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1. ABSTRACT

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 Landmark Longwall Automation project was commenced in July 2001. The major outcome of automation using on-face observation has been divided into ten outcome areas that have been fully scoped for a three-year initial project life. A major facilitating technology has been the implementation inertial navigation system (INS) technology 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.

2. BACKGROUND

In 2000 the Australian Coal Research (ACR) Board committed 1^c of the 5^c levy per export tonne to *Landmark* projects. The Landmark project concept was designed to enable the Australian Coal Association Research Program (ACARP) to target a small number of key strategic industry problems and to commit greater funding to their resolution. The ACARP Research Committee identified increasing automation in the coal industry as a means to both improve productivity and enhance health and safety. Consequently, longwall automation was nominated as a potential Landmark project area offering both immediate and long term benefits to the industry. This paper reports on the development of the Landmark longwall automation project scope and presents results from the first seven months of work.

The ACARP Longwall Automation Steering Committee (LASC) together with two invited research providers with successful track records in the ongoing ACARP program, CSIRO and CMTE, developed a detailed research proposal to advance longwall automation. This process included reviews of past automation attempts, analysis of current level of installed and utilised automation in Australian and overseas mines, adoption of newly-developed technology for future automation and extended consultation with OEM groups, both in Australia and overseas.

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3. AUTOMATION ISSUES

The review 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 disregarded. 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 and transport operations 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.

Key face-monitoring sensors have been identified and the project scope includes several sensor developments that will steadily supplement or replace human observations. These include equipment condition monitoring, collision avoidance for flippers, convergence monitoring in the gate roads and preliminary AFC block-up surveillance.

4. 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 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
4. Longwall equipment (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. Minesite trials and demonstrations
9. Acceptable commercialisation plan
10. Implementation plan for progressive automation

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

5. 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 project is summarised in the Gantt chart of Figure 1.

MILESTONES	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 & 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 & Reliability												
Reliability Analysis				♦								
FDI demo on off-line data											♦	
Trend analysis software 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.

5.1 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 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 (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.

As can be seen from the project schedule, work in the first year is concentrating on development of a real-time shearer position display 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 second first-year outcome concerns the enhanced shearer initiation of chock advance to move chocks to exact geometry determined by the INS system. 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) and the first trials of automatic control of shearer haulage based on the paradigms, models and underground operator 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 2 shows 3D position data that has been received from the shearer using a 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.

