# EXPERT SYSTEMS APPLICATIONS IN POWERED SELF-ADVANCING SUPPORT SELECTION

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ABSTRACT

Rule-based expert system shells are demonstrated to be useful in assisting mining engineers in the selection of mining equipment for a given set of mining and geological conditions. This application, utilizing a commercial shell system, is concerned with self-advancing hydraulic supports in longwall mining systems and illustrates how a small expert system may be implemented. A hypothetical case study is presented to show how the system works.

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## 1. INTRODUCTION

One of the distinctive features of modem underground coal mining systems is the increasing involvement of heavy duty mining equipment, particularly powered, self-advancing supports. In a longwall mining system, powered supports often account for two thirds of the capital investment Carefull selection of the correct powered supports is a prerequisite to the successful application of mechanised longwall mining technology. Correct determination of the supports will result in:

a) a better working environment
b) higher productivity due to decrease in suspension time
c) lower operating costs.

The incorrect determination of the supports may cause severe economic loss ( less service life and/or low utilization efficiency) and troubles in their operation, however the selection of supports is not a simple task since;

1) various kinds of mining machines have been designed and manufactured to accommodate widely differing mining conditions and selecting the proper machines for the specified conditions and environment is thus often time consuming and complex.
2) mining conditions and environment have the characteristics that they cannot be readily described or modelled in classic mathematical language.
3) considerable uncertainty exists in the assumed mining/geological conditions
4) the relevant knowledge or theory of mining strata control is not yet completely developed.

Thus, if the task of selecting a piece of equipment is given to different group of mining engineers, who have been working in different mining conditions and consequently have different experience, different answers are likely to be produced.

## 2. EXPERT SYSTEMS

Expert systems are advanced computer programmes which aim to solve problems that, until recently, were considered inappropriate for computerisation. Such systems are called expert' because they tend to utilise knowledge, or expertise, rather than standard data in their operation and appear to have a certain amount of intelligence. In the area of technical project assessment these systems have been suggested as a means to improve the objectivity of complex, technically based decision making.

Potential benefits of expert systems include:

1) The overall level of expertise is improved .within an organisation. Such systems free experience staff from low-level problems, which are time consuming but still require their attention, to concentrate on complex,high-level problems that have direct economic bearing on operations.
2) The expertise of many people can be contained within one system and thus a consultancy service is effectively available at minimal cost once the system is developed.
3) Expertise is retained within the expert system and thus does not disappear when staff leave, retire or go on holiday. Especially important considering the projected shortage of technical staff in the near future.
4) As expertise is rapidly available and accessible to junior staff (if required) training costs can be reduced significantly due to self-training.
5) Speed of operation is improved considerably.
6) Consistent answers are produced time after time.
7) Usually require minimal, or no, computer literacy from operators.
8) Can handle uncertain or missing information with few problems.
9) Can handle complex interaction problems.
10) Can be developed quickly. Useful prototype systems can typically be operational within 6 months of initiation and performance can then be improved rapidly.

The birth of expert systems has greatly changed the impression that computers passivel work with a well-defined algorithmic approach which is effective in processing numeric da but manipulate symbolic information poorly. Since the first practical expert system, DENDRAL, appeared in 1965, the theory and tools of expert systems have been well developed. Today many papers and books can be readily found to discuss expert systems (Harman & King, 1985).

## 3. EXPERT SYSTEM SHELL (EXPERTECH XI PLUS)

The expert system application developed by the authors to assist in powered support selection is implemented on an IBM PC compatible using an expert system shell from iixpertech (Xi Plus) Summarized m Figure 1 are three mam components in an Xi Plus expert system application:

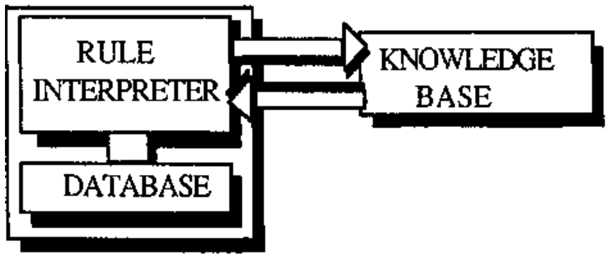


Figure 1 Main Components of an Expert System

An inference engine provides facilities for backward-chaining (goal driven), forward-chaining (data-driven) and mixed forward- and backward- chaining. Xi Plus is capable of dealing with probability, uncertainty or impression. This capability will be significantly enhanced when its ability to interface with external programs and data is utilized.

