An integrated risk management approach for underground coal pillar extraction in South Africa

by G. Lind*

Synopsis

Analysis for pillar extraction potential (A-PEP) is an intelligent tool, which could 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. The safe and economic extraction of underground coal pillars is of paramount significance and importance to the South African coalmining industry to ensure continuity of supply of this fossil fuel. Pillar extraction practices in South Africa have been responsible a significant proportion of safety and fatality statistics in relation to its relative output (less than 5 per cent of total South African coal production) and, as a result, research was undertaken in local pillar extraction operations and extended to similar operations in New South Wales, Australia to assess a way forward for pillar extraction in South Africa. It was found that, although little in the way of new technologies has emerged in this field in the recent past, significant contributions could be made in the field of risk analysis to obtain a generic design methodology for pillar extraction in South Africa. The resultant A-PEP tool to assess pillar extraction potential is based on certain physical, risk and economic factors, which combine to indicate operational success in terms of economic, health and safety attributes. At the time of A-PEP's development there was a lack of operating underground coal pillar extraction operations, which made it difficult to validate its applicability. Since then, however, A-PEP has been successfully tested and validated against two unique underground coal pillar operations, which is the discussion of this paper. One operation is situated in the Witbank coalfield and is extracting pillars, which are 20 years old and at a depth of 80 metres below surface, while the other operation is situated in the Highveld coalfield-which is extracting 6 month-old-pillars underneath a massive dolerite sill at a depth of 220 metres. A-PEP has shown that its predictive nature is consistent the workings at both operations, irrespective of their unique conditions, and as such it can be successfully used as a mine planning tool. The A-PEP mine planning tool thus represents a positive step toward an 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.

Introduction

A research initiative[1] 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 gain 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[2–4] showed that little in the way of new technologies, ideas or mining methods has been developed in South Africa in recent years (except for the NEVID method). (Incidentally, NEVID is an acronym named after the inventors of the mining method—Neels Joubert and David Posthma.)

As this research attempted to develop a design methodology for pillar extraction to increase the utilization of coal resources, looking at the history of pillar extraction in 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[5] are used to ensure the success[6] of this mining practice there. 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 for analysis of pillar extraction potential), which is a user-friendly, intelligent tool enabling the

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potential for pillar extraction of an operation to be assessed by inputting certain physical, risk and economic factors, which was presented at APCOM 2003[7]. That initial work was based on a hypothetical scenario to show the workings of A-PEP but, due to a lack of sites willing to have their pillar extraction operations scrutinized at that stage, its applicability against real-world operations could not be assessed. Since then A-PEP has been tested against two operating pillar extraction sites (one each in the Witbank and Highveld coalfields), the results of which are the focus of this paper.

A risk analysis for underground pillar extraction

A risk analysis is based on the concept that hazards have consequences and the product of these define the risk in a quantifiable manner. The method of hazard identification and associated consequences thus need to be rated for the analyses to be meaningful. To achieve this, the following steps are identified[8]:

- Model the process of the operation (e.g. by means of a flow chart)
- The boundary of the analysis needs to be defined (i.e. beyond which the analysis is not applicable)
- Any reasonable deviations (planned or unplanned) from the process model that may be likely to occur must be identified
- A review of the process model must be conducted to identify potential loss scenarios that may occur
- A risk score needs to be created for each loss scenario by defining risk as a combination of consequences and probabilities.

Qualitative scoring methods provide a common base on which to assess the various risks and the method used is represented in Tables I, II and III. Generally a 5 x 5 matrix of probability and consequence enables one to define the risk score of a particular scenario. The design and choice of the inputs depend on the type of operation and those represented in Tables I, II and III are those suggested by the author, which formed the basis of interpretation of the risk assessment.

Table I

Probabilities of an occurrence

A	Common or frequent occurrence
B	Likely to occur
C	Could happen
D	Not likely to occur
E	Practically impossible

Underground coal pillar extraction by its very definition implies that the risk analysis for this operation needs to consider coal pillars, their location underground and the operation associated with their extraction. By inference, the boundaries of the risk assessment should be limited to the boundaries of one panel that is planned for extraction. This would include the influence that may be exerted above the workings (which would thus include the overlying strata and surface structures). It is therefore important to note that a risk analysis would be required for each significant change in conditions or locations, etc. The results of the risk analysis presented here will focus on three aspects:

- Issues pertaining to the start of the panel (i.e. planning issues)
- Issues related to the location within a panel; and
- Issues associated with the general operational issues pertaining to pillar extraction (i.e. production issues).

The above list is by no means exhaustive, but enables one to identify and categorize the major hazards located at each phase of the mining operation.