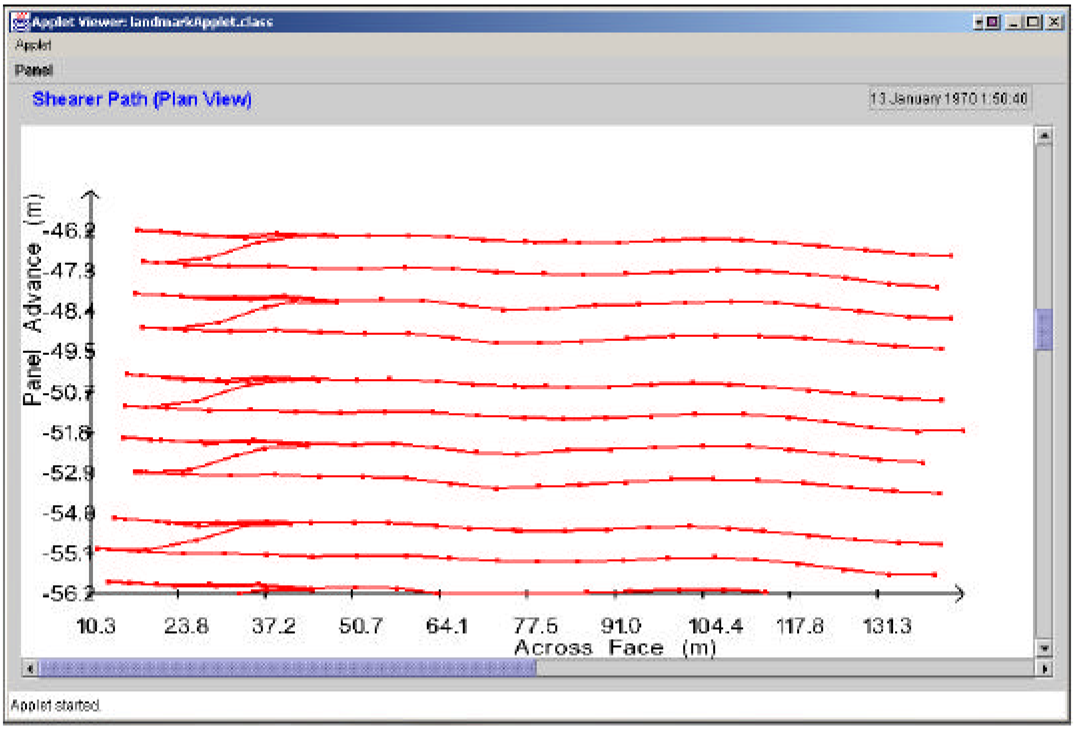

Figure 2 Plan View of Actual Shearer Position

5.2 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 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 first 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 roof and floor measurements at each shear. This information can be added as extra information to the existing OEM memory cut horizon control systems. Figure 3 shows the (as mined) seam profile extracted from actual shearer position information.

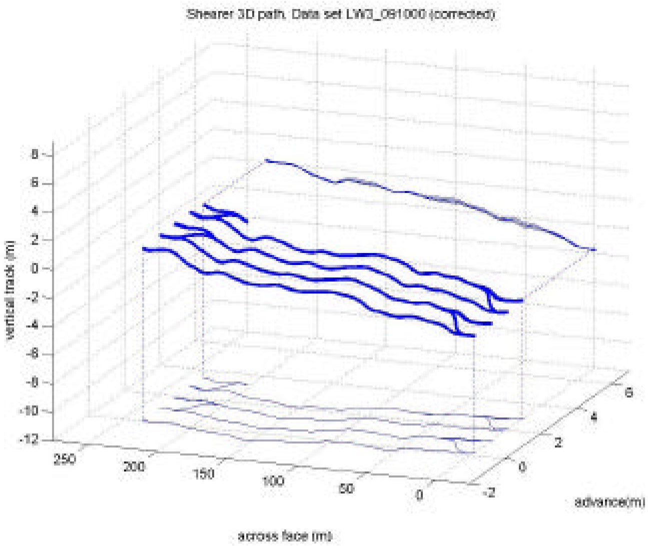

Figure 3 Extracted Seam Profile

Later in the project, other data (3D seismic, radio imaging etc) will be incorporated into the model used to predict optimal horizons.

Also in the first year work, will commence 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.

The mine survey referred to above has been carried out and prospective areas for CID sensor research, pick force/vibration sensing and optical marker band detection have been confirmed.

5.3 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.

The first requirement is for a reliable shearer-main gate end communications method for the transfer initially of 3D shearer position data, and then as part of a redundant link for shearer control.

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 equipment from various vendors. Data transfer between Landmark hardware, shearer and powered support systems is of critical importance. Establishment of an appropriate protocol is also a goal of the first year of the project.

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 operator station using video cameras placed on face equipment. These systems will require supporting wideband links which will be developed in years two and three.

In the project to date 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. In the first stage of the project a simple point-to-point link between the shearer and main gate has been implemented as an economical way to enable the performance of the link to be measured.

A similar link using a radio modem was used in ACARP project C9015 (Reid 1997) and a range of approximately 50 metres was achieved. In that project, position information was stored on-board the shearer and downloaded when the shearer was in range. Results so far using the wireless equipment have been very encouraging with ranges of the order of 200 metres being achieved with a point-to-point link.

