SAFETY IN MINES RESEARCH ADVISORY COMMITTEE

SIMRAC

Final Project Report

Title: DEVELOP A MORE RELIABLE MEANS OF ASSESSING SAFETY RISK DUE TO ROCKBURSTS AND ROCKFALLS AS A MANAGERIAL DECISION SUPPORT TECHNIQUE

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DEVELOP A MORE RELIABLE MEANS OF ASSESSING SAFETY RISK DUE TO ROCKBURSTS AND ROCKFALLS AS A MANAGERIAL DECISION SUPPORT TECHNIQUE.
GAP112

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EXECUTIVE SUMMARY

The GAP112 project was initiated to create techniques for processing falls of ground (FOG) data. Those techniques were tested with data from East Rand Proprietary Mines (ERPM).

The first part of this report concerns seismic events that caused falls of ground. The study shows that damage is not only controlled by the magnitude and distance between a seismic source and panel but also other factors. Seismic events with large magnitudes (or seismic moments) and large source size can be less damaging than seismic sources with similar magnitudes but smaller source sizes. Damaging seismic events are characterised by very large stress drops. The average stress drop for all seismograms is 6.8 MPa, while the average stress drop of a damaging event is 17 MPa. The fact that peak ground velocities as small as 0.005 m/s can cause damage - is a striking feature.

Statistical analysis of falls of ground shows that panels with no geological features represent a more stable system than panels with geological features.

Large number of falls of ground in panels with no geological features have about 10 m of linear extension of damage. Panels with geological features have typically 30 m length associated with falls of ground. Panels with no geological features represent a more stable system than panels with geological features. The average number of FOG of the first and second groups are 0.59 and 1.82 respectively.

The mean time to failure and availability of panel with and without a geological feature have been obtained. Reliability techniques have been used to solve problems where the stope has an arbitrary number of panels. The mean time to failure for an average panel is 88 days, for panel without a geological feature it is 123 days and for panel with a geological feature is 40 days. Reliability techniques allow for quick estimation of mean time to failure,in more complicated situation where panels are with and without geological feature. Since a damaged panel can be repaired, the availability of a repairable system is a function of its failure rate and of its repair rate. The steady state availability for average panel is 0.97, panel without geological features is 0.98, and panel with geological features is 0.93.

The seismic, geological and mining features are the prominent attributes of the risk forecasting in a stope face. For all those features the rating and the important factors are computed. To test the accuracy of the constructed hierarchy, priority values obtained from expert opinions have been compared with data from the mine.

The analytic hierarchy process (AHP) is used to structure the decision support model. The AHP organizes the complex problem into its smaller constituent parts and guides the decision maker through a series of pairwise comparison judgments to express a relative strength of the elements in the hierarchy. The seismic, geological and mining features are the prominent attributes of the risk forecasting. For all those features the rating and the important factors are computed. The measurements are obtained for regional support as possible actions that would affect the safety. The risk associated with the different techniques of the negotiation of a geological discontinuity is evaluated.

To test accuracy of the constructed hierarchy, priority values obtained from expert opinions have been compared with data from the mine. Essential discrepancy occurs only in the interpretation of risk in geologically undisturbed panels along a pillar. Perfect agreement between the expert's opinion and data is observed in evaluation of risk in panels close to geologic features.

Neural network modelling was used successfully in ERPM to identify the critical production parameters that control the occurrence of falls of ground. The unsupervised learning algorithm was applied to categorise production and associated fall of ground parameters. The unsupervised network is especially useful when there is not a priori knowledge of the categories into which the patterns are to be classified. Each month of production was represented by a vector with the following input parameters: change in production during one month period , total length of active stopes in section, average rate of advance in section and number of panels with geological features. Associated with the fall of ground parameters are the following: linear extent of damage with significant closure in panels, linear extent of damage with scattered falls in panels, linear extent of damage in no panel area, and delay in production. The input patterns file was built using only production variables.

It was established that a section of a mine has months of production with high and low risks of occurrence of FOGs. Production months with the highest rate of stope advance and a high number of panels with geological features are associated with the highest risk of falls of ground with significant closure in panel area. These production variables, however, have no profound influence on the scattered falls.

The computer program for the quantitative assessment of safety risk has been developed. The program exploits a database and employs statistical methodology and decision making techniques. The software has been developed in the Windows environment to achieve user friendliness.

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    (options: towards solid, remnant extraction, along pillar)
- Presence of Geological Structure (options:
  mining obliquely to geological structures,
  unfavourable to geological structures)
  - Type of Mining
    (options: away from geological structure, towards geological structure, remnant extraction, at or through geological structure, along pillar).

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1. INTRODUCTION

This project was a continuation of 1993 project entitled " Multivariate analysis of parameters associated with rockburst and rockfalls'.

The main focus of the project was to create techniques for processing FOG data, to design an intelligent data base, which allows data management and the calculation of the safety risk in different mining situations. The data base utilizes both: FOG data and expert judgement.

Risk analysis has many different meanings. It is usually quantified in term of probability of loss and severity of loss. In modern risk analysis we need to determine not just what is likely to happen, but also to identify the critical element of risk.

To address the problem of estimation the risk of occurrence of damage and/or accident in the stope face area, one has to include factors such as: level of seismicity, geological complexity, mining layout, classes of stope support and distance between seismic source and FOG. Additionally, one must evaluate the efficiency of local and regional support; the measurement of efficiency is given in number of accidents at specific conditions.

The risk cannot be modelled using analytical technique. We have to turn to statistical and decision making techniques. Both those techniques require the use of experience and data base. The easy access to FOG data, accident statistics and expert opinions is a key tool to assess the true safety risk.

The project was focused on the following problems:
(1) the collection of FOG data
(2) the design of intelligent data base;
(3) the development of a statistical method for estimation the probability of FOG occurring;
(4) the development of a decision making model which enables one to logically dissect a risk assessment into its less complex factors;
(5) the development of model of falls of ground

The project objective was to give the rock mechanic practitioner a means of assessing the safety risk under specific mining conditions. This was achieved by writing a computer program that performs the following tasks:

1 Data base
2 Graphical Presentation of Fall of Ground (FOG) Data
3 Statistical Analysis of FOG Data
4 Decision Support Model for Risk Assessment from Expert Judgement (Rating Risk)

The primary output of the project - the working version of software has been finished. All planned components of software are working. The computer program includes most of results obtained in this project during previous years of work.

Enabling Outputs:
1994 (man days 110)
1. Extension of the FOG data base
2. Methodology to analyses the FOG data
3. Hierarchy structure of critical factors of risk

1995 (man days 110)
4. Further extension of FOG data base
5. Intelligent data base for FOG
6. Model of falls of ground

1996 (man days 110)
7. Program that assesses the safety risk
8. Testing the prototype on site
9. Final software that assesses the safety risk and loss in production due to FOG

2. DAMAGING SEISMIC EVENTS IN EAST RAND PROPRIETARY MINES Ltd.,

This part of report is concerned with seismic events that caused falls of ground (FOG). Seismic source parameters of damaging events and ground motion parameters at the sites of damage are investigated. Linear extensions of damage versus seismic source parameters and ground motion parameters are analyzed.

East Rand Proprietary Mines (ERPM) has made available a seismic database from 01/09/91 to 30/06/94. The database contains the following seismic source parameters: date, time, location, seismic moment, seismic energy, corner frequency and stress drop. In addition reports of falls of ground have been collected for many years. For a period of 22 months both seismic and falls of ground data were available for a K1 shaft of ERPM. The selected database of falls of ground covers a period of 52 months. Falls of ground data comes from four the following working places 81W, 81E, 79E, 77E, 76E, 74E, 73E, 72E.

A set of seismic events which, most likely, caused falls of ground cannot be easily identified. Whilst times of seismic events are usually well known, the time of occurrence of the falls of ground is sometimes known only with the precision of a few hours. From the total database of 1650 seismic events and 344 falls of ground, only a set of 64 falls of ground and the most likely associated seismic events has been selected for analysis.

Significant ground motions during seismic events cause some structural damage or modifications. Ground motion levels are controlled by three main factors: i.e. seismic source, propagation path of wave and the local rock conditions. The available data allowed the calculation of the parameters of damaging events and to carry out an estimation of the ground conditions at the site where damage occurred.

In hazard assessments it is crucial to establish the parameters of seismic events causing damage. A widely recommended method of assessing a stope support system (e.q. Wagner 1982, Kaiser 1993) uses a plot of seismic event magnitude versus the distance between seismic source and a site of the damage. There is an expectation of no damage, when seismic event with a small magnitude at large distance is monitored. Figure 1 shows data from a rock damage observations, each point representing a damage in one panel. In several cases two or three points with the same magnitude are located very close to each other. This represent a seismic event that caused damage in several panels of a stope. Data show a well defined region of no damage. A striking feature of the plot is that the line separating a region of no damage from the damaged one relates to the peak ground velocity of 1 cm/s (McGarr et al., 1981).

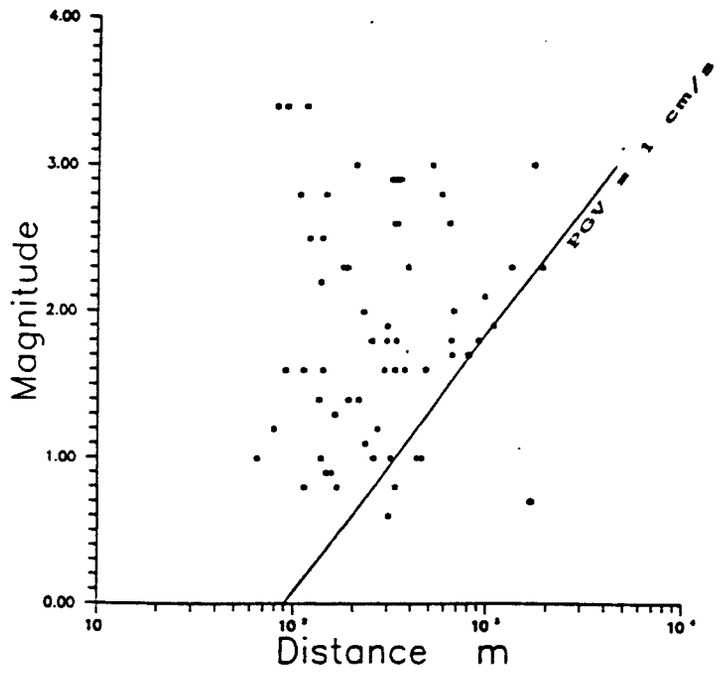


Figure 1. Data from a rock damage observation, each point representing a damage in one panel. The plot of seismic event magnitude versus the distance between seismic source and a site of the damage.

Data shows that the average stress drop for all seismograms is 6.8 MPa, whilst the average stress drop of a damaging event is 17 MPa.

In some seismological applications the parameters of seismic events are presented on plots showing the relationship between the seismic moment and corner frequency. These plots are used to find some features of a selected series of seismic events. Figure 2 contains the seismic source parameter of seismic events responsible for falls of ground in ERPM. Data shows the expected variations of the parameters. In a systematic way a smaller seismic moment is associated with a larger corner frequency. This indicates that a subset of seismic events which caused damage, does not concentrate around any specific frequency range, therefore - on the global scale of a mine- the resonance frequencies do not exist. The only suspicious feature is a lack of seismic events with the corner frequencies lower than 12 Hz. The catalogue of seismic events located in analysed region has 26 seismic events with the corner frequency smaller than 12Hz and magnitudes of those events range from 2.0 to 3.3. Despite such large magnitudes, not a single event caused damage. The explanation probably lies in the low stress drops of those events, mostly smaller than 2MPa. This strengthen the concept of using stress drop together with magnitude (or seismic moment) in assessing the support system in a mine.

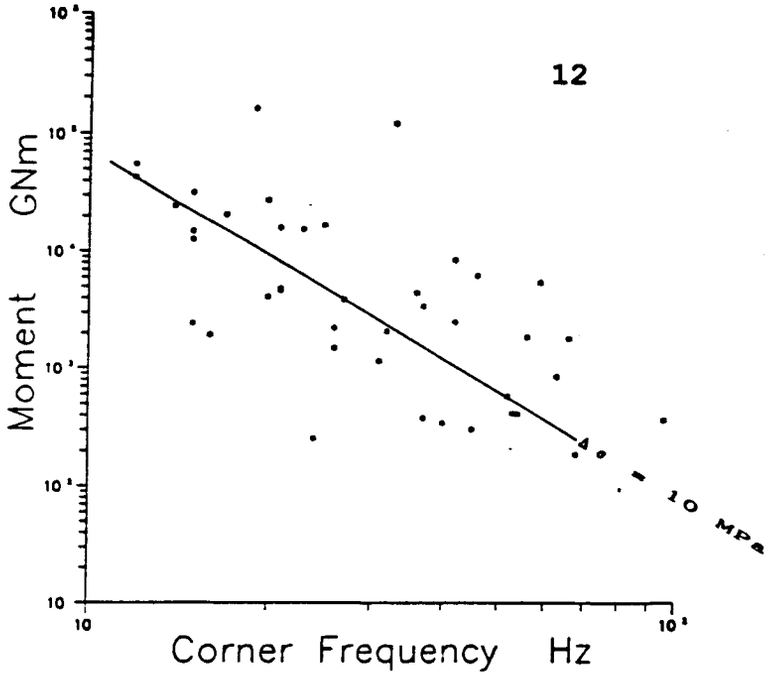


Figure 2. The seismic source parameters of seismic events responsible for falls of ground in ERPM.

