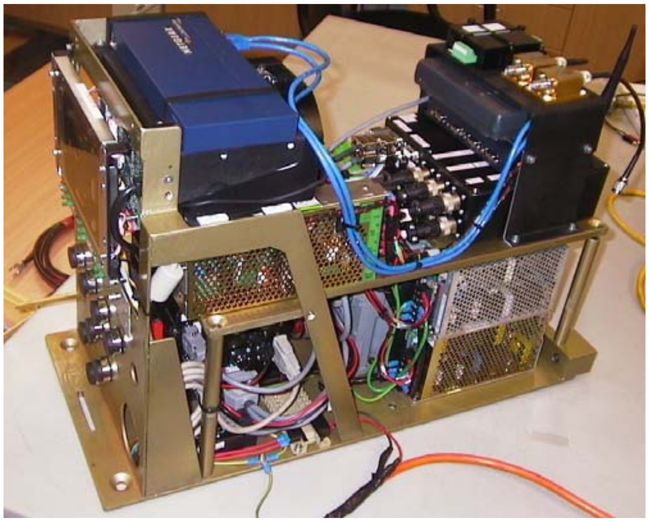

Figure 2: A view of the SPMS equipment rack, [after (1)]

Outcome 2: Horizon control

Goal: To provide automatic horizon control responding to actual changes in seam profile. For general applicability the horizon control strategy needs to account for the variability in strata and operating conditions of Australian longwall mines.

Achievements:

- Enhanced horizon control using INS-based measurement of vertical shearer track has been successfully bench tested. This system uses a computer generated cut model which is in turn used to steer the 3D position of the shearer drums. (Figure 3)
- Optical marker band detection has been successfully demonstrated underground.
- Thermal infrared detection of coal interfaces and detection of marker features in the seam have been shown underground.
- A procedure for automatic horizon control during fault conditions has been developed.

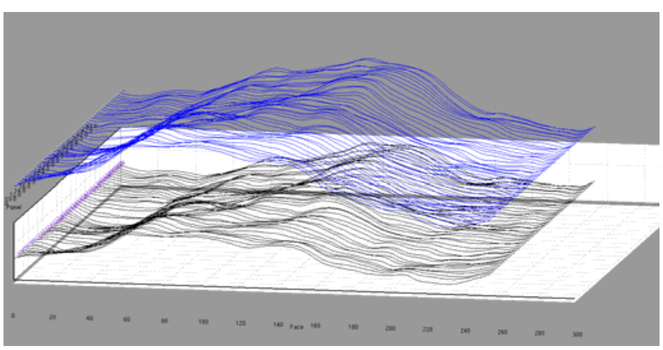

Figure 3: The cut model extracted floor and roof surface constructed from real SPMS data. In this data set a constant extraction height is assumed in the absence of accurate and reliable shearer drum height information, [after (1)].

Landmark Extension Project Scope:

1. *Enhanced Horizon Control (EHC)*
   - Complete implementation of Landmark compliant Ethernet/IP interface to control system.
   - Communicate accurate and stable real-time shearer pitch and roll data to shearer control system via direct Ethernet/IP interface to SPMS.
   - Trial Landmark EHC with fully-functional shearer horizon control algorithms.
2. *Optical marker band detection*
   - Despite the initial promising results, implementation of a full-face system will be expensive and will pose significant maintenance issues. Accordingly further development of a more compact system to concentrate on the gate ends of the face will proceed.
3. *Thermal infrared sensing*
   - Liaise with shearer OEMs to identify a secure mounting location for the IR camera.
   - Investigate general applicability of the method.
4. *Controlled traversing cut*
   - Demonstrate controlled traversing cut-derived shearer flight paths in a mine with fault issues.

Ground Control Aspects:

Initially, the only perceived benefits of this project component were to remove the operator from the immediate shearer position and to have improved production and dilution characteristics. Trials have demonstrated the ability to measure shearer position to 25mm accuracy. Australian operators are indicating that being able to cut to this accuracy is the most significant outcome for ground control of all the Landmark work. This is especially significant in conditions of soft floor and thick seams.

In addition, the controlled traversing cut allows for the first time a longwall to traverse though a fault zone without direct operator input. It does require an accurate 3D block model of the fault zone with data points at around 10 metres spacing. This is achieved through 3D Seismic surveys or drilling programs.

Outcome 3: Open Communications

Goal: To develop a communications method to facilitate the flow of information between landmark-developed sensors and systems and longwall system elements sourced from various manufacturers.

