Development of a Pre-Driven Recovery Evaluation Program for Longwall Operations

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DEVELOPMENT OF A PRE-DRIVEN RECOVERY EVALUATION PROGRAM FOR LONGWALL OPERATIONS

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ABSTRACT: Many longwall coordinators are examining the use of pre-driven recovery roadways. This method, if performed successfully can improve the overall efficiency and safety of moving longwall equipment from panel to panel. However, it is difficult to assess the feasibility of using pre-driven recovery unless extensive research is carried out or a consultant is used to analyse the particular situation. A number of previous case studies have been analysed to discover which parameters have the greatest influence on the success of pre-driven recovery. Floor strength, Coal Mine Roof Rating (CMRR), extraction depth, Roof Density Index (RDI), standing support and mining rate were the main parameters impacting on the successful implementation of pre-driven recovery roadways. These parameters have been incorporated into a program that was developed to assess the feasibility of using pre-driven recovery roadways. The Pre-driven Recovery Evaluation Program (PREP) is simple to operate and it will enable new longwall mining operations as well as current operations to quickly determine the suitability of the method to their site.

INTRODUCTION

Pre-driven recovery is a very important aspect of longwall mining. Pre-driven recovery rooms are used to safely remove longwall equipment once extraction of a panel has been completed. This method, if performed successfully can improve the overall efficiency and safety of shifting longwall equipment from panel to panel. Pre-driven recovery can significantly reduce the longwall downtime due to panel change, and therefore considerably improve the profit margin of the operation.

The method of pre-driven recovery is slowly replacing the conventional method and to-date over 100 full or partial pre-driven recovery roads have been used in the US, Australian and South African underground coal mines (Thomas, 2008). The majority of these cases have proven to be extremely successful and improved the overall efficiency and safety of the operation as they were performed under appropriate strata conditions using the correct ground support. However, it is difficult to evaluate the feasibility of using pre-driven recovery unless carried out by strata specialists.

Analysis of past case studies has been used to discover the main parameters that influence the success of pre-driven roadways. These parameters have been incorporated into a program to assess the feasibility of using pre-driven recovery for a given situation and hence improve the overall safety and efficiency of longwall equipment recovery.

CURRENT LONGWALL RECOVERY METHODS

The moving of longwall equipment from one panel to the next is a critical efficiency issue to any longwall operation. The two main longwall recovery methods that have been practiced to date are the conventional and pre-driven recovery methods.

Conventional Method

Currently the average move time for longwall operations is around 20 days, while move times as long as 30 days are recorded. The move time can vary depending on face width, panel length (distance of move), experience of mine personnel, and amount of equipment installed on the new face prior to start up of the actual move (Bauer *et al*. 1989). The preparation for the conventional recovery method usually occurs at 15 m from the extraction point. The roof of the mine is supported by installing bolts and wire mesh along the longwall face at the end of each panel advance (Bauer *et al*. 1989). The bolts are installed either by hand-held drilling equipment or specialised single boom bolters designed specifically for this application (Tadolini, Zhang and Peng, 2002).

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Figure 1 illustrates a sectional view of the conventional recovery method.

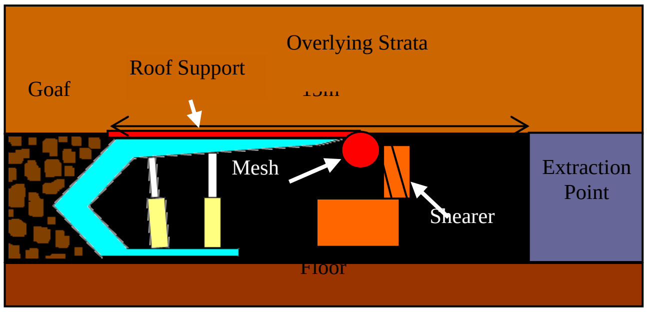

Figure 1 - Schematic of conventional recovery method

Pre-driven Recovery Roadways

As an alternative to the conventional method, mines have investigated and utilised pre-driven recovery rooms for longwall face moves. In this method an entry is developed and supported ahead of time so that the required combinations of standing and internal support can be installed prior to the longwall face approaching the extraction point.

The roadway is created using a continuous miner and generally has a width of around 5 m, however the width can range up to 12 m depending on the size of the equipment being recovered and ground conditions (Science Communication Services, 1990). The longwall is then able to extract the remaining fender at full speed before holing into the recovery roadway. Figure 2 represents a cross-sectional view of the pre-driven recovery method.