Next problem is the estimation of values of the seismic wave parameters at the various panels, that were damaged by seismic events. The peak ground velocity (PGV) at a panel have been investigated. The theoretical model of seismic source leads to the relationship between the PGV and a distance. Stress drop and corner frequency of a seismic event are parameters of this relationship (McGarr, 1984, equation 3). Figure 3 shows the estimated (not observed) PGV versus distance between seismic source and site of damage. The fact that PGV's as small as 0.005 m/s can cause the damage - is a striking feature. Similar low values of damaging PGV were observed by Butler and van Aswegen (1993) in OFS region. Figure 3 shows that the most damage occurred at PGV smaller than 1 m/s.

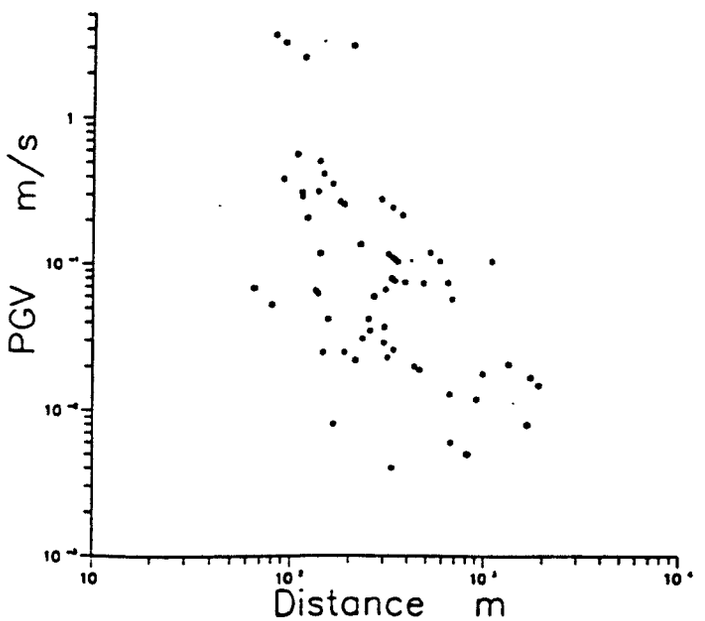


Figure 3. The peak ground velocity (PGV) versus distance between seismic source and site of damage.

Unexpected low values of PGV are associated with site effects. In general site effects are controlled by unusual amplification of ground motion parameters or inadequate support. These results suggest that more intensive research of site effects in stopes should be done.

It is anticipated, that the increase in the PGV or the energy flux rate should control the increase in damage. Figure 4 shows the PGV versus linear extension of damage caused by seismic events. The points relate to total damage across all panels caused by a seismic event. Plot uses three different symbols to represent damage in three different regions of mine. In panels with large dyke or faults a trend of increasing size of damage with increasing PGV can be seen. Stopes with a small number of geological features do not manifest a clear relationship of PGV with size of damage.

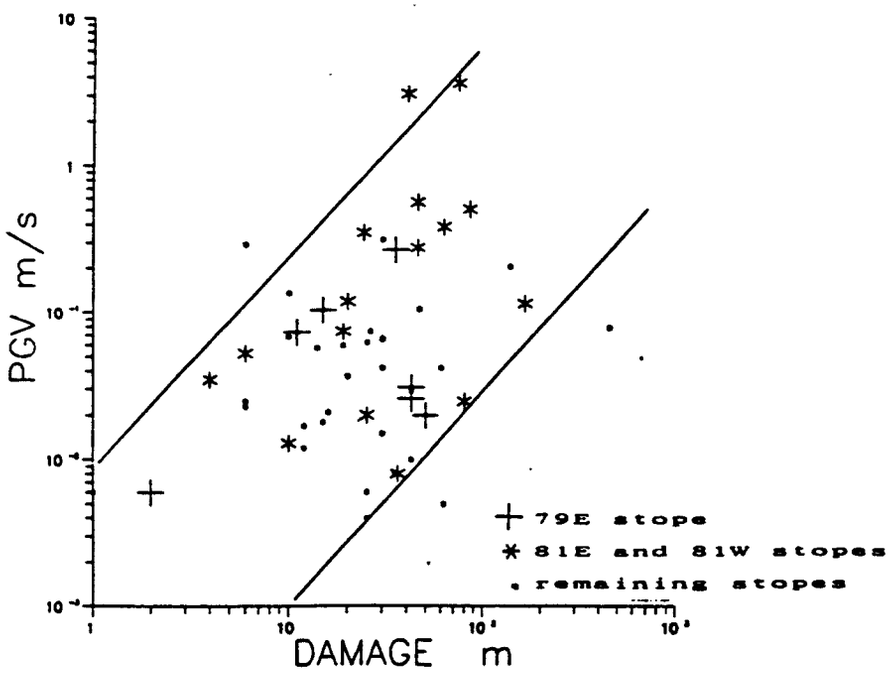


Figure 4. The peak ground velocity versus linear extension of damage caused by seismic events.

Discussion (Hazard implication):

Seismic events generated in a medium with large geological faults, usually do not have large stress drops and - as such - are not normally damaging. On the other hand, events associated with dykes can generate larger stress drops, and are, therefore, more hazardous.

3. STATISTICAL ANALYSIS OF FALLS OF GROUND FROM THE ERPM MINE.

Generally, falls of ground (failure) will occur if load exceeds strength. Such failures occur primary due to two causes: overloading and degradation of strength. Therefore, if in our design strength exceeds load, we should not have failures. For most products neither load nor strength are fixed, but are distributed statistically. The probability of failure due to the load exceeding the strength can be modelled by the rules of statistic. For systems involving moderately large numbers the predictive power of deterministic laws diminishes.
The methods used to quantify reliability are the mathematics of probability and statistics. In reliability work we are dealing with uncertainty. In fact this is the case in much of modern engineering, and the probabilistic as opposed to the deterministic approach to engineering problems is becoming more widely applied.

The area of statistical analysis is a vast one to survey. To reduce the scope of this task, consideration only was given to techniques which have been applied to a real life problems (Billinton and Allen,1983; Frankel, 1984; Goble, 1992; O' Connor, 1991).

3.1 Experimental FOG Frequency

Falls of ground in mine occur unexpectedly. This project is directly concerned in assessing the risk. An attempt must be made to understand the nature of both the frequency of such unexpected events and the size or severity of FOG. The basic task in making decisions about the risk, such as classifications of panels and developing a technique for monitoring the change of risk.

Figure 5 shows the FOG frequencies plots, the number of FOG versus the size of damage (severity). To gain a better understanding of FOG properties, plots should present raw, unsoothed data. Three such plots show respectively: (1) the FOG occurring in panels without geological features, (2) the FOG occurring in panels with geological features and (3) the FOG causing accident. The dominant feature of the first plot is the peak at 10m, produced by a large number of small faults. Panels with geological features do not manifest similar peaks, but - instead - the plot is relatively flat up to 30 m. This suggests that panels with geological features tend to have larger damage than panels without feature. Most likely the damage in these panels follow the extended geological feature. At 30m, the first and the second plots have strong peaks. The peak of 30m is associated with the typical length of panel. There are cases of damage with linear extension much larger than the length of panel and this is due to including damage in dip travelling ways, dip gullies, reef drives, strike gullies, footwall drives, hangingwall drives, strike travelling ways and track cuts.

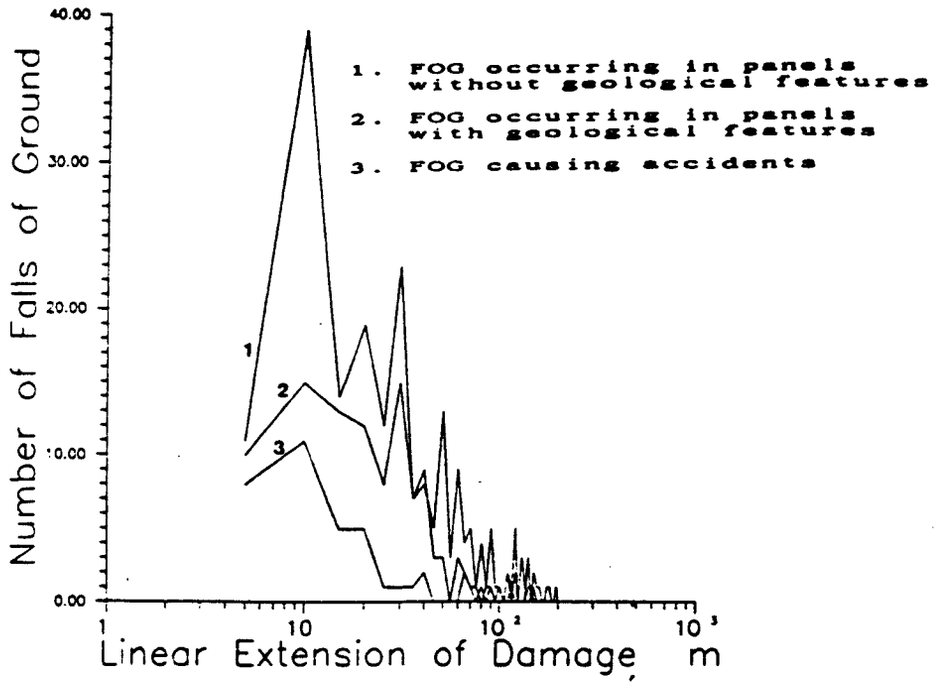


Figure 5. The falls of ground frequency plots.

FOG's which caused significant large damage are not responsible for accidents. The FOG that caused accident have mostly damage smaller than 20m and the maximum number of FOG is at 10 m. A similar result was obtained in the frame of the GAP001/1993 project, where data were collected from a mine in the Carletonville region.

Similar calculations for three types of FOG were performed for the delay in production as a severity parameter. Most FOG caused delays in production of less than 4 days and the maximum number of FOG was at 2 days.

3.2 Control charts for the mean

The statistical quality control procedures have been developed mainly for the early detection and speedy correction of trouble. A quality control engineers want to ensure that the production process is operating as intended. For this purpose control charts are used to monitor current production.

Control charts based on the mean and standard deviation are universal. The mean value of the monthly rate of number of FOG per 100 m of stope for all panels is 0.83 and standard deviation is 0.64. The computed value for the standard deviation is used to establish the control limits that determine whether or not the

process is in statistical control. For this purpose the 3-sigma limits are traditionally computed from the data and about 99.7% of the values generated by a normal distribution will fall within 3-sigma limit. For a controlled process to fall outside those limits would be extremely unlikely. The monthly rate of number of FOG may occasionally shift to some unusually high level. It means that the process is out of control. After closer inspection of data it can be seen that the monthly rate of number of FOG per 100 m of stope in ERPM have been out of control, in 1990 mining most of FOG occurred in the stopes 76E and 77W.

Table 1 shows a real distribution of FOG across different stopes in the ERPM mine. From visual inspection it is clear that a few FOG occurred in each panel per year, but their distribution is definitely not homogenous. Each chosen panel is transformed, from panel close to geological feature, within a few months time, into panel without geological feature.

3.3 Mean time to failure for series of panels in different geological situations

An important application of reliability analysis is the prediction of an overall system's reliability, using - as building blocks- the reliabilities of individual components. The reliability of the system is then a function of the reliabilities of its components. Active stope can be treated as system with several panels in different geological conditions.

The FOG data have been separated into two groups. The first group forms the FOG occurring in panel without geological features . The second group is formed from the FOG that occurred in panels with geological features. Data shows that panels with no geological features represent more stable system than panels with geological feature. The mean values can be used as quantitative measure of risk in two different conditions. The mean values of the first and second groups are 0.59 and 1.82 respectively. The process in the second group was several times outside the calculated limit.

A series system is defined as any system in which all components must work for the system to work. Taking the pessimistic perspective, a series system fails if any component fails.

For risk assessment purposes an active stope with several panels can be treated as a series system. Failure rates for components in a series system can be added.

3.4 Availability of the repair panel

In this section a system with a single repairable component (one

panel) is described. Repairable systems are typical in an industrial environment. Since panels can be repaired, a new measure of system success that allows for repair and renewed operation is needed.

The mean time to repairs (MTTR) of one panel is 2.78 days per FOG (1009 days of delay / 363 FOG) in ERPM mines. The repair rate of panel is $\mu = 0.36$.

Availability is defined as the probability that an item will be available when required or as the proportion of total time that the item is available for use. Therefore the availability of a repairable item is a function of its failure rate , λ and of its repair rate, μ, where $\mu = 1/MTTR$. For a simple unit, with a constant failure rate λ and a constant mean repair rate μ, the steady-state availability is equal to $\mu/(\lambda+\mu)$.The steady state availability for average panel is 0.969,for panel without geological features is 0.978, and panel with geological features is 0.935. Since repair rate, μ, is expressed in units 1/day, then failure rate, λ, has to be as well expressed in units 1/day (1 month = 22 days).

3.5 Reliability information from failure data - " Total time on test"

This part of the report describes monthly variations of the average number of falls of ground in different geological situations. It shows an example of the application of the reliability theory to monitor unusual trends in the rate of falls of ground in different geological conditions.

