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An Integrated Approach at Reducing The Risks Associated with Underground Coal Pillar Extraction of Bord and Pillar Development Areas in South Africa

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ABSTRACT: The Analysis for Pillar Extraction Potential (A-PEP) tool is an expert system which can be used as a preliminary output indicator when considering the secondary extraction of regional support pillars in the Witbank and Highveld coalfields of South Africa based on certain physical, nsk and economic factors which combine to be indicative of operational success in terms these attributes A-PEP has been successfully tested and validated against an underground coal pillar operation and it has shown that its predictive nature is consistent to the workings at the operation and as such it can be successfully used as a mine planning tool The A-PEP mine planning tool represents a positive step as a risk management tool in its integrated approach to underground coal pillar extraction when considering legal and operational aspects which could form the basis for legislative guidelines when considering the future of pillar extraction in South Africa

1 INTRODUCTION

A research initiative (part of the Coaltech 2020 collaborative research programme) investigated the status of underground coal pillar extraction in an attempt to provide the industry with a framework from which an attempt could be made to safely and economically extract the reserves remaining in the form of regional stability pillars in the Witbank and Highveld coalfields Various pillar extraction operations in South Africa were visited to gam recent experiences with this mining method The results of these visits, together with an extensive literature review of local pillar extraction planning and design considerations (Beukes, 1989, Livingstone-Blevins & Watson, 1982, Plaistowe *et al,* 1989) showed that little in the way of new technologies, ideas or mining methods have been developed m South Africa in recent years (except for the NEVED method) As this research attempts to develop a design methodology for pillar extraction to increase the utilisation of coal resources, looking at the history of pillar extraction m South Africa provided a good platform of general practices but did not provide any solutions as to how to take this mining technique (considered an art more than a science) successfully into the future A solution to this problem was to look at other pillar extraction techniques outside of South Africa to identify what elements of these operations could be adopted or adapted for use in the Witbank and Highveld coalfields A study tour to New South Wales in Australia was undertaken (where seven underground pillar extraction operations were visited) to assess what mining methods and design criteria are used to ensure the success of this mining practice there Although the predominant extraction there is based on rib-pillar techniques (which is an unlikely method in South Africa going forward) which differs vastly from the traditional removal of previously developed pillars, it was believed that their success factors could be emulated This visit highlighted some pertinent success factors associated with pillar extraction and these formed the basis for the development of a design methodology and planning tool called A-PEP (an acronym of Analysis of Pillar Extraction Potential) which is a user-friendly, intelligent tool enabling the potential for pillar extraction of an operation to be assessed by inputting certain physical, risk and economic factors This paper highlights some of the major findings of the research investigating means of safely and economically extracting underground pillars in the Witbank and Highveld coalfields

1.1 Review of pillar extraction experiences in New *South* Wales, Austral»

The visit to pillar extraction operations in. New South Wales in Australia in the first half of 2001 was aimed primarily at ascertaining whether any new pillar extraction technologies exist which may be of benefit to future pillar extraction operations in South Africa. Australia has a long history of pillar extraction dating back some 60 years (Shepherd & Chaturverdula, 1992); most notably having developed the rib pillar extraction technique (more commonly known as the Wongawilli method). Another innovation developed in Australia and which has found application in the USA is the single- or double-sided Outside Lift and Christmas Tree methods (Mark & Chase, *i* 999). The operations in New South Wales are however moving away from the pillar extraction techniques in favour of the safer and more productive longwall method of mining. Nonetheless some important design considerations were obtained from pillar extraction experiences in New South Wales (MeKensey, 1992); the most notable of which included the specific legislative guidelines for pillar extraction, the use of Mobile Breaker Line Supports (MBLS's), geotechnical mapping and the intensive training undergone by all underground personner (Lind, 2002(a); Lind, 2002(b)). All of these initiatives have their birth in the risk-based approach taken, which is the focus of the design methodology for pillar extraction developed for South Africa situations.

The operations visited in New South Wales were a combination of partial and full pillar extraction methods. All of the mining methods were designed around specific health and safety, economic and environmental requirements of the individual operations. The choice of a partial versus a full extraction system appeared to be based on the following factors:

- Surface subsidence;
- Nature of the immediate 20 m roof; and
- Geological nature of the potential goaf zone.