Identifying high-risk hazards

Identifying what forms part of a risk analysis is important so as to establish the limitations of that particular risk analysis. Any risk analysis is a subjective process based on experience at that particular point in time. This particular risk analysis is based largely on the experiences in South Africa and New South Wales, Australia. The purpose of conducting this broad risk analysis is to present a framework from which detailed risk analyses can be conducted by operations in the Witbank and Highveld coalfields before an application to conduct this type of mining operation is made to the Department of

Table III

Risk scoring and zones of high, medium and low risk

		Probability				
		A	B	C	D	E
Consequences	1	1	2	4	7	11
	2	3	5	8	12	16
	3	6	9	13	17	20
	4	10	14	18	21	23
	5	15	19	22	24	25

1-6	High risk
7-19	Medium risk
20-25	Low risk

Table II

Consequences of an occurrence

	People	Production	Equipment
1	Fatality or permanent disability	More than 1 day loss in production	Damage greater than R1 million
2	Serious lost time injury (requiring hospitalization)	1 shift – 1 day loss in production	Damage between R500 000–R1 million
3	Moderate lost time injury (broken limb)	More than one half of one shift loss in production	Damage between R100 000–R50 0000
4	Minor lost time injury (dressing station injury)	Less than one half of one shift loss in production	Damage between R5 000–R50 000
5	No lost time injury	Less than one hour loss in production	Damage less than R5 000

Minerals and Energy by the stakeholders associated with the extraction operation. This, too, is a suggested methodology and should be altered to suit individual circumstances. By obtaining a risk score for the probability and consequence of each risk, all the risks can then be rated according to its score.

The results of the risk rating versus the frequency per risk at that particular rating can be seen in Figure 1. In total, there are 369 consequences to the 98 hazards identified, of which the start of the panel (planning issues) and general operational issues (production issues) contributed the bulk of the issues. It is interesting to note the high number of issues ranked at the median. This is probably a result of limited available information pertaining to those issues, coupled with a level of uncertainty as to how relevant the issues were.

Of importance to note from Figure 1 is that of the high-risk range (risk ratings from 1–6 as defined in Table III) the planning issues feature, more than either the location or production issues in three of those ranges (i.e. higher for risk ratings of 1, 5 and 6). This would indicate that issues with severe consequences are more likely to occur if the planning process is not well thought out and processed. Also, around the median of the graph in Figure 1, planning issues are cited almost twice more often than the other issues, indicating that uncertainties in the planning phase of pillar extraction need to be thoroughly understood before such a system is put into place.

According to the risk rating presented in Table III, those hazards which had consequences rated from 1–6 are considered high risk issues. Where the combination of the hazard and the consequence provided a high risk rating, the hazard and not the consequence has been identified as being high risk (even if there were other consequences associated with that hazard, which gave a medium or low risk rating).

Of the 80 high risk consequences, a list is obtained (Table IV) of high-risk hazards for which to suggest mitigating controls so as to minimize the health and safety risks associated with pillar extraction. The significance of the location within a pillar extraction panel is of less consequence when compared to the issues pertaining to the start of a panel (planning issues) and the general operational issues associated with pillar extraction. It is perhaps more appropriate for the two issues associated with the location within a panel being extracted thus to be included under the heading of general operational issues, as they are ultimately related to the operation stage rather than the planning stage.

Having identified pertinent hazards associated with an underground coal pillar extraction panel, mitigating controls for these issues, so as to minimize the risk associated with each, can be identified.

The issues discussed here are difficult to separate into individual components as they together form the basis of a holistic system that needs to be considered when designing a

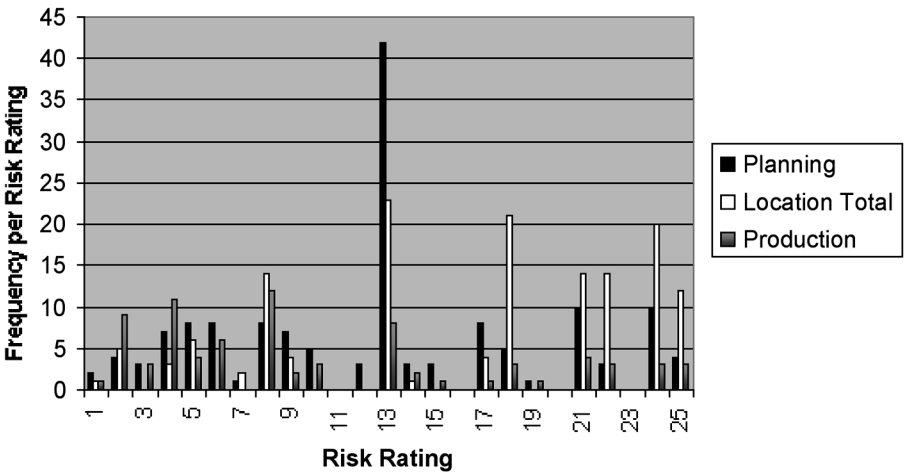

Figure 1—Risk rating versus frequency per risk rating for the hazards and consequences associated with underground coal pillar extraction

Table IV

High-risk hazards for which mitigation is required for pillar extraction in the Witbank and Highveld coalfields

Start of panel	Location within a panel being extracted	General operational issues
Original design parameters and conditions Presence of water Presence of gases Massive roof conditions	Goaf behaviour Pillar behaviour	Creation of large unsupported spans The role of remote controlled continuous miners Cutting parameters Interruptions in production activity The role of temporary supports The role of intersections Venturing into the goaf Pre-splitting of pillars Junction of new and old areas

pillar extraction operation. Although the research has produced some mitigating control factors, it is ultimately for the individual operations to decide what these are pertaining to their individual operations and how they will be implemented; hence these will not be discussed here.