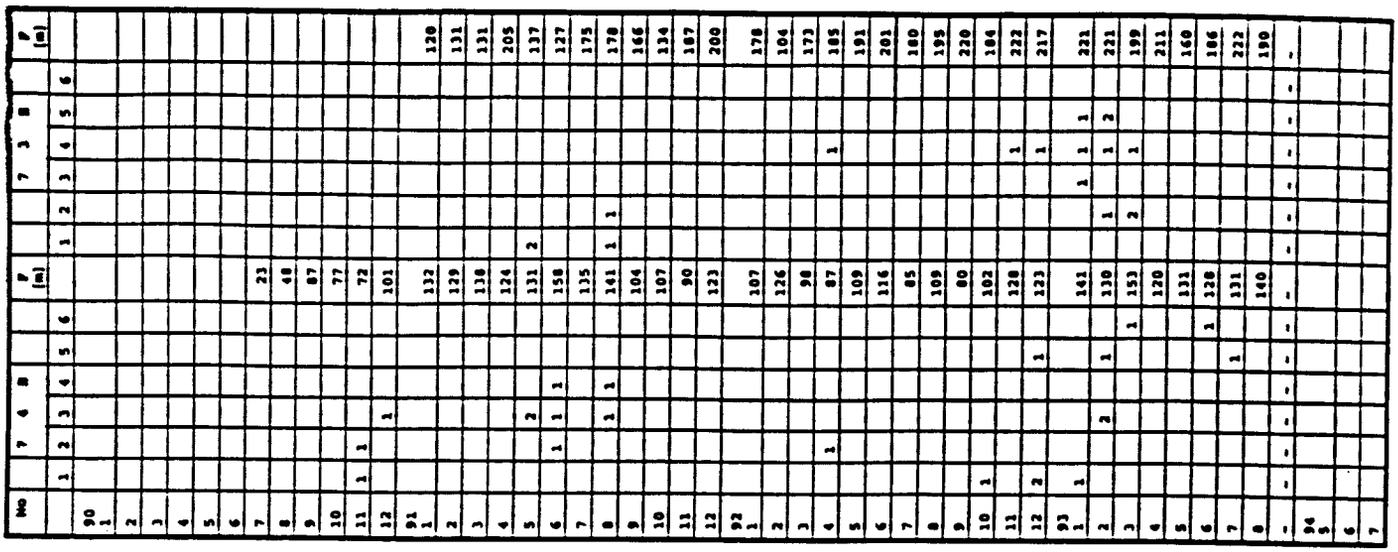
One aspect of reliability analysis is the finding of a distribution model that provides an appropriate fit to the system under investigation. Reliability engineers are concerned with identifying the entire appropriate failure-time distribution, which may be used to predict the reliability of a system. The exponential distribution (Poisson process) is one of the more common failure-time distributions.

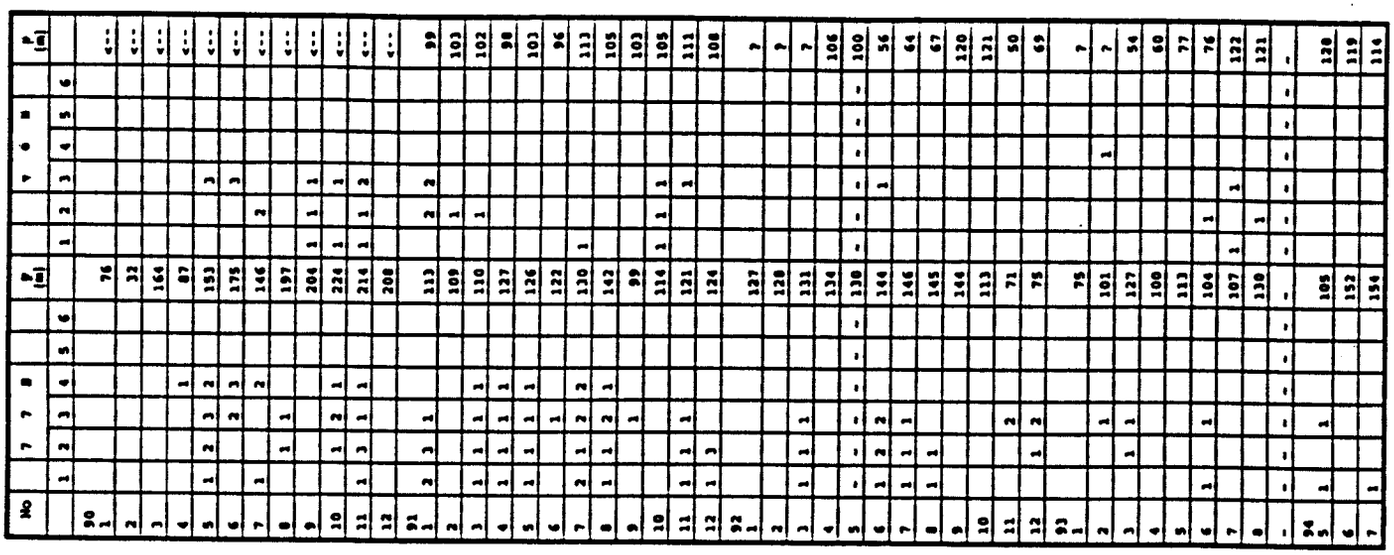
There are a number of simple graphical procedures which can be used to help determine, whether a system is improving or deteriorating. Such techniques are particularly useful for seeking out the data's salient features and for checking the assumptions made in fitting formal models to the data.

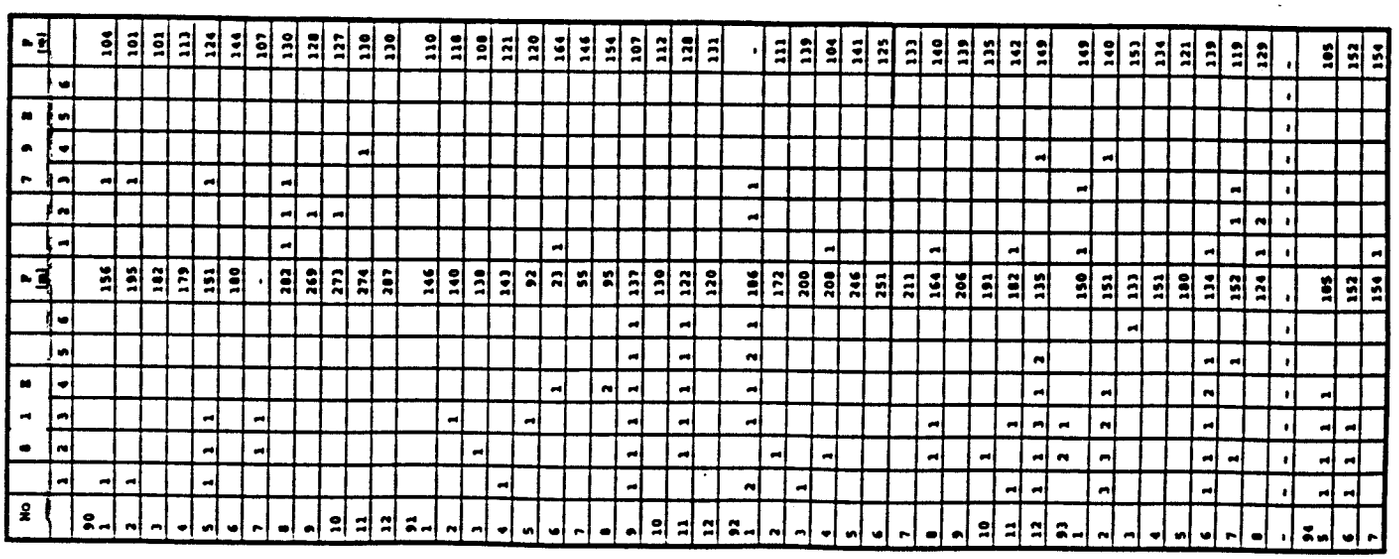
One simple approach is to plot the number of failures against the calendar time. This 'total time on test' (TTT) is used to identify interesting properties to be studied in more depth. Plots of cumulative failures versus cumulative time identifies trend in the system. If a trend has been shown to exist, system improves or deteriorates and sequences of failures are not identically distributed (not Poisson process), then the interarrival times of the improving system tend to become larger,

Table

Falls of ground in the following stopes: 81E.79E,77E,76E,74E and 73E ERPM mine for the period of time 01.01.90.- 07.04.94. In the first column, the month is listed, the panel's number of stope are listed in the following six columns, the length of active face is in next column. The number in cell indicates number of falls of ground.







hence a plot of cumulative number of FOG will tend to be concave down (a "happy system").

Figure 6 a shows the TTT plot for FOG panels without geological features. The abscissa and ordinate are normalized using total time of observation and total number of FOG. The data almost follows a straight line (i.e. constant failure intensity), therefore the Poisson probability models can be applied. Figure 6 b shows the TTT plot for FOG occurring in panels with geological features and panels next to stabilizing pillars. In the initial stages the interarrival time becomes smaller and this implies that the system is deteriorating. In the next stage when the data from the "happy system" has been included, the interarrival times became larger. In September 1994 the system deteriorated and the failure rate function increased. It is quite obvious that the homogeneous Poisson process model will give a very bad fit.

A deviations from the normal in the TTT-plot have to be supplemented by further information in order to interpret the results. However it is a good indication of a possible system component ageing and can thus be used to estimate, whether the maintenance periods can be prolonged or should be shortened as seen from a reliability point of view. The final decision about the maintenance conditions of the components needs additional information, which can be extracted from the system.

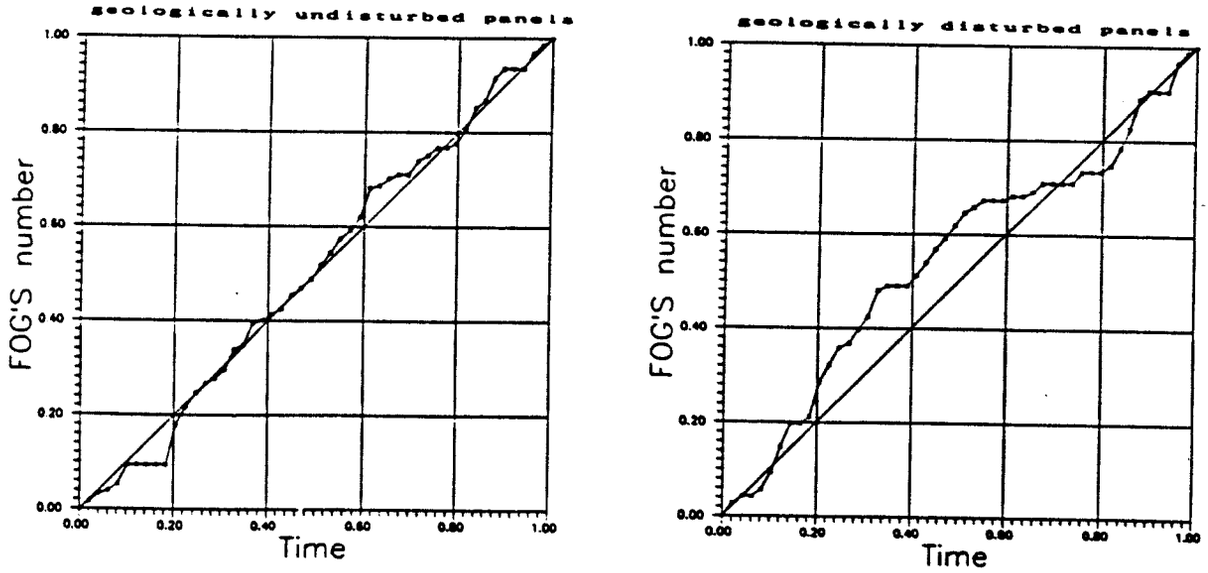


Figure 6. Plots of cumulative failures versus cumulative time: (A) TTT plot for FOG panels without geological features. (B) TTT plot for FOG panels with geological features.

4. DECISION SUPPORT MODEL FOR RISK ASSESSMENT FROM THE EXPERT JUDGEMENT

The object of this section of report is to assist a rock mechanic engineer make an assessment of the risk in the panel by giving some sort of ranking to it. This is a risk of occurring damage and/or accident associated with rockburst in a panel. The panels can be ranked in order of preference by their total safety value to meet the safety needs.

In order to address the problem of the estimating the risk of occurrence of damage and/or accidents in the panel area, one has to include factors such as: seismicity, geological complexity and mining configuration. Therefore, we require a methodology, which allows the accommodation of subjective and uncertain information that is obtained from the expert judgment.

4.1 ANALYTICAL HIERARCHY PROCESS

The AHP is a technique for organizing the information and judgments used in making complex decisions. The approach chosen for analysing this multiple criteria decision problem is based on the Analytic Hierarchy Process introduced by Saaty (1980). The AHP provides a decision framework, which enables one to logically dissect a decision into its less complex component parts and then arrange these parts (factors) into a hierarchic structure. A complex problem is further broken into segments of roughly equal importance. Once the hierarchy is developed, the AHP enables us to use subjective pairwise comparison judgments to quantify the relative importance of the parts of a problem.

Priorities are set on the basis of the relative impact (importance) of each factor on the next higher level within each hierarchical level. The elements on the lowest level with the highest impact is the action to be chosen.

The next phase in the AHP is to obtain inconsistency in the decision maker's judgement. Consistency ratios were computed to measure the extent, to which inconsistencies exist among the pairwise comparisons conducted in the judgement. The trade-offs and synthesis of the group judgements are obtained to determine the best decision.