Where the roof is massive and problems with goafing anticipated, partial pillar extraction was conducted. Also, if surface subsidence was expected that would negatively affect the usage thereof, partial pillar extraction was conducted. The nature of the immediate roof strata, ranging from the seam roof to 20 m above the seam, plays a critical role when the goaf is formed and how cantilevering of the goaf strata leads to collapses which is one of the most important design factors in deciding whether to conduct fuir or partial pillar extraction (Anderson, 1993). Generally for New South Wales conditions, when the W:D ratio (width of the panel to the depth below surface) is greater than 1.4, full caving can be expected and when the ratio is greater than or equal to 2 one can expect surface disturbances and this was used as a guide for designing an extraction method. Where favourable conditions existed, full pillar extraction was conducted whenever possible.

Of the full pillar extraction operations, two utilised modified Wongawilli methods designed to suit their individual conditions and where the fender geomechanics and their behaviour with this extraction method are well understood (Shepherd & Lewandowski, 1998). Also, all of the full pillar extraction operations visited had no restriction on the amount of surface subsidence that they created. There was also no sterilisation of overlying economic reserves resulting from the full pillar extraction operations.

All the pillar extraction operations conducted lifting of pillars on retreat and at an angle of 60° and generally in open ended lifts (except in one case where small ribs at times were left between lifts as a result of high stresses in places). Double sided lifting was practiced at all the collieries visited, made possible by the introduction of remote controlled continuous miners and remote controlled MBLS's. A study in the USA found that MBLS's influence the overlying strata up to 18 m (Maleki & Owens, 2001). In terms of the inference that the immediate 20 m roof dictates the goafing behaviour (Anderson, 1993), this indicates that MBLS's are a successful means of controlling the immediate overlying strata during pillar extraction and ensuring that goafing occurs in a controlled manner.

Generally, the trend in New South Wales is to move away from the pillar extraction method of mining in favour of longwall mining. This move is primarily for safety reasons although the successes obtained from the use of MBLS's in reducing goaf overrun and enabling increased productivity and safety ensures that in certain instances pillar extraction can be used[12].

2 A DESIGN METHODOLOGY FOR PILLAR EXTRACTION IN SOUTH AFRICA

Following the successful study tour to pillar extraction operations in New South Wales it was identified that South Africa has no up-to-date design

methodology from which decisions can be made as to whether an operation would be able to conduct pillar extraction safely and economically. It became clear after the visits in Australia that the Mine Health and Safety Act (Act 29 of 1996) in South Africa provided inadequate guidelines to assist an operator with regard to underground pillar extraction. These guidelines in the Mine Health and Safety Act (MHSA) are currently limited to specific subsections which may be considered out dated or no longer applicable. Rather, the MHSA requires that employers (mine owners) as far as reasonably practicable provide a safe operation and healthy environment irrespective of the type of mining method to ensure that all risks associated with the operation are identified and remedial action planned for and implemented before such permission is granted (Chapter 2.1 of the MHSA). Again this legislation is in no way prescriptive as to the nature or the content of what constitutes a reasonably practicable argument to remove or mitigate risks and their associated hazards of pillar extraction. This implies that the application to conduct pillar extraction can and do change from operator to operator. This is not unusual as circumstances will be different from one operation to another. However, inconsistencies will exist in the content and quality of the various applications made to the Department of Minerals and Energy (DME). It is thus at the discretion of the Principal Inspector of Mines to grant approval for pillar extraction based on the content of the application. Further, the Principal Inspector of Mines does not grant approval for mining methods and extraction layouts for pillar extraction in particular, but rather ensures compliance of such a mining practice on a case by case basis in terms of the MHSA. The MHSA however requires that mandatory Codes of Practice exist in coal mines to:

- Combat roof fall accidents on collieries;
- « Prevent coal dust explosions in underground mines; and
- Ventilate mechanical miner sections in coal mines.