It is virtually impossible to present here the exact nature of the expected operational risks of all operations. This stems partly from the inconsistency in the definition of risk, but more likely because each operation is unique. Further, there is no single method that is the correct one for any particular situation[9] but the chosen method should be in sufficient detail to match the objectives of the scope of the study that has been achieved.

The findings of issues represented here from recent South African and Australian experiences attempt to identify and group some specific risks that may be common to all pillar extraction operations. This list is by no means complete, but represents an accurate and up to date list that should be considered by all operators before making application to the Principal Inspector of Mines to conduct pillar extraction, which should be considered by all potential extraction operations. The risk analysis will change from operation to operation, but the methodology presented here is likely to be common to all operations on a broad-based level.

This risk analysis is thus a firm basis from which to develop a generic tool, which is able to assess preliminary secondary extraction potential, which is now discussed.

The analysis for pillar extraction potential (A-PEP) planning tool

The A-PEP planning tool fundamentally attempts to predict the suitability and potential success for pre-developed bord and pillar workings for secondary pillar extraction through drawing together the risk-based framework upon which it is based. A similar approach[10] was attempted to estimate secondary mining potential (SMP) of inactive and abandoned Appalachian highwalls in the early 1990s. This approach consisted of 16 parameters grouped into four major categories (geologic conditions, existing infrastructure, site conditions and environmental conditions) to make this judgement. This SMP approach attempted to understand the surface conditions, whereas A-PEP looks specifically at the underground environment.

The A-PEP design tool calculates various output parameters based on inputs, which would enable the decision maker 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.

A-PEP takes relevant physical parameters and assesses the 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 contributing to the overall risk rating.

The operational risks considered by A-PEP constitute the bulk of the overall risk rating and highlight those operational issues that could negatively impact a pillar extraction operation if not considered. The issues are assigned a risk rating of 1–10 (1 being the lowest and 10 the highest) for each of the ten most critical issues identified as factors that 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 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 two real-life pillar extraction operations. These case studies served as the validation that the A-PEP tool was able to predict the extraction method when data from the operations were input.

A-PEP case study 1: Colliery A in the Witbank coalfield

The pillars being extracted at Colliery A were created in the mid-1980s (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 requiring special protection) and belongs to the mine, ensuring that pillar extraction can occur without any additional permission from the Department of Minerals and Energy. The extraction sequence is shown in Figure 2.

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 started to take load as extraction ensue. This has resulted in a number of injuries, with the pillar corners slabbing off when the load on the pillars increases 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 for persons being injured or killed in these areas. The factor of safety permissible for pillar extraction at Colliery A is between 1.6–1.8. The pillar extraction section has a monthly production target of 44.500 tons, although 96.000 tons per month has been achieved. The section utilizes an HM31 continuous miner together with three 20-ton shuttle cars. Use is made of roofbolt breakerlines, which are spaced 1 m from one another to control the line of break of the roof. The immediate roof consists of interbedded shales and sandstones. These

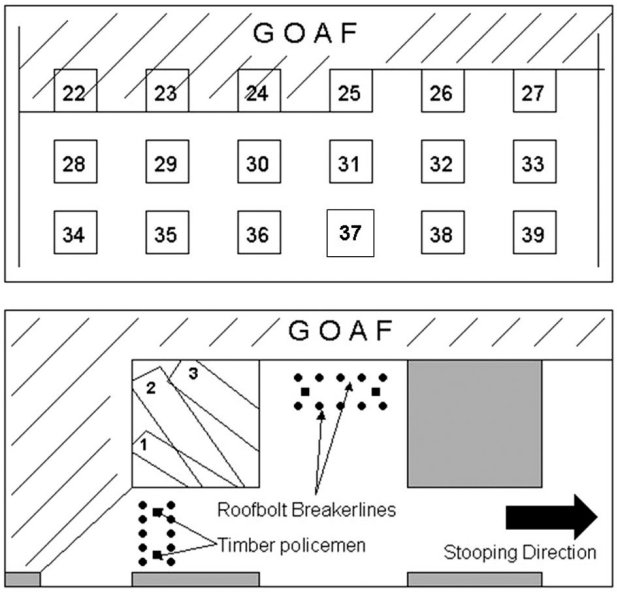

Figure 2—Pillar extraction sequence as used at Colliery A

conditions are considered ideal for goaf formation in this area as it breaks readily[11] 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 when load increases (see Figure 2). 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 slip that may run through the panel, to allow controlled ventilation to the new panel as well as to mitigate 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. Geological Mapping is a visual inspection of the panel prior to extraction, which helps to identify any geological features, previous support patterns and types, etc. 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 of any joints 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. 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 1 is permissible for the individual pillars and which is drawn on each pillar in the section before extraction commences. Depending mainly on the presence of faults or slip, instruction is given to extract cuts 1 and 2, 2 and 3 or 1, 2 and 3 (see Figure 2). 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 as and when required 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 minimize this occurrence, the final lift (no. 3 in Figure 1) is now only cut to half its planned distance. Since the final cut 3 is determined by an imaginary diagonal line from pillar corner to pillar corner (i.e. no specific dimensions for this cut), there is flexibility in the extraction process. This has ensured that a stronger snook (higher width to height ratio) than was previously left remains. (A snook is the remnant portions remaining once the pillar has been extracted.) This was done by trial and error and it 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 3, 4 and 5.

