Quantification of Fault Uncertainty and Risk Management in Longwall Coal Mining: Back-Analysis Study at North Goonyella Mine, Queensland

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A method for fault uncertainty and risk assessment based on the concept of stochastic simulations is used to back-analyse data from mined out longwall panels at North Goonyella mine, Queensland. The results from back-analysis show that (i) fault risk can be quantified; (ii) quantified fault risk can be integrated into longwall design and assist decision making; and (iii) if the simulation technologies were available earlier, geological risk at North Goonyella would have been substantially better understood, therefore could have had a major positive economic impact. Lastly, a comparison between North Goonyella and a specific part of the Goonyella-Riverside area suggests that the latter is less risky for a comparable longwall design. The study shows the contribution of the quantified risk approach to reducing coal mining investment risks and facilitating more informed decisions.

INTRODUCTION

Fault uncertainty and risk have widely recognised adverse impacts on the exploration and mining of underground coal deposits, especially for longwall mining. Geological uncertainties may cause significant delays in production schedules, impose substantial changes to mine plans, reduce expected recoverable coal quantities, adversely affect safety, and heavily influence the financial viability of a mine. As Australia’s coal mining industry is becoming increasingly reliant upon longwall mining, there is a need to implement: more effective quantitative and practical approaches to geological risk modelling, uncertainty assessments, and integration of risk management. This will enable mining companies to better plan underground exploration activities and longwall operations.

The recently completed ACARP project C7025, “Quantification of fault uncertainty and risk management in underground coal mining” contributes to meeting the above needs. The methods developed, case studies and tests are detailed in Dimitrakopoulos et al (2001), and the tools assisting the implementation of the methods are presented in Li et al (2001).

A key aspect of the above project is the back-analysis at the North Goonyella mine. Back-analysis aims to:

- assess the effectiveness and validity of methods for fault uncertainty and risk quantification developed by the project in a mined out part of the mine, where all faults have been mapped in detail,
- show that if the technologies from the above project were available earlier, the fault related risk at North Goonyella would have been more accurately understood, therefore improving decision-making, and
- complementary to the above is the comparison of quantified risk at North Goonyella to that of Goonyella-Riverside.

These three aspects of the ACARP project are presented in this paper.

The results reported here are based on a new method developed for modelling fault uncertainty and quantifying risk. The method and the back-analysis are based on the concept of spatial stochastic simulations. The key idea in stochastic fault simulation is that from an initial set of fault data, one can generate multiple equally probable models (realisations) of the faults within a study area. The combination of these equally probable models provides the means to quantify fault risk. Characteristics of fault simulations include:

- fault realisations are based on and reproduce all the available data and geological interpretations available, and
- realisations reproduce the statistical characteristics of the fault data including the key “power-law” relationships of fault size distributions and length versus maximum throw of the fault data.

For further information on the method, the reader is referred to the ACARP C7025 project report available from ACARP.
BACK-ANALYSIS: STEPS AND ASSUMPTIONS

North Goonyella mine is located in the Bowen Basin, Central Queensland. Back-analysis uses mined out longwalls of the mine where faults have been mapped in detail. Geological interpretations or other information are not available. Figure 1(a) shows the available and completely known dataset. The steps involved in back-analysis are as follows:

- the completely known fault data are sampled to generate a sample fault dataset as shown in Figure 1(b),
- 50 fault simulations are run, based on the sample fault data set and its statistical characteristics,
- fault probability maps derived from the simulations are compared to the complete fault dataset, and
- a longwall design is used to quantify fault risk and is compared to the known risk of longwall panels in the study area.

The back-analysis study assumes that there would be a reasonable level of exploration carried out in the parts of the area to be considered, and that the proportion of known smaller faults reflects the levels to which such faults are known after typical exploration activities.

FAULT SIMULATION, UNCERTAINTY ASSESSMENT AND RISK MAPPING

Two simulated realisations of the fault populations in the study area are shown in Figure 2. The comparison to the complete dataset in Figure 1(a) provides an insight to the concept of fault simulations. The specifics of the fault simulation within the study area are beyond the scope of this paper and are given in the C7025 project report. Figure 3(a) shows the fault probability map generated from the 50 fault realisations used here. The fault probability map can be assessed and compared against the completely known fault dataset.