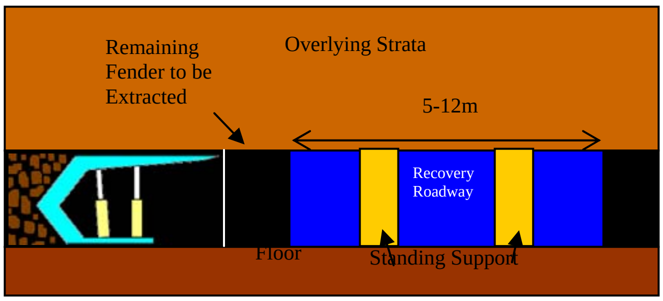

Figure 2 - Schematic of pre-driven roadway recovery

Strata behaviour during pre-driven recovery

It was discovered that once the unconfined fender has yielded, it will not carry any appreciable load owing to its poor post failure strength (Science Communication Services, 1990). At this stage, the supports and barrier pillar edge bear the load of a 16 m long cantilever and the roof strata behaves as though the face was at the edge of the barrier pillar (Figure 3). Consequently, the strata above the longwall face undergo various degrees of tensile failure ahead of the face line. As the remaining fender yields, the tensile strains are transferred to the barrier pillar edge and are considerably increased. At this point, if the cantilevered roof cannot support itself and fails, the shields will be carrying the majority of the load (Science Communication Services, 1990).

To improve the success of the recovery, it is therefore recommended that the longwall is checked and given a major service thirty metres before the pre-driven road is to be holed. From this point onwards the longwall is operated continuously until the recovery road is holed. The reason for this is to attempt to keep the front abutment pressure moving across the roadway into the solid outbye pillar. This is considered to be a vital element in the approach.

Suitable ground conditions

McCowan and Hornby (1989) found that the use of full length pre-driven recovery roads under laminate or mudstone/siltstone roof strata was a high risk operation from which the derived benefit could not be justified. It was found that if the cantilever fails through the weak intact rock or an inherent geological feature, then loads will be produced that exceed the support capacities. Therefore, the use of full length pre-driven recovery roads is not recommended under a laminate or mudstone roof without adequate passive support (McCowan and Hornby 1989).

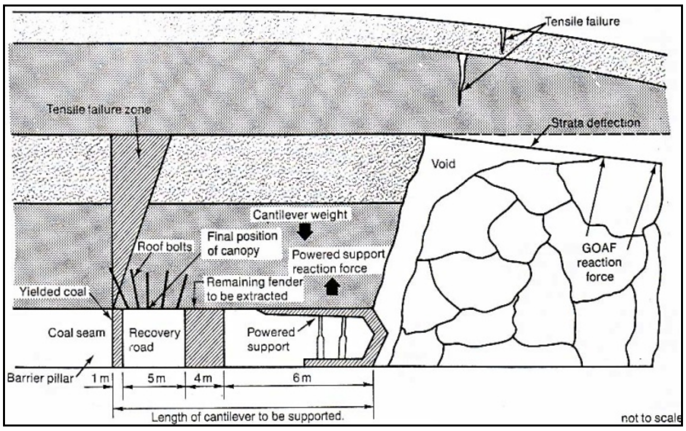

Figure 1 - The structures and forces involved in roof failure associated with a full-length, pre-driven recovery road (Science Communication Services, 1990)

From research conducted by ACIRL (Science Communication Services, 1990) it was discovered that laminated strata have a lower shear modulus than more massive strata, which in turn results in more flexibility within the strata. This increased bending results in greater loading on the fender, leading to greater increased face and recovery road-rib side yielding. The reason for this is that the laminated roof is less able to support itself along with the overburden. As the overlying stratum is unable to support itself, higher capacity supports are required for softer or laminated roof types (Science Communication Services, 1990). Therefore it is reasonable to suggest that laminate or mudstone/siltstone roof strata are unsuitable ground conditions for pre-driven recovery roads unless adequate passive support is installed.

Selection of support design

Peng (2007) found that the safest support design is to use a combination of standing supports and roof bolting. Both the roof bolting and standing support systems can be designed to independently support the room, or combined as a system, thereby utilising their individual advantages. Experiences have shown that with proper design this system can ensure a successful outcome (Peng, 2007).

The combination of the internal bolting system and the standing concrete supports are critical for the successful and safe recovery of the longwall equipment. A combined support system that is too soft or too stiff can result in excessive recovery room closures or brittle failures of the concrete crib systems (Tadolini, 2003). Figure 4 shows the installation of pumpable cribs. Note that a bag containing a softer material has been placed between the crib and the roof to allow for the cribs to be slightly compressed.

