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# A Knowledge-Based Expert System for Managing Underground Coal Mines in the U.S.

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**Abstract**—Research by the U.S. Bureau of Mines (BOM) on the reasons why some mines are more productive than others has revealed the importance of good mine management practices. The Mine Management Support System is being developed, under the cosponsorship of the BOM and the West Virginia Energy and Water Research Center, as a knowledge-based expert system for better management of underground coal mines. Concentrating on capturing the complex body of knowledge needed to enhance efficient management of a mine, it will encompass information and preferred rules on work scheduling, work practices, regulations impinging on the accomplishment of work, responses to operating problems, and the labor-management work agreement. Different components of the mine system, modeled using an object-oriented layering technique, will be displayed graphically to aid in coordinating work plans, and to present locations of equipment, supplies, and proposed subsystem components.

## I. INTRODUCTION

### A. Operating Environment

A MINE manager's primary responsibility is to manage the productive output of men and machines the most cost-effective way subject to a host of constraints. The ideal way to do this is through complete automation. There exists, however, many constraints that impede the level of automation, as well as truly optimal mine performance. The constraints can be categorized into the following general areas:

- 1) reliability and availability,
- 2) changeable and hazardous conditions,
- 3) regulations and work agreements,
- 4) isolation,
- 5) design limitations, and
- 6) self-imposed limitations.

The reliability and availability of the production equipment,

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the workforce, and the support systems of a mine have a large impact on mine performance. Varying, often hazardous, conditions of roof, rib, and floor, methane and water influx, confined work space, and poor man-machine interfaces also have an important impact on productivity and cost. For some types of extraction with a continuous mining machine, varying and hazardous conditions are an anticipated part of the mining cycle. The coal mining industry is one of the most regulated industries in this country. Considering the impact of federal and state mining laws alone, the realization comes that there is a tremendous amount of restriction on operations and a vast amount of knowledge about rules that the manager must master. Add to this the requirements of adhering to provisions of the UMW-BCOA National Coal Wage Agreement or other work assignment policies that may exist in nonunion mines and the managerial tasks grow considerably more complicated.

Isolation is a problem unique to mining. Not only are mining complexes often located in remote areas of the country, but underground operations often progress far from the managerial control center on the surface. Communications and logistics can be real problems.

In the mining industry, operations are also limited by characteristics of the reserve in planning for the use of technology. Truly new technology is generally slow in progressing, with incremental development of existing technology dominating design considerations.

Self-imposed constraints exist in both tradition and philosophy. Mine operators use traditional mining methods to extract the reserve, traditional labor classifications to schedule work, and often follow long established practices in getting work done. Operators also generally follow long established philosophies regarding labor relations, the investment of capital, and the degree of managerial control exerted at different organizational levels.

The ultimate goal of the industry is nevertheless to *control* the mining process such that it virtually becomes a *process flow* system with few interruptions and negligible health and safety problems. In light of the massive constraints, accomplishment of this goal will be difficult; still, progress is being made.

### B. State of Computerization

No large-scale integrated mine monitoring/MIS/expert system applications have yet been developed for the coal mining

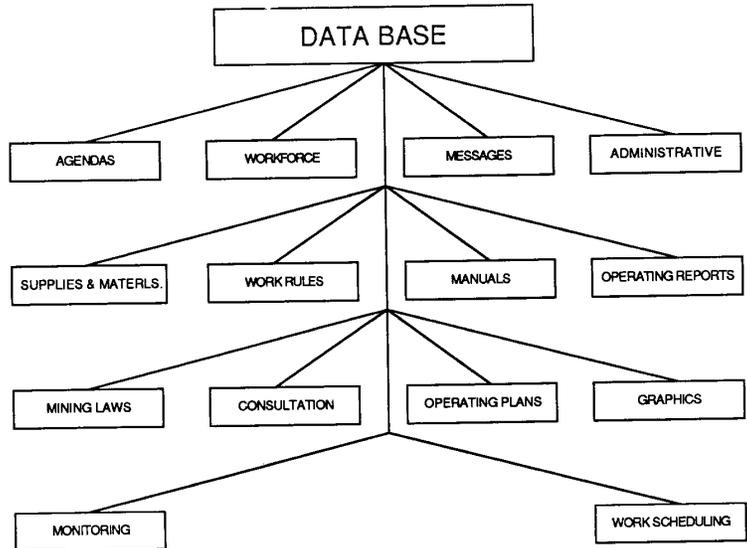


Fig. 1. Knowledge base requirements.

