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DEVELOPMENT OF A METHOD FOR LAYOUT SELECTION USING ANALYTICAL HIERARCHY PROCESS

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ABSTRACT: One of the most critical and complicated steps in mine planning is the selection of a suitable layout based on geological, geographical, geotechnical and economical parameters. These parameters influence the choice of different layouts of coal mine workings and normally examined on the basis of experience gained in the coalfields. The wide ranging combinations of geological, geotechnical and mining conditions make the selection of the optimum design and layout for a particular situation a difficult task. Variations in these parameters result in multiple feasible mine layouts; where each layout entails some inherent problems and the optimal layout is the one that offers the lowest problems. These variations in designs result in complex multi-decision situations that cannot be solved by a simple technique. This paper develops a method based on an analytical hierarchy process to select the most viable panel orientation for longwall operation. A back analysis of this technique was conducted at a mine located in central Queensland. The geological and geotechnical aspects of the mine resulted in variations in the recommended panel orientations. Three different mine layouts with variable geological and geotechnical impacts were evaluated and the optimum mine layout was determined. This paper also challenged the viability of the obtained results by performing a consistency check at every critical stage of the project.

INTRODUCTION

The selection of mine layout is one of the most critical and problematic phase in mine planning stage. Subsequent operating factors such as ground support requirements, equipment selection and ventilation are entirely influenced by the mine layout. The ultimate goal of mine layout selection is maximising the company's profit and resource recovery while providing a safe environment for the miners by selecting a suitable layout with the fewest problems among the feasible alternatives. Analytical Hierarchy Process (AHP) is a multi-criteria decision method that uses hierarchical structures to solve complicated, unstructured decision problems, especially in situations where there are important qualitative aspects that must be considered in conjunction with various measurable quantitative factors (Shahriar, *et al.*, 2007). The AHP is still being applied in numerous and diverse fields such as software selection, project selection and measuring business performance; however, it has not been applied widely in the Australian mining industry, particularly in mine layout selection. Unlike the traditional approaches utilised for layout selection, AHP makes it possible to select the best layout in a more scientific, semi-quantitative manner that preserves integrity and objectivity (Ataei, *et al.*, 2008). AHP models are transparent and easy to comprehend and apply. The AHP models are unique in their identification of multiple attributes where minimal data is required, and minimal time is consumed (Ataei, *et al.*, 2008).

Analytical Hierarchy Process theory

The AHP methodology was first developed by Saaty (Saaty, 1990). The AHP is a tool that is used to combine qualitative and quantitative factors in the selection of a process. It is based on mathematical framework formed by matrix and vector algebra that can easily be performed in Microsoft® Excel. The mathematical framework starts with a pairwise comparison of the relative weight or dominancy of each criterion over another (Musingwini and Minnitt, 2008). To make the comparisons, scaling of numbers is required to indicate the weight and the dominancy of a particular element over another element with respect to the criterion to which they are compared. This scale is used to express the evaluator's preference of criterion over another by assigning numbers that ranges from 1 for equally importance to 9 for extreme importance (Yavuz, *et al.*, 2007). The relative weight of each pair of criteria, C_i over C_j is denoted by v_{ij} such that $v_{ij} = \frac{1}{v_{ji}}$ for $i \neq j$ and v_{ii} = 1, for all *i*. These weights form a square matrix A, of order n; corresponding to the number of criteria. This matrix is referred to as, reciprocal matrix because of the weight of one criterion over another and is equal to the weight of the second criterion over the first one

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(Musingwini and Minnitt, 2008). After the construction of the pairwise comparison matrix, Saaty (1990) proposed an eigenvector (priority vector) approach for the estimation of the overall weights of criteria from a matrix of the pairwise comparisons. The eigenvector has an intuitive interpretation in which it is an averaging of all possible ways of thinking about a given set of alternatives (Ekipman, 2003). The eigenvector, w is established such that $Aw = \lambda w$, where λ is the corresponding eigenvalue of matrix A (Musingwini and Minnitt, 2008).

The final stage of the AHP model is the evaluation of the pairwise comparison matrix for consistency. The matrix is consistent if the relative importance is cardinal and/or ordinal consistent. For example, for cardinal consistent matrix, if criterion C_2 is twice as important as criterion C_1 and criterion C_3 is three time as important as C_2, then it follows that criterion C_3 should be six times as important as C_1. For consistent ordinal matrix, if C_1 is preferred to C_2 and C_2 is preferred to C_3, then C_1 should be preferred to C_3 (Musingwini and Minnitt, 2008). However, this consistency is rarely achieved since AHP deals with human judgements which are characteristically inconsistent. Therefore AHP provides a way of measuring the degree of inconsistency in judgements as well as the method to reduce this measure, if it is deemed to be too high (Saaty, 2003).

Identification of main factors related to longwall layout selection

There is large number of geological, geotechnical and coal quality factors that have an impact on longwall layout selection. Large numbers of factors (criteria) are not desired while conducting the pairwise comparison. Large number of factors would lead to computational difficulties and it is considered as a time-consuming process which may result in an unrealistic outcome. Therefore, 14 geological, geotechnical and coal quality factors were identified by a team of experts as the main factors for longwall layout selection;

- Depth of cover;
- Seam inclination;
- Coal quality;
- Gas make;
- Roof and floor strata;
- Geological structures;
- *In situ* stress;
- Multiple seam mining;
- Surface restrictions;
- Surface subsidence;
- Access to reserve;
- Reserve losses due to layout;
- Seam thickness; and
- Roof cavability.

CONSTRUCTION OF AN AHP MODEL

Pairwise comparison of identified factors

From the identified factors, a 14×14 matrix was constructed using the above critical factors. The number scale proposed by Saaty (1990) was utilised in rating each pair of factors to quantify the dominancy of a factor over the other. Therefore, in order to obtain these ratings a workshop was held which involved experts in the longwall mine planning and design process from different functional areas and questionnaire were posed such as; what is the relative importance of factor *i* (matrix row) as opposed to factor *j* (matrix column)? The use of verbal scale instead of numerical scale in the AHP model is to enable the decision-maker to incorporate subjectivity, experience and knowledge in an intuitive and natural way (Ataei, *et al.*, 2008). Due to the dependency of the assigned rates on the location of the proposed mine, central Queensland, was selected to be the region of interest and the rates of the pairwise comparisons were assigned accordingly.