The next stage of the project involves implementing a face-wide distributed wireless Ethernet communications system. Based on the performance measured so far, only two or three extra nodes in the distributed system will be required for continuous shearer communications across the 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. Particular issues arising in communications between various system components are covered in the next section.

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.

5.4 OEM Involvement

This is a key outcome for the success of the project. OEMs 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. 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 case, and in earlier work on dragline automation (Winstanley 1997), an approach has been adopted whereby all motion commands, whether from an automation controller or manual 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.

5.5 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.

5.5.1 Operator Station

In the first year the operator station will be constructed, computer systems for Landmark process control and operator visualisation purposes specified and installed. In addition, process control-level software will be developed to service the face alignment and horizon control project outcomes. The operator station shown in Figure 4 has been designed and is being constructed.

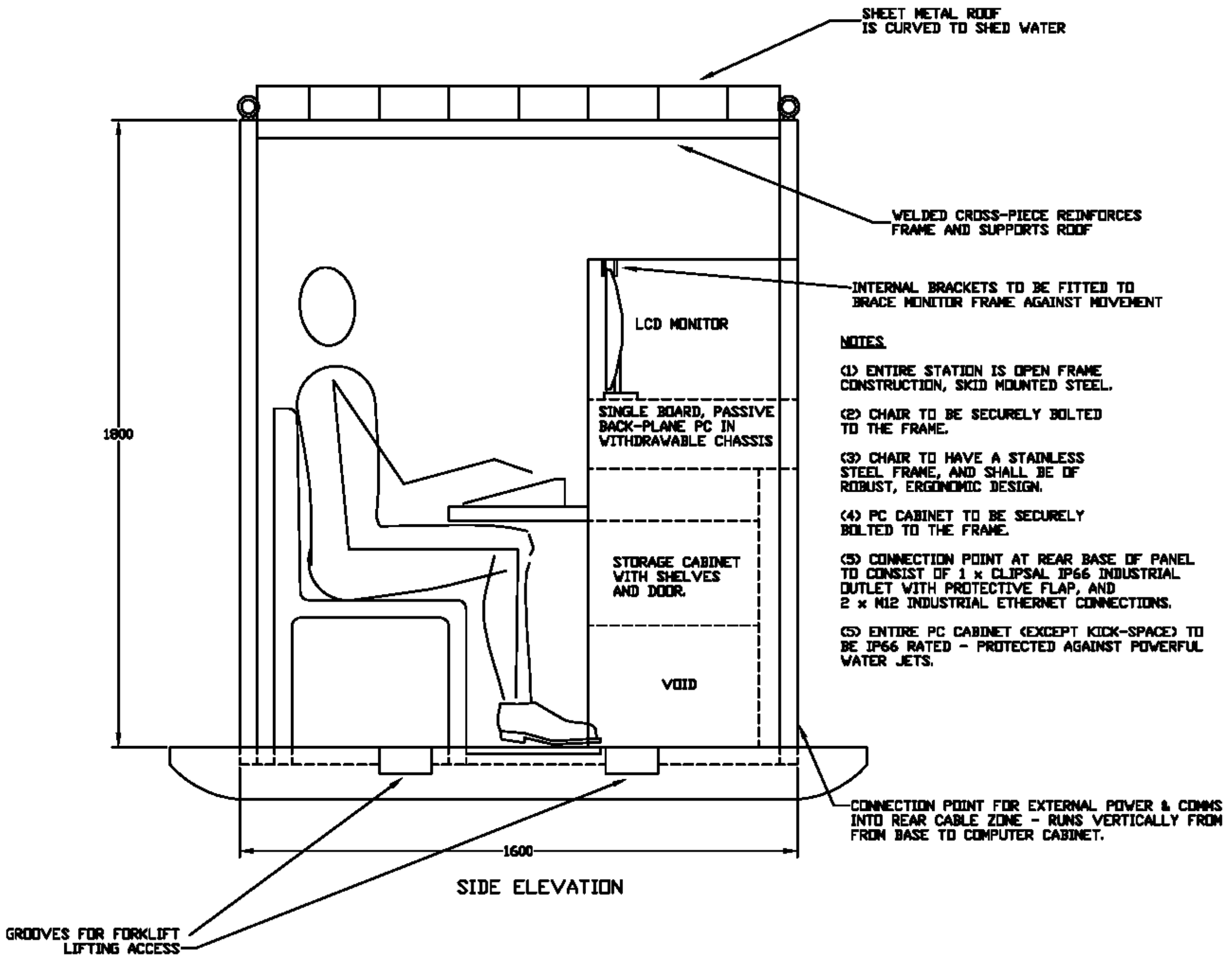

Figure 4 Underground Operator Station

5.5.2 Automatic longwall process

In the first year, process maps to characterise current longwall mining extraction methods will be 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.

5.5.3 System display

Visualisation software will be developed to produce high quality representations of the state of the longwall system on the underground operator station user interface. Preliminary visualisation models, an example of which is depicted in Figure 5, have been created.