It is however possible to successfully recover equipment from a pre-driven roadway without the use of standing support. This has been proven at the US Steel, Mine 50 where traditional methods involving standing support are not feasible due to the difficulties of the plough face mining through these types of support (Smyth *et al*, 1998). Smyth *et al*. (1998) stated that recent development of new cable support systems provides an option for cut through entry support. Mine 50 and Jennmar Corporation personnel have worked together to design and apply the cable systems in the cut-through entries and full face recovery room to eliminate standing support. To date, a number of full face recovery rooms and cut-through in-panel entries have been successfully mined (Smyth *et al*, 1998)

DATA ANALYSIS

In recent years, the National Institute for Occupational Safety and Health (NIOSH) compiled a comprehensive international database of past case histories of parameters associated with pre-driven recovery roadways (Oyler *et al*, 1998). An analysis of the NIOSH data was conducted to identify the various mining parameters that lead to the overall success of pre-driven recovery roadways.

Figure 4 - Installation of pumpable cribs (Peng, 2007)

Effect of mining parameters on pre-driven recovery roadways

The mining parameters that were analysed included:

- Floor strength
- Depth of extraction
- Coal mine roof rating (CMRR)
- Seam height
- Panel width
- Room length
- Shield capacity
- Roof density index (RDI)
- Standing support
- Advance rate

The outcome of the pre-driven roadways were categorised into three groups. These were:

- Successful outcome
- Failure due to face break or roof fall
- Failure due to major overburden weighting

Each parameter was individually graphed to observe the impact that it had on the success of this mining method. From the data analysis it was found that floor strength, depth of extraction, CMRR, RDI, standing support and advance rate were parameters that had the most influence on the success of pre-driven roadways.

Floor Strength

A higher percentage of weighting failures occurred in mines with soft floor conditions as seen in Figure 5. In some conditions where the fender pillar is thin and likely to punch into the floor, the potential for failure may be increased due to soft floor conditions. However in some successful soft floor cases, the soft floor conditions were credited with delaying the fender yield and therefore contributing to the success of the recovery room.

Depth of Extraction

A wide range of cover depths from case histories were included in the analysis. However there was no strong relationship found between depth of extraction and major failure due to overburden weighting (Figure 6). Generally, it can be seen from Figure 6 that failures due to face breaks or roof falls were somewhat more likely to occur at greater depths. This is most likely due to the increase in horizontal stresses on the surrounding strata of the pre-driven recovery roadway in the deeper mines. Also due to the increase in horizontal stress, deeper mines typically install higher densities of roof reinforcement to help compensate for these stresses.

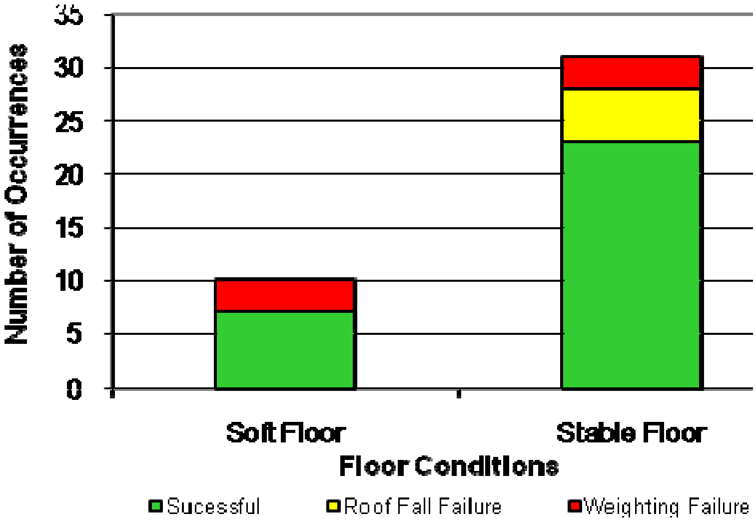

Figure 5 - Histogram showing impact of floor conditions on recovery roadway outcomes

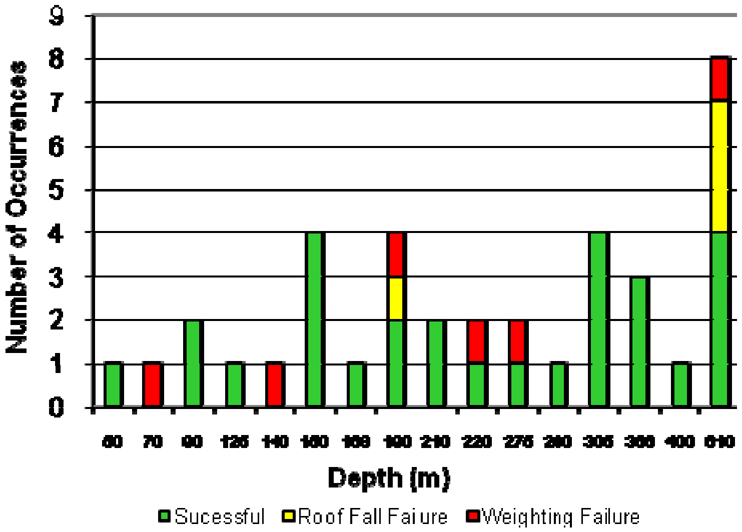

Figure 6 - Histogram showing impact of depth of cover on recovery roadway outcomes