As can be seen in Table 1, *in situ* stress was rated as highly important compared to the other factors, while surface restrictions and surface subsidence were rated as least important due to minimal restrictions on the surface.

Relative priorities

The estimation of the relative priorities of the identified factors in the pairwise comparison matrix was achieved through the estimation of the eigenvector (priority vector). There are several methods that are available for estimating eigenvector. The computation of the eigenvector of a matrix can be accurately performed using Matlab® software. However this software is not user-friendly; therefore it requires competent user of the softwares. Also, calculated results in Matlab® involve risks associated with human errors encountered during data input; therefore, errors-checking is a difficult task as data input process is required to be repeated for multiple of times to reduce this risk.

Table 1 - Pairwise comparison matrix of the identified factors

	Depth of Cover	Seam Inclination	Coal Quality	Gas Make	Roof and Floor Strata	Geological Structures	In-situ Stress	Multiple Seam Mining	Surface Restrictions	Surface Subsidence	Access to reserve	Reserve losses due to the layout	Seam Thickness	Roof Cavability
Depth of Cover	1.00	7.00	0.13	1.00	1.00	3.00	0.11	7.00	8.00	8.00	1.00	0.33	2.00	2.00
Seam Inclination	0.14	1.00	0.11	0.13	0.13	0.33	0.11	1.00	0.25	1.00	0.14	0.11	0.14	0.13
Coal Quality	8.00	9.00	1.00	9.00	0.50	3.00	1.00	8.00	5.00	8.00	4.00	3.00	6.00	6.00
Gas Make	1.00	8.00	0.11	1.00	0.17	0.33	0.11	5.00	0.25	6.00	0.14	0.14	0.33	0.20
Roof and Floor Strata	1.00	8.00	2.00	6.00	1.00	6.00	0.50	6.00	8.00	8.00	4.00	1.00	1.00	1.00
Geological Structure	0.33	3.00	0.33	3.00	0.17	1.00	0.25	7.00	8.00	9.00	0.50	1.00	1.00	1.00
In-situ Stress	9.00	9.00	1.00	9.00	2.00	4.00	1.00	9.00	9.00	9.00	7.00	3.00	8.00	5.00
Multiple Seam Mining	0.14	1.00	0.13	0.20	0.17	0.14	0.11	1.00	5.00	6.00	0.33	0.14	0.13	0.17
Surface Restrictions	0.13	4.00	0.20	4.00	0.13	0.13	0.11	0.20	1.00	1.00	0.20	0.13	0.14	0.14
Surface Subsidence	0.13	1.00	0.13	0.17	0.13	0.11	0.11	0.17	1.00	1.00	0.13	0.11	0.13	0.13
Access to Reserve	1.00	7.00	0.25	7.00	0.25	2.00	0.14	3.00	5.00	7.69	1.00	0.33	5.00	2.00
Reserve Losses (due to the layout)	3.00	9.00	0.33	7.00	1.00	1.00	0.33	7.00	8.00	9.00	3.00	1.00	7.00	5.00
Seam Thickness	0.50	7.00	0.17	3.00	1.00	1.00	0.13	8.00	7.00	8.00	0.20	0.14	1.00	0.50
Roof Cavability	0.50	8.00	0.17	5.00	1.00	1.00	0.20	6.00	7.00	8.00	0.50	0.20	2.00	1.00
Sum	25.87	82.00	6.05	55.49	8.63	23.05	4.22	68.37	72.5	89.69	22.15	10.64	33.87	24.26

Microsoft® Excel has therefore been used to estimate the eigenvector by implementing an approximation method that is based on normalisation (Kardi, 2006). The process of normalisation for a given reciprocal square matrix ($n \times n$) includes the following steps:

1. Summation of each column of the reciprocal matrix.
2. Division of each element of the matrix with the sum of its own column, this is called normalisation of relative weight, where the sum of each new column is one (1).
3. The normalised principal eigenvector can be estimated by averaging across the rows.

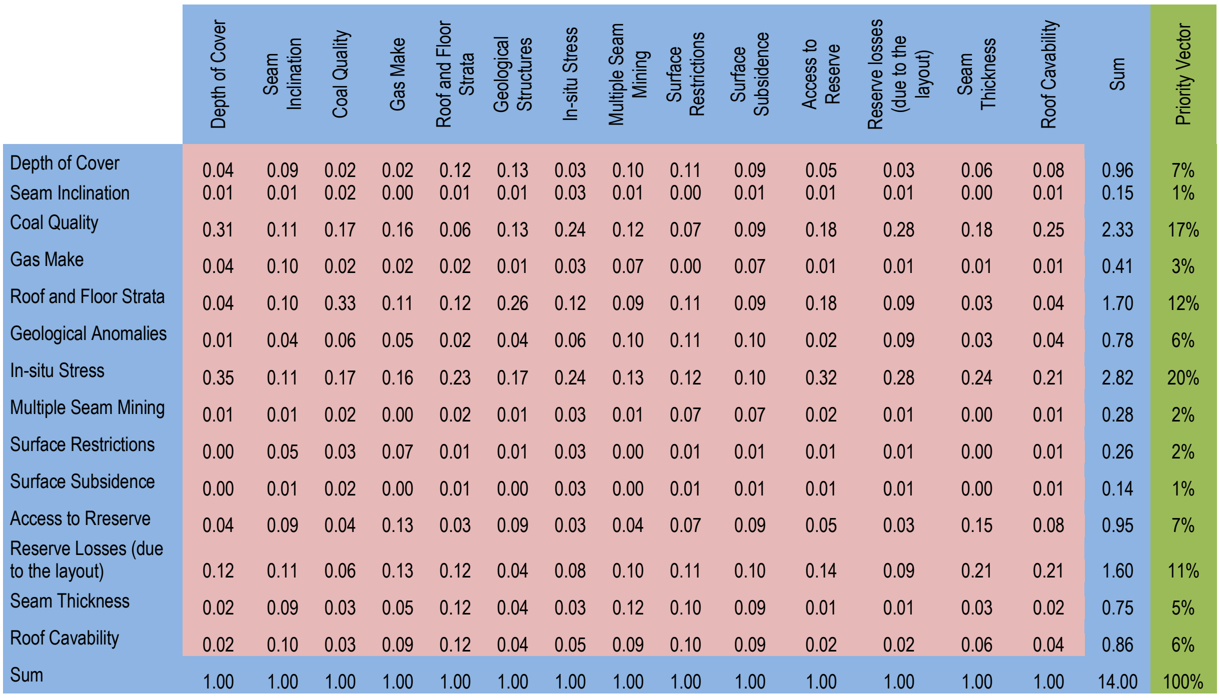
The application of the normalisation process on the identified factors' matrix is shown in Table 2. The eigenvector of the pairwise comparison matrix has also been calculated using Matlab® to confirm the validity of the results obtained by the approximation method. The approximation method results were very close to those calculated using Matlab®, with only 0 to 5% deviation. Therefore the use of the approximation method through the normalisation process was considered acceptable.