For structuring the elements of the problem into a hierarchy, various factors that affect the expected level of risk of rockburst are first identified (Table 1). The hierarchy-1 pyramid is structured by enumerating the relevant levels that should enter into the risk assessment. The overall goal is the assessment of occurring fall of ground in panel. This damage can cause fatalities.

Table 1
Hierarchy Pyramid

GOAL / FOCUS : Assessment of risk of panel

Level 1 History of seismicity levels in the past.
Level 2 Geological Features
Level 3 Influence mine technique
Level 4 Alternative - Regional Support

The problem is decomposed into four hierarchical decision levels. The highest level, seismicity, includes the possible scenario. The second level contains the geological features. The third level illustrates mining configuration. The lowest level includes alternative plans.

The hierarchy shown in Figure 7 depicts all the relevant and dominant issues affecting the safety in panels. Uncertainty about the occurrence of events is far beyond the control of the decision maker. However, the historical (past) record of seismicity can help to establish likelihood of the damage associated with seismic events. The first level of hierarchy, seismicity, is broken into three scenarios, namely, low level of seismicity (LL of S), moderate level of seismicity (ML of S), and high level of seismicity (HL of S). Table A1 (see Appendix A) shows the definition of each scenario. The defined levels of seismicity should be associated with the number of seismic events per unit of time or released seismic energy. However, the unique understanding of this term does not exist, therefore different physical parameters are used to estimate the seismicity by different experts. The AHP does not need "hard" data and can easily accommodate this sort of subjectivity.

The second level of hierarchy organizes the geological features, which are the most important compounds responsible for nonhomogenous distribution of stress in rock. After intensive search through the literature and discussion with experts we decided to decompose level into three factors: mining in panel Geologically Undisturbed, mining Obliquely to Geological Structure and mining Unfavourable to Geological Structure.

The third level illustrates different mining configuration depended on geology. In the geologically undisturbed rock the mining can take place in three following ways: Towards Solid, Remnant Extraction, Along Pillar. When the stope face is closer than 30m from the geological structure, mining takes place in five following ways:
'Away from Geological Structure','Towards Geological Structure', 'Remnant Extraction','Along Pillar' and 'At or Through Geological Structure'.

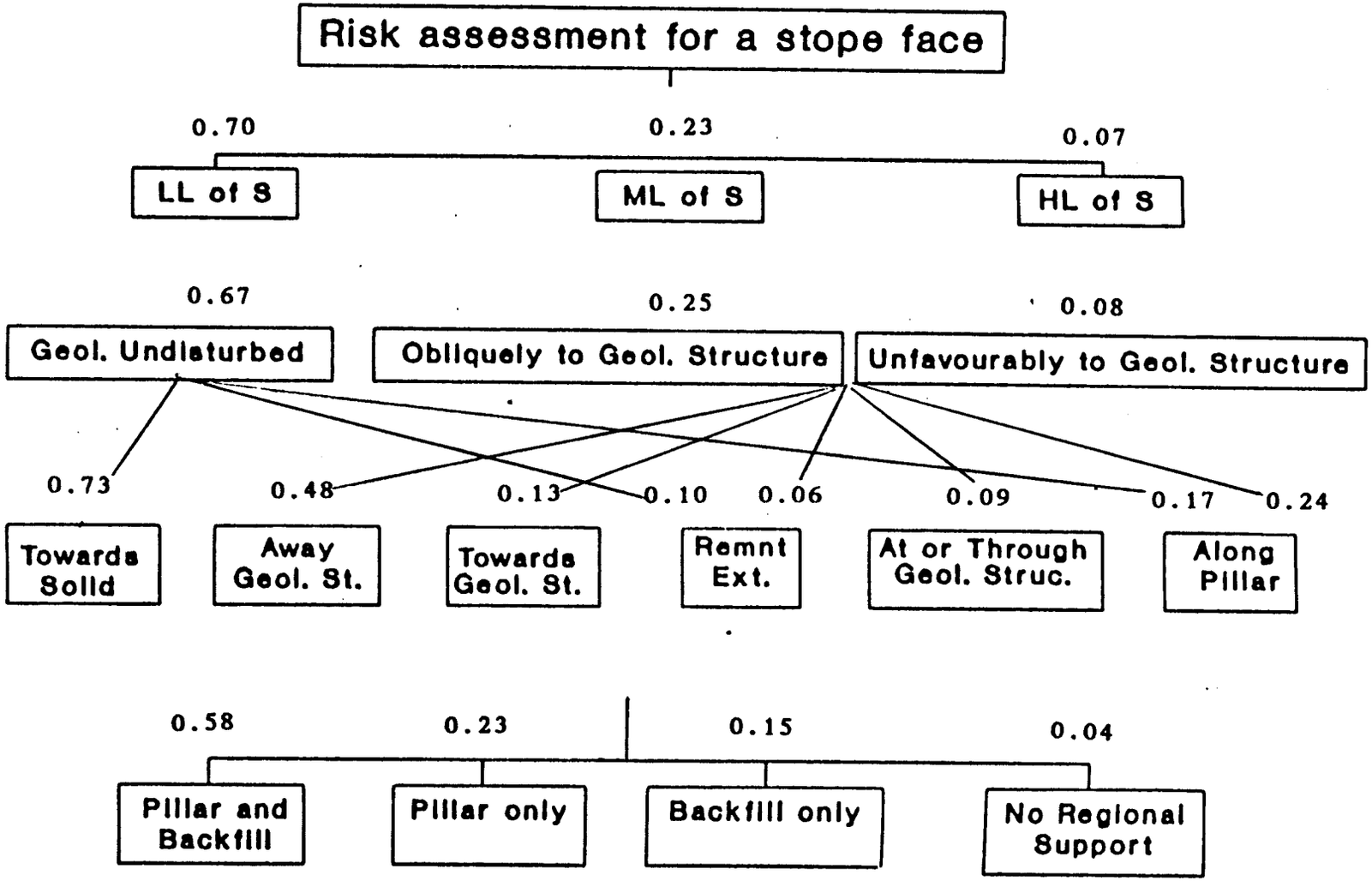

Risk assessment for a stope face
0.70
0.23
0.07
LL of S
ML of S
HL of S
0.67
0.25
0.08
Geol. Undisturbed
Obliquely to Geol. Structure
Unfavourably to Geol. Structure
0.73
0.48
0.13
0.10
0.06
0.09
0.17
0.24
Towards Solid
Away Geol. St.
Towards Geol. St.
Remnt Ext.
At or Through Geol. Struc.
Along Pillar
0.58
0.23
0.15
0.04
Pillar and Backfill
Pillar only
Backfill only
No Regional Support

Figure 7

At the development stage of hierarchy the third level has more factors; especially the last one - " At or Through Geological Structure" has been decomposed into several techniques of negotiation of geological discontinuities. An expert has however a problem with ranking of level of risk even in two following examples of the configuration: (1) approaching large geological structure from one site as opposed to approaching this large geological feature from two sites, (2) mining through a geological structure by distress re-development, over mining through geological structure by rolling up (or down) to the new reef position. The situations listed above are so strongly dependent on very local conditions in mine, that no routine approach could be established.

4.2 Survey findings

A questionnaire - survey was employed to determine the relative weights of levels of hierarchy. After extensive pre-testing, the questionnaire was presented to professionals to obtain expert judgment on weights and priorities of the objectives. Judgments were obtained from the rock mechanic practitioners and scientist specialists in seismology, rock mechanics and geology. For each respondent, weights and relative ranking were calculated. In addition, the internal consistency of the judgement by each respondent was calculated. The overall group consistency of judgment was also determined using the geometrical mean methods.

The individual consistency ratio for this study ranges from 0.009 to 0.17 . Amongst the 10 respondents, 7 had consistency ratio within an acceptable range 0.00 to 0.10 and the remaining 3 respondents had their consistency ratio within a tolerable range 0.1 to 0.20. These values indicated high level of the consistency of all judgement despite different levels of internal consistency in individual responses. Tables 2 to 5 show the results of their ratings.

The first task is to come up with a numerical measure of the various pairwise comparisons. Table 2 provides the pairwise comparison of seismic scenarios in relation to the focus. There is a very strong preference for a low level of seismicity over the high level of seismicity. The consistency of judgement is determined by the consistency ratio,CR, (see Saaty,1987).

Table 2
First level - seismicity level

Factor	Priority value
Low level of seismicity	0.698
Moderate level of seismicity	0.229
High level of seismicity	0.073
CR	0.052

Panels in respect to the most influential geological features are classified as following:
- Geologically Undisturbed,
- mining Obliquely to Geological Structure and
- mining Unfavourable to Geological Structure.

For three different seismicity levels the quantified priority for each type of panel is presented in Table 3. Changes of priority values with increasing seismicity levels can be observed. At a low level of seismicity the influence of geological features is less dominant than in scenario with a high level of seismicity.

Table 3
Second level - geological features

Factor \ Priority value for	LL of S	ML of S	HL of S
Geologically Undisturbed	0.592	0.672	0.711
Obliquely to Geological Structure	0.277	0.247	0.210
Unfavourable to Geological Structure	0.131	0.081	0.079
CR	0.000	0.085	0.078

Table 4 illustrates the third level of hierarchy, the broad spectrum of mining features which are expected to play a dominant role in risk assessment. The rating of mining features with respect to mining Obliquely or Unfavourable to Geological Structure is called Geological Structure.

Table 4
Third level - mining features

Factor	Priority value
Geologically Undisturbed Towards Solid	0.734
Geologically Undisturbed Remnant Extraction	0.099
Geologically Undisturbed Along Pillar	0.168
CR	0.046
Geological Structure Away from Geological Structure	0.481
Geological Structure Towards Geological Structure	0.130
Geological Structure Along Pillar	0.243
Geological Structure Remnant Extraction	0.060
Geological Structure At or Through Geological Structure	0.086
CR	0.033

Table 5 shows priority in the case of combined geological and mining features. Contribution of each component to risk can be gathered from detail inspection of priority values. For example, the remnant extraction in geologically undisturbed medium has the same level of risk as mining along pillar obliquely to geological structure (see Table 5 line 4 and 5). The mining situation described by lines from 6 to 9 has the similar level of risk.

It is interesting to note that, mining towards the solid in geologically undisturbed stope is more than three times safer than mining along a pillar (see Table 5 line 1 and 2).

Table 5
Rating Stope Faces
Including geological and mining features
at moderate level of seismicity

value	Combined Factors	Priority
1	Geol. Undisturbed mining Towards Solid	0.493
2	Geol. Undisturbed mining Along Pillar	0.112
3	Obliquely to and Away from Geol.Structure	0.119
4	Geol. Undisturbed Remnant Extraction	0.066
5	Obliquely to Geol.Str. and Along Pillar	0.060
6	Unfavourable and Away from Geol.Structure	0.039
7	Obliquely to and Towards Geol.Structure	0.032
8	Unfavourable to Geol.Str. and Along Pillar	0.020
9	Obliquely to and either At or Through Geol.Str.	0.021
10	Obliquely to Geol.Str. Remnant Extraction	0.015
11	Unfavourable to and Towards Geol.Structure	0.011
12	Unfavourable to and either At or Through Geol.Str	0.007
13	Unfavourable to Geol.Str.,Remnant Ext.	0.005

The next step is to obtain the quantitative risk forecast in real life conditions, where seismicity scenario has to be estimated. This is done by weighting the possible seismicity (Table 2) for each possible stope. The detailed interpretation is left to the reader to compare his own expertise with the "average" opinion of experts.

4.3 Comparing expert's priority values with data from ERPM

To test accuracy of the constructed hierarchy, priority values obtained from expert opinions have to be compared with data from mine. Falls of ground and seismic data from ERPM mine have been used for the comparison purposes. As ERPM mine does not cover all possible scenarios, the hierarchy had to be simplified to get straight comparison with data from the mine.

Figure 8 summarises comparison of expert priority values with data from ERPM. Essential discrepancy occurs only in interpretation of risk in geologically undisturbed panels along pillars. Experts believe that geologically undisturbed panels along pillars are more dangerous (0.168) than mining in geological undisturbed panels towards solid (0.734). But data show that the risk in geologically undisturbed panels along pillar (0.459) is of the same order of risk as mining towards solid (0.442). Perfect agreement between the expert's opinion and data is observed in evaluation of risk in panels close to geological features.