Figure 3 compares various fault probability maps, showing that the technologies used in this study can predict risk particularly well. More specifically, Figure 3(b) shows the probability map based upon the faults in the sample dataset alone (70 faults with throw ≥ 1m). As discussed earlier, the quantification of risk based on the sample data seems severely reduced in comparison with that seen in Figure 3(a), which is the probability map resulting from 50 fault realisations (about 207 faults with throw ≥ 1m). Figure 3(c) presents the probability map from the completely known fault dataset (231 faults with throw ≥ 1m). The fault simulation technologies are able to use an exploration-like level of information to generate a more reasonable assessment of fault risk throughout the study area when compared to the spatially limited and incomplete sample dataset alone that could be any “exploration data”.

The probability map based upon 50 fault realisations, shown in Figure 3(a) can be compared to the probability map of the complete data set in Figure 3(c). In Figure 3, locations numbered with ‘1’ highlight an actual high-risk part of the study area that is predicted by the fault simulation methods developed in this project. Number 2 highlights a part of the study area in which risk is overestimated by the fault simulation methods. Number 3 highlights a part of the study area in which a high-risk area (in the probability map based upon the realisations) is slightly shifted with respect to its position in the completely known fault dataset.

It should be noted that the risk assessments based strictly on the sample dataset underestimate risk within the mining area, as is expected. The probability map
about which the least is known, they can be explored (their exploration may be prioritised) and then classified with greater certainty.

INTEGRATION OF QUANTIFIED RISK IN LONGWALL DECISION MAKING AT NORTH GOONYELLA

The levels of risk associated with a longwall layout used at North Goonyella mine are assessed in this section. In all cases presented here, risk is calculated and reported for an equivalent longwall panel size of 200m x 2000m. Risk is calculated and reported for a given (constant) longwall panel size in order to be physically and statistically meaningful and can be calculated for any longwall panel sizes as needed.

Figure 4 shows the probability and risk associated with the mine and the longwall panels when all faults within the completely known dataset with throws greater than or equal to 1m are considered. This is the ‘true risk’ scenario. Figure 5 shows the fault probability and risk associated with the mine and the longwall panels based upon the probability map obtained from fault simulation. Spatial distribution of risk, the histogram of the risk distribution and the related descriptive statistics are shown. The assessment of risk shown in Figure 5 is very close to that of the actual scenario shown in Figure 4.

Figure 6 shows the fault probabilities and risk associated with mine longwall panels based upon the sample fault dataset only. The spatial distribution of risk, the histogram of the risk distribution and the related descriptive statistics are shown. Figure 6 shows a fault risk assessment that could be anticipated at a relatively early stage of exploration without the use of computerised fault modelling technologies. By comparing Figure 6 with the risk distribution of the completely known fault dataset in Figure 4, it can be seen that the use of exploration data alone results in severe underestimation of geological risk.

Comparison of Figure 4 and Figure 5 suggests that the use of fault simulation technologies provide an excellent assessment of the actual fault risk levels in the North Goonyella example. A comparison of Figure 4 to Figure 6 shows that the estimated fault risk is far closer than that obtained using the sample fault dataset alone.

Exploration provides fault data, which is commonly used ‘as is’ which implicitly corresponds to the level of risk in the faults identified in the dataset. If technologies such as seismic methods are used, faults below resolution are not detected and as a result any ‘risk’ assessment based on the dataset ‘as is’, will underestimate the true risk. The opposite is also possible, for example, other geophysical methods such as aeromagnetics are highly interpretative and may

resulting from the fault realisations provides a substantially closer estimate to the actual risk scenario than that based upon the sample dataset.

Data collection expenditure (drilling or geophysical surveying) is one additional example where quantification of geological risk has the potential to improve current practices. For instance, if one considers Figure 3, the expenditure for further seismic surveys may be prioritised and there may be two or three approaches to the task. The first involves the targeting of low risk panels to verify the simulation predictions. Secondly, if an ambitious approach is decided upon, the risky parts of the area may be investigated to determine if indeed there are significant faulting concerns or not. Thirdly, as the middle values of fault probability (eg 40 to 60%) reflect those areas

Figure 2 Two fault realisations using the sample fault dataset at North Goonyella mine (faults shown have a throw ≥ 1m).
result in the over representation of interpreted faults which if used 'as is' will produce an overestimated risk assessment.

Qualitative risk assessments are, in addition to the above, difficult to use because they implicitly reflect fixed information similarly to the use of the dataset 'as is'. Furthermore, quantitative assessments are highly subjective and a relative measure, not a physically meaningful probability to be used for risk assessment. This is perhaps obvious, but also useful to recall in uncertainty modelling and risk assessment. To enhance the understanding of an area, further exploration could be carried out which may be costly and would not guarantee uncertainty reduction or the optimisation of data collection. Using fault simulation technologies provides a means to utilise exploration data to gain a more complete and quantitative understanding of a relatively unknown area than would otherwise be achievable (from qualitative investigations). Simulation technologies such as those developed in this project could be utilised in combination with the information acquired from remote sensing surveys. Although the example presented here is simple, it shows that probabilistic models, in combination with current exploration, offer a way to obtain a more complete picture.