As can be seen in Table 2, *in situ* stress was calculated to have the highest calculated priority (20%) as it has been considered as highly important against other identified factors in the pairwise comparison. On the other hand, surface restrictions, seam inclination and surface subsidence were calculated to have the lowest priorities (1 to 2%). These factors were considered with low dominancy or priority due to the fact that the mine in consideration is located in central Queensland, where there are lower restrictions on surface impact compared to other regions. It is highly important to note that the given the rates and the calculated priorities of these factors are subject to alteration if other regions were considered. For example, if a mine in New South Wales was considered, surface restrictions and surface subsidence would be expected to be given higher ranking and hence higher priorities as it has higher restrictions on surface impact.

Consistency measure

When dealing with tangibles, pairwise comparison judgment matrix may be perfectly consistent but irrelevant and far off the mark of the true values (Saaty, 2003). Therefore, a small degree of inconsistency may be considered as good practice and forced consistency without the knowledge of the precise values may lead to an undesired compulsion. Inconsistency of a matrix indicates the contradiction in preference of a pairwise comparison to another. It is important to note that the AHP does not require the decision-makers to be consistent but, rather, it provides a measure of inconsistency as well as a method to reduce this measure if it is deemed to be too high (Ekipman, 2003). Saaty (1990) stated that AHP estimates consistency by determining the principal (maximum) eigenvalue, $\lambda_{\max}$.

Table 2 - Normalised matrix of the identified factors



	Depth of Cover	Seam Inclination	Coal Quality	Gas Make	Roof and Floor Strata	Geological Structures	In-situ Stress	Multiple Seam Mining	Surface Restrictions	Surface Subsidence	Access to Reserve	Reserve losses (due to the layout)	Seam Thickness	Roof Cavability	Sum	Priority Vector
Depth of Cover	0.04	0.09	0.02	0.02	0.12	0.13	0.03	0.10	0.11	0.09	0.05	0.03	0.06	0.08	0.96	7%
Seam Inclination	0.01	0.01	0.02	0.00	0.01	0.01	0.03	0.01	0.00	0.01	0.01	0.01	0.00	0.01	0.15	1%
Coal Quality	0.31	0.11	0.17	0.16	0.06	0.13	0.24	0.12	0.07	0.09	0.18	0.28	0.18	0.25	2.33	17%
Gas Make	0.04	0.10	0.02	0.02	0.02	0.01	0.03	0.07	0.00	0.07	0.01	0.01	0.01	0.01	0.41	3%
Roof and Floor Strata	0.04	0.10	0.33	0.11	0.12	0.26	0.12	0.09	0.11	0.09	0.18	0.09	0.03	0.04	1.70	12%
Geological Anomalies	0.01	0.04	0.06	0.05	0.02	0.04	0.06	0.10	0.11	0.10	0.02	0.09	0.03	0.04	0.78	6%
In-situ Stress	0.35	0.11	0.17	0.16	0.23	0.17	0.24	0.13	0.12	0.10	0.32	0.28	0.24	0.21	2.82	20%
Multiple Seam Mining	0.01	0.01	0.02	0.00	0.02	0.01	0.03	0.01	0.07	0.07	0.02	0.01	0.00	0.01	0.28	2%
Surface Restrictions	0.00	0.05	0.03	0.07	0.01	0.01	0.03	0.00	0.01	0.01	0.01	0.01	0.00	0.01	0.26	2%
Surface Subsidence	0.00	0.01	0.02	0.00	0.01	0.00	0.03	0.00	0.01	0.01	0.01	0.01	0.00	0.01	0.14	1%
Access to Rreserve	0.04	0.09	0.04	0.13	0.03	0.09	0.03	0.04	0.07	0.09	0.05	0.03	0.15	0.08	0.95	7%
Reserve Losses (due to the layout)	0.12	0.11	0.06	0.13	0.12	0.04	0.08	0.10	0.11	0.10	0.14	0.09	0.21	0.21	1.60	11%
Seam Thickness	0.02	0.09	0.03	0.05	0.12	0.04	0.03	0.12	0.10	0.09	0.01	0.01	0.03	0.02	0.75	5%
Roof Cavability	0.02	0.10	0.03	0.09	0.12	0.04	0.05	0.09	0.10	0.09	0.02	0.02	0.06	0.04	0.86	6%
Sum	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	14.00	100%

The principal eigenvalue was obtained from the summation of products between each element of the eigenvector (priority vector) and the sum of the columns of the pairwise comparison matrix (Kardi, 2006). The principal eigenvalue of the pairwise comparison matrix for the identified factors was estimated to be 18.13. A consistency Index (CI) was then calculated from $\lambda_{\max}$ to measure the deviation from consistency using the relationship defined by Equation 1.

$$CI = \frac{\lambda_{\max} - n}{n-1} \tag{1}$$

Using Equation 1 and the estimated principal eigenvalue, the value of CI was estimated to be 0.32. For a perfectly consistent matrix, $\lambda_{\max} = n$; where *n* is the number of identified factors; and hence a CI value of zero is expected. Since the calculated CI value is greater than zero, inconsistency was expected in the pairwise comparison matrix.