Apart from these Codes of Practice, additional portions of the MHSA pertaining to the proposed mining method need to gain approval from the Principal Inspector. In particular Chapter 5 of the Regulations of the Act pertaining to the protection of the surface is given special consideration. Aspects under this chapter include protecting the workings from flooding (through boreholes and any other potential ingress of water), protecting surface structures (such as road, power lines, buildings, etc.) and monitoring any surface subsidence of the workings if these are less than 240 metres below the surface.

The MHSA merely requires that an experienced geotechnical engineer conducts an investigation into, and participates in the design of, any area that is considered for pillar extraction (specifically focusing on the direction of extraction, the method of extraction and the method of temporary support during extraction). The MHSA further requires that risk analyses be undertaken to aid an operator in providing a safe and healthy work environment (especially where the mining method involves letting down the roof) and thus mitigate any risks through the implementation of Codes of Practice and specific mine standards to enforce these Codes of Practice. Thus a suitable risk analysis process for pillar extraction which identifies high risk factors associated with this mining method and suggests some mitigating controls that will aid an operator in complying with the conditions of the MHSA when considering pillar extraction is required.

2.1 A risk analysis for underground pillar extraction in South Africa

A risk analysis is based on the concept that hazards have consequences and the product of these define the risk in a quantifiable manner. Although this risk analysis process has been detailed before[13] it is worth highlighting some of the pertinent issues again.

The risk assessment and control used to develop the framework for the design methodology has been adapted from generic risk models (Tweedale & Joy, 1997). Such a "Broad Brush Risk Assessment" should cover a high proportion of the total mine activity and by its very nature cannot be expected to go into a high degree of detail. One of the pertinent circumstances for which this type of assessment can be conducted includes a need by management to feel confident that they have an understanding of not only the risks involved in the operations of the mine (which an experienced mine manager already has) but also of their relative magnitude and the range and adequacy of the safeguards of all types (Tweedale, 1997). The context (be it strategic or organisational in nature) needs to be established so that the risk assessment has "buy-in" from the necessary stakeholders. A case in point here is the need from an environmental, legislative and profitability point of view to conduct pillar extraction on such a broad-based platform so as to ensure the long-term supply

of coal to the South African and international markets from areas which have been lying dormant for many years since primary development.

There are many different methods available foi undertaking a risk study and that the selection of the appropriate method depends on the circumstances of the study[14]. Further, any of the several methods which can be used will give comparable results. It is for these reasons that the risk analysis process presented here was chosen as appropriate in utilising the Workplace Risk Assessment and Control (WRAC) process to identify the pertinent risks associated with pillar extraction. The WRAC method of identifying risks is discussed in great detail by more experienced references (Joy, 1994; Tweedale & Joy, 1997) than this author and should be consulted for greater insight.

The results of the risk analysis conducted for pillar extraction in the Witbank and Highveld coalfields are summarised in Figure 1 (Lind, 2002(c)). In total there were 369 consequences to the 98 hazards identified. The majority of the consequences are related to the pre-production (planning) phase while the operational (production) issues feature high in the risk rating. There are also a high number of issues ranked at the median which indicates that those issues have limited available information pertaining to them in relation to their potential significance. The high risk range is considered to be those with a rating up to and including 6 and in this range the planning and production issues are represented equally. This merely indicates what we intuitively know: should the planning process not be adequate and the necessary operational restrictions be put in place the potential for a serious mishap increases.

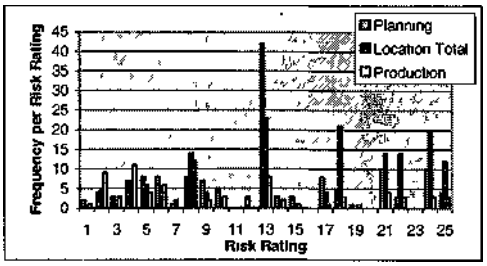

Figure 1 : Risk rating versus frequency per risk rating for the hazards and consequences associated with underground coal pillar extraction

This risk analysis process identified the major risks that need to be considered prior to pillar extraction (Table 1) in South Africa.