From Figures 3, 4 and 5 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 3 we see that the age of pillars is flagged because it has been five or more years since they were originally developed (the pillars were formed ten to fifteen years ago). The safety factor is 1.62 which is within the range required by Colliery A to consider conducting pillar extraction. This has not taken into account the effects of pillar slabbing as a result of their 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 4 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

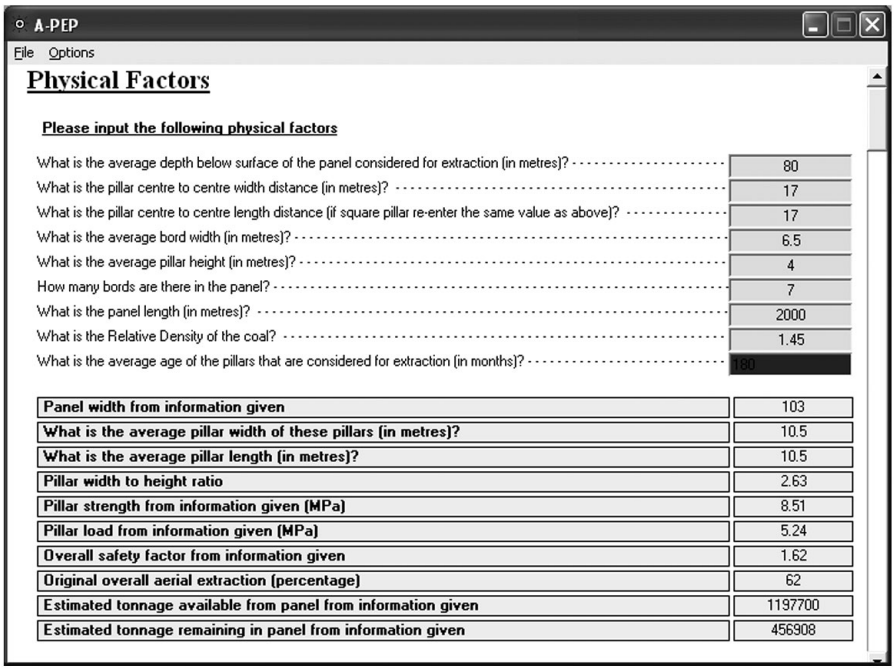

Figure 3—A-PEP physical factors output for Colliery A

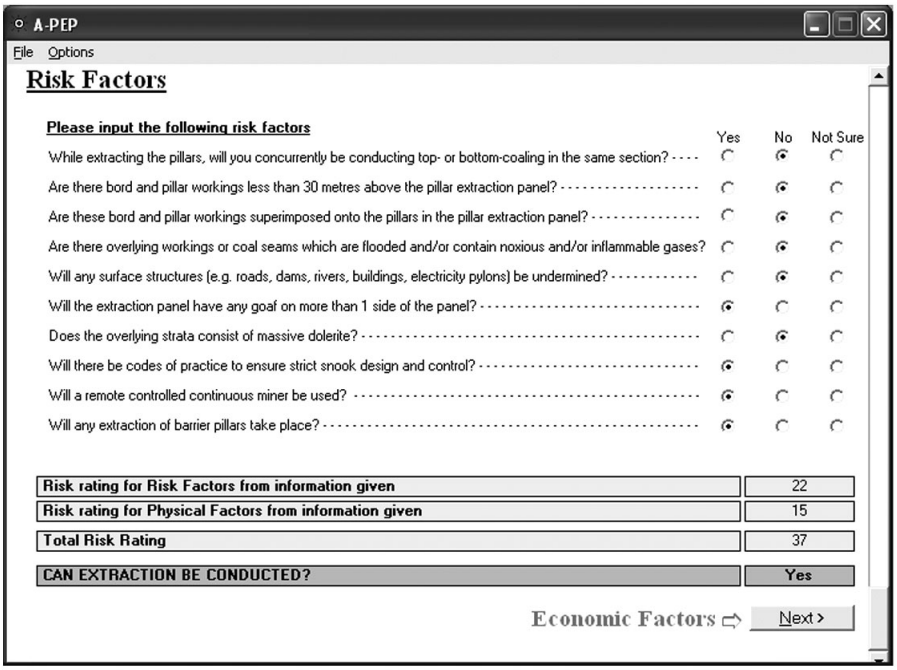

Figure 4—A-PEP risk factors output for Colliery A

recommend that pillar extraction be conducted. Figure 4 shows that A-PEP in fact suggests that full pillar extraction be conducted when considering the above physical parameters and operational risk parameters.

There are a myriad full pillar extraction methods and 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 for full pillar extraction comprises the letting down of the roof against the goaf line in a controlled manner, whereas partial pillar extraction utilizes the yield pillar technique of letting down the roof in a controlled manner over time.

This validation process against an operating pillar extraction site in the Witbank coalfield has shown that A-PEP is able to predict the type of pillar extraction based on its risk-based requirements.