In order to measure the level of inconsistency of a matrix, the Consistency Ratio (CR) was required to be calculated. As a general rule, a CR of 0.10 or less is considered acceptable (Saaty, 1990). The CR is calculated by assessing the value of CI against judgements that are made by experts and completely at random. Saaty (1990) simulated large sample of random matrices of increasing order and calculated their corresponding CIs which are Random Indices (RI). For matrices of order between 1 and 15, Saaty established the corresponding RI. The CR was calculated by dividing the CI (0.32) by its corresponding RI (1.57), to give a value of 0.2. The calculated CR was clearly higher than the acceptable ratio of 0.1, which made the pairwise comparison matrix inconsistent. Therefore, a revision and reconsideration on the subjective judgements was required.

AHP MODEL VALIDATION

Methodology

Consistent matrices are essential because when dealing with intangibles, human judgments are usually inconsistent, and if the decision-maker is able to improve inconsistency to near consistency, then that could improve the validity of the priorities of a decision (Saaty, 2003). This can be done through the revision of all the data entries in the pairwise comparison matrix and reconsideration of the entries that cause the inconsistency. However, this process can be time consuming as the size of the matrix increases, considering the size of the matrix within this paper is 14 × 14.

Several alternatives, mostly based on various optimisation techniques, have been proposed to help improve consistency. Saaty (2003) proposed a method based on perturbation theory to find the most inconsistent judgment in the matrix. This method could be followed by the determination of the range of values to which that judgment can be changed and whereby the inconsistency could be improved and then asking the decision-maker to consider changing the judgment to a plausible value in that range (Benítez, *et al.*, 2011). This paper utilised this method in an iterative manner to assist the decision-maker to detect and adjust inconsistencies and to represent more acceptable judgements (Li and Ma, 2007).

The first step in Saaty perturbation theory is the detection of the matrix entry that is causing the inconsistency. Inconsistency detection is based on the fact that:

$$\sum_{\substack{i=1,j=1\\ i\neq j}}^{n} a_{ij}\,\frac{w_j}{w_i} = \lambda_{\max} \qquad (2)$$

Where w_i and w_j are the eigenvector entry that corresponds to the matrix entry a_{ij}.

This relationship suggests that examination is required for the entry a_{ij} for which $a_{ij}\frac{w_j}{w_i}$ is the largest, and determine if this entry can reasonably be made smaller. This is because the entry with the largest $a_{ij}\frac{w_j}{w_i}$ value indicates that it has the largest impact on the inconsistency. The reduction of this entry is preferable as such a change will result in a new comparison matrix with smaller eigenvalue and hence more consistency.

The second step in this method is to estimate the most consistent value for the matrix entry. Harker (1987) has shown that the most consistent value for the entry a_{ij} can be estimated by:

1. Replacing the entries $a_{ij}$and its reciprocal, a_{ji}, by zeros, and the two corresponding diagonal entries by two;
2. Calculating the new eigenvector, w'; and
3. Estimating the new (consistent) value of the entry a_{ij} by considering $a_{ij}' = \frac{w_i'}{w_j'}$, where a_{ij}' is the consistent value of entry a_{ij}, and w_i' and w_j' are the entries of the new calculated eigenvector that correspond to the entry a_{ij}.

Results

Implementing Saaty's method, the pair; multiple seam mining and surface restrictions; was identified to have the largest $a_{ij}\frac{w_j}{w_i}$ value. Proceeding with Saaty's method, the most consistent value was estimated. However, another workshop was required to validate the estimated value, as simply substituting the most consistent value into the matrix creates a forced consistency situation which is undesirable. The pair had an initial value of 5, but applying Saaty's method; a new value of 1 was estimated for the pair. In order to validate the new estimated value, another workshop was held with the same experts, deciding on a value of 2. From the substitution of the new value of the entry and the estimation of the new priority vector, a new CR of 0.19 was estimated.

The application of Saaty's method has resulted in a 5% reduction of the CR; however, this reduction was considered insufficient to achieve the desired consistency. Therefore, multiple iterations were performed with the subsequent largest inconsistent judgements. The identified new values for the inconsistent pairs were substituted into the original pairwise comparison matrix as highlighted in Table 3 and the new priority vector was estimated. From the modified pairwise comparison matrix and the new estimated priority vector, a new CR was estimated to be 0.13. The estimated value of the CR was still above the acceptable consistency limit (0.1); however this degree of inconsistency was still considered as acceptable since forced consistency is undesired.

CASE STUDY: MINE A

Overview

The second stage of the AHP is the construction of pairwise comparisons between various alternatives (mine layouts) under each criterion (factor). In order to complete this stage, a mine at the feasibility stage, Mine A, located in central Queensland was used as a case study. Longwall mining was selected to be utilised for coal extraction. The geological and geotechnical aspects of the mine resulted in variations in the recommended panel orientations. This paper has evaluated three different panel orientations with variable geological, geotechnical and coal quality impacts.

Table 3 - Modified pairwise comparison matrix and priority vector of the identified factors