Achievements:

- A standard information interchange protocol between equipment from different suppliers has been developed.
- A broadband communications link to the longwall shearer to support automated longwall shearer-based instrumentation has been developed. The wireless communications link to the shearer has been one of the major successes of the project. Along-face coverage has been very reliable and the link is now an established part of the mine's production system. Power line carrier tests have been promising.
- The introduction of the Ethernet/IP open-system communication standard and associated development of the automated longwall device and control system specifications has been completed. This has been fundamental to the overall success of the project. This has provided a solid platform for ongoing development and acceptance of an open industry-

wide (non-OEM specific) standard for the interconnection of mining equipment.

Extension Scope:

In the Landmark Extension Project, the broadband power-line communications to the shearer will be fully tested, as a redundant wideband communications link to the shearer would add enormously to the robustness of shearer automation systems.

Ground Control Aspects:

Broadband radio communications and a uniform communication standard will allow the application of real-time monitoring and integration of geotechnical data on the face. For example, on-face camera monitoring of conditions is now possible and new instrumentation, if compatible with the standard, can be incorporated with OEM face data and then utilised in the information system used by the mine.

Outcome 4: OEM Involvement

Goal: To maintain OEM commitment to the Landmark process over a range of activities.

Achievements:

- OEM involvement was maintained at a high level during the project. Since only one major test site was provided for in the project scope, the number of OEMs able to participate actively in the field components of the current project work program has been limited. Because all OEMs need to be part of the delivery of longwall automation products to the industry, it was necessary to involve the other manufacturers actively in the project.
- Initial OEM concerns surrounding the requirement for free flow of information between longwall components from different vendors were allayed with the definition of the Ethernet/IP communications protocol. The work program of the various project outcomes involved all major OEMs and served to keep them abreast of project developments.
- CSIRO has built strong communication and technical links with the Longwall OEMs in Australia, Great Britain, Germany and the United States, which further strengthened the successful project outcomes. This effort included a facilitation role and resulted in significant input to the project by all major longwall equipment manufacturers. In particular this has been through in-kind contributions in the form of:
    - Modifications to shearer to accommodate Landmark equipment.
    - Development of Landmark-compliant equipment control software for roof supports and shearers.
    - Provision of personnel to participate in design reviews and risk assessments.
    - Participation in laboratory and underground testing of Landmark Longwall Automation systems.

Recognition should be given to the vital role the OEMs have played in assisting the advances in longwall automation made in this project.

Landmark Extension Project Scope:

- Continue to strengthen relationships with equipment manufacturers.
- Broaden the direct involvement of OEMs in trial sites
- Gain a commitment from OEMs to make Landmark outcomes a core part of their products.

Outcome 5.1: Information System

Goal: The original goals consisted of:

- To develop an underground monitoring station.
- To implement software for visualisation of automation system operation in the monitoring station.
- To achieve software design and maintenance requirements that permit the information system to be implemented in the monitoring station for single user operation and to run using off-the-shelf computer hardware. The information system also to report exceptions in the performance of face equipment in keeping with the on-face observation concept of the project.

Goals were revised during the project. As the overall project proceeded, the work scope of the automated Longwall Information System changed significantly. It was realised that high quality 3D visualisation of face equipment and conditions would be essential to give users monitoring the system remotely confidence that the automation system is operating correctly.

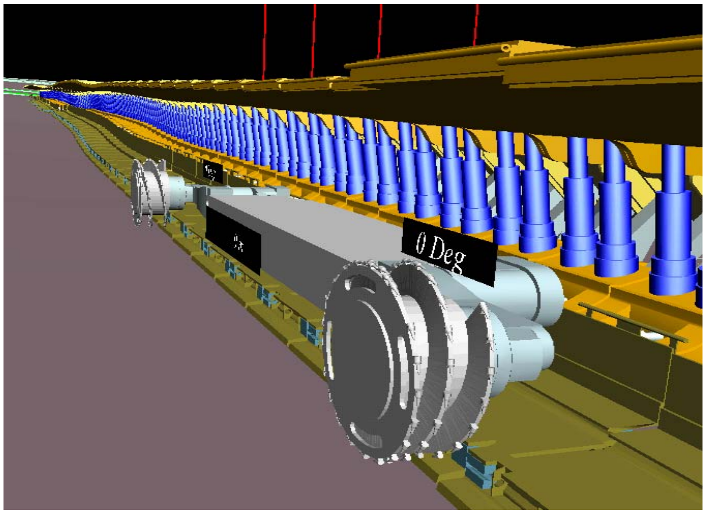

Figure 4: 3D Model screen, [after (1)]