Coal Mine Roof Rating

A very strong correlation was found between CMRR and weighting failures as showed in Figure 7. All of the six weighting failures occurred where the roof was relatively weak (CMRR< 50). This provides an indication that if the CMRR is less than 50 then unless the roof is heavily supported; weighting failures are likely to occur. However there is less evidence of roof falls being related to roof strength.

Mining Rate

A slow mining rate seemed to be a strong predictor of both types of failure. It can be seen in Figure 8 that even though the same amount of failures occurred a higher percentage of failures were associated with slow mining rates compared to normal mining rates.

This is why it is extremely important that the longwall is stopped around 30m before the fender pillar and is fully serviced. This ensures that breakdowns are less likely to occur which will reduce the advance rate of the longwall face during this critical stage of operation.

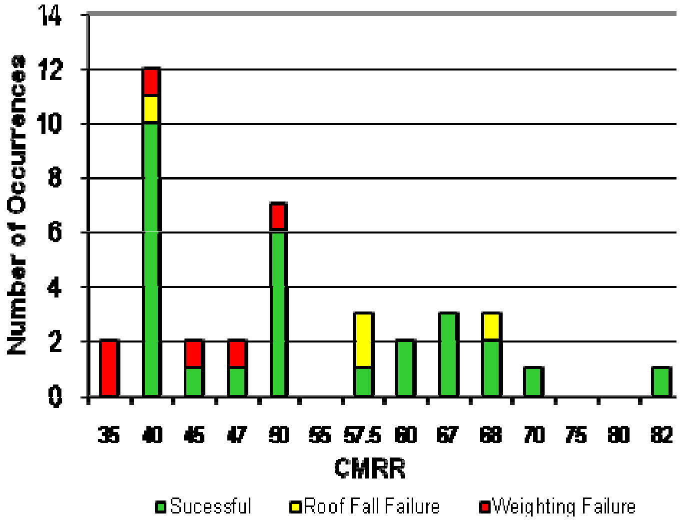

Figure 7 - Histogram showing impact of CMRR on recovery roadway outcomes

Figure 8 - Histogram showing impact of mining rate on recovery roadway outcomes

Roof Reinforcement
Roof reinforcement includes all intrinsic support elements such as roof bolts, cable bolts, and trusses. The reinforcement is quantitatively measured by determining the load capacity of each element per unit area of roof supported by the element and multiplied by the length of the element.

This Reinforcement Density Index (RDI) has the units of MPa.m. It can be observed from Figure 9 that heavy roof reinforcement was apparently successful in reducing the incidence of roof fall type failures. However roof reinforcement was not successful in preventing weighting failures.

Standing Support
Figure 10 shows that standing support has a dramatic influence on the success of pre-driven recovery rooms. A characteristic of every one of the weighting failures is the lack of standing support.

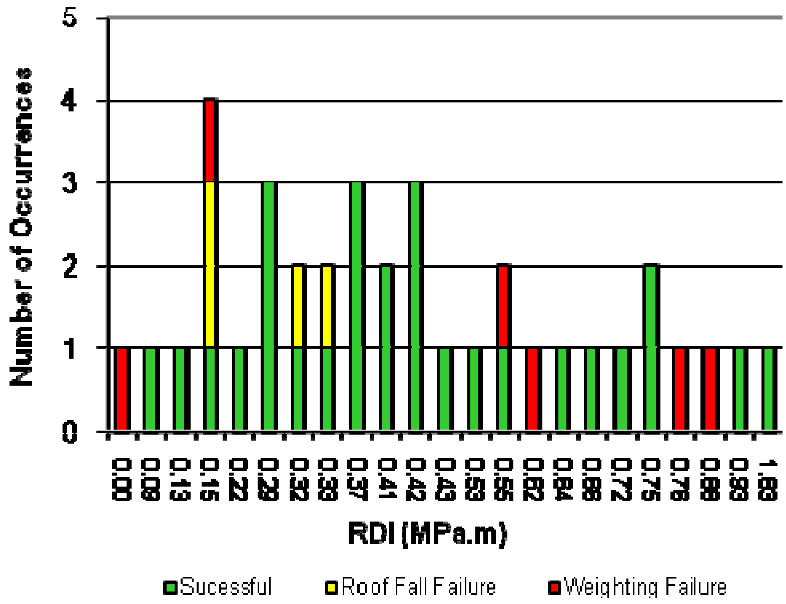

Figure 9 - Histogram showing impact of RDI on recovery roadway outcomes

It has been recorded in two instances where after a severe weighting failure developed in a room without standing support, adjacent rooms were mined successfully with standing support (Oyler *et al*, 1998). From these cases it has been indicated that standing support can be the difference between success and failure of a pre-driven recovery operation.