	Depth of Cover	Seam Inclination	Coal Quality	Gas Make	Roof and Floor Strata	Geological Structures	In-situ Stress	Multiple Seam Mining	Surface Restrictions	Surface Subsidence	Access to Reserve	Reserve losses (due to the layout)	Seam Thickness	Roof Cavability	**Priority Vector**
Depth of Cover	1.00	7.00	0.13	1.00	1.00	**1.00**	0.11	**5.00**	**5.00**	8.00	1.00	0.33	2.00	**1.00**	**6%**
Seam Inclination	0.14	1.00	0.11	0.13	0.13	0.33	0.11	**0.25**	0.25	1.00	0.14	0.11	0.14	0.13	**1%**
Coal Quality	8.00	9.00	1.00	9.00	0.50	3.00	1.00	8.00	5.00	8.00	4.00	**2.00**	**4.00**	6.00	**17%**
Gas Make	1.00	8.00	0.11	1.00	0.17	0.33	0.11	5.00	0.25	6.00	0.14	0.14	0.33	0.20	**3%**
Roof and Floor Strata	1.00	8.00	2.00	6.00	1.00	**2.00**	0.50	6.00	8.00	8.00	**3.00**	1.00	1.00	1.00	**11%**
Geological structure	1.00	3.00	0.33	3.00	0.50	1.00	0.25	**5.00**	**6.00**	9.00	0.50	**0.50**	1.00	1.00	**6%**
In-situ Stress	9.00	9.00	1.00	9.00	2.00	4.00	1.00	9.00	9.00	9.00	7.00	3.00	**5.00**	5.00	**21%**
Multiple Seam Mining	0.20	4.00	0.13	0.20	0.17	0.20	0.11	1.00	**2.00**	**2.00**	0.33	0.14	0.13	0.17	**2%**
Surface Restrictions	0.20	4.00	0.20	4.00	0.13	0.17	0.11	0.50	1.00	1.00	0.20	0.13	0.14	0.14	**2%**
Surface Subsidence	0.13	1.00	0.13	0.17	0.13	0.11	0.11	0.50	1.00	1.00	0.13	0.11	0.13	0.13	**1%**
Access to Reserve	1.00	7.00	0.25	7.00	0.33	2.00	0.14	3.00	5.00	7.69	1.00	0.33	**1.00**	2.00	**7%**
Reserve Losses (due to the layout)	3.00	9.00	0.50	7.00	1.00	2.00	0.33	7.00	8.00	9.00	3.00	1.00	**4.00**	**1.00**	**11%**
Seam Thickness	0.50	7.00	0.17	3.00	1.00	1.00	0.13	8.00	7.00	8.00	0.20	0.14	1.00	0.50	**6%**
Roof Cavability	1.00	8.00	0.17	5.00	1.00	1.00	0.20	6.00	7.00	8.00	0.50	1.00	2.00	1.00	**7%**

Geological and geotechnical conditions

Due to the sensitivity associated with the data collected from Mine A, only general trends of the geological, geotechnical and coal quality data were provided in this paper.

Overall the *in situ* horizontal stress is oriented at N30E. There is only one major normal fault with a dyke oriented at EW direction. The fault has a throw of 6 m down to the north. Surface restrictions are represented by a projected railway line and a creek running across the expected mining activity area as shown in Figure 1. Other geological, geotechnical and coal quality aspects vary in the easterly direction, as shown in Table 4.

Table 4 - Geological, geotechnical and coal quality trend

Factor	Unit	East	West
Depth of cover	m	250.00	550.00
Rank		1.20	1.45
Volatiles	%	25.00	19.00
Gas make	m^3/t	7.00	12 to 13
Seam Thickness	m	5.00	6.50

Other factors such as multiple seam mining, roof and floor strata and roof cavability were considered to have the same conditions within the active mining areas.

Proposed mine layouts

Figures 1, 2 and 3 represent the three proposed layouts against the horizontal stress, major fault and other surface features.

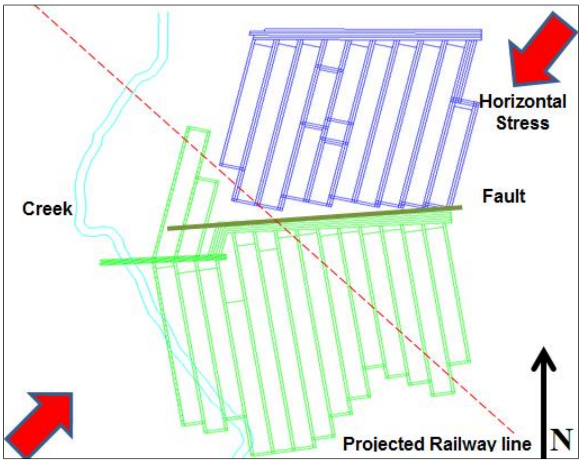


Figure 1 - First proposed mine layout

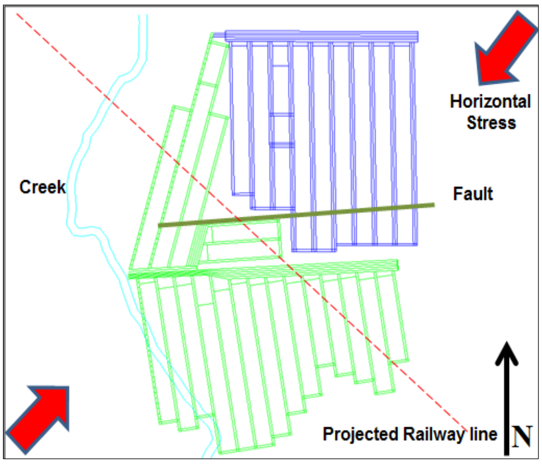


Figure 2 - Second proposed mine layout

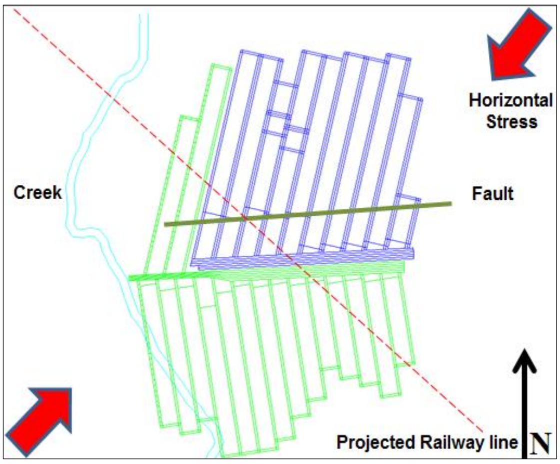


Figure 3 - Third proposed mine layout

Layouts comparisons

The three proposed different longwall layouts have different mining directions, panel orientations and panel configurations. These variations in layout were expected to have various geological, geotechnical and coal quality impacts, such as:

- In terms of coal quality, layout 2 was more preferable than layouts 1 and 3 as it provided a consistent coal quality per panel compared to the other two layouts.