Achievements:

- A powerful tool set has been constructed for automation and general process management.
- Visualisation systems incorporating database and graphical user interface software, allowing multiple users access to tailored information, have been developed and an integrated information system to merge automation, geotechnical, mine design and equipment performance data has been put in place, (Figure 4).
- Initial implementation has clearly shown that relevant forms of information can be made available to different people at different locations at the mine site and appropriate interaction with the system can occur from various locations including on the surface and at the maingate. However, primarily due to the

requirements of Beltana operations, the original concept of the underground outbye monitoring station has not yet been realised.

Landmark Extension Project scope:

It is likely that, as the automation of longwall equipment gains maturity and as people are withdrawn from immediate face areas, the monitoring station and visualisation systems associated with it will attract more attention and work will be directed to implement an enhanced range of solutions, building on what is now available, to satisfy future monitoring and control needs. To facilitate the next stage of development and implementation, intensive feedback on the use of these tools by mine operational and management personnel is required and this needs to be incorporated into the design process.

Outcome 5.2: Automation Sequence Development – Process Design

Goal: To develop automation systems for shearer haulage control to enable automation of specific production sequences.

Achievements:

- A plan to facilitate the design of operating sequences and transfer them to the shearer control system has been developed. However due to contractual commitments, the OEM and the mine directly took on this outcome. This successful application of shearer haulage automation has resulted in significant productivity improvements at the mine (2).

Landmark Extension Project Scope

Further implementation of this plan will be undertaken on a one-on-one basis with partnering OEMs.

Ground Control Aspects:

Automated shearer haulage is a state based system that defines different modes of operation for the shearer depending upon its position on the face and operating conditions. Both face end cutouts are included in this process. This results in an even profile for floor and roof and has significant advantages where there are soft conditions or when the roof or floor is being graded from a high cutting profile mid-face to a lower cutting horizon in the gates. Conversely, it will have similar benefit in thin seam conditions where the gate roads are higher than the profile being cut in the block.

Outcome 6: Production Consistency and Reliability.

This outcome deals with a number of topics concerned with achieving production consistency and reliability in an automated longwall system.

<u>Coal Flow Optimisation</u>

Goal: To investigate sensors and methods to monitor face operations not directly connected with automation of extraction equipment, in particular to monitor coal flow on the face and to detect the formation of lumps and block-ups in the face and Armoured Face Conveyor (AFC) areas.

Achievements:

- Monitoring critical areas with video equipment has been shown to be feasible.

- Tests using laser profiles and infrared sensors show promise. The advantage of these technologies is that the same equipment can be used to monitor face conditions, detect face features for horizon control and monitor coal flow on the AFC. Millimetre wave radar also shows promise for these applications particularly through its performance in poor visibility due to dust.

Landmark Extension Project scope:

In the extension project, further parametric studies are being undertaken to examine sensing methods to monitor coal flow (video, conveyor profile scanning, motor currents etc.) A systems engineering approach will then be used to model coal flow optimisation using integrated control of the shearer, AFC and stage loader.

<u>Improved Face Convergence Monitoring</u>

Goal: To conduct a survey of existing roof support (chock) monitoring systems and to make recommendations regarding implementation of improved chock monitoring systems in an automated longwall face.

Achievements:

Experience at Ellalong, Appin and North Goonyella (3) highlighted both the advantages of collecting closure data for geotechnical analysis, and the difficulties with installation and unreliability of existing systems.

Landmark Extension Project scope:

A newly-developed tilt meter-based wireless convergence monitoring system, which overcomes many of the disadvantages of existing equipment, will be deployed at Broadmeadow mine (Figure 5)

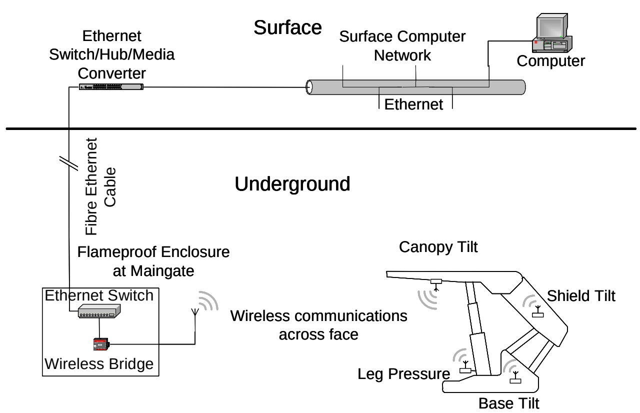

Figure 5: Schematic of the CSIRO convergence monitoring system, [after (1)].