Table 1 : High risk hazards for which mitigation is required for pillar extraction

START OF A PANEL
Original design parameters and conditions
Presence of water
Presence of gases
Massive roof conditions
LOCATION WITHIN A PANEL BEING EXTRACTED
Goaf behaviour
Pillar behaviour
GENERAL OPERATIONAL ISSUES
Creation of large unsupported spans
The role of remote controlled em's
Cutting parameters
Interruptions in production activity
The role of temporary supports
The role of intersections
Ventunng into the goaf
Pre-sphtting of pillars

Apart from the successful mitigation of the consequences associated with the risks in Table 1, the choice of extraction (full, partial or no extraction) needs to be decided for the design methodology to be appropriate. An important geotechnical point is to ensure that either an exclusive system of full or partial extraction be conducted, but never a combination of the two for various reasons[18]. The design methodology should therefore be able to distinguish between these two extraction approaches. Figure 2 represents the aspects stemming from the risk analysis process which acts as a simplified aid in deciding on whether full or partial or no extraction should take place. One of the important conclusions drawn from the flow chart in Figure 2 is that partial pillar extraction could be employed under most conditions.

Deciding on the type of extraction will require that Codes of Practice be drawn up and the necessary mining standards set in place to achieve the objectives of these Codes of Practice. Figure 3 shows a process stemming from Figure 2 to achieve the necessary structures before which to submit an application to the DME to conduct underground pillar extraction. The factors could either be categoiised collectively or in combination from which to draw up Codes of Practice and the standards to satisfy the regulations of the MHSA as well as the high risk issues identified through the risk analysis. These issues are of course not exhaustive but can be considered as

being likely for any pillar extraction operation to consider in South Africa.

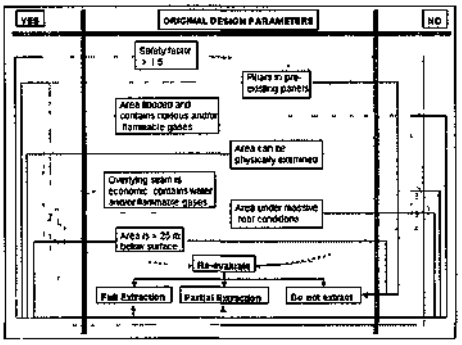

Figure 2: Risk based decisions to decide on full or partial or no extraction

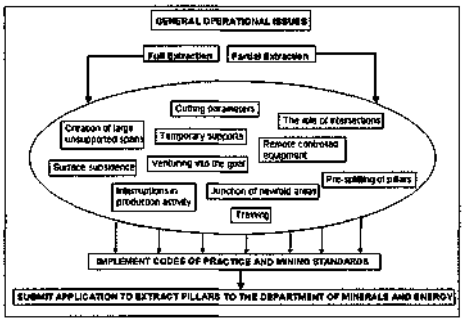

Figure 3: Risk areas needing Code of Practice coverage

The risk issues discussed here begins to highlight the most important issues which will need consideration and action before pillar extraction can be considered. The approach detailed here in deriving this design methodology stems from the requirements of the Mine Health and Safety Act and high risk factors identified through a risk analysis (which produced a number of high risk elements from both a planning and operating perspective) from recent experiences in both South Africa and New South Wales in Australia. All of these elements are now drawn together into a planning tool (A-PEP) which can be used to create an initial assessment of the potential pillar extraction area.

3 THE ANALYSIS FOR PILLAR EXTRACTION POTENTIAL (A-PEP) PLANNING TOOL

The research up to this point consists of a risk based design methodology prioritizing pertinent risks associated with pillar extraction. The research was taken a step further to attempt to predict the suitability of pre-developed bord and pillar workings for secondary pillar extraction. An attempt to estimate secondary mining potential (SMP) of inactive and abandoned palachian highwalls was conducted in 1990 (Lineberry *et al,* 1990). That approach consisted of 16 parameters grouped into four major categories (geologic conditions, existing infrastructure, site conditions and environmental conditions) to make this judgment. The objectives of that research were to review available literature for current and future methods for safe and economical secondary mining of the abandoned and inactive mining sites and to categorize the conditions for the application of each method[20]. That research attempted to understand the surface conditions and although not extensively tested against real cases it provided a risk-based framework from which to draw conclusions as to the SMP. The Analysis of Pillar Extraction Potential (A-PEP) was designed to draw together the risk based framework and pertinent legislative features to assess the secondary mining potential of underground coal pillars.