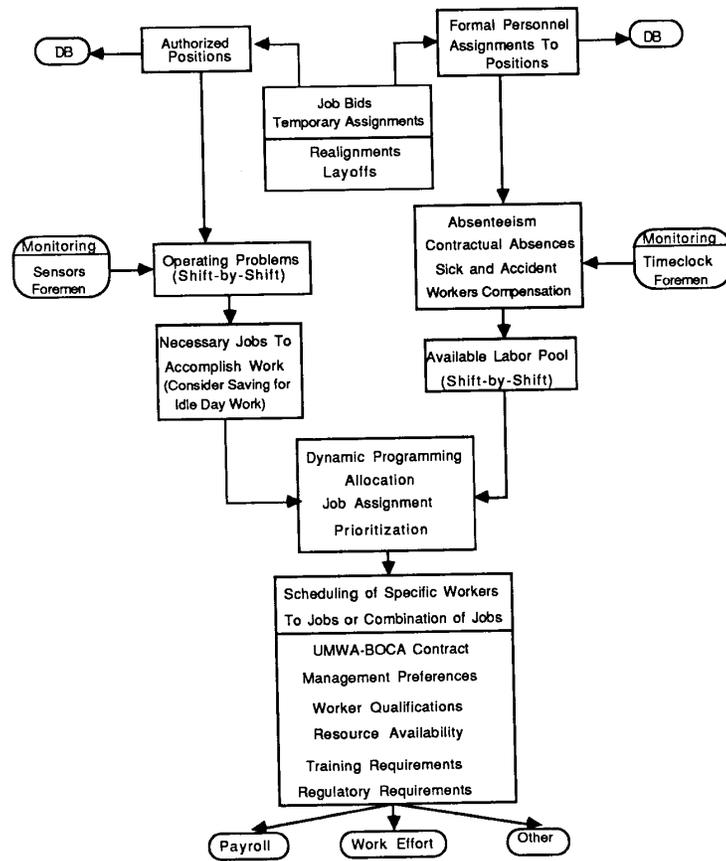


Fig. 2. Schematic of interactions in mining work assignments.

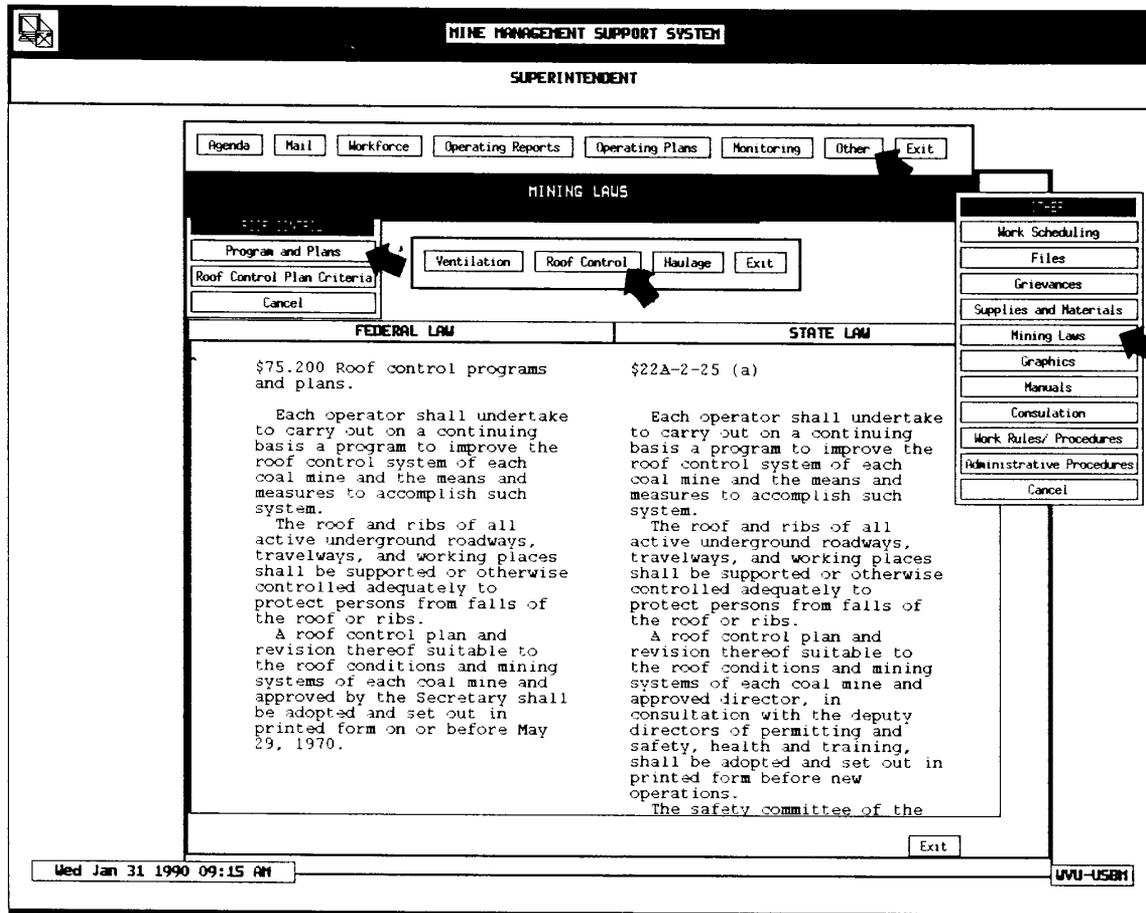


Fig. 3. Conceptualization of user interface with deeply nested windows.

industry [1]. The state of computerization can best be delineated by focusing on the applications in the separate areas.