Figure 3 Probabilities from: (a) 50 fault realisations and the fault simulation approach in this study, (b) the sample fault dataset alone, without the use of fault simulations; and (c) from the completely known fault dataset and the real fault probability map in the study area.

IS A LONGWALL MINE AT GOONYELLA-RIVERSIDE AS RISKY AS NORTH GOONYELLA MINE?

A comparison can be made between the levels of risk at North Goonyella Mine and a potentially mineable part of Goonyella-Riverside. The histograms of risk associated with a longwall panel layout can be seen in Figure 7. The longwall layout shown for North Goonyella Mine is the same as that used above in the quantification of fault risk. The layout shown for the Goonyella-Riverside area has been designed without consideration of quantified geological risk — while the "exploration data" is available. Using the base map of fault locations, it is apparent that risk is fairly high and may be classified as such using a qualitative approach. It is only through quantifying risk using true probabilities that the difference in geological risk between the two areas can be grasped. Using the longwall layouts presented, the average fault probability at North Goonyella is 61%, and for the study area at Goonyella-Riverside it is 39%. The comparison shows that the longwall layout designed for Goonyella-Riverside has, on average, a substantially reduced level of risk compared to the mined-out
Figure 4 Spatial distribution of fault probability and 'true' risk in a longwall layout at North Goonyella in (a); histogram and descriptive statistics of same in (b) using the completely known dataset.

Figure 5 Spatial distribution of fault probability and risk in a longwall layout at North Goonyella mine in (a); histogram and descriptive statistics of same in (b) as calculated using the fault probability map generated from realisations based on the sample fault dataset.

Figure 6 Spatial distribution of fault probability and risk in a longwall layout at North Goonyella mine in (a); histogram and descriptive statistics of same in (b) as calculated based on the sample dataset only.
Goonyella is particularly well predicted from a subset of faults (sample dataset) within the same area and the fault simulation method. More specifically, this means that if the technologies from this project were available at the time North Goonyella Mine was designed, subsequent substantial fault related risk could have been better analysed. Providing the opportunity to ‘design out’ the impact of faulting. The comparison of mined out longwalls at North Goonyella to a potential longwall mine located in the Goonyella-Riverside area provides an eloquent example of the use of quantified uncertainty and risk for investment decision-making. The ability to compare risk in a longwall layout at Goonyella-Riverside to that in North Goonyella is uniquely based on the quantification of geological risk.

The back-analysis study also shows that the traditional use of geological data from exploration programs ‘as is’ may severely underestimate geological risk. Qualitative risk assessments, although technically simpler, may be misleading and difficult to use because they implicitly reflect information similar to that from exploration programs taken ‘as is’. Furthermore, qualitative assessments are highly subjective and do not provide an objective “number” (probability) as needed for risk comparison. Qualitative risk assessments are generally difficult to link meaningfully to mine design and planning, whereas quantitative risk assessments that incorporate local geological understanding offer accurate risk assessments and can be used directly and routinely in longwall mine design and planning.

Coal reserve risk is a specific topic that the methods and examples presented in this paper can be applied to. Reserves can be classified based on their fault risk level and the possibility of not being recovered from mining.

Cost effective data collection, be it additional drilling or geophysical surveys, can be supported and strategies for prioritised data gathering developed based on fault risk quantification.

Lastly, technologies developed in this project can serve as a starting point for further development of risk quantifying technologies that can offer an inexpensive method to acquire information to substantially assist decision-making in both longwall exploration, longwall mine design, mine development and operations.

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Figure 7 Spatial distribution of fault probability and histograms of risk for North Goonyella Mine (left) based on mined out dataset and for part of the Goonyella-Riverside area (right) based upon simulations using the available sample dataset and calculated for given layouts and a panel size equivalent of 200m x 2000m.

Figure 8 (a) 'True' classification of mineable coal reserves based on quantified fault risk, calculated from the completely known fault dataset; (b) estimated classification of mineable coal reserves based upon quantified fault risk, calculated following use of the computerised fault simulation technologies developed for this study and; (c) estimated classification of mineable coal reserves based upon quantified fault risk, calculated from the sample fault dataset only.
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