It is for this reason that the A-PEP tool is considered of value to the estimation of underground pillar extraction potential as it forms an adequate basis from which future adjustments can be made. The following valuable statement which should be borne in mind when designing such an assessment tool (Lineberry *et al,* 1990):

> *"… and at least an engineering 'feel' for ranges and limits influencing choice. Some subjectivity and judgment unavoidably remain...but should still provide a valuable checklist in selecting or evaluating a secondary mining method. "*

The A-PEP design tool calculates various output parameters based on inputs which would enable an operator to make certain preliminary decisions in terms of:

- Whether or not the potential for pillar extraction exists based on physical and risk ratings;

- What type of pillar extraction (full or partial) can be conducted based on the physical and risk ratings;
- What type of mining methods can be employed based on the full extraction or partial extraction recommendation; and
- If pillar extraction is recommended, the economic benefit that can be achieved is calculated from additional inputs.

The use of A-PEP is demonstrated with the aid of a case study (in the Witbank coalfield) in South Africa later in this paper while the mechanics of the tool are briefly discussed here.

A-PEP takes relevant physical parameters (see Figure 5) and assesses original geological and primary extraction characteristics to profile the area under consideration. Criteria such as the original design parameters, time since primary extraction as well as the characteristics of the coal seam are evaluated. A-PEP considers depth below surface, the age of the pillars as well as the overall width of the panel as the most critical of these physical factors and these contribute to he overall risk rating (see Figure 6).

The operational risks considered by A-PEP constitute the bulk of the overall risk rating and highlight what was confirmed in the risk analysis process that operational issues could m Lutvely impact a pillar extraction operation if r.it considered. The issues are assigned a risk ratiri'i of between 1 - 10 for each of the ten most critica! issues identified by the research as factors which could lead to potential hazardous situation. The way in which the questions are answered will ascertain the relevant risk. Of these ten issues the presence of overlying coal seams, the presence of surface structures and the presence of an overlying massive strata (such as the strong dolerite sill which overlies much of the Highveld coalfield) are considered the dominant factors which need to be planned for when considering pillar extraction (although all ten issues have a risk rating attached to them). The overall risk score is a combination of the physical factors mentioned and the ten operational risk factors which give a preliminary indication as to whether pillar extraction can take place and the potential method that can be employed.

The use of the A-PEP planning tool is demonstrated here against a real life pillar extraction operation. This case study serves as the validation that the A-PEP tool is able to predict the extraction method when data from the operations were inputted.

3.1 Case study: colliery A in the Witbank coalfield

The pillars being extracted at Colliery A were created in the mid-1980*s (the exact date is unknown) and are situated approximately 80 m below the surface. The surface land is unrestricted (in that there are no surface structures or features of significance) and belongs to the mine ensuring that pillar extraction can occur without any further permission from the Department of Minerals and Energy. The extraction sequence is shown in Figure 4.

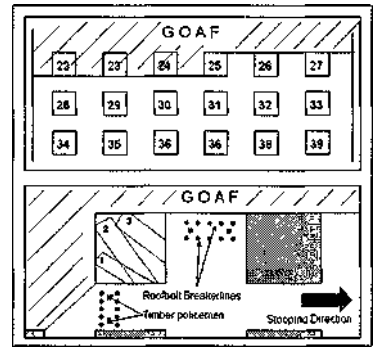

Figure 4: Pillar extraction sequence as used at Colliery A

The seam height is 6 m and the section originally mined the bottom 4 m leaving a 2 m coal roof. The original pillar centre distances were 17 m square with 6.5 m bords with 7 bords in the panel which were created using drill and blast methods. As a consequence pillar slabbing of 0.5 m has been measured when the pillars start to take load, which is slightly more than the expected 0,25 - 0,3 m (Madden 2003). This has resulted in a number of injuries with the pillar corners slabbing off when the load on the pillars increase as the pillar extraction progresses. These slabs are too large to bar down by hand and are made into "no-go" areas (indicated by stonedust markings on the pillar corners) to prevent the potential of persons being injured or killed in these areas. The factor of safety permissible for pillar extraction at Colliery A is 1.8 (although 1.6 is permissible dependant on the goafing angle). It appears as if the goaf angle has a correlation with the safety factor in that the steeper the goafing angle the lower the safety factor needed to conduct safe pillar extraction (Madden, 2003). For example at Colliery A a goaf angle of 60° requires a safety factor of 1,8 while a goaf angle of 85° requires a lower safety of 1,6. The pillar extraction section has a monthly production target of 44,500 tons al-