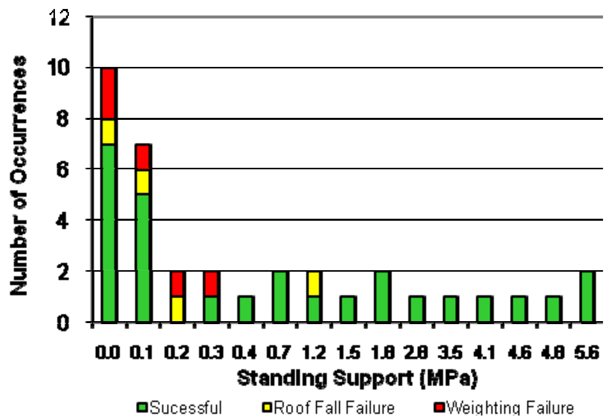

Figure 10 - Histogram showing impact of standing support on recovery roadway outcomes

Multivariate analyses

A multivariate analysis was used to obtain a possible insight into the parameters that most influenced pre-driven roadways and help set particular design guidelines.

CMRR and Standing Support

Weighting failures are closely associated with CMRR and standing support as shown by Figure 11. A highly significant relationship indicates that when the CMRR was greater than 50, little support was necessary. It can be seen from Figure 11 that for a CMRR equal to 40, the successful cases used a standing support density of at least 1.0 MPa. For CMRR values ranging from 45-50, standing support densities as low as 0.5 MPa were sufficient in preventing or controlling weighting failures. However the cost of standing support is small compared to the cost of a weighting failure, and therefore it is recommended that the observations from Figure 11 should not be taken as a recommendation to estimate standing support.

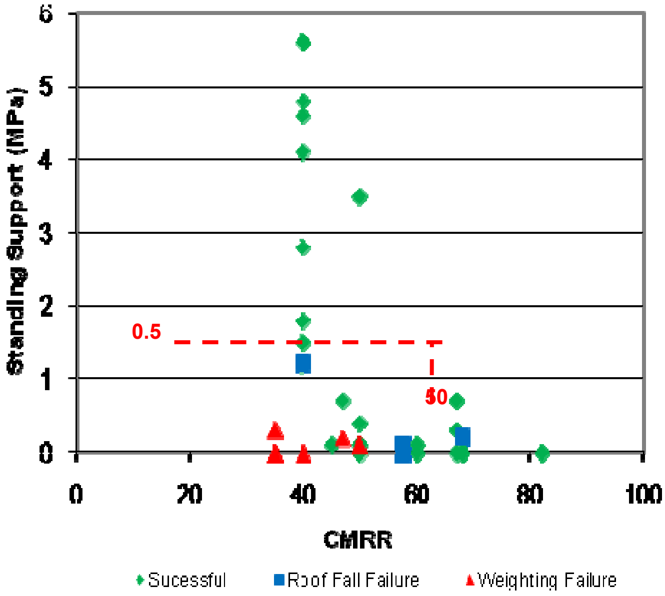

Figure 11 - Combined influence of CMRR and standing support density on recovery roadway outcomes

RDI and Standing Support

From the multivariate data analysis it was discovered that the majority of pre-driven roadway failures were associated with either a low density or no standing support and a low RDI (Figure 12). The majority of the failures were associated with roadways where the standing support density was less than 0.5 MPa. In terms of roof reinforcement, the majority of pre-driven roadway failures were recorded where the RDI was less then 0.8 MPa.m.