A database holds the current status when consulting a knowledge base. Xi Plus maintains this, holding a record of information entered and conclusions reached in the current session.

A knowledge base consisting of five main elements (see Figure 2)

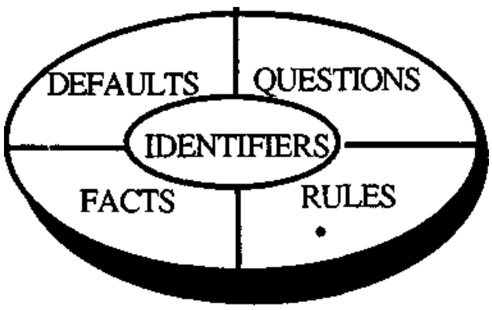


Figure 2 Knowledge Base

1) Identifiers: Names of entities which are given values.
2) Facts: Statements which are true und \ all conditions.
3) Rules: Expressing the essential knowledge of the subject Most Xi Plus rules take the classic if .... **then**. . . . form.
4) Questions' A means of obtaining information from the user.
5) Defaults: Values used in the absence of other information.

Consulting facilities built in to Xi Plus provide a powerful tool for querying how and why to obtain the answers. This consulting system is shown in Figure 3.

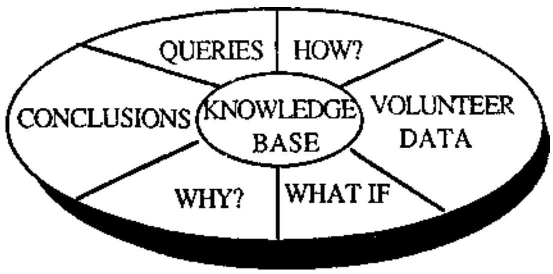


Figure 3 Consultant System

## 4. POWERED ROOF SUPPORT SELECTION

A hydraulic powered support consists of four main components: canopy, caving shield, hydraulic legs or props, and base plate. According to the way in which the components are interrelated, a support may fall into one of three basic types: chocks, shields and chock shields. Each type of support is designed to cater for certain roof types. However, common parameters include:

(1) Type.
(2) Number of props.
(3) Supporting height: maximum (extended)
minirnum(closed)
(4) Applicable gradient.
(5) Supporting resistance: setting load
yield load

(6) Centers distance
(7) Beam dimensions: length
width
(8) Supporting area.
(9) Ratio of roof contact.
(10) Sustainable maximum unit area pressure from roof.

When the type of support is determined, the supporting height range and supporting distance range are decisive parameters. Type of support and supporting resistance range re in turn dependent upon roof type.

## 1.1. Roof Classification

In gently inclined seams roof formations are customarily divided into immediate roof and main roof according to the severity of disturbance caused*by the excavation of the coal seam. Movements of the immediate roof and main roof have different effects on roof control at the longwall face:

The immediate roof is the key to roof control. This application classifies the immediate roof into three kinds:

1 ) Unstable roof (fragmentary roof) such as strength-low shale roof, coal roof and reproduced roof in slicing seam,.
2) Moderately stable roof, such as a sandy shale roof.
3) The main roof directly lies upon the coal seam. This kind of roof is strong enough to hang on a large scale, without caving.

The behaviour of the main roof has an important influence on face ground pressure, such as the cyclic pressure on supports. The roof classification system to be used in this project divides the main roof into five types as follows:

1) No or insignificant periodic weighting from the main roof exists. The essential feature of the roof formation is that the thickness of the immediate roof is more than 4 times that of the seam thickness.
2) Periodic weighting exists. The immediate roof is about 2~4 times as thick as the coal seam. A strong main roof then lies above the immediate roof.

3) Periodic weighting is severe. The main roof is directly above the coal seam,however sometimes, there is a thin false roof between the coal seam and the main roof.
4) The immediate roof is extremely strong and thick. Caving methods are barely applicable.
5) The roof bends plastically to form a safe working space. No artificial supports are normally needed. The roof in this case is composed of limestones and/or sandstones with well-formed joints, fissure and cracks.