though 96,000 tons per month have been achieved. The section utilises a HM31 continuous miner with three 20-ton shuttle cars. Use is made of roofbolt breakerlines which are spaced 1 m from one another. The immediate roof consists of interbedded shales and sandstones which is considered ideal for goaf formation in this area as it breaks readily (Madden, 2003) which is attributed to the roofbolt breakerlines being successful in this area. As a rule of thumb at Colliery A, the roof needs to consist of a minimum of 5 m of this sandstone roof irrespective of the depth below surface to be considered for pillar extraction. Timber policemen props are used to give an indication of roof movement (see Figure 4). The mining direction is left to right (as is the ventilation) with holing of the barrier pillar taking place on the left-hand side of the section on every split during extraction. This is done to allow the mine overseer immediate access to the adjacent panel (which will be extracted after this panel has been extracted) to inspect any faults or slips which may run through the panel, to allow controlled ventilation to the new panel as well as to facilitate against any inrushes of water and/or gas from this panel. This allows a measure of continuous risk analysis to be done on the extraction operation and helps facilitate planning on a shift by shift basis.

The extraction planning process followed at Colliery A includes Geological Mapping (GM) which was introduced as part of the planning process in June 2002. It is based on the work done in New South Wales and which is now common practice in the pillar extraction operations there (Sheppard, 2001). The Geological Mapping is conducted in the adjacent new panel while the current panel is being extracted. Of importance at Colliery A is the marking any slips or faults and other geological features and/or anomalies (such as floor rolls) on the plan which is considered to be part of the risk process employed at the mine. The Geological Mapping results are put onto the section plan so that the section miner and supervisors are always aware of the potential hazards in the section. The mine also has a comprehensive Code of Practice for pillar extraction in which all the section personnel are trained to be competent in. A copy of this Code of Practice is available at the section waiting place as well as from all line management. From this it is decided whether the three cut extraction sequence shown in Figure 4 is permissible for the individual pillars which is drawn on each pillar in the section before extraction commences. Dependant mainly on the presence of faults or slips instruction is given to extract cuts 1 and 2, 2 and 3 or 1, 2 and 3 (see Figure 4). In all cases the lift through the pillar centre is taken.

As a result of the time lapsed since the pillars were first created there is a rehabilitation programme associated with the pillar extraction process. The most significant part of the rehabilitation programme is resupporting the roof as systematic roof support was absent during the primary extraction phase since the original roofbolts were 0.7 m long point-anchor installed with wooden headboards. The panel rehabilitation requires that 2.1 m full column resin bolts are installed to secure the coal roof into the overlying strata. This onerous task has resulted in 540 bolts being installed (1 m apart with 4 bolts in a row) around each pillar (including the roofbolt breakerlines). In additional to the resupporting cost, the panel requires new belt infrastructure, ventilation construction and the area to be swept clean.

There have been a total of 8 continuous miner burials, all of which have occurred in the final cut (3rd pillar lift) since pillar extraction was started at Colliery A in 1997. In an attempt to minimise this occurrence the final lift (no. 3 in Figure 4) is now only cut to half its planned distance. This has ensured that a stronger snook (higher width to height ratio) than was previously left remains. This was done by trial and error and was found that cutting shorter than halfway leaves too strong a snook which does not break while cutting further than halfway increases the potential of the snook failing prematurely and burying the continuous miner. Since the introduction of this measure in mid-2002 there has not been a continuous miner burial nor have there been any adverse problems associated with the goaf formation. Using this background information A-PEP was populated and the results shown in Figures 5, 6 and 7.