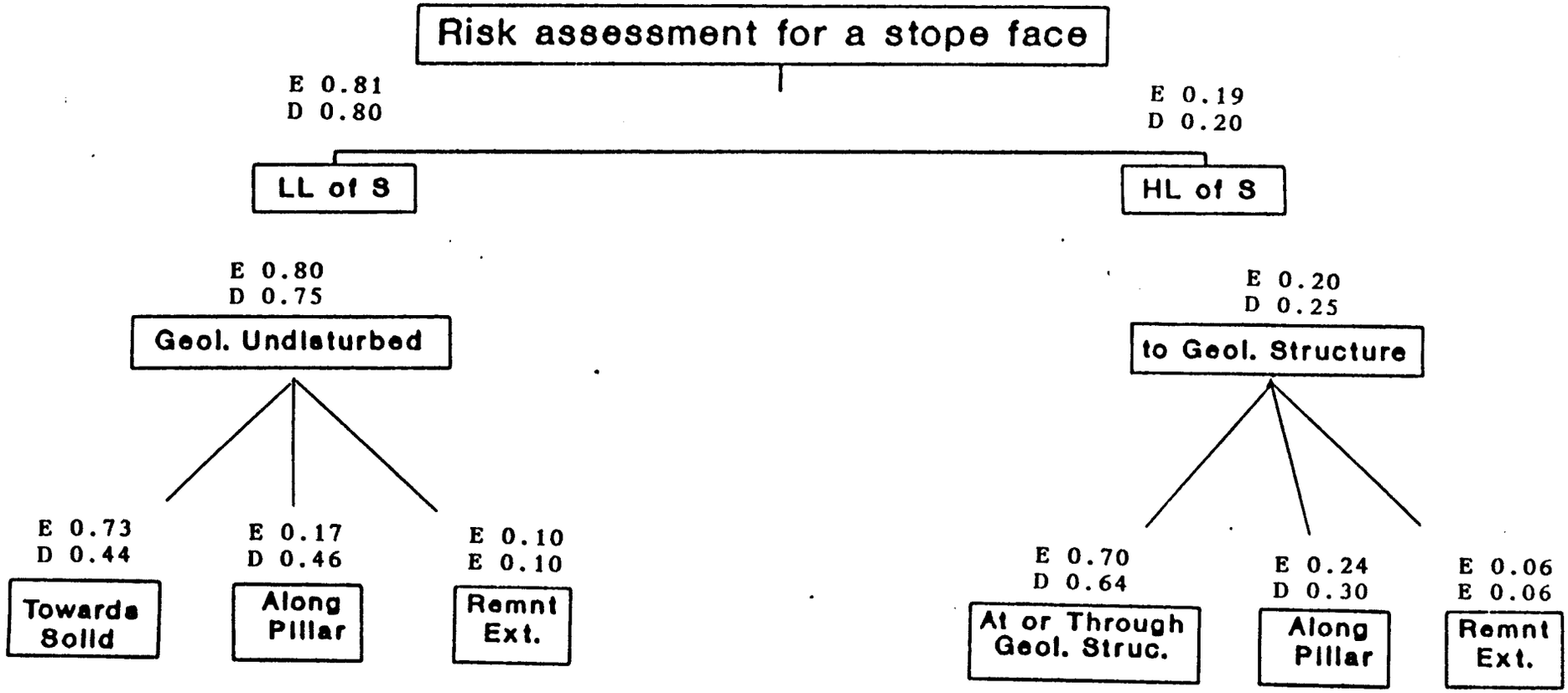

Risk assessment for a stope face
E 0.81
D 0.80
LL of S
E 0.19
D 0.20
HL of S
E 0.80
D 0.75
Geol. Undisturbed
E 0.73
D 0.44
Towards Solid
E 0.17
D 0.46
Along Pillar
E 0.10
E 0.10
Remnt Ext.
E 0.20
D 0.25
to Geol. Structure
E 0.70
D 0.64
At or Through Geol. Struc.
E 0.24
D 0.30
Along Pillar
E 0.06
E 0.06
Remnt Ext.

Figure 8

5. MODEL OF FALLS OF GROUND - NEURAL NETWORK CLASSIFIERS

The main object of this report is to develop a technique to investigate the predictability of damage occurring underground. Neural network modelling is used successfully to identify critical production parameters that control the occurrence of falls of ground in ERPM.

Mining activity can be treated as a dynamic process. The process usually has several input variables such as production quantities, and several output variables such as falls of ground. The aim of the investigation is to estimate the effects of the input variables on the output variables. Estimating the predictability of damage occurring may be approached using a classification procedure. For example, production patterns belonging to class "A" might relate to a cluster of "High Level of Damage", and production patterns belonging to class "B" might relate to a cluster of "Low Level of Damage". Many managerial decisions involve classifying an observation into one of several groups.

A neural network is composed of neurons as the processing elements. Each neuron receives input(s), processes the input(s) and delivers a single output. Key elements in a neural network are weights, which express the relative importance of each input to a processing element. A neural network can be organized in several different ways, that is the neurons can be interconnected in different ways. For clustering data, the self organizing feature map is useful.

In self organization models, the input patterns are provided, and the network organizes (trains) itself. Because it is an unsupervised type of network, all the user has to inform the network is the number of categories desired. A self organization network, also known as Kohonen (1982) network, consists of two layers: an input layer and an output layer. Each neuron in the input layer is connected to each neuron in the output layer via a variable connection weight. The patterns of "N" variables are presented to the input layer, then propagated to the output layer, which has one neuron for each of "K" possible categories. Generally, the best way to implement a classification model is to use a separate output neuron for each class.

Training is done by requiring the neuron, corresponding to the class being presented, to be highly activated, while all other neurons are required to be nearly off. The training process consists of presentation a pattern vector to the network one at a time. The winning neuron is selected by making a series of calculations after each pattern presentation. Weight adjustments are then made using a neuron neighbourhood and learning rate parameters.

A self organized map has been applied to categorize production

parameters in one section of ERPM mine. Various monthly production parameters collected over several years are input to a Kohonen map and the network is trained to recognize separate categories. The network looks at production conditions and self classifies them. Two categories were selected for self categorization in anticipation that the network would separate them naturally into low and high risk categories based only upon their production characteristics. Therefore the FOG parameters were not included in the input patterns. Data collected from ERPM mine can be presented in the following form:

PRODUCTION PARAMETERS - INPUT PARAMETERS:
-length of active stope
-length of active stope exposed to geological feature
-production [tons]

FALL OF GROUND PARAMETERS - ASSOCIATED PARAMETERS:
- FOG in panels with significant closure
- FOG in panels with scattered falls
- FOG in no panel area with significant closure
- FOG in no panel area with scattered falls
  - number of falls of ground for each type of FOG
  - linear extension of damage for each type of FOG
- delay in production [days]

Inputs are the following variables: $\Delta P/P_2, H_{ave}, H_{max}, (-\Delta L), \Delta L, L_{geol}$, where $\Delta P/P_2$ is the normalised change in production during period of one month;, H_{ave} is the calculated average rate of advance in shaft per month; H_{max} is the calculated maximal rate of advance; $(-\Delta L)$ is the monthly maximal decrease of length of stope;, ΔL is the portion of stope exposed to geological features such as dykes and faults. This example used production data that exposed the change in the rate of stope advance and the geological conditions in the stopes.

5.1 Classification of production months

The inputs were successfully classified into two different winning output neurons. Figures 9 shows two classes of production characteristics that were found with self organized maps. Class 1 marked with a "filled triangle" symbol will be called "High Risk" and Class 2 marked with an "open triangle" symbol will be called "Low Risk". Since it is difficult to show clusters in six dimensions of space using a 2D graphic, the following figures present the relation between production variables only, where a clear decision line can be seen.

Figure 9 shows the most important finding from a practical point of view, as the portion of active stope exposed to geological features and the rate of advance per month can be estimated at the beginning of the month. Three well defined regions of safety are marked by two lines. On the top of the figure is a cluster of "High Risk" that can be interpreted as following: if a section

of mine (of about 1 000 m of active stope) has 23 %-25 % of stope with dykes and faults, the mining is definitely of high risk. The bottom of the figure shows "Low Risk" clustering, which is bounded by a line indicating 16 % stope exposed to geological features and average rate of advance of 8 m/month. The area between two clear clusters has elements of high and low risk.

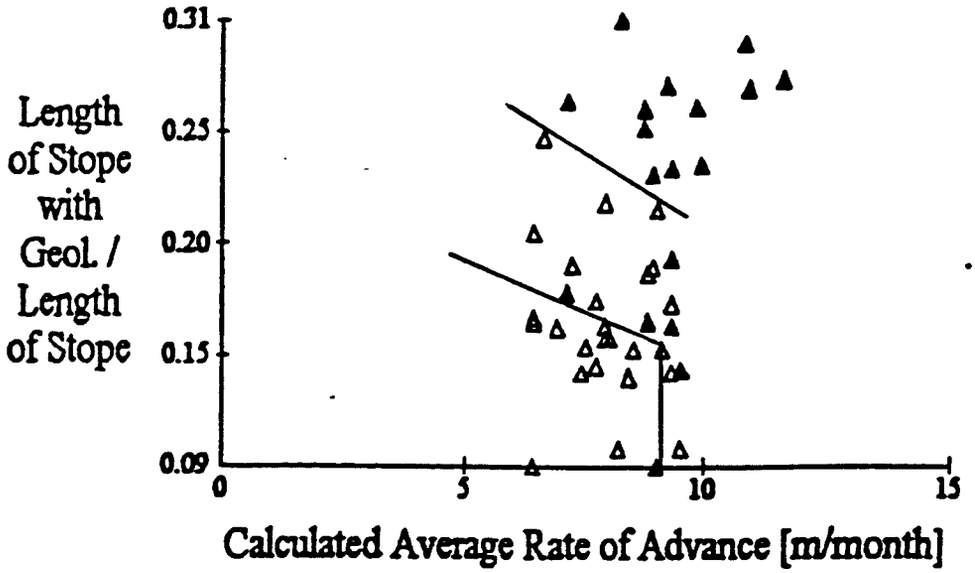


Figure 9. Length of stope with geological features over the total length of stope, L_{geol}/L, versus the calculated average rate of advance, H_{ave}= P/(L * 1,0 * 2,7)[m]. Each triangle represents a month of production.

It has to be emphasised that the calculated rate of advance is not measured directly. It is obtained from the ratio of the production [tons] to the length of stope [m], with the assumption that the height of the stope is 1 m and the density of quartzite is 2,7 g/cm^3.

5.2 Cluster of falls of ground

The next series of figures aims to show how classes of production created by a self organized map relate to falls of ground data. It is important to note that the FOG data was unseen during the process of classification of the production data.

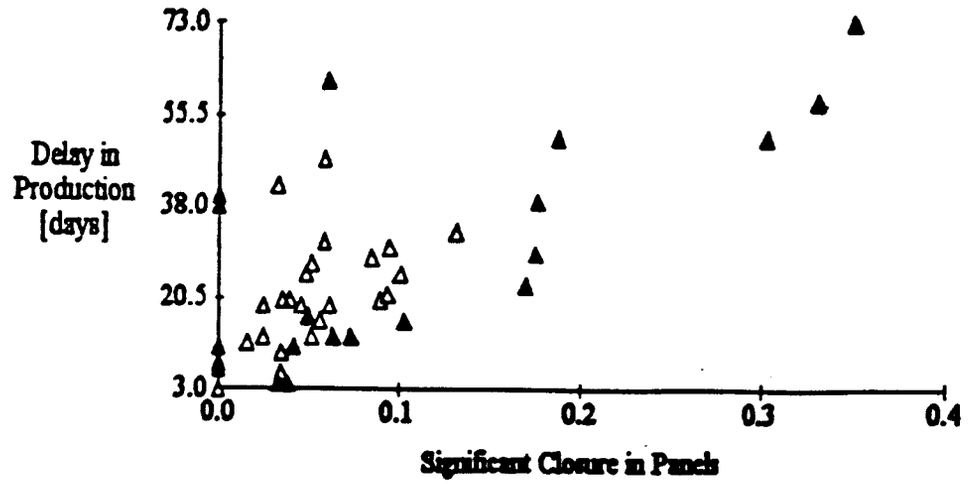


Figure 10. Delay in production versus the linear extent of damage associated with significant closure in panels divided by the total length of scopes in section, $L_{closure-panel}/L$.

Figure 10 demonstrates that the large amount of damage due to FOGs (described as a significant closure in panels) occurred during a time period when production characteristics can be classified as "High Risk". It can be concluded that, if production variables indicate "High Risk", then nearly one month out of every two (exact number 7/18) will have significant damage occurring in panels covering more than 0,15 part of an active stope (see horizontal axis Figure 10). The large delay in production in most cases relates to the "High Risk" class. A delay in production greater than 38 days occurring only in 2 cases out of 10 is classified as a "Low Risk" month.

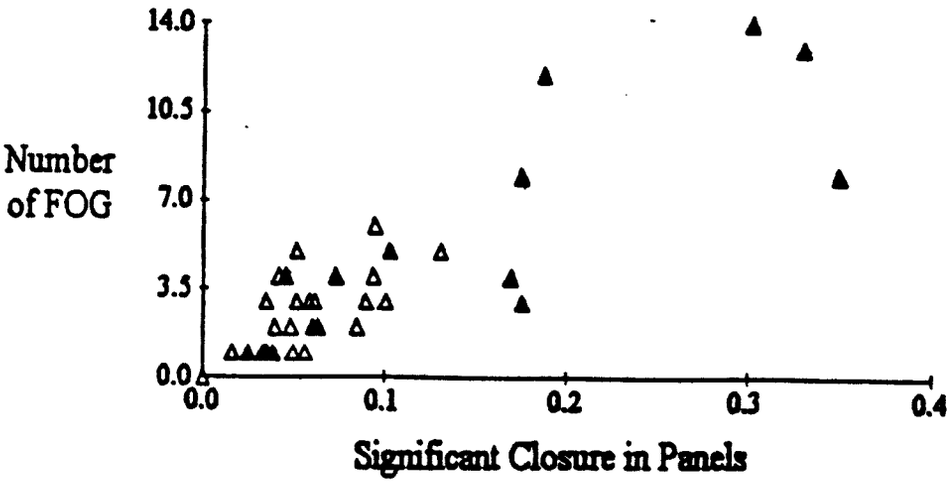


Figure 11. Number of FOGs, $No_{closure-panel}$, versus the linear extent of damage associated with significant closure in panels divided by the total length of stopes in section, $L_{closure-panel}/L$.