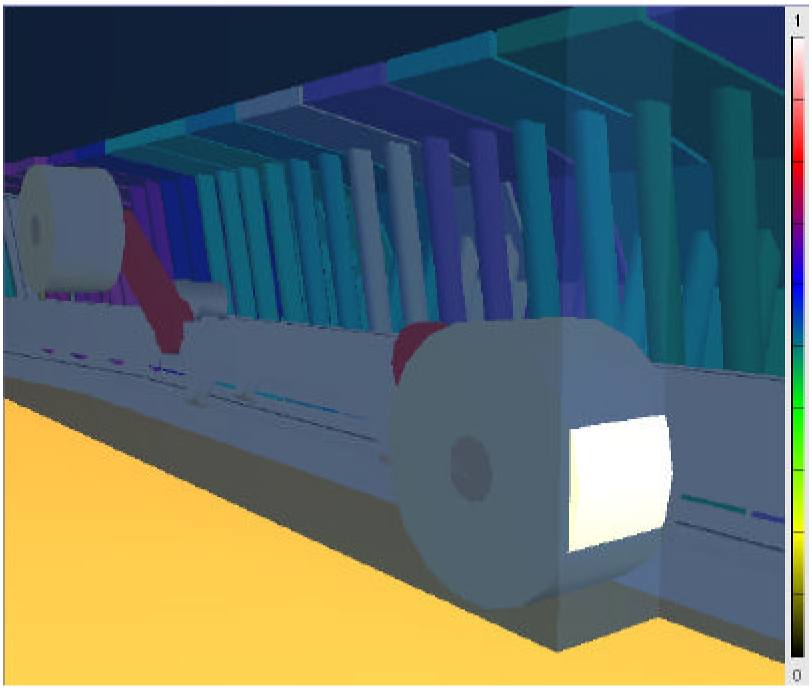

Figure 5 Longwall Visualisation

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.

5.6 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 gate road 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.

Collision avoidance: In the first year, the existing OEM collision avoidance systems will be utilised. In the second and third years, a sensing system will be developed to measure the separation distance between the shearer and chock 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 operator station.

Convergence monitoring: The latest developments in support leg convergence monitoring methods will be surveyed. 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.

5.6.1 Condition Monitoring and Reliability

A proper understanding of the reliability of the existing system is essential. In the first year a 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 will be developed.

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 be 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 to 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 this one-year 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.

In the fault detection segment of the work the first year program comprises analysis of on-line maintenance log data. In the remainder of the project statistical analysis of data will be followed by development of software to generate remote monitoring displays. Fault detection and isolation (FI) software will be developed and demonstrated on off-line data.

The third work area comprises trend analysis and sensor self-testing. External trends that need to be monitored will be identified and trend analysis software will be demonstrated on off-line data.