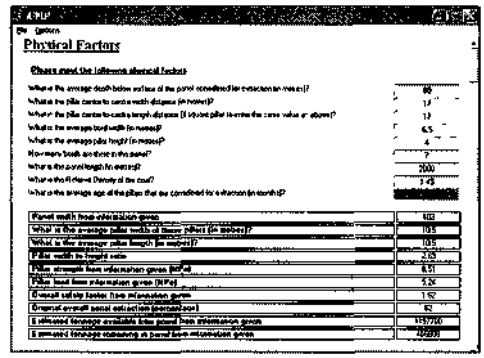

Figure 5: A-PEP physical factors output for Colliery A

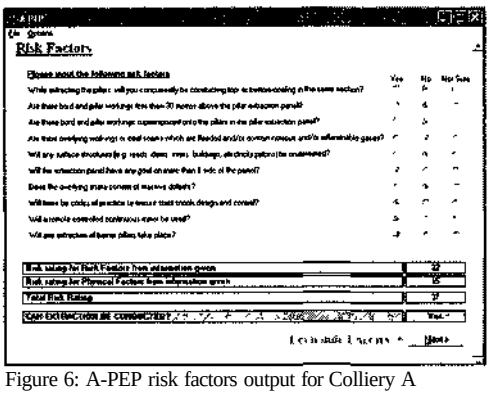

Figure 6: A-PEP risk factors output for Colliery A

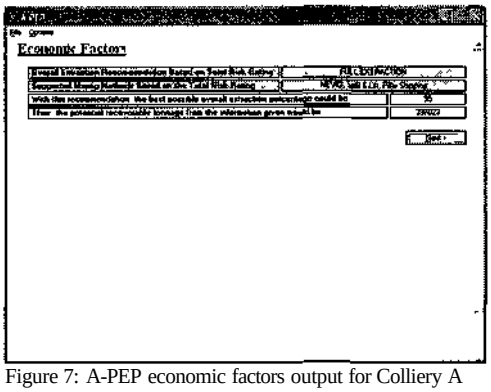

Figure 7: A-PEP economic factors output for Colliery A

From Figures 5, 6 and 7 it is seen that the A-PEP planning tool is able to predict the extraction method employed at Colliery A when all the relevant physical and risk factors are evaluated. From Figure 6 we see that the age of pillars is flagged because it has been 5 or more years since they were originally developed (the pillars were formed 10 - 15 years ago). The safety factor is 1.62 which is within the range required by Colliery A to consider conducting pillar extraction which indicates that the goaf angle for this panel is greater than 80°. This analysis has not taken into account the effects of pillar slabbing as a result of them being formed by drill and blast methods however (the assumption being that the pillars will remain intact until additional load is placed on them as the goaf line progresses with the pillar extraction operation). From the summary in Figure 6 it is seen that the operational risks are low and that these, when combined with the physical risks, have a total risk ranking of 37. This value is considered low enough by A-PEP to recommend that pillar extraction be conducted. Figure 7 shows that A-PEP in fact suggests that full pillar extraction be conducted when considering that above physical parameters and operational risk parameters.

Because there are a myriad of full pillar extraction methods, A-PEP only makes some suggestions of mining methods that would be appropriate for the given set of circumstances. The pillar extraction method employed at Colliery A can be described as being a full pillar extraction operation. The definition assumed here of full pillar extraction comprises the letting down of the roof against the goaf line in a controlled manner whereas partial pillar extraction utilises the yield pillar technique of letting down the roof in a controlled manner over time.

4 CONCLUSION

This paper has highlighted that the process followed in implementing pillar extraction techniques and processes remains one which is unstructured in its general approach in South Africa. This paper attempts to provide a basis from which consideration can be given to the general and most likely risks that will be encountered by an operator when faced with a pre-developed bord and pillar area for which he wants assess its pillar extraction potential (based on the success of this mining method in Australia). The A-PEP tool (which is based on a risk analysis of the pillar extraction mining method) has been introduced and has shown that it is able to correctly predict an appropriate secondary extraction method based on information pertaining to the unique geological and initial mining conditions of an operating pillar extraction operation in the Witbank coalfield.

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