- Considering the longwall panel length of the three layouts, layout 3 has the greatest panel length than other layouts. Therefore, layout 3 would require more complex gas drainage and hence least preferable compared to other layouts.
- Considering the location of the major fault, layout 1 was strongly more preferable than layouts 2 and 3 as the fault was avoided in layout 1, whereas it cut through the longwall panels in the layouts 2 and 3.
- All the layouts have different panel orientations to the *in situ* horizontal stress; therefore, various impacts with respect to stability of the layouts were expected. Layouts 1 and 2 are proposed to retreat from South to North, in which the stress notch is minimal and potentially notch only in the tailgate, which will be supported. On the other hand, layout 3 is proposed to retreat from North to South, in this case there may be maingate stress notch, which is undesirable as the conveyor belt will be placed in the gateroad. Also layout 1 has potentially lower stress notch on the tailgate than layout 2, since layout 1 is aligned more with the *in situ* horizontal stress. Therefore, from the horizontal stress notching point of view layout 1 was considered as most preferable, while layout 2 was more preferable than layout 3.
- The only surface restrictions are represented by the railway line and the creek. Layout 1 was considered to be more preferable than the other two layouts. This because larger sections of the railway line are above the mining activity area in the other two layouts compared to layout 1.
- Considering the access to reserve, access to layout 3 can be established relatively quickly and at lower cost from the existing workings of the mine. Whereas layouts 1 and 2 will require conveyor drift, man and material vertical shaft. Therefore, layout 3 was considered strongly more preferable than layouts 1 and 2.
- Due to the various panels configuration between all the layouts, layout 3 was considered to have the least reserve losses compared to layout 1 and 2. Also layout 1 has also lower losses than layout 2.
- Impacts with respect to the other factors such as depth of cover, seam inclination, roof and floor strata, multiple seam mining, surface subsidence, seam thickness and roof cavability were considered to be similar for all the layouts. All the layouts were therefore considered equally important with respect to these factors.

Pairwise comparisons of the proposed layouts

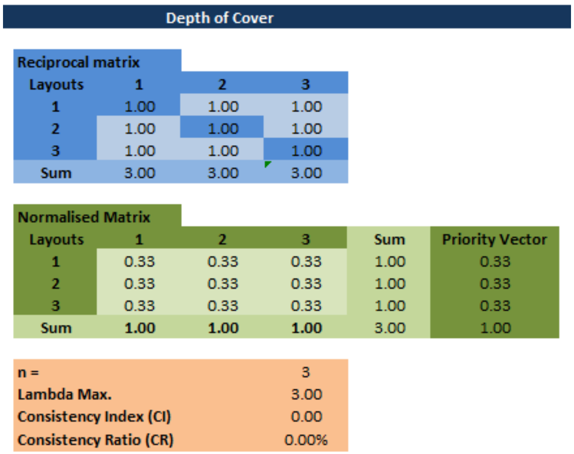
The second phase of the AHP is the construction of layouts pairwise comparison matrices and the assignation of rates for the alternatives (layouts) with respect to each criterion (factor). This was performed through the construction of a workshop with the same experts where questionnaires were posed to compare alternative *i* against alternative *j* with respect to a particular criteria. This comparison was performed using the same number scale proposed by Saaty (1990). The eigenvector (priority vector), the principle eigenvalue ($\lambda_{\max}$) and the consistency ratio (CR) were calculated in the same manner as the pairwise comparison of the identified factors as shown in Tables 5 to 12.

The three layouts had an equal importance with respect to other factors such as seam inclination, roof and floor strata, multiple seam mining, surface subsidence, seam thickness and roof cavability. Therefore, the pairwise comparison matrix and the estimated priority vector for these factors were expected to be identical to the pairwise comparison matrix and the estimated priority vector of the three layouts with respect to depth of cover as shown in Table 5.

Overall priorities and the optimum mine layout

The final stage of the AHP model is the estimation of the overall composite weight of each layout based on the estimated priority vector of both identified factors and layouts. Table 13, shows the priority vector of the identified factors, the priority vector of the layouts with respect to each identified factor and the estimated overall weight of the layouts. The overall weight has been estimated by the summation of the product between the priority value of an identified factor and its corresponding priority value of a particular layout.

Table 5 - Pairwise comparison of the three layouts with respect to depth of cover



Depth of Cover

Reciprocal matrix

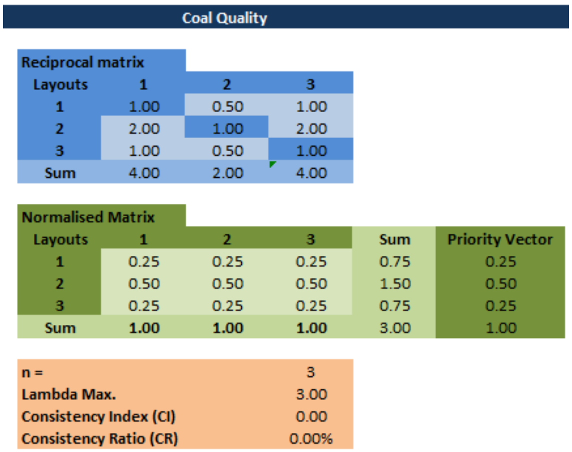
Layouts	1	2	3
1	1.00	1.00	1.00
2	1.00	1.00	1.00
3	1.00	1.00	1.00
Sum	3.00	3.00	3.00

Normalised Matrix

Layouts	1	2	3	Sum	Priority Vector
1	0.33	0.33	0.33	1.00	0.33
2	0.33	0.33	0.33	1.00	0.33
3	0.33	0.33	0.33	1.00	0.33
Sum	1.00	1.00	1.00	3.00	1.00

n =	3
Lambda Max.	3.00
Consistency Index (CI)	0.00
Consistency Ratio (CR)	0.00%

Table 6 - Pairwise comparison of the three layouts with respect to coal quality



Coal Quality

Reciprocal matrix

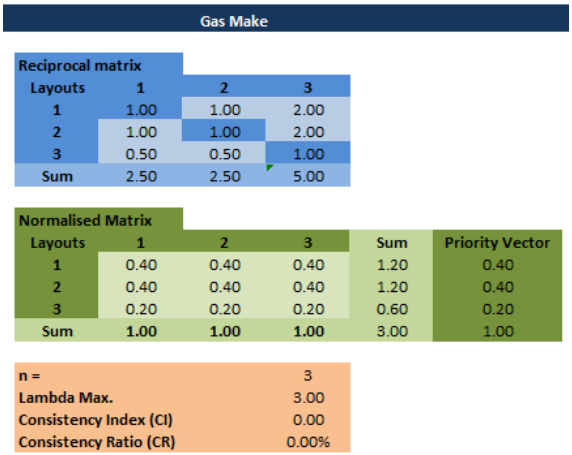
Layouts	1	2	3
1	1.00	0.50	1.00
2	2.00	1.00	2.00
3	1.00	0.50	1.00
Sum	4.00	2.00	4.00