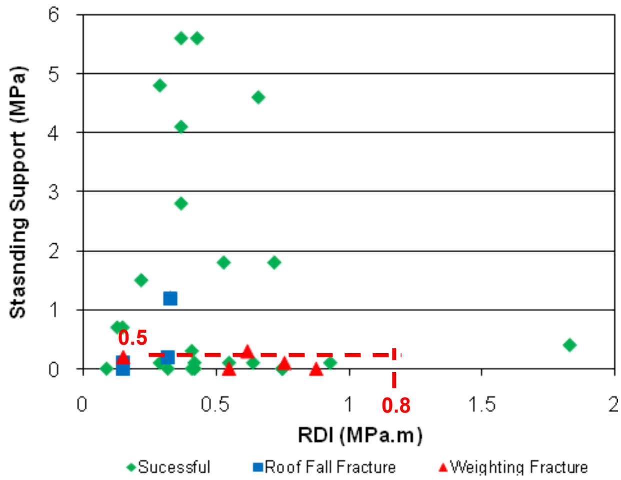

Figure 12 - Combined influence of RDI and standing support on recovery roadway outcomes

Figure 12 indicates if a particular pre-driven roadway has standing support less than 0.5 MPa and a RDI less than 0.8 MPa.m, then the likelihood of failure is dramatically increased. It was recorded that 8 out of the 20 cases (40%) that used a combination of support in this range encountered failures of pre-driven roadways.

From the analysis it can be observed that the majority of successful cases used high densities of standing support to counteract the need for high densities of roof support. On the other hand, high densities of roof support have also been used to offset the need of high densities of standing support.

PRE-DRIVEN RECOVERY EVALUATION PROGRAM

Microsoft Excel was used to develop a program to evaluate the feasibility of using pre-driven recovery based on the most significant parameters identified as having an influence on a successful outcome.

Development of the program

The final version of the Pre-driven Recovery Evaluation Program (PREP) can be seen in Figure 13.

The evaluation program was created using the Developer tab in Microsoft Excel 2007. From the data analysis six of the most influential parameters of pre-driven roadways were selected to be incorporated into the evaluation program. Scroll bars and list boxes were incorporated into the program to allow the user to clearly see what option they have chosen and reduce the chance of selection errors from occurring.

An evaluation of the inputs into the program is provided so that the user can clearly understand the feasibility of their particular pre-driven roadway. The evaluation has four possible outcomes based on the total value from each of the parameters:

- Strongly Recommended (100-75)
- Recommended (75-50)
- Not Recommended (50- 25)
- Strongly Not Recommended (25- 0)

Also a bar graph was incorporated into the program and linked to the overall result to provide a visual rating out of one hundred.

The data for each parameter along with the formulas used to calculate the overall rating was hidden in a second sheet so that the user of the program would not be confused by the data. For each of the parameters a formula was applied to weight the data based on the importance and overall impact that each particular parameter had on the overall success of the pre-driven roadway.

Conditional Formatting was also applied to the program to give the user a visual response to the result of the recommendation. A colour scheme ranging from red (strongly not recommended) to green (strongly recommended) was used as this gave a recognisable and distinct indication of the result.

Clear instructions on how to activate the program are also provided. In order to use the program the developer tab must be activated followed by enabling the macros. The file must then be closed and re-opened before the program can be used.

Figure 13 represents the best case scenario for the pre-driven recovery evaluation program. The best case is given when the following parameters are entered into the program:

- CMRR is high
- Floor strength is Normal (>20MPa)
- Depth of Extraction is shallow
- RDI is high
- Standing Support is high
- Mining Rate is high

Testing the Program

Values from the case histories were entered into the program to ensure that it provided the correct result.

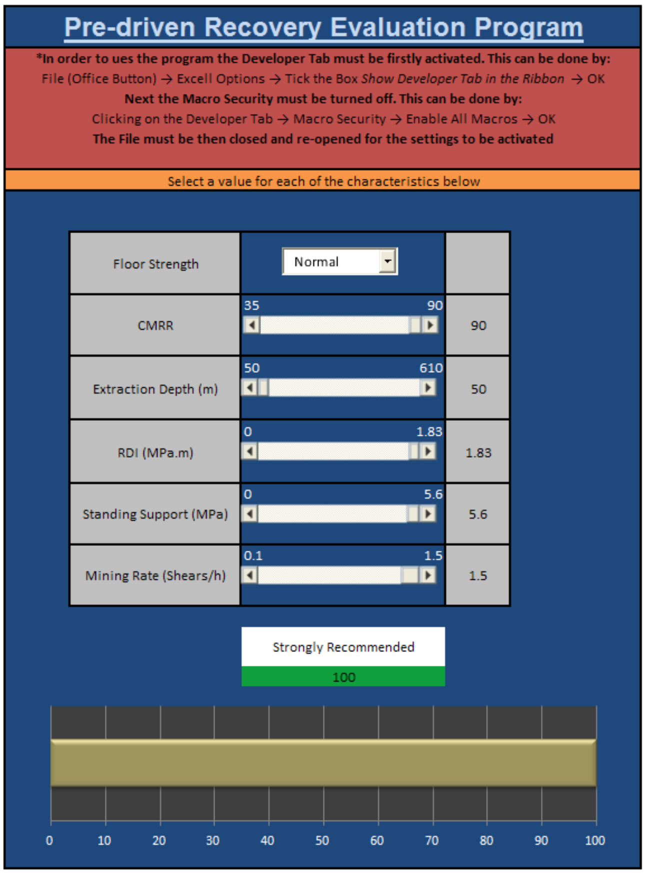

Figure 13 - Pre-driven Recovery Evaluation Program

Example of a Successful Outcome
The parameters from Table 1 were entered into the Pre-driven Recovery Evaluation Program.