A preliminary analysis has been carried out with the trend data collected over 7 months of longwall operation, recording 223 variables at one observation per minute. The historical record of machine failure that accompanied the data is in the form of summarised production reports, which contains information as to the time and duration of the failure, and a comment field for incident description. Phase recognition is used to extract the required failure classifications from this large dataset, to provide a means of evaluation for the failure detection and classification process. Some difficulties have been encountered in synchronising the machine failure data with the electronic trend data.

A Fischer Discriminant Analysis (FDA) was carried out on the data. This analysis produces a new dataset, via linear or non-linear projection, which is of equal dimensionality as the original set. The projections are orthogonal, and are developed with criteria to maximise the separation (in multivariate space) between classes of data, while minimizing the spread within each class.

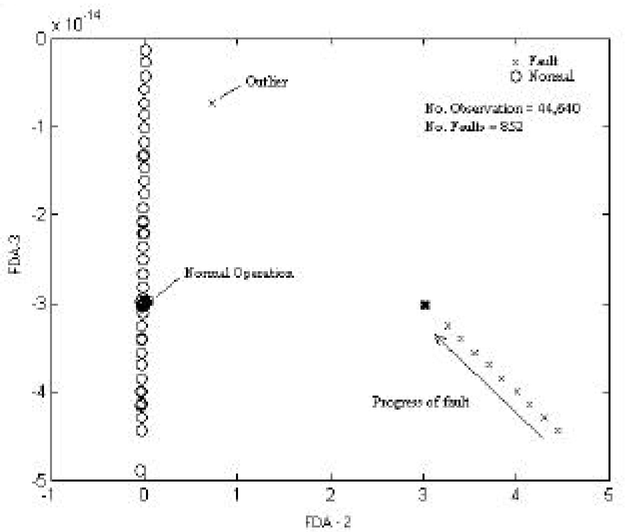

Figure 6 Linear Fisher Discriminant Analysis

Figure 6 presents the results of an FDA to detect an armoured face conveyor (AFC) tailgate-drive stall, a common maintenance event. The developed projections clearly separate normal operational data from observations occurring within a few time-steps of a fault. It should be noted that Figure 6 contains 44,640 data points, but observations of the same class, cluster together so that there are relatively few points visible. These early results suggest the feasibility of implementing an on-line trend and condition monitoring system. The principal obstacle is obtaining good quality machine failure data to form a reference for the automatically collected sensor data.

5.7 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 would be 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 operator station. Additionally, because system operational data will be available over the minesite local area network, off-line training will also be possible on the surface using on-line information. The training process will be refined as more experience is gained with the automation system by mine operational personnel.

5.8 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.

5.9 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.

5.10 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.

6. 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 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 seven months and several important milestones have been achieved:

- On-line 3D shearer position information is now available
- Wireless Ethernet communications has been shown to be a viable face communications system
- A standard communications method between OEM and Landmark control systems has been established
- Early 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.

7. REFERENCES

Winstanley G, Corke P, Roberts J, 1997. Dragline Automation, in *Proceedings* of the 4th International Symposium on Mine Mechanisation and Automation, pp B-1-B9, (Brisbane).

Hainsworth D W, 1997. Automatic Horizon Control of Coal Mining Machinery, in *Proceedings* of the 4th International Symposium on Mine Mechanisation and Automation, pp B6-11-B6-20, (Brisbane).

Reid, D C, Hainsworth, D W, and McPhee, R J, 1997. Lateral guidance of highwall mining machinery using inertial navigation, in *Proceedings* of the 4th International Symposium on Mine Mechanisation and Automation, pp B6-1-B610 (Brisbane).

Reid, D C, Hainsworth D W, Ralston J C, and McPhee R J, 2001. Longwall shearer guidance using inertial navigation (ACARP project C9015), CSIRO, Exploration and Mining Report 832F.