The monthly damage associated with significant closure in panels occurs as a series of low level damage. Figure 11 shows the strong correlation (0,87) between the number of FOGs and the linear extent of damage. A single FOG usually causes no more than 20 m of damage. Damage of 60 m can occur during months of "High Risk" and "Low Risk".

5.3 Relationship between the production variable and the FOG variable

The next series of figures shows the direct relationship between production variables and FOG data. Some of these relations are significantly strong. The network succeeded in separating production conditions into "High Risk" and "Low Risk".

Figure 12 shows significant closure in panels versus three production variables (calculated average rate of advance, calculated maximum rate of advance and length of stope with geological features). Three lines were drawn separating the cluster with "High Risk" from the rest. The area separated by those lines can be used in a decision making process.

A line is drawn on each graph to separate clusters of "High Risk" from the rest of the data. The rest of the data have months with both high and low risk. The months with significant closure in panels larger than 15 %-17 % of the total length are predicted by the self organized network as high risk from analysis of only the input production variables. A similar rule can be resolved from delay in production data versus production variables (see Figure 13).

These conclusions (rules) are drawn from the data and it can be expected that, at another site, the numerical values in the rules could vary, but the basic character of the relationship will remain unchanged.

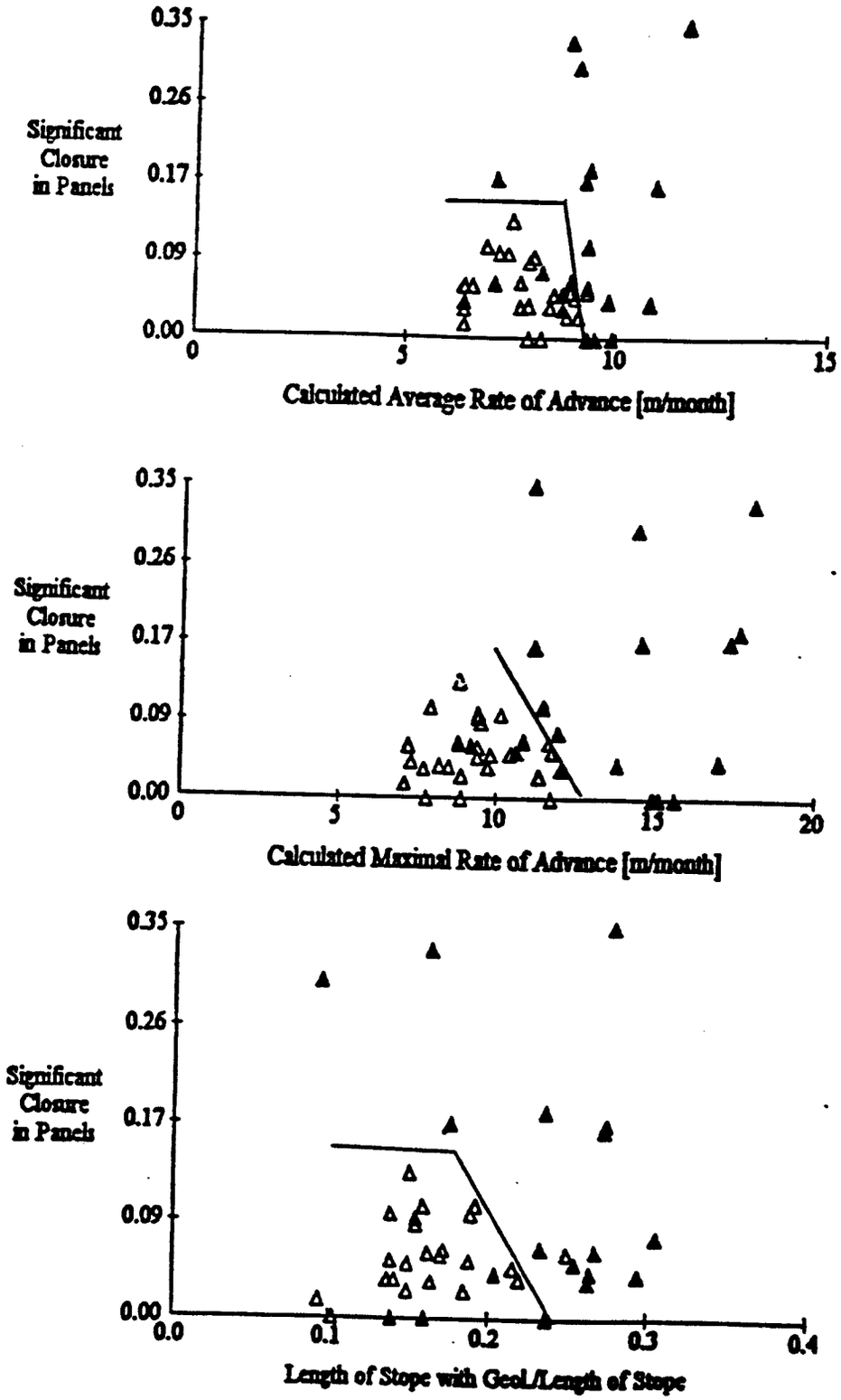


Figure 12. Significant closure in panels due to FOG versus the calculated average rate of advance (top), the calculated maximum rate of advance (middle), and the length of stope with geological features (bottom). Lines separate clusters of a high risk from the rest of the data.

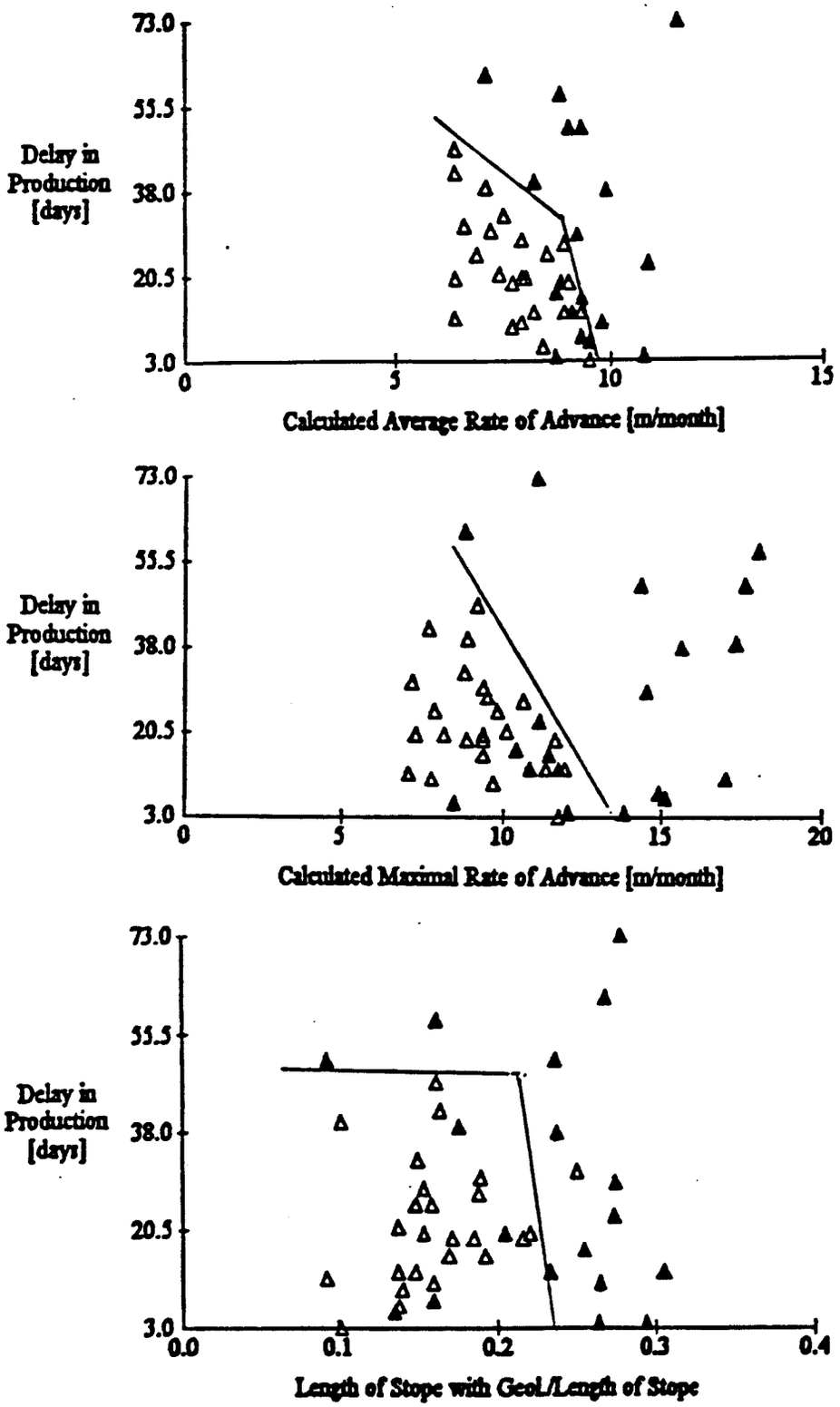


Figure 13. Delay in production due to FOG versus the calculated average rate of advance (top), the calculated maximum rate of advance (middle), and the length of stope with geological features (bottom). Lines separate clusters of a high risk from the rest of the data.

6.0 SOFTWARE DEVELOPMENT : FALLS OF GROUND DATA BASE AND QUANTIFYING RISK ASSESSMENT

This chapter describes the final version of the computer program. The primary output of the project - the working version of software has been finished. All planned components of software are working. The computer program includes most of results obtained in this project during previous years of work.

The initial work was dedicated completely to the development of the main body of computer program for the quantitative assessment of safety risk due to rockbursts and falls of ground. In the second stage the software was tested. A list of suggestions for modification and improvement to the software was obviously long. There were also a lot of suggestions to avoid misunderstanding and mistakes which the user can make while working with the software. There was however no change to the technique of data processing. This constituted the creation of a second version of the software. All changes make the software easier and more understandable by the user. Finally the software has been tested in the East Rand Proprietary Mines (ERPM) and Western Areas Gold Mine.

The project objective is to give the rock mechanic practitioner a means of assessing the safety risk under specific mining conditions. This will be achieved by supplying a computer program that performs the following tasks:

1 Data base
2 Graphical Presentation of Fall of Ground Data
3 Statistical Analysis of FOG Data
4 Decision Support Model for Risk Assessment from Expert Judgement (Rating Risk)

The program exploit a data base and employs statistical methodology and decision making techniques.

When designing this software, my challenge was to let the user quickly discover the benefit of using it. This can be accomplished by using only the most important parameters, allowing flexibility in inputing them, and the graphical representation of data. This is also why the software was written using the windows environment to achieve user friendliness.

For a user the most difficult part of program is entering the data. All calculations and plotting is done by using visual controls.

The user gets a deep insight of his data within a few seconds. In other instances he would have to compile this data from many sources which could take weeks.

Figure 14 shows the first screen which appears after loading FOG

program. In the upper left corner of screen is a group the four data base buttons (buttons 'Select Data Base', ''Close Data Base' , 'View Data Base' and 'Add New Record'). In the lower left corner is a group of three buttons which process the following modules: graphical presentation of FOG data (button 'Graph'), statistical analysis of FOG data (button 'Statistical Analysis') and decision support model for risk assessment from expert judgement (button 'Rating Risk'). After the selection of data base in the upper left corner text 'Data Not Loaded' is replaced with a name of currently used data base (eg. ERPM).