## 4.2.Determination of Type of Support

### 4.2.1. Chocks

Chocks are mainly used for a roof with a high degree of competency. The existence of relatively severe periodic weighting is favourable to chocks stability. If the ground pressure in the broken roof is from above the face conveyor, chocks will lose their stability.If the roof is extremely hard and caved on a large scale, then chock supports with high yielding load and good longitudinal stability and good at inducing caving should be considered. If the roof is not very hard and the seam noticeably varies in thickness and dip, or in slicing mining faces, relatively small and light chocks with comparatively low yielding load are recommended.

### 4.2.2. Shields

Shields work well with a broken roof since they mainly withstand pressure from above the conveyors. Periodical pressure resulting from the main roof does not exist or can be ignored if it does. Shields provide a smaller working space than chocks.

### 4.2.3. Chock-shields

As the name indicates, they are based upon both chocks and shields, and possess the advantages of both them. They are advisable for a strong and fairly stable roof which is somewhat easily fragmented into medium size pieces. Periodical pressure originated from the main roof should not be excessive.

## 4.3. Determination of Support Resistance

**The resistance of the powered support is the key parameter that controls the support characteristics and die structural strength of the support. The yielding load should meet the maximum roof pressure and roof rock compression strength.**

**The determination** of support resistance is **based on one** of **the following criterion:**

1) **to prevent** excessive **convergence** of C^v **roof during** the supporting cycle, but **having a minimum** value to **induce** cav uı. it the rear edge of the support
2) to prevent **any** bed separation over **the** fact, -ea whatsoever

**The popular estimation method of the yielding** load is **the bulk factor** estimation method **which is derived from investigation into the strata movement, roof and floor behaviours and interactions between the roof, the support and the floor in faces with similar working conditions. The formula is (Peng & Chiang, 1984):**

$$p = r \quad Ih - S / n \qquad (1)$$

where p = vWd'ng load of each Lj: uf tlu < • j poi *o be used to withstand the roof
r = w.i'f v *Ivv* w tight *ut* il ' ks ir fwmg zone
S = i T". 'ITI'IPI ı>n yol ' » *\K ' t ᴾ support
n = numbei of legs ot a suppoıt uru
X,h = height of the caving zone(estimated):

The height of the caving zone, is estimated by (Peng & Chu'ng, 1984):

$$\mathbf{Ih = (H-d)/(k-l)} \qquad (2)$$

**where H = mining height**
**d = sagging of the lowest uncaved strata, no greater than do maximum allowable sagging without breaking,**
**k = bulking factor ranging from 1.2 to 1.8.**

**Using k=1.2 ~ 1.5 and d = 0, we obtain £h = (2~5)-H. If** a **safety factor 2 is considered, then Ih = (4~10)-H.**

## 4.4. Determination of Height of Support

The height of the support can be determined by the mining height and its potential variations. The maximum and minimum supporting heights can be estimated (Peng & Chiang, 1984):

$$Hmx = Mmx - S1 + K \quad (3)$$

$$Hmn = Mmn - S2 - a - K \quad (4)$$

where Mmx= upper limit of the mining height;

S1 = roof convergence at the point of front leg with reference to faceline

Mmn= lower limit of the mining height;

S2= roof convergence at the point of rear leg with reference to faceline;

a= flexible height needed when advancing (about 50 mm);

K= preparatory height in case that the mining height goes out the limits.

SI and S2 can be obtained by underground observations, or estimated in formulas:

$$S1 = a \cdot Mmx \cdot L1 \quad (5)$$

$$S2 = a \cdot Mmn \cdot L2 \quad (6)$$

where a= coefficient associated with roof condition, normally 0.05;

L1= minimum distance from faceline to front legs of the support,

L2= maximum distance from faceline to rear legs of the support.

## 5. SYSTEM IMPLEMENTATION

In the previous section, the knowledge of how to choose a proper support has been reviewed, this constituting the kernel part of the knowledge base of the expert system. For a complete system, however, a database is needed to hold the specifications of the supports. Although ten parameters are previously given, only five of them will be examined in the selection process;

1) supporting capacity
2) supporting height
3) applicable gradient
4) supporting area
5) roof contact ratio.