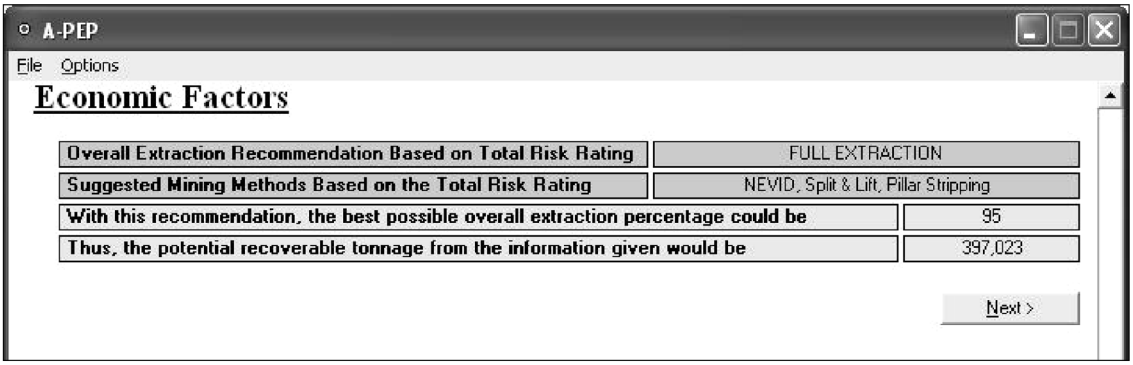

Figure 5—A-PEP economic factors output for Colliery A

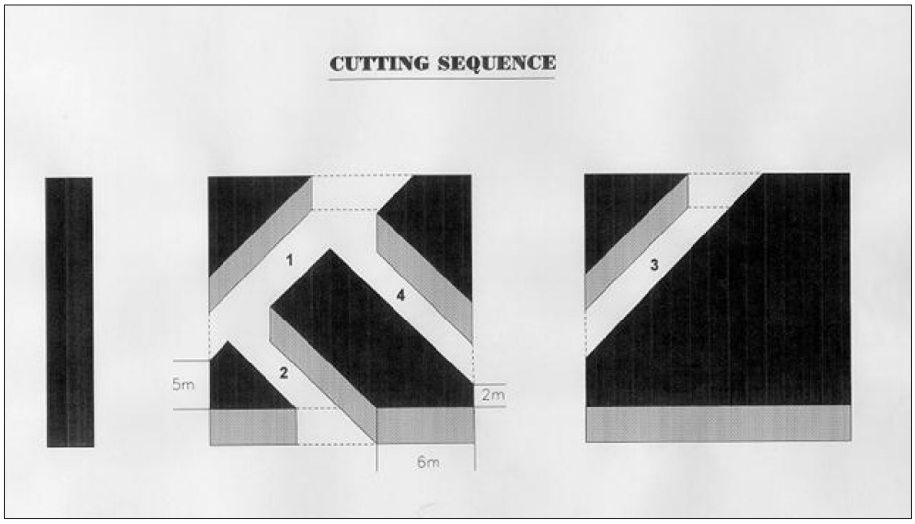

Figure 6—NEVID pillar extraction sequence as used at Colliery B[9]

A-PEP case study 2: Colliery B in the Highveld coalfield

Colliery B is situated in the Highveld coalfield in Mpumalanga province of South Africa. Up until 1997 the mine had employed a combination of 'split and lift' and 'split and quarter' mining layouts to varying degrees of success. Colliery B lies between 170–220 m below an unrestricted farmland surface (allowing pillar extraction to take place) and is overlain by a massive dolerite sill, which is separated from the coal-seam by a laminated, competent sandstone roof which is systematically supported using full column resin bolts (4 bolts in a row spaced 1 m apart). The coal-seam ranges from 1.8–3.5 m in height with an average of 2.5 m with pillar centers 28 m square and bord widths of 6.5 m. The varying degrees of success were, by and large, determined by the interaction of the extraction method and the behaviour of the massive overlying dolerite sill, which has a tendency to hang up and eventually to break violently when the critical span is reached (which varies depending on the interaction of adjacent mined out and goafed panels). This violent and unpredictable behaviour has resulted in various combinations of loss of life, loss and burial of the continuous miner, the associated loss in production, as well as other damage caused by the accompanying windblasts.

The extraction methods underwent iterative changes from the use of timber breakerlines to the now commonly used roofbolt breakerlines to try to negate the effects of the unpredictable roof behaviour and the goaf overruns into the production section. On average, one continuous miner was buried in the goaf for every three panels mined, and in 1996 twelve continuous miners were buried at Colliery B and its neighbouring colliery. This situation required that something drastic be done to avert the situation or to close the mine as the risk to life and property was too high to continue. This led to the introduction of the NEVID extraction method, which since its introduction has extracted 150 panels with a total of seven incidences where the continuous miner has been buried, 2 occurrences of the goaf overrunning the breakerlines and 5 local roof falls, which has shown a significant improvement over previous extraction methods employed at Colliery B. The NEVID method of extraction is shown in Figures 6 and 7.