Normalised Matrix

Layouts	1	2	3	Sum	Priority Vector
1	0.25	0.25	0.25	0.75	0.25
2	0.50	0.50	0.50	1.50	0.50
3	0.25	0.25	0.25	0.75	0.25
Sum	1.00	1.00	1.00	3.00	1.00

n =	3
Lambda Max.	3.00
Consistency Index (CI)	0.00
Consistency Ratio (CR)	0.00%

Table 7 - Pairwise comparison of the three layouts with respect to gas make



Gas Make

Reciprocal matrix

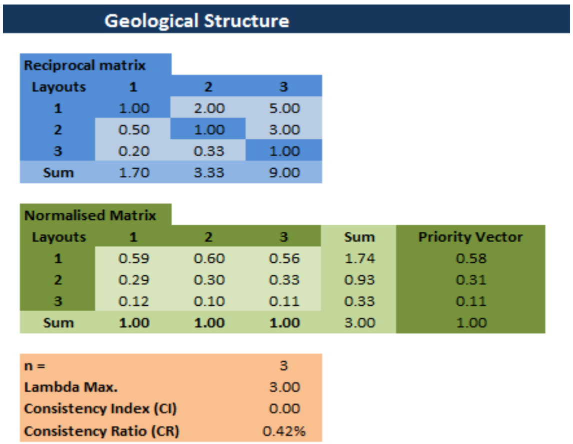
Layouts	1	2	3
1	1.00	1.00	2.00
2	1.00	1.00	2.00
3	0.50	0.50	1.00
Sum	2.50	2.50	5.00

Normalised Matrix

Layouts	1	2	3	Sum	Priority Vector
1	0.40	0.40	0.40	1.20	0.40
2	0.40	0.40	0.40	1.20	0.40
3	0.20	0.20	0.20	0.60	0.20
Sum	1.00	1.00	1.00	3.00	1.00

n =	3
Lambda Max.	3.00
Consistency Index (CI)	0.00
Consistency Ratio (CR)	0.00%

Table 8 - Pairwise comparison of the three layouts with respect to geological structures



Geological Structure

Reciprocal matrix

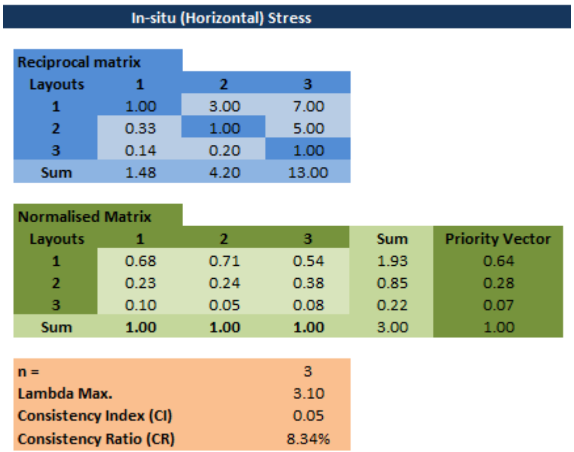
Layouts	1	2	3
1	1.00	2.00	5.00
2	0.50	1.00	3.00
3	0.20	0.33	1.00
Sum	1.70	3.33	9.00

Normalised Matrix

Layouts	1	2	3	Sum	Priority Vector
1	0.59	0.60	0.56	1.74	0.58
2	0.29	0.30	0.33	0.93	0.31
3	0.12	0.10	0.11	0.33	0.11
Sum	1.00	1.00	1.00	3.00	1.00

n =	3
Lambda Max.	3.00
Consistency Index (CI)	0.00
Consistency Ratio (CR)	0.42%

Table 9 - Pairwise comparison of the three layouts with respect to *in situ* stress



In-situ (Horizontal) Stress

Reciprocal matrix

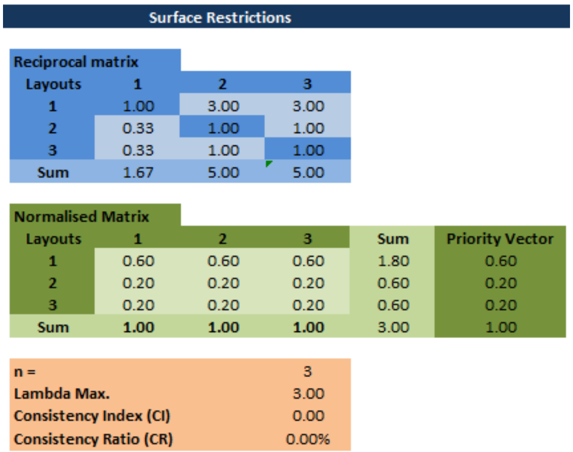
Layouts	1	2	3
1	1.00	3.00	7.00
2	0.33	1.00	5.00
3	0.14	0.20	1.00
Sum	1.48	4.20	13.00

Normalised Matrix

Layouts	1	2	3	Sum	Priority Vector
1	0.68	0.71	0.54	1.93	0.64
2	0.23	0.24	0.38	0.85	0.28
3	0.10	0.05	0.08	0.22	0.07
Sum	1.00	1.00	1.00	3.00	1.00

n =	3
Lambda Max.	3.10
Consistency Index (CI)	0.05
Consistency Ratio (CR)	8.34%

Table 10 - Pairwise comparison of the three layouts with respect to surface restrictions



Surface Restrictions

Reciprocal matrix

Layouts	1	2	3
1	1.00	3.00	3.00
2	0.33	1.00	1.00
3	0.33	1.00	1.00
Sum	1.67	5.00	5.00