As an experimental study, nine supports were used to form the database to test the system. Normally within Xi plus there are two ways to encode them without external programs interfacing. One way is to represent them as facts. For example, a chock's features can be described as follows:

FACT ch_l_yield_load = 70
FACT ch_l_gradient = 25
FACT ch_l_max_height = 3.8
FACT ch_l_min_height =2.1
FACT ch_l_supporting_area = 12.5
FACT ch_l_contact_ratio = 75%

The other way is to represent them as rules. If the above facts are expressed as rules, they would be:

IF chock support is chock_l
THENyield_load = 70
AND gradient = 25
AND maxjieight = 3.8
AND minjieight = 2.1
AND supporting_area = 12.5
AND contact_ratio = 75%

Here we treat them as rules.

A support is chosen based on roof type, supporting capacity and supporting height, each of which is again dependent upon many other factors. The initial items include:

About coal seam: Thickness including maximum and minimum,
seam variability,
seam gradient
About roof: Stability (ease of caving),
degree of joints development,
thickness and bulking factor of the immediate roof,
stability of the main roof,
rock density.

Before the search for solution starts, these items must be given values in either explicit or implicit forms. For example, roof type is specified as type 1, this implies that the immediate roof is present, roof formation is definately composed of soft rocks and hard rocks and thickness of the main roof and rock bulking factors are not needed. As can be expected, values for some items can only be qualitative.The utilization of qualitative expression naturally requires a grading scheme. The example is with periodic weighting generated by movement of the main roof, the usei ought to have die opportunity to answer the question on severity with any selection from the menu.

Significant,
Moderate,
Low,
Unknown.

After a problem (or a task) is presented to the program, the program begins to seek the solution and ask the user questions.The expert system mimics the human thought process. The procedure that a mining engineer may use to choose a support is:

1) From the given conditions, he calculates the technical parameter values that the suport to be decided should satisfy,
2) Based upon the parameters, or more likely, a limited subset of them, he considers and eliminates each support type in turn until he is left with a single solution or list of possible solutions.
3) When two or more solutions are available, he compares mem on economic grounds to decide one that has the least cost.
4) However, in engineering, particularly mining engineering, associated calculations are often not very accurate due to the imprecision of the relevant information, therefore one principle is that two solutions are taken to be approximately the same if they have a difference of less than 5% or 10%.
5) If two or more solutions are obtained, technical comparison is again used to decide which one has technical advantages. If no solution appears, he either redefines his initial requirements or makes a compromise based on his past experience.

This application system, following the above route, sorts the list of possible supports with respect to the initial requirements. Then the program selects the one that best matches with die requirements. In most applications the deciding factors will be the cost and/or availability of the supports, but where this is not the case, the system will present the possible solutions to die user.The result from the expert system can of course take two other forms, either no solution or a single solution. The most satisfactory result is the single solution. The problem of no solution is the most difficult to address, the user has to compromise. In this system at this stage, the approach is to redefine the initial requirements.

The final version should be able to identify the most demanding conditions and make a compromise.

## 6. EXAMPLE

An example is now presented to demonstrate some features of the system. The mining conditions in this example are:

| | |
|---|---|
| Gradient | 22°; |
| Seam Thickness | 1.8 - 2.5 with mean of 2.1 meters; |
| Immediate Roof | 2 meter thick shale with good completeness and few joints, |
| Next Stratum | 4 meter thick sandy shale |
| Next Stratum | 2.5 metre well-fissured limestone. |

When the system starts searching for a solution, questions will be automatically asked to gain information following the order shown in Figure 4.The system first identifies the mam roof type and the immediate roof kind to determine type of support. After the roof pressure to be sustained is estimated, a support is chosen. If the roof pressure is too high for the support, then another one is chosen. When all the supports are examined and no one satisfies the roof pressure requirement, then the system reports a solution cannot be found and the selection is finished. If, however, there is one suitable, then the supporting height range is calculated. Similarly the support height requirements are examined to see whether the loaded support is feasible or not. If feasible, then seam gradient condition is inspected. If satisfied again, then this type of support is feasible/ In the database of the system, three types of support for each of chock, shield and chock-shield are held as listed in Table 1. The result for this example is chock-shield type 3.