The introduction of the NEVID method of pillar extraction yielded immediate successes. The main reason for this is that the length of cut into the pillar by the continuous miner is significantly reduced when compared with the previous split and quarter methods. All the lifts into the pillar are made at 45°. Another aspect of the method's success is the absolute

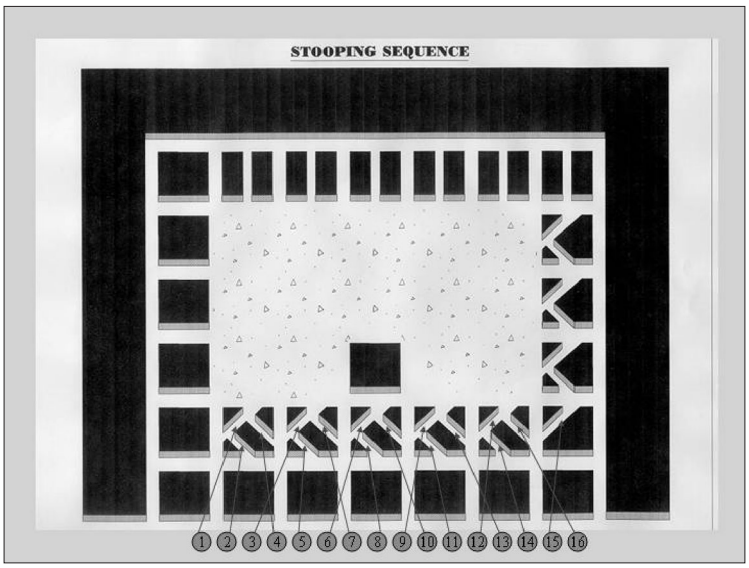

Figure 7—NEVID pillar extraction sequence layout as used at Colliery B[9]

discipline from the section personnel in that all the lifts in the extraction sequence are marked using survey pegs and direction lines, which are strictly adhered to for directional cutting. This ultimately means that the snooks are pre-designed to the exact strength (width to height ratio) required to ensure that the roof is let down in a controlled and manageable fashion. In addition to the snook formation, a stopper pillar is left every three rows, as shown in Figure 6, after it was found that the snooks created were sometimes inadequate for controlled letting down of the roof and sometimes failed unexpectedly. This stopper pillar has the function of a yield pillar to take additional load off the pillars, which are being extracted while they are spaced far enough apart to crush as required, particularly when the goaf hangs. It has been established that Colliery B has a horizontal to vertical stress ratio of 2.2[12]—meaning that a 200 m depth has equivalent conditions to a depth of 440 m. This has made the importance of the stopper pillar even greater during pillar extraction as the panels operate in high-stress zones.

The very first NEVID method extraction panel employed had the roof hang for 7 rows before the roof came down gradually around the stopper pillars, which effectively minimized the negative effects previously experienced by the overlying massive dolerite sill. When a panel is fully developed, it is extracted on retreat so as to minimize the stress build-up on the pillars as well as the effects of weathering (through the effects of time). The time between the start of primary development and the start of secondary extraction ranges from 12–18 months. As a result of this, there is no panel rehabilitation required as the roof has been recently supported to the mine standard to cater for both primary development and secondary extraction support requirements and the belt infrastructure is already in place. The evolution of the NEVID method since its inception in 1997 has seen the introduction of panel zoning in 2001, which is a hazard identification process incorporating geological mapping fundamentals to zone a panel during the development phase into low-to high-risk zones based on the geological information.

Using all of this background information, A-PEP was populated and the results shown in Figures 8, 9, 10 and 11.

From Figure 8 it is seen that the overall safety factor is 2.23 which is within the range recommended for conducting pillar extraction (which is required to be above 1.8 at Colliery B). A-PEP has given the base information and now requires that the operational risk factors be assigned, which is summarized in Figure 9.

From the summary in Figure 10 it is seen that the operational risks are significant enough for a recommendation to be made not to conduct pillar extraction. This is based on the significant risks that the presence of the overlying dolerite sill presents in this area. A-PEP at this stage will not allow any further analysis to take place unless a re-evaluation of the risks has taken place. Should there be confidence that the dolerite sill can be successfully undermined, the risk can be mitigated and the decision changed to indicate that, although there is a dolerite sill present, its effects on the pillar extraction method can be minimal with the correct planning. The NEVID method is able to reduce the effects of the dolerite sill as previously discussed and we can thus, with a certain amount of confidence, change the effect it has in A-PEP, as shown in Figure 10.

Understanding the potential adverse effects of the dolerite sill changes the decision to one of recommending that pillar extraction be conducted as the combination of physical and risk factors is low enough to recommend full pillar extraction, as shown in Figure 11.

By understanding and instituting mitigating measures for the effects of the dolerite sill, A-PEP is able to correctly suggest that full extraction (and in this case that the NEVID method) may be appropriate for the given set of circumstances. The definition of full pillar extraction comprises the letting down of the roof against the goaf line in a controlled manner, whereas partial pillar extraction utilizes the yield pillar technique of letting down the roof in a controlled manner over time.