1) *Mine Monitoring Systems*: Although the benefits of mine monitoring systems are being publicized widely now, less than 100 of them are used in the more than 1700 underground coal mines in the U.S. [2]. However, if ventilation rule changes proposed by the Mine Safety and Health Administration (MSHA) are approved, then the use of atmospheric monitoring systems (AMS) should grow rapidly. Approval would lead to the elimination of the costly petitions for modification that are required and that constitute the greatest deterrent to growth at present. A recently formed IEEE Industry Applications Society committee is currently working on the formulation of an AMS recommended-practice standard to help operators formulate specifications for and install such systems.

2) *Computers and Software*: From a recent survey [3], almost two-thirds of the coal mines in the U.S., both surface and underground, use some type of computer. All of the operators of mines producing more than 500 000 net tons per year who responded to the survey use computers. Significantly, 53% of the small mines producing between 10 000 and 50 000 net tons per year also use computers. However, soft-

ware applications are primarily oriented toward data processing, with maximum use in payroll, accounting, and reporting. The next highest use of software is in reserve analysis, mine planning, surveying, and mapping. Sophistication in applications is lacking, especially in technical areas, but the potential is great now that computers essentially pervade the industry.

3) *Automation*: The ultimate goal is automation of mining systems and subsystems. Automation is becoming a reality in some areas, in various stages of development. These areas include conveyor belts [4], highwall mining [5], longwall mining [6], continuous mining [7], [8], and truck dispatching [9].

The industry has not nearly reached the process flow state that is realized in preparation plants, but great progress is being made. The impact of environmental conditions, high reliability of hardware, and better software are aspects yet to be conquered before full automation is achieved.

4) *Expert Systems*: More effective control of the use of manpower and other resources is an area that could reap great benefits in improving mining efficiency, productivity, and safety. Toward this goal, *control*, the development of knowledge-based expert systems, coupled with increasing use of mine monitoring systems, is encouraging. Expert systems for improving foreman performance [10], machine perform-

**MINE MANAGEMENT SUPPORT SYSTEM**

CLERK

**MINE PERSONNEL FILE**

**MINE PERSONNEL RECORD**

Type:

LAST:

FIRST:

MIDDLE:

BIRTHDAY:  -  -

SSN:

AREA CODE:

PHONE:

STREET:

CITY:

STATE:

ZIP CODE:

START DATE:  -  -

**MINE PERSONNEL FILE**

001	Grayson	Larry	R011747193220	41296686008R	1, Box 605
002	Matts	Michael	C0622582005928384127259576418		Walnut St.
003	Moody	Michael	R9 1 702397345893042967867138		Huffman St.
005	Shiquan	Yuan	1009542304567793042327957223		Euclid Ave
006	Venkateshwar	Varada	042166234992223042960342569		A Clark St.
007	Bavis	Michael	C0622582005928384127259576418		Grant Ave.
008	Adler	Larry	R0217501894033823049668600637		Noam St.
009	Reddy	Nagendra	0103572208933063042932918450		Medical Center Rd. #B 2
010	Alan	Sue	J0219591855500033042934000Hallerk		Rd

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Fig. 4. Screen dump of existing user interface.

ance [11], [12], and the benefit from mine monitoring systems [13] are being pursued. These expert system approaches to assisting mine management will provide diagnostic, anticipatory, and consultative responses to operational situations and problems, rather than continue the reactive approach which characterizes the traditional response mode in the industry.

## II. OBJECTIVES OF MMSS

To provide mine managers with a valuable tool to assist decisionmaking in an operational environment, many objectives have been formulated for development of the mine management support system (MMSS). They are summarized as follows.

- 1) Build a knowledge base to encompass the information demands of mine supervisors at various levels in the mine organization.
- 2) Develop a rule-based system to prioritize supervisor agendas, work scheduling for an operational shift, and delivery of supplies and materials in response to operating contingencies.
- 3) Develop a consultation system that can be invoked by employees, with proper access, to obtain timely information or instructions on important policies, procedures, mining laws, and operating plans for better response to operating problems.

4) Tie summary output from a mine monitoring system into the data base for dynamic warning of adverse conditions in the mine atmosphere or equipment, including the generation of messages to key personnel and reprioritization of work to eliminate the conditions.

5) Develop extensive graphics capabilities to display objects mine-wide using a layering technique for subsystems [10].

6) Develop a simple to use but secure user access system.

7) Develop the system such that it is incrementally implementable.

8) Co-develop the system with management from modern progressive longwall mining complexes to ensure its practicality and usefulness.

## III. MMSS CONCEPTUAL DESIGN

It is important today that industrial managers get more powerful tools that can enhance their competitiveness in a world economy. To this end, MMSS is being developed as both a planning and an operational tool. The literature shows that most operationally oriented expert systems have been too site specific to be of great benefit for the intended industry [14]. MMSS will be specifically designed to avoid this pitfall, but it will allow individual mine operators to build necessary site specific information into the knowledge base. The philosophy