Table 1 Database of 9 supports

| | Yield Load (tons/prop) | Height Range (m) | Gradient (°) | Props |
|---|---|---|---|---|
| Chock Support | 170 | 2.1-5.0 | 30 | 4 |
| | 60 | 1.3 - 2.5 | 25 | 4 |
| | 100 | 1.7-3.2 | 20 | 4 |
| Shield Support | 150 | 1.4-2.5 | 20 | 4 |
| | 80 | 1.6-2.7 | 18 | 4 |
| | 40 | 2.0-3.7 | 15 | 4 |
| Chock-Support Support | 120 | 1.7 - 3.5 | 22 | 4 |
| | 100 | 1.0-2 0 | 25 | 4 |
| | 70 | 1.4-2 8 | 30 | 4 |

## 7. DISCUSSION AND CONCLUSIONS

Support selection is one important aspect of mine design and planning. To date, the automatic computerisation of this task has received little attention. This may be because the relevant knowledge is not yet completely formed, particularly of ground strata mechanics. In many cases, rule of thrumb and accepted practices are still widely used. Thus subjective judgement is inescapablely involved. In order to avoid personal bias and to make full use of available human expertise, an expert system would seem to offer a sensible route to computer-aided selection.

This expert system application is relatively elementary, however it **has** proved very useful in assisting die mining engineer in selecting and evaluating **self-advancing supports.** When this system is incorporated into an operation simulation system, **a complete set of** computer systems of longwall mining evaluation will be formedin this **work, the factors** under consideration in many cases lack adequency in data, and their **influences are often** judged in linguistic terms, instead of the mathematical language in which **present day digital** computers understand and process. In summary, this system has **about 100 rules. The** structure of the system guarantees the system is friendly and accessible **even to the users** who are not familiar with the technical aspects of the system.

As stated previously, two pieces of important work concerning **conflicting solutions are not** yet solved:

(a) determination of the most appropriate selection when **no solution is obtainable.**
(b) assessment of technical preference when two or **more solutions are found.**

Further work on this expert system is concentrating on:

(1) knowledge refinement, including installation **of more expertise**
(2) reasoning process improvement,concerning inexact **reasoning and indefinite knowledge representation.**

## REFERENCES


BODKIN K. E., Expert System for Colliery Problems, Collery Guardian, Vol.236 No7, 1988

BROWN D. J. & SINGH R. N.. ' An Expert System for Slope Stability Assessment, Part I', International Journal of Surface Mining, Vol.1, No.2, December 1987.

DENBY, B., Intelligent Computer Systems in Surface Mine Design and Planning, Nottingham University Mining Department Magazine, 1987

DENBY B. & ATKINSON T., ' Expert System Applications in the Mining Industry', Mining Engineer, May 1988

FAUCONNIER C. J. & KERSTON R. W. O. 'Increased Underground Extraction of Coal', The South African of Mining and Metallurgy', Johannesburg 1982

GHOSH A., HARPALANI S. & DAEMEN J. J. K., Expert System for Coal Mine Roof Bolt Design, 28th US Symposium on Rock Mechanics, Univ. of Arizona, Tucson, 1987

GUO W., 'Computer Aided Scheduling of Underground Mining Production', Ph.D. Thesis, University of Nottingham, 1989

HARMON P. & KING D., Expert Systems: Artificial Intelligence in Business, John Wiley & Sons, New York, 1985

PENG S. S. & CHIANG H. S., Longwall Mining, John Wiley & Sons, New York, 1984

ROSENMAN M. A. GERO J. S., HUTCHINSON P. J. & OXMAN R. 'Expert Systems Applications in Computer-aided Design', Computer-aided Design, Vol.18, N0.10, December 1986

SANTA CRUZ C. & KOHLERJ.L. 'Expert system for failure diagostic improvement in mining equipment', 20th APCOM.USA 1988

WOLD M. B., A Blocking Physical model of Longwall Caving Under Strong Roof Conditions, 26th US Symposium on Rock Mechanics, Vol.2, Rapid City, 1985