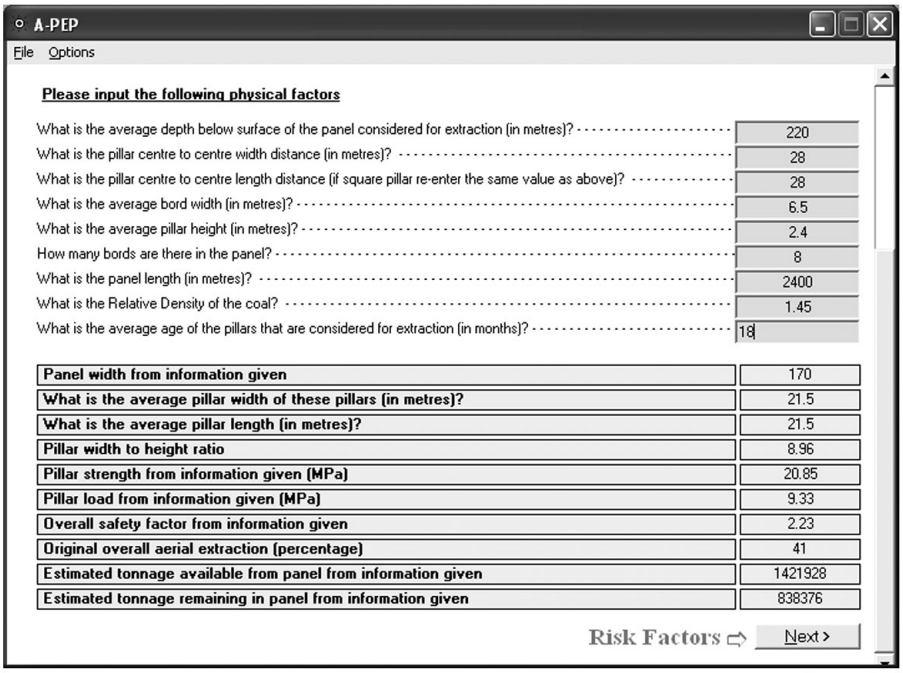

Figure 8—A-PEP physical factors output for Colliery B

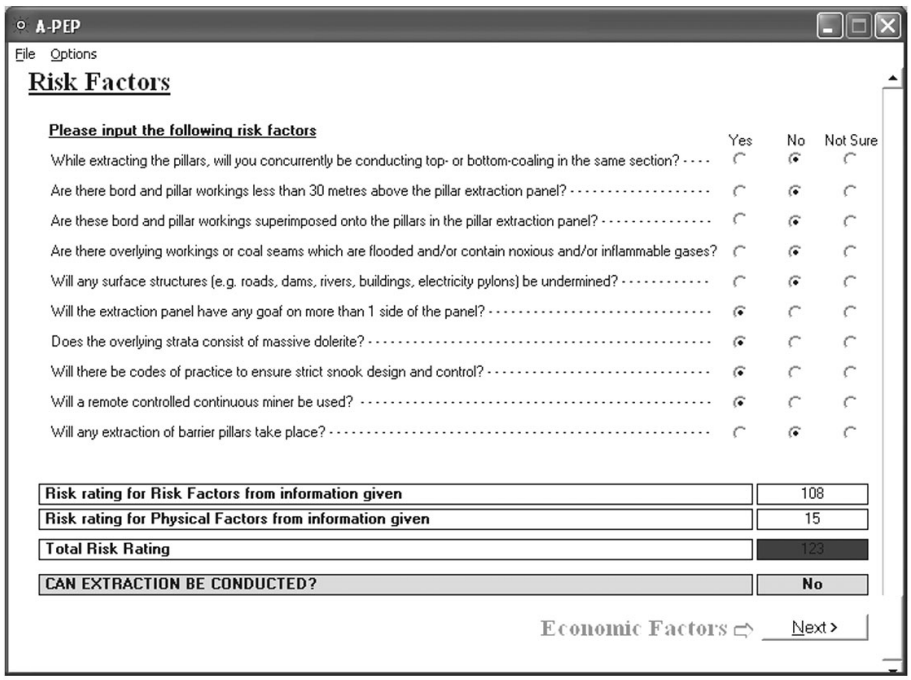

Figure 9—A-PEP risk factors output for Colliery B

The process followed at Colliery B in preparing to conduct pillar extraction is progressive when considering South African standards. The use of risk assessments and analysis is on par with the methods used in Australia[13] and the USA. There is a structured manner for deciding on the exact nature of the extraction, with each individual pillar having its own risk-based decision as to the number of cuts, the number of lifts per cut, as well the pre-emptive design of the stopper pillar. The NEVID method used at Colliery B follows the fundamental of leaving the centre of the pillar intact to ensure that the maximum load carrying capacity is utilized for the maximum yielding capability of the remaining snooks. Of ultimate importance here is that the A-PEP tool was able to correctly suggest a suitable mining method when considering the physical and the operational risks and factoring in mitigating circumstances during the evaluation. It is only with the proven success of the NEVID method under the dolerite sill (massive roof strata condition) that this effect