Table 1 - Parameters for a successful outcome

Country	**Australia**
State	**NSW**
No. of Rooms	**4**
Soft Floor	**No**
Depth (m)	**290**
CMRR	**50**
Seam Height (m)	**3**
Panel Width (m)	**200**
Room Length (m)	**200**
Shield Capacity (t)	**590**
RDI MPa.m	**1.83**
Standing Support MPa	**0.4**
Slow Mining	**No**
Outcome	**Successful**

Figure 14 shows that the program provided the correct result for the given parameters and it is recommended that pre-driven recovery be used.

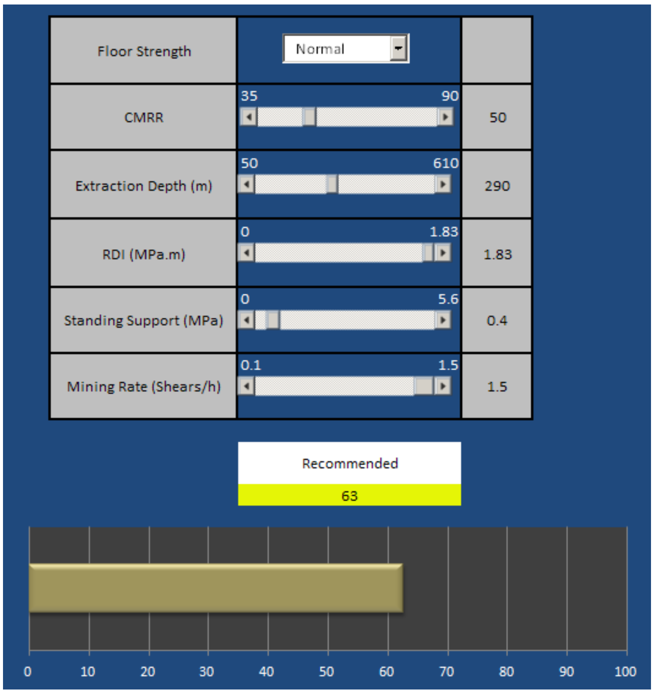

Figure 14 - Results of a successful outcome

Example of Failure Due to Face Break or Roof Fall
The parameters from Table 2 were entered into the Pre-driven Recovery Evaluation Program.

Table 2 - Parameters for failure- face break or roof fall

Country	**US**
State	**MD**
No. of Rooms	**1**
Soft Floor	**No**
Depth (m)	**190**
CMRR	**40**
Seam Height (m)	**2.6**
Panel Width (m)	**229**
Room Length (m)	**229**
Shield Capacity (t)	**599**
RDI MPa.m	**0.33**
Standing Support MPa	**1.2**
Slow Mining	**Yes**
Outcome	**Failure**

As shown by Figure 15 the program provided the correct evaluation and gave a result of 'Not Recommended'. This was mainly due to the fact that the majority of the parameters were less than average and the mining rate was slow.