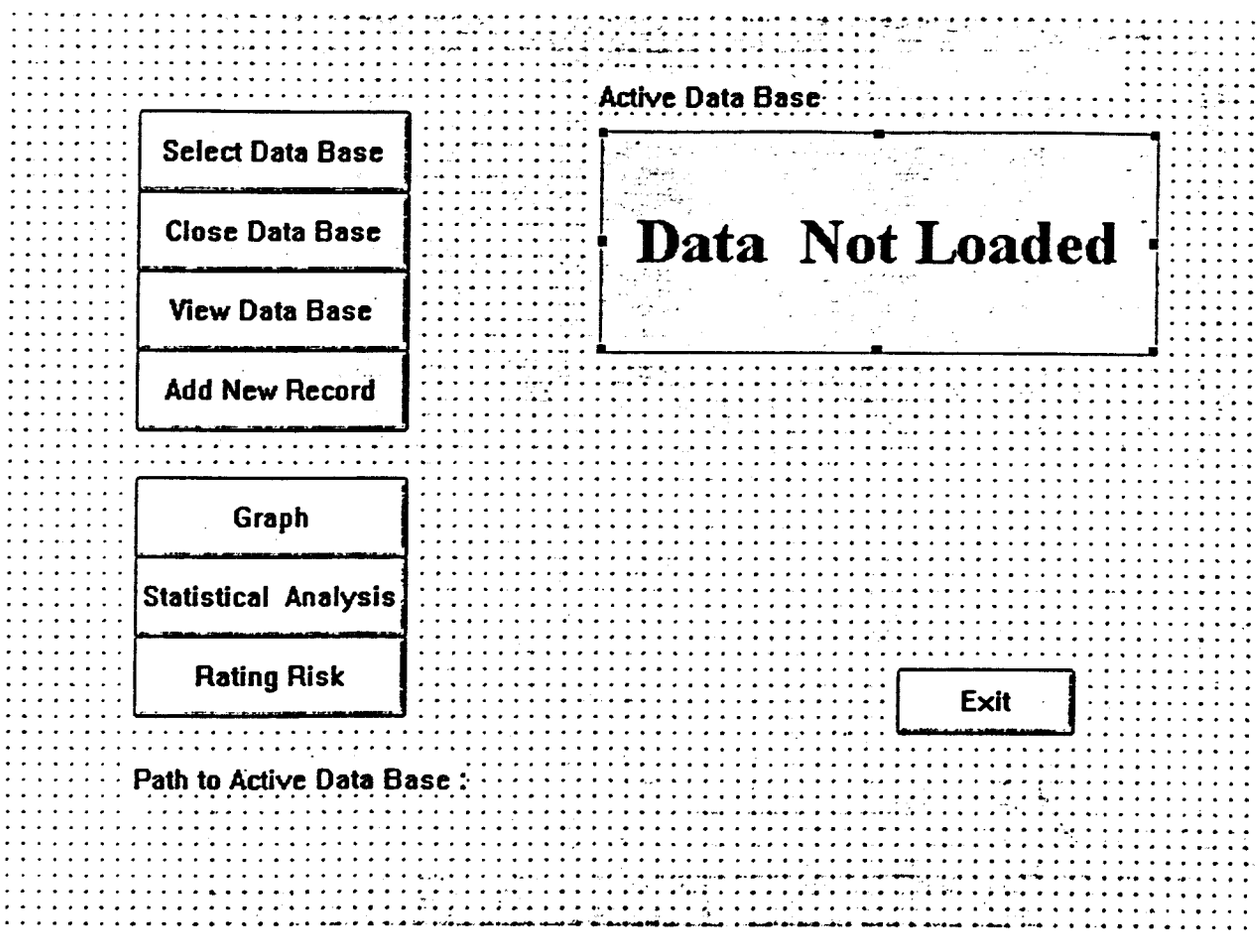


Figure 14 The first form which appearers on screen after loading FOG program. Seven buttons are used to process all major modules of program.

6.1 Data base

The program allows the user to perform the following tasks with FOG data base: select database, close database, view old FOG records and add new records(see Figure 1). Viewing is made by displays on-screen of numerical values of database in spreadsheet format. The user can modify fields in the records. The record of FOG includes information about damage, geology features, type of mining and seismic event. Providing full information is not always possible so program is able to accept partial information as well. Optimal structure of a FOG record is presented below:

Damage Information:

Data, Time, Shaft, Working Place,
Accident (options: fatalities, injuries)
Excavation (options: panel, gully, drive, others)
Damage in Panel Area (parameters: length, width, thickness)
Type of Damage (options: scattered falls,significant closure)
Damage in no Panel Area (parameter: length)
Type of Damage (options: scattered falls, significant closure)

Geology/Mining Information:

Presence of Geological Feature (options: yes, no)
Mining Geological Structure (options: obliquely, unfavourable)
Type of Mining in a presence of geological features (options: away from geological structure, towards geological structure, remnant extraction, at or through geological structure, along pillar)
Type of mining in geologically undisturbed area (options: toward solid, remnant extraction, along pillar)
Production Parameters per Panel(production per month [tons], length of active panel [m],Rate of advance [m/month]

Seismic Information:

Is FOG associated with seismic event?
(options: yes, no, not known)
If FOG is caused by seismic event user is requested to enter the following parameters (magnitude, distance between FOG and event [m], seismic energy [KJ], seismic moment [GNm], stress drop [MPa])

6.2 Graphical Presentation of FOG Data

The objective is to display, on screen, a plot of any two parameters of series of FOG. User can select vertical or horizontal axis the following parameters : date, delay in

production, fatality, injuries, damage in panel area (length, width, thickness), extent of damage in no panel area, production [tons], panel length, rate of advance, seismic source parameters (magnitude of seismic event, distance between seismic source and FOG, seismic energy, seismic moment and stress drop). If the selected information is not available in data base - a record is simply ignored. Program does not produce an error message.

5.3 Statistical Analysis of FOG Data

This module provides reliability analysis to the FOG group. Extended study of application reliability techniques to FOG was done in report GAP112, 1995. Module 'Statistical Analysis' is the computer implementation of previous study.

Firstly, the user has to select a subset of FOG data by selecting a set of parameters (see Figure 15). The user has to enter the interval of time, shaft, working places, total length of active stope in selected working places, excavation (options: all data, panels, others), geological structure (option: all data, panel without geological structures, panels with geological structures), type of damage (options: all data,scattered falls, significant closure).

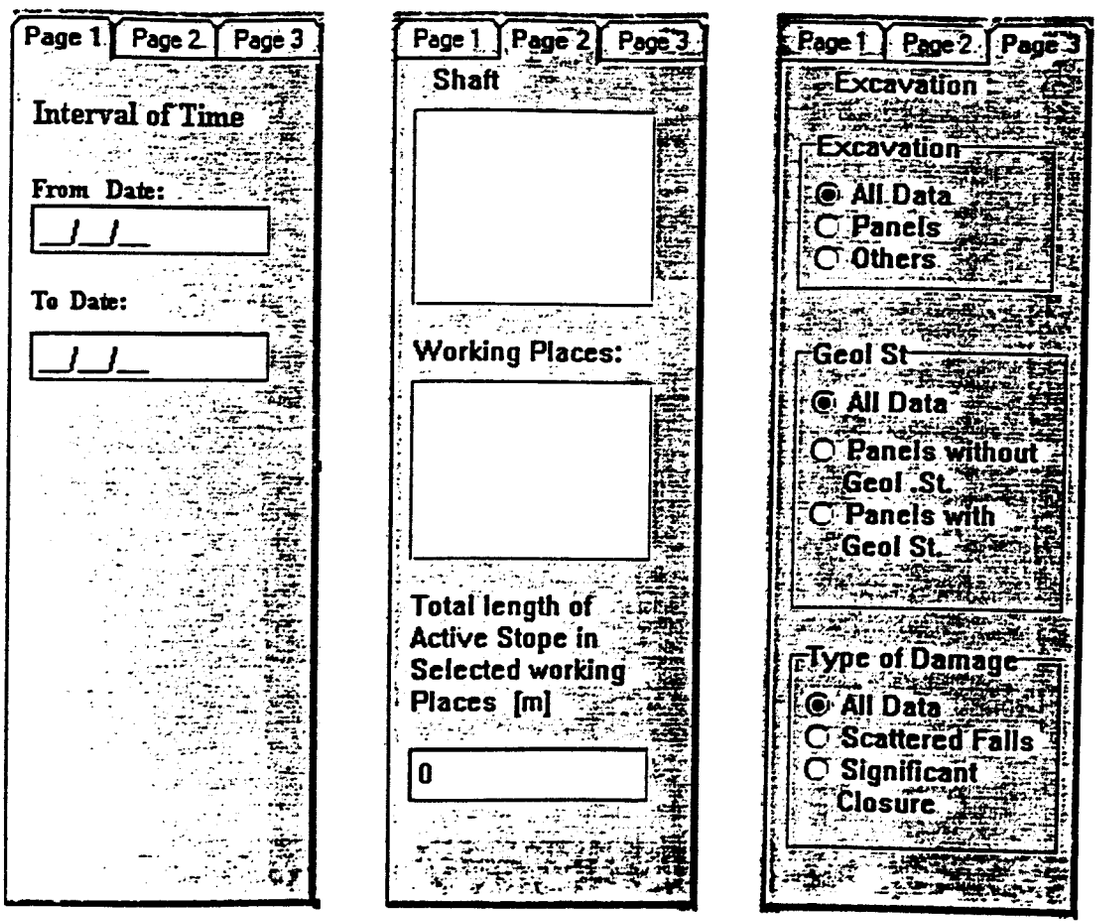


Figure 15 Options for selection of subset in data base.

Task 1: Risk analysis

For the selected subset of the data base the following three parameters can be calculated: mean time to FOG, mean time to fatality and mean time to injury.

The mean time between failures (e.g FOG, fatality or injury) is estimated by the total measured operating time divided by the total number of failures. The mean time to failure is expressed in the following units: 30 m of active stope and 30 days

The graphic tool displays the probability that the active stope will fail - it means that one of the following event will occur: FOG, fatality or injury - during a specified time. The graph displays in the result window in upper right corner of screen (press bottom 'Process'). The graphics tool allows user to print result (press bottom 'Printer').

Task 2: Risk Analysis for series of panels.

User can calculate mean time between FOG for series of panels in the work place with different number of panels with and without geological structure.

Task 3: Availability of the repair panel.

Since panels can be repaired, a measure of system success that allows for repair and renewed operation is needed. Availability is defined as the probability that a panel will be available when required.

Task 4: Frequency Statistic.

This presents graphs with the number of FOG versus linear extent of damage, the number of accidents (injuries and fatalities) versus linear extent of damage and production loss versus length of damage.The frequency statistic is one of the most important sets of information which characterize a group of events. It is able to precisely indicate what is a typical extent of damage and how this damage relates to accidents.

6.4 Decision Support Model for Risk Assessment from Expert Judgement (Rating Risk)

This module allows user to calculate the relative risk at a selected site and compare this with synthesized expert opinion. The analytic hierarchy process is used to structure the decision support model. The analytic hierarchy process organizes the complex problem into its smaller parts. The seismic, geological and mining features are the prominent attributes of the risk forecasting. Detail study of this subject was presented in report GAP112, 1994. 'Rating Risk' module is the computer implementation of the previous study (see Figure 16). User can select either

expert rating or a rating of his own preferences (see Figure 16).

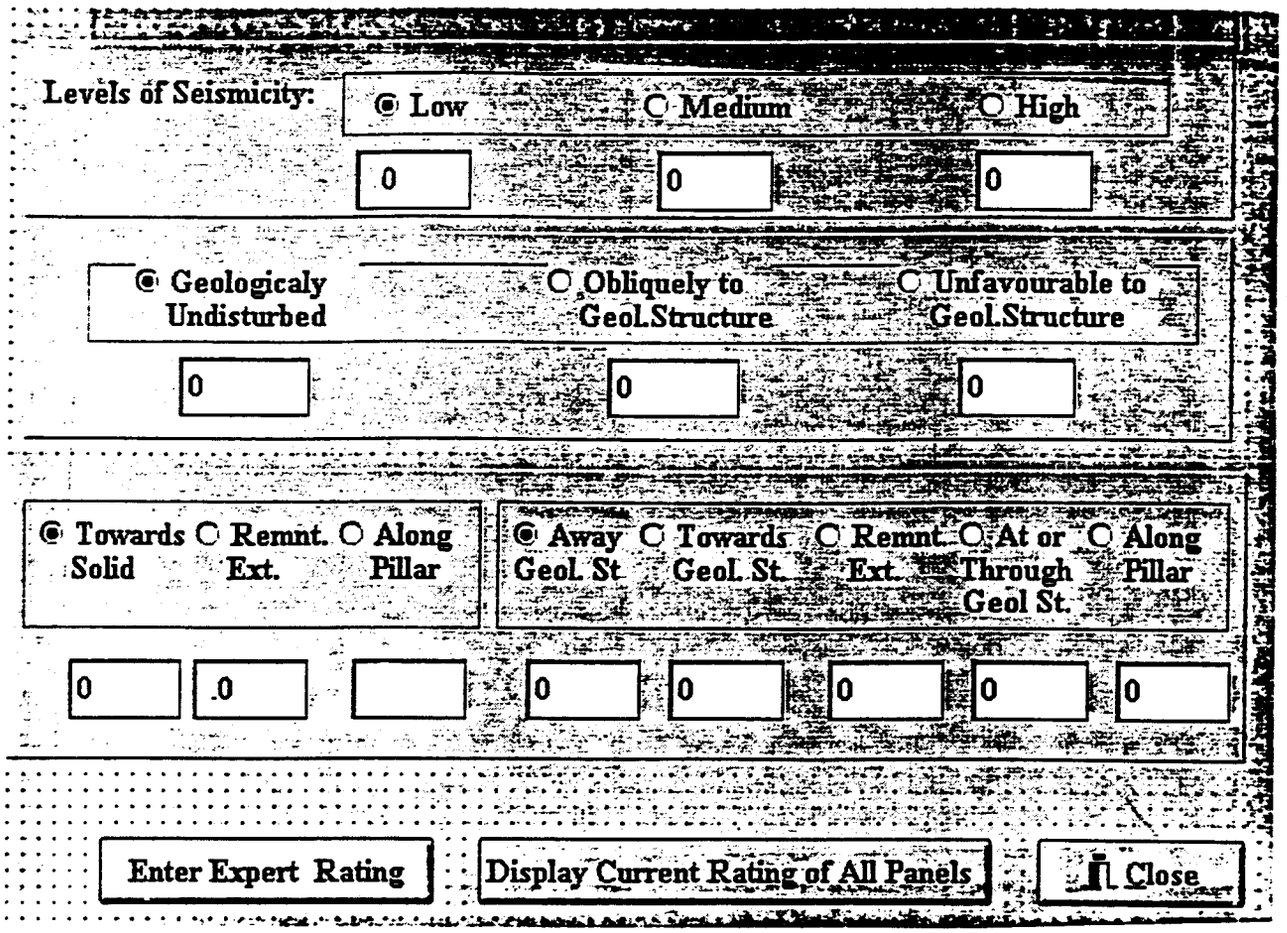


Figure 16. Rating risk. Structuring of hierarchy for risk assessment:
- **Level of seismicity (options: low, medium, high)**
- **Geologically Undisturbed**
  - **Type of Mining**
    (options: towards solid, remnant extraction, along pillar)
- **Presence of Geological Structure (options: mining obliquely to geological structures, unfavourable to geological structures)**
  - **Type of Mining**
    (options: away from geological structure, towards geological structure, remnant extraction, at or through geological structure, along pillar).