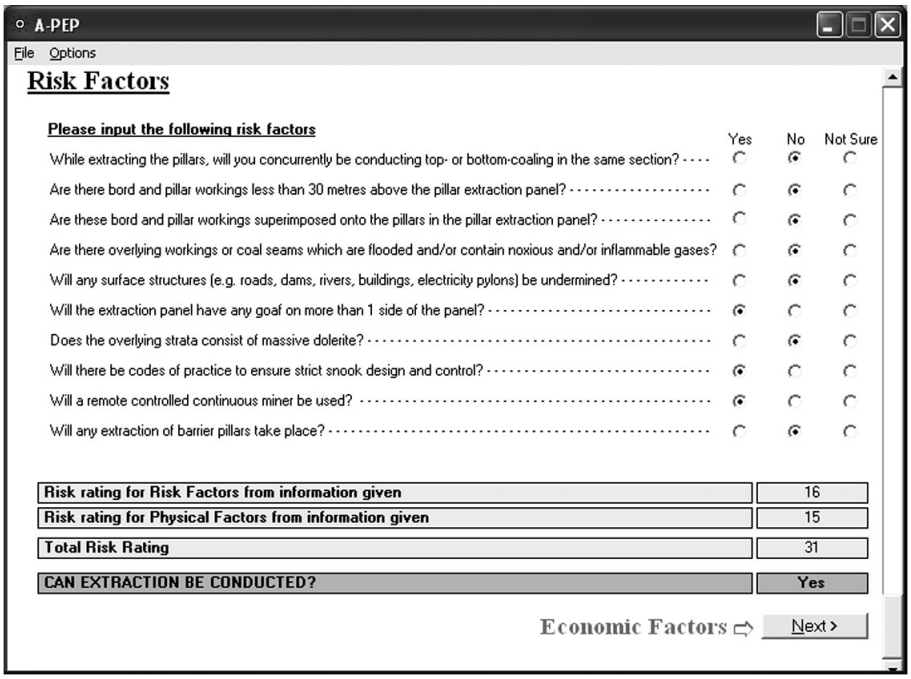

Figure 10—Revised A-PEP risk factors output for Colliery B

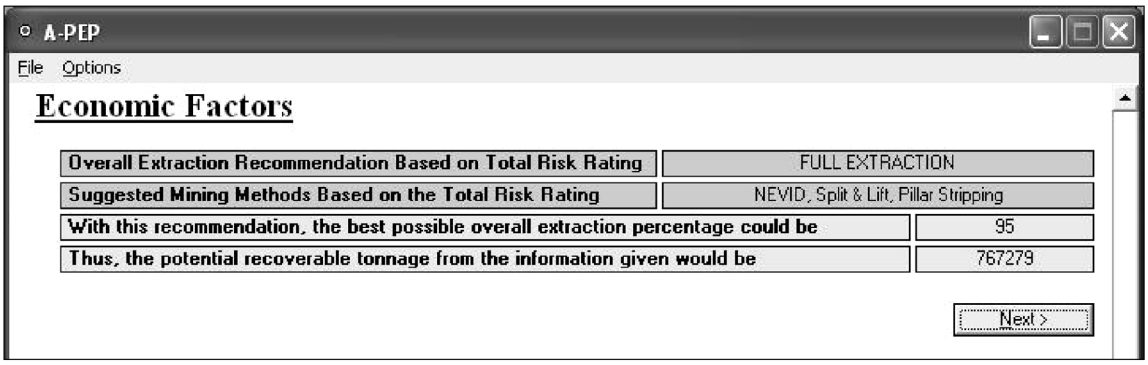

Figure 11—A-PEP economic factors output for Colliery B

in the A-PEP analysis can be negated and the analysis completed to show that full pillar extraction is an option. It should, however, be noted that the success of the NEVID method in this area and its application in other areas requires specific appraisal and assessment[14].

Conclusion

This paper has shown that the art of underground pillar extraction has evolved from a trial and error approach, which can be assimilated into key areas at the planning stage, to be able to predict the potential success of conducting pillar extraction through the use of A-PEP. This is done through considering the general and most likely risks that will be encountered by a decision maker when faced with a pre-developed bord and pillar area for which pillar extraction is contemplated. The A-PEP tool (which is based on a multi-faceted risk analysis of the pillar extraction mining method) 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 two operating pillar extraction operations in the Witbank and Highveld coalfields (Table V). 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 further planning adjustments can be made in this region.

Since this work was first conducted, a number of new facets has emerged, which is the focus of future work in this area. The major thrust is better quantifying and understanding the risks that the dolerite sill presents (which A-PEP considers as a high risk), even though mechanisms such as the NEVID method exist, which can counter the potentially hazardous impacts of the sill. Additionally, the role of mobile roof supports (MRSs), such as those used in Australia, the USA and currently being trialled by an operation in the Witbank coalfield, in assisting with controlled goafing is being critically looked at so as to improve the integrity of the A-PEP tool.

Table V

Comparison of the two A-PEP case studies

	Colliery A	Colliery B
Coalfield	Witbank	Highveld
Depth below surface (m)	80	200
Pillar centres (m)	17 x 17	28 x 28
Pillar height (m)	4	2.4
Bord width (m)	6.5	6.5
Time elapsed since primary mining (years)	10–15	1–1.5
Dolerite sill present	No	Yes
Mining method used	Full pillar extraction utilizing up to 3 cuts	NEVID full pillar extraction
A-PEP recommendation	Full pillar extraction	Full pillar extraction

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