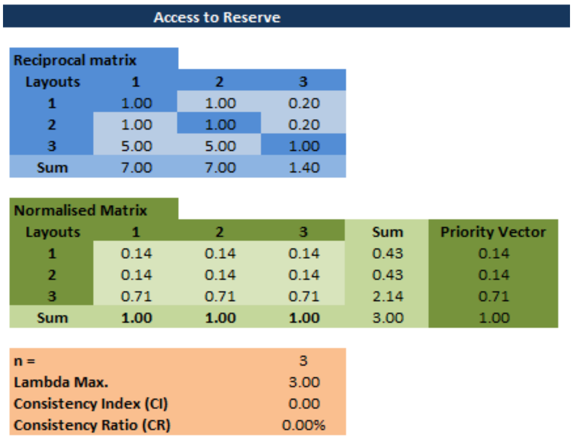
Normalised Matrix

Layouts	1	2	3	Sum	Priority Vector
1	0.60	0.60	0.60	1.80	0.60
2	0.20	0.20	0.20	0.60	0.20
3	0.20	0.20	0.20	0.60	0.20
Sum	1.00	1.00	1.00	3.00	1.00

n =	3
Lambda Max.	3.00
Consistency Index (CI)	0.00
Consistency Ratio (CR)	0.00%

From Table 13, it is evident that layout 1 is the optimum mine layout with a weight of 0.38; followed by layouts 2 and 3 with equal weight of 0.31. These results were expected as layout 1 had higher priority than the other two layouts with respect to *in situ* stress, which also had the highest priority against other factors.

Table 11 - Pairwise comparison of the three layouts with respect to access to reserve



Access to Reserve

Reciprocal matrix

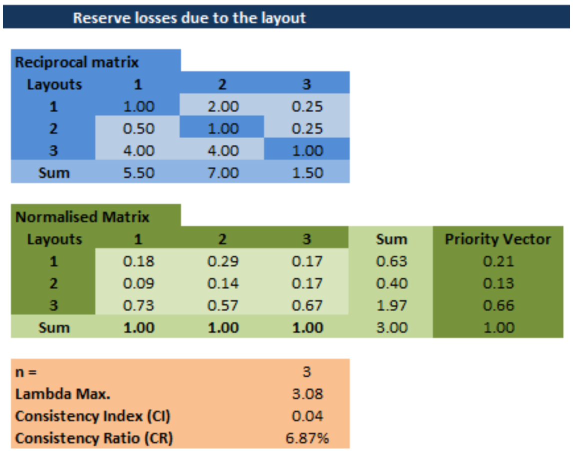
Layouts	1	2	3
1	1.00	1.00	0.20
2	1.00	1.00	0.20
3	5.00	5.00	1.00
Sum	7.00	7.00	1.40

Normalised Matrix

Layouts	1	2	3	Sum	Priority Vector
1	0.14	0.14	0.14	0.43	0.14
2	0.14	0.14	0.14	0.43	0.14
3	0.71	0.71	0.71	2.14	0.71
Sum	1.00	1.00	1.00	3.00	1.00

n =	3
Lambda Max.	3.00
Consistency Index (CI)	0.00
Consistency Ratio (CR)	0.00%

Table 12 - Pairwise comparison of the three layouts with respect to reserve losses



Reserve losses due to the layout

Reciprocal matrix

Layouts	1	2	3
1	1.00	2.00	0.25
2	0.50	1.00	0.25
3	4.00	4.00	1.00
Sum	5.50	7.00	1.50

Normalised Matrix

Layouts	1	2	3	Sum	Priority Vector
1	0.18	0.29	0.17	0.63	0.21
2	0.09	0.14	0.17	0.40	0.13
3	0.73	0.57	0.67	1.97	0.66
Sum	1.00	1.00	1.00	3.00	1.00

n =	3
Lambda Max.	3.08
Consistency Index (CI)	0.04
Consistency Ratio (CR)	6.87%

Table 13 - Overall priorities and the overall composite weight of the layouts

Factors	Factors Priorities	Layout Priorities		
		1	2	3
Depth of cover	0.06	0.33	0.33	0.33
Seam inclination	0.01	0.33	0.33	0.33
Coal quality	0.17	0.25	0.5	0.25
Gas make	0.03	0.4	0.4	0.2
Roof and floor strata	0.11	0.33	0.33	0.33
Geological structures	0.06	0.58	0.31	0.11
In situ stress	0.21	0.64	0.28	0.07
Multiple seam mining	0.02	0.33	0.33	0.33
Surface restrictions	0.02	0.60	0.20	0.20
Surface subsidence	0.01	0.33	0.33	0.33
Access to reserve	0.07	0.14	0.14	0.71
Reserve losses due to the layout	0.11	0.21	0.13	0.66
Seam thickness	0.06	0.33	0.33	0.33
Roof cavability	0.07	0.33	0.33	0.33
Composite weight		0.38	0.31	0.31

Overall consistency measure

It is still essential to estimate the overall consistency of the hierarchy as this will give an indication on the validity of the AHP results. The overall consistency of the hierarchy was estimated by dividing the sum of the weighted CI by the sum of the weighted RI. The overall consistency of the AHP has been estimated to be 0.1, which indicates that the results are consistent and valid.

CONCLUSIONS

This paper summarised development of a method for layout selection using the AHP. Due to the broadness of the proposed study, the scope was directed to the development of a method for longwall layout selection in the central Queensland region. The geological, geotechnical and the coal quality aspects that influence the selection of panel orientation were identified.

These inter-relationships between the factors and the dependency of a factor on the other indicated the necessity of AHP as a decision-making tool. From the identified factors, an AHP model has been created. A pairwise comparison matrix has been constructed for the identified factors, where *in situ* stress has been identified as the most important factor with priority of 0.21 for the selection of a longwall layout. On the other hand, surface subsidence and surface restrictions have been identified as the least important as there are limited restrictions on surface in central Queensland compared to other regions.

A longwall mine at the prefeasibility stage, located in central Queensland, was assessed using the methodology developed. Three proposed layouts were compared with respect to each identified factor and their priorities were calculated. The results from the pairwise comparisons of the identified factors and the layouts were then combined and further evaluated to select the optimum mine layout.

The results of each stage in the AHP model were validated through the estimation of the consistency. For inconsistent matrices, a method has been implemented to improve the consistency of the judgements and transform the inconsistent matrix to a near consistent one.

The results revealed that the AHP model developed in this paper can be used as a basis for implementing longwall layout selection. If new critical factors and hence new criteria emerge to satisfy decision-makers need, then they can be included in the AHP model to select the optimum layout. Unlike the traditional approaches to layout selection, the AHP method requires less data and reduces the time consumed in the decision-making process.

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