Ground Control Aspects:

On-line monitoring of face convergence is a significant outcome for improved ground control. As well as giving shield closure, the system will also give a full 3D convergence and tilt of the shield along its entire length. Thus it will distinguish between tip closure and closure at the back of the shield.

<u>Chock Pressure Analysis</u>

Goal: To present powered support leg pressure data in the most useful form for a mine site to gain a greater understanding of geotechnical conditions on the face and thereby influence the operation of the longwall.

Achievements:

3D chock pressure maps were derived from mine information that gave timely and informative feedback to operational and mine design personnel. New time-based analyses gave the mine trend information on face pressures versus production rate.

Landmark Extension Project scope:

The 3D leg pressure graphs based on chock cycles and the time-based analyses will be integrated with, and made available through the Landmark Information System Client.

Ground Control Aspects:

The system will allow the mine to formulate its requirements as far as chock pressure analyses are concerned. Integration with 3D face position allows the mine to combine and display pressure data with other available data such as geological structures. The shearer measurement system can be combined with reed-rod data to give an exact position of each shield at the time the pressure readings are taken. This information can be kept as a 3D map record for the entire longwall block and will allow the mine to provide information for the adjacent block and to be included in hazard plans.

For the face operator, the leg pressures can be displayed in a leg colour format in the 3D visualisations displays as outlined above. This would give the operator real-time information on leg pressures and will assist in planning maintenance requirements – in terms of individual leg setting issues and for timing with weighting cycles.

<u>Void Monitoring Systems</u>

Goal: To investigate current sensors, systems and technologies applicable to the direct monitoring of voids in the roof above the longwall face.

Achievements:

Millimetre wave radar and laser rangefinder systems were found to be the best prospective technologies. However, the problems involved in suitable mounting arrangements on the shearer will impact on the practicality of their use. The smaller the sensor, the better the chance for successful deployment.

Landmark Extension Project scope:

Point laser rangefinders and thermal infrared monitoring offer the best potential for direct void monitoring. An experimental program will be carried out to field test these devices.

Ground Control Aspects:

Removal of operators from the immediate face vicinity requires this technology to detect face voids remotely. Until this technology can be delivered as a robust arrangement, observers on the face will still be required.

<u>Collision Avoidance</u>

Goal: To develop an active sensing system to measure the distance between shearer and supports directly.

Collisions between shearer drums and roof supports can be caused by failure of supports to move out of the path of the shearer or by extreme angles being set up between the AFC pans and support pontoons causing interaction. Existing OEM collision avoidance systems are based on calculation of relative positions through geometry and various angle measurements.

Achievements:

Other work programs in the Landmark project have confirmed prospective technologies for distance measurement in the face area.

Mounting sensors on the shearer remains a significant problem when dealing with the harsh environment in terms of physical robustness and visibility. Future work should concentrate on the development of mounting systems for on-shearer instrumentation. This is not being included in the extension scope.

<u>Gateroad Monitoring</u>

Goal: To develop a real-time monitoring system to detect unstable gateroad convergence and to initiate the response requirement from operators.

Gate road roof stability will be greatly affected by adjacent mining activities and goaf caving developments as the longwall face is retreated.

Achievements:

- Hardware and software have been developed for detecting gateroad convergence and preliminary testing has been carried out in simulated surface trials and subsequently underground to validate the concept.
- The instrumentation is capable of detecting and measuring changes in gateroad profile to the required accuracy for identifying geotechnical effects of mining.

Extension Scope and Ground Control Aspects:

A production trial of the gateroad convergence monitoring system will occur at Broadmeadow mine in the extension project. The system will give the convergence difference between two or three gateroad cross sections that are in fixed distances with respect to the maingate drive. For example, if one location is at the outbye end of the stageloader and the other at the maingate drive itself, there will be on-line monitoring of the profile difference (convergence) between these two points. The mine can then set TARPs (Trigger Action Response Plans) to react to excessive convergence in order to prevent gateroad falls.

<u>Condition Monitoring and Reliability</u>

This component was managed by CRCMining within the Landmark project. The five focus areas were reliability analyses, maintenance strategies, fault detection and isolation, AFC chain tension measurements and shearer vibration monitoring. The results were significant and are fully reported in (1) and will not be detailed further in this paper. Condition monitoring and reliability is not a component of the extension project.