Figure 17 displays the rating of panels using recommendations of a group of experts. Group of experts proposed following values of weights (see Figure 16)

levels of seismicity: 70, 23, 7,
geological features: 67, 25, 8
types of mining : 73, 10, 17, 48, 13, 6, 9, 24

User can modify some values of weights. Figure 17 shows as well an example of the panels rating obtained using the following

weights for geological features : 75, 20, 5. Comparison of these two lists shows how changes in value of weights effect rating risk of panels.

No	Risk Class	Rating	Seismicity	Geological Structure	Mining
1	A	100.00	Low;	Geol. Undisturbed;	Towards Solid
2	A	32.90	Moderate;	Geol. Undisturbed;	Towards Solid
3	A	24.50	Low;	Obliquely to Geol.St.;	Away from Geol. St.
4	A	23.30	Low;	Geol. Undisturbed;	Along Pillar
5	A	13.70	Low;	Geol. Undisturbed;	Remnt Ext.
6	A	12.30	Low;	Obliquely to Geol.St. ;	Along Pillar
7	A	10.00	High;	Geol. Undisturbed;	Towards Solid
8	B	8.06	Moderate;	Obliquely to Geol.St.;	Away from Geol. St.
9	B	7.85	Low;	Unfavourable to Geol.St.;	Away from Geol. St.
10	B	7.65	Moderate;	Geol. Undisturbed;	Along Pillar
11	B	6.64	Low;	Obliquely to Geol.St.;	Towards Geol. St.
12	B	4.60	Low;	Obliquely to Geol.St.;	At or Through Geol. St.
13	B	4.50	Moderate;	Geol. Undisturbed;	Remnt.Ext.
14	B	4.03	Moderate;	Obliquely to Geol.St. ;	Along Pillar
15	B	3.93	Low;	Unfavourable to Geol.St.;	Along Pillar
16	B	3.07	Low;	Obliquely to Geol.St.;	Remnt.Ext.
17	B	2.58	Moderate;	Unfavourable to Geol.St.;	Away from Geol. St.
18	B	2.45	High;	Obliquely to Geol.St.;	Away from Geol. St.
19	B	2.33	High;	Geol. Undisturbed;	Along Pillar
20	B	2.18	Moderate;	Obliquely to Geol.St.;	Towards Geol. St.
21	B	2.13	Low;	Unfavourable to Geol.St.;	Towards Geol. St.
22	B	1.51	Moderate;	Obliquely to Geol.St.;	At or Through Geol. St.
23	B	1.47	Low;	Unfavourable to Geol.St.;	At or Through Geol. St.
24	B	1.37	High;	Geol. Undisturbed;	Remnt.Ext.
25	B	1.29	Moderate;	Unfavourable to Geol.St. ;	Along Pillar
26	B	1.23	High;	Obliquely to Geol.St.;	Along Pillar
27	B	1.01	Moderate;	Obliquely to Geol.St.;	Remnt.Ext.
28	C	0.98	Low;	Unfavourable to Geol.St.;	Remnt.Ext.
29	C	0.79	High;	Unfavourable to Geol.St.;	Away from Geol. St.
30	C	0.70	Moderate;	Unfavourable to Geol.St.;	Towards Geol. St.
31	C	0.66	High;	Obliquely to Geol.St.;	Towards Geol. St.
32	C	0.48	Moderate;	Unfavourable to Geol.St.;	At or Through Geol. St.
33	C	0.46	High;	Obliquely to Geol.St.;	At or Through Geol. St.
34	C	0.39	High;	Unfavourable to Geol.St.;	Along Pillar
35	C	0.32	Moderate;	Unfavourable to Geol.St.;	Remnt.Ext.
36	C	0.31	High;	Obliquely to Geol.St.;	Remnt.Ext.
37	C	0.21	High;	Unfavourable to Geol.St.;	Towards Geol. St.
38	D	0.10	High;	Unfavourable to Geol.St.;	Remnt.Ext.

No	Risk Class	Rating	Seismicity	Geological Structure	Mining
1	A	100.00	Low;	Geol. Undisturbed;	Towards Solid
2	A	32.90	Moderate;	Geol. Undisturbed;	Towards Solid
3	A	23.30	Low;	Geol. Undisturbed;	Along Pillar
4	A	17.50	Low;	Obliquely to Geol.St.;	Away from Geol. St.
5	A	13.70	Low;	Geol. Undisturbed;	Remnt Ext.
6	A	10.00	High;	Geol. Undisturbed;	Towards Solid
7	B	8.77	Low;	Obliquely to Geol.St. ;	Along Pillar
8	B	7.65	Moderate;	Geol. Undisturbed;	Along Pillar
9	B	5.76	Moderate;	Obliquely to Geol.St.;	Away from Geol. St.
10	B	4.75	Low;	Obliquely to Geol.St.;	Towards Geol. St.
11	B	4.50	Moderate;	Geol. Undisturbed;	Remnt.Ext.
12	B	4.38	Low;	Unfavourable to Geol.St.;	Away from Geol. St.
13	B	3.29	Low;	Obliquely to Geol.St.;	At or Through Geol. St.
14	B	2.88	Moderate;	Obliquely to Geol.St. ;	Along Pillar
15	B	2.33	High;	Geol. Undisturbed;	Along Pillar
16	B	2.19	Low;	Unfavourable to Geol.St.;	Along Pillar
17	B	2.19	Low;	Obliquely to Geol.St.;	Remnt.Ext.
18	B	1.75	High;	Obliquely to Geol.St.;	Away from Geol. St.
19	B	1.56	Moderate;	Obliquely to Geol.St.;	Towards Geol. St.
20	B	1.44	Moderate;	Unfavourable to Geol.St.;	Away from Geol. St.
21	B	1.37	High;	Geol. Undisturbed;	Remnt.Ext.
22	B	1.19	Low;	Unfavourable to Geol.St.;	Towards Geol. St.
23	B	1.08	Moderate;	Obliquely to Geol.St.;	At or Through Geol. St.
24	C	0.88	High;	Obliquely to Geol.St.;	Along Pillar
25	C	0.82	Low;	Unfavourable to Geol.St.;	At or Through Geol. St.
26	C	0.72	Moderate;	Unfavourable to Geol.St. ;	Along Pillar
27	C	0.72	Moderate;	Obliquely to Geol.St.;	Remnt.Ext.
28	C	0.55	Low;	Unfavourable to Geol.St.;	Remnt.Ext.
29	C	0.47	High;	Obliquely to Geol.St.;	Towards Geol. St.
30	C	0.44	High;	Unfavourable to Geol.St.;	Away from Geol. St.
31	C	0.39	Moderate;	Unfavourable to Geol.St.;	Towards Geol. St.
32	C	0.33	High;	Obliquely to Geol.St.;	At or Through Geol. St.
33	C	0.27	Moderate;	Unfavourable to Geol.St.;	At or Through Geol. St.
34	C	0.22	High;	Unfavourable to Geol.St.;	Along Pillar
35	C	0.22	High;	Obliquely to Geol.St.;	Remnt.Ext.
36	C	0.18	Moderate;	Unfavourable to Geol.St.;	Remnt.Ext.
37	C	0.12	High;	Unfavourable to Geol.St.;	Towards Geol. St.
38	D	0.05	High;	Unfavourable to Geol.St.;	Remnt.Ext.

Figure 17. Upper list shows rating of risk in panels proposed by group of experts. Bottom list shows rating of risk in panels with modification in respect to weights of geological features.

7. Conclusion and Recommendation

Damaging seismic events in East Rand Proprietary Mines

The first part of this report concerns seismic events that cause falls of ground. This study shows that damage is not only controlled by the magnitude and distance between a seismic source and panel but also by seismic stress drop and site effect.

Statistical Analysis of falls of ground

Statistical analysis of falls of ground shows that panels with no geological features represent a more stable system than panels with geological features.

Large number of falls of ground in panels with no geological features have about 10 m of linear extension of damage. Panels with geological features have typically 30 m length associated with falls of ground. Panels with no geological features represent a more stable system than panels with geological features. The average number of FOG of the first and second groups are 0.59 and 1.82 respectively.

Using FOG data it became possible to introduce:
- measurement of risk by estimation of mean time to falls of ground in stope with arbitrary numbers of panels with geological features and panels without geological features.
- measurement of availability of stope with arbitrary numbers of panels with geological features and panels without geological features.

Decision support model for risk assessment

This report had shown how the AHP can be used to synthesize expert judgments in order to forecast the risk of occurrence of damage associated with rockbursts in a panel. The results obtained from the AHP analysis provide the priority structure and weighting factors for the assessment of the risk of a stope face.

Firstly, weighting factors of the decomposed problem are estimated at all levels, namely: seismicity, geological, mining and regional support. The quantified ratings of all factors in separation give a significant insight because they highlight the factors which have the greatest impact on the overall risk.

Despite the fact that the data forces a significant simplification of expert hierarchy, the agreement between the expert's opinion and the data is remarkable. This suggests, that in a case where the data are not available the expert's opinion organized in a form of Analytic Hierarchy Process can be used.

Neural network classifiers

Neural network modelling was used successfully to identify the critical production parameters that control the occurrence of falls of ground. It was established that production months with the highest rate of stope advance and a high number of panels with geological features are associated with the highest risk of falls of ground with significant closure in panel area. These production variables, however, have no profound influence on the scattered falls.

The issue of prediction is one of the most basic learning tasks. In this report, prediction is viewed as a form of model building. To build a model of the FOG, the neural network requires learning from the production data. The self organized network serves as a model of the FOG process that is controlled by production parameters. Kohonen's network is appropriate for an estimation of the FOG parameters because the various items of production can be encoded as an input vector.

The production and FOG examples selected for the training must be distributed over the class being represented. They should include patterns that, though clearly belonging to the identified class, are somewhat borderline, having attributes that place them near another class. We suggest that production and FOG patterns have to be selected from area with both the extensive damage as well very low damage to learn attributes of both areas.

As this project develop, it became evident that the self organized map does a better job of classification than most common used back propagation network.

Software development

The computer program for the quantitative assessment of the safety risk has been developed. The software was tested in the East Rand Proprietary Mines and Western Areas Gold mine. The program has been developed in the Windows environment to achieve user friendliness. The program has well developed graphics. The program exploits a database and employs statistical methodology and decision making techniques.

Mr Andy Brown, Rock Engineering Manager reviewed the computer program with specific attention to applicability of output to rock engineers and mine managements. His comment was "... I feel that this model could be applied by the rock mechanic engineers as a tool for hazard identification and risk association for planning purposes only. The assistance with regard to this planning could be effected on a monthly, quarterly and annually basis - not a day to day basis. This model should only be used as a tool for guidance and not for absolute decision making...."

Expected Benefits:

- The user will be able to visually inspect his own data
- The user will be able to compare his own data with that from other mines
- The user will have access to expert opinion

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APPENDIX A

Table A1

Level 1 History of seismicity levels in the past.
HL of S = High level of seismicity or precursor to event is observed (e.g. seismic quiescence, foreshock, large stress drop)
ML of S = Moderate level of seismicity or lack of information
LL od S = Low level of seismicity

Seismicity: The description of earthquakes with respect to space, time, and size. Seismicity within a specific source zone or region is usually quantified in terms of a Guternberg-Richter relationship (EEERI Committee on Seismic Risk,1984)

Level 2 Geological Features
Geological Undisturbed = Stope face is more than 30m away from geological feature
Obliquely to Geological Structure = The orientation of panels is not parallel to geological structure. Hazardous Geological structure is approached as obliquely as possible, more than 30 degree angle from parallel.
Unfavourable to Geological Structure = Unfavourable face advance direction. Stope face alignment is parallel to the general faulting.

Level 3 For Geologically Undisturbed
Towards Solid = Overall mining direction towards solid
Remnant Extraction = Final extraction against solid abutments, pillar of width of 20m and 40m, shaft pillar
Along Pillar = Stope face is next to stabilizing pillar

Level 3 For Geological Structure
Away from Geological Structure = Mining is away from geological structure
Towards Geological Structure = Mining is towards geological structure
Remnant Extraction = Final extraction against solid abutments, pillar of width of 20m and 40m, shaft pillar
At or Through Geological Structure = Negotiation of geological discontinuity. Several techniques used to negotiate geological discontinuity are analysed in separate hierarchy-3.
Along Pillar = Stope face/panel is next to stabilizing pillar

Level 4 Regional Support and Backfill
Pillar only = Stope protected by stabilizing pillar
Backfill only = Stope/panels protected by backfill
Pillar and Backfill = Hybrid system involving a combination of pillar and backfill
No Regional Support = no pillars , no backfill , unprotected stope