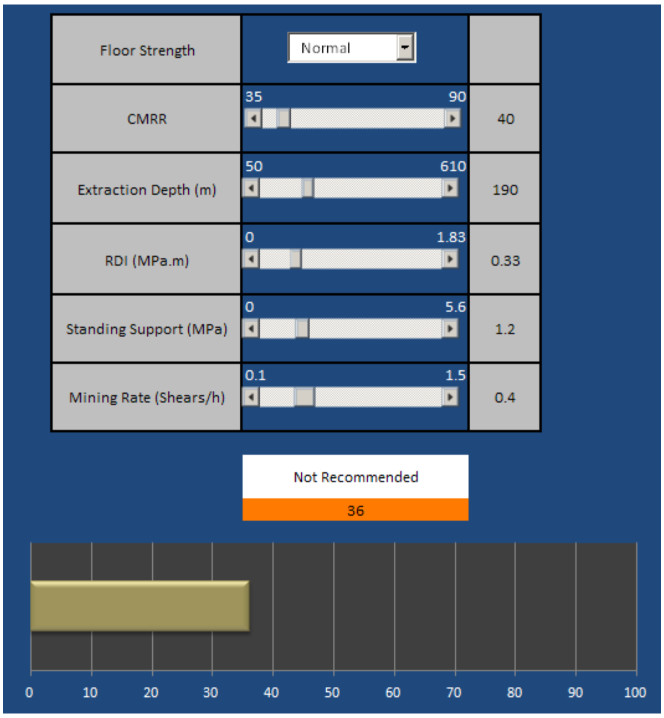

Figure 15 - Results for failure due to face break or roof fall

Example of Failure Due to Major Overburden Weighting

The parameters from Table 3 were entered into the Pre-driven Recovery Evaluation Program.

Table 3 - Parameters for failure - major overburden weighting

Country	**S. Africa**
State	
No. of Rooms	**1**
Soft Floor	**Yes**
Depth (m)	**70**
CMRR	**35**
Seam Height (m)	**3**
Panel Width (m)	**200**
Room Length (m)	**100**
Shield Capacity (t)	**327**
RDI MPa.m	**0.55**
Standing Support MPa	**0**
Slow Mining	**Yes**
Outcome	**Failure**

Figure 15 shows that the program provided the correct result and gave a result of 'Strongly Not Recommended'. This was mainly due to the mine having a low CMRR and no standing support. It also had a soft floor and a slow mining advance rate.

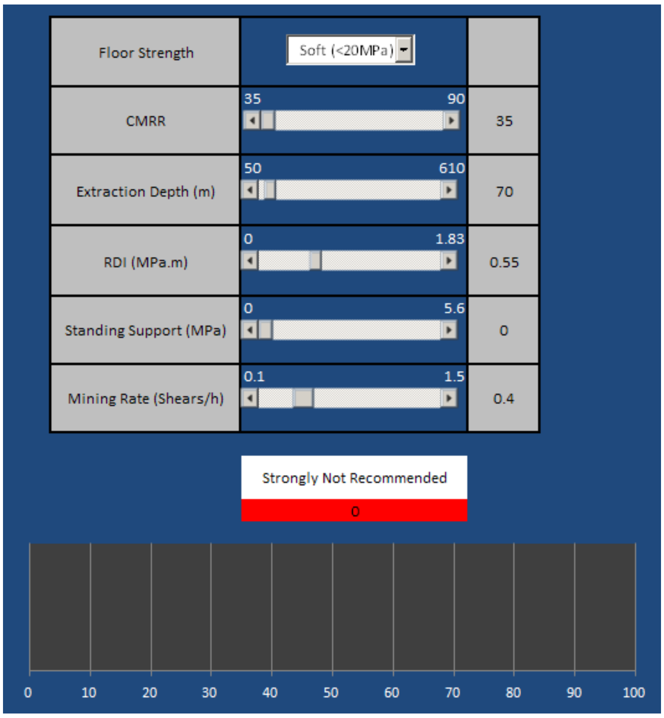

Figure 16 - Results for failure due to major overburden weighting

CONCLUSIONS

Pre-driven longwall recovery rooms can be used to safely recover longwall equipment from the current coal panel. This particular method can also reduce the time needed to extract the longwall equipment as support is applied to a pre-driven room prior to the longwall face reaching the take-off point. Therefore the longwall can maintain a constant advance rate compared to the conventional method where considerable production delays occur due to face preparation.

It has been recommended that the use of full length pre-driven recovery roads under laminate or mudstone/siltstone roof strata was found by research and experience to be a high risk operation from which the derived benefit was not feasible. It was also found that the combination of the internal bolting system and the standing concrete supports are critical for the successful and safe recovery of the longwall equipment.

Although there have been some catastrophic failures in the past from the use of pre-driven roadways, the majority of pre-driven roadway operations have proven to be successful. It was discovered from the data analysis that floor strength, depth of extraction, CMRR, RDI, standing support and advance rate all play a vital role in the success of pre-driven recovery. These parameters along with their individual amount of influence on the final outcome were incorporated into an Excel macro-driven program, the *Pre-driven Recovery Evaluation Program*. This program has been designed to be user friendly and clearly display the final recommendation both numerically and visually as to whether the use of a pre-driven recovery roadway will produce a successful outcome.

The *Pre-driven Recovery Evaluation Program* will provide excellent assistance for new longwall mining operations as well as current operations desiring to change to pre-driven recovery to assess the feasibility of this particular method for longwall equipment recovery. It is however recommended that the program only be used as a guide and if pre-driven recovery is being strongly considered, that a strata specialist be used to fully assess the situation.

ACKNOWLEDGEMENTS

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