Outcome 7: Redefined Functions of Face Operators

Goal: To identify personnel characteristics required in the workforce for operation of the Automated Longwall face and to develop the framework for a training package to assist in the design of training programs.

Achievements:

- A study of manning requirements has been performed.
- Key positions and personal attributes have been identified.
- Generic roles and authorisations have been established.
- A training matrix has been completed.

- A framework for individual training packages has been developed.

Landmark Extension Project scope:

In the extension project, the focus will be on the mode of delivery of training material to workers in the automated face environment. The development of a simulator for training purposes based on the Landmark Information System will be delivered as part of this scope.

Outcome 8: Implementation plan

Goal: To effectively manage the field program at Beltana, the major test mine, and other relevant locations such as OEM facilities.

Achievements:

A protocol was established to facilitate trials of Landmark project outcomes that satisfied the operational requirements, particularly of the participating mines, where the test platform for the research program was the main profit centre for the mine. This protocol included a phased introduction of new technology from bench trials to unsupervised production trials and included a series of risk assessment during this process. In the extension project this successful protocol will also be employed.

Outcome 9: Commercialisation

Goal: To facilitate the technical transfer and presentation of project outcomes to the industry.

Achievements:

- A project website (www.longwallautomation.org) was set up to facilitate presentation of project outcomes to the industry. This website has been used to communicate system specifications and technical papers as well as general items of interest. This has raised the interest level in the project area. In the commercialisation process, a number of responses from both OEMs and 'systems integrators' were received and initial discussions have been held with the respondents.
- Three products were identified for immediate commercialisation:
    a. Automatic Face alignment
    b. Automatic Creep Control
    c. INS-based Horizon control
- A commercialisation process was established. A document calling for expressions on interest in commercialising the CSIRO-developed IP was advertised nationally in June 2004. A number of responses were received and discussions held with the respondents.

Landmark Extension Project scope:

The next phase of the process is to demonstrate the technologies to the respondents at the test mine(s) scheduled for May 2005.

Full proposals addressing explicit selection criteria will be called for from short listed companies in approximately June 2005 with a view to appointment of commercial partner(s) by the end of 2005.

Other areas that will be considered for commercialisation include:

- Shearer Position Measurement System. Mines have indicated that they want this product now for manual response even before the automatic products are available.
- Face geotechnical monitoring system.
- Gateroad convergence monitoring system.
- CID based automatic horizon control.
- Controlled traversing cut.
- Retreat measurement system.
- 3D visualisation and information system.
- Training simulator.

Outcome 10: Implementation Plan for Progressive Automation

Goal: To benchmark all longwall mines in Australia in order to establish their current automation status and to provide a roadmap outlining steps necessary to achieve particular levels of automation.

Achievements:

All mines were surveyed and current automation status documented. An industry-wide picture of upgrades and new equipment required for compatibility with Landmark automation systems has been produced. These will be individually presented to the mines during 2005.

Conclusion

As can be seen, substantial progress has been made in all the initial defined project outcome areas. In particular the major influences on longwall operations have been:

- New sensor development for closed loop control of face equipment.
- Integrated operation of face components through open communications systems.
- New data flow and management methods and technologies.
- Identification of skills and qualities of people required for automated longwall operations.
- Development of new on-line condition monitoring and fault detection technologies.
- Development of new geotechnical monitoring tools.

The extension project will develop proof-of-concept outcomes from the original project to commercial prototype stage and set up a commercialisation process to allow the longwall industry to access these outcomes. Two mines, Beltana and Broadmeadow have committed, in conjunction with the extension project, to purchase commercial prototype versions of the systems. They will provide the test platform to allow these systems to become sufficiently robust to be offered commercially.

We believe that the outcomes of the Landmark project and its extension will change the operating benchmarks for longwall mining. The commercial payback for these systems are so significant that, within 10 years, we believe that all Australian faces will, at a minimum, have a Shearer Position Measurement System installed and most will be using an automatic straightening cut. At least half will also be using some form of automatic horizon control system.

Within the context of this conference the outcomes for geotechnical monitoring and control and the integration of these systems with the face information systems are also quite significant. The use of convex face profiles, automatic gateroad convergence monitoring and fully integrated leg pressure and shield closure monitoring will result in increased safety and higher productivity from our longwall faces. The spin-offs from having improved face alignment and horizon control to ground control are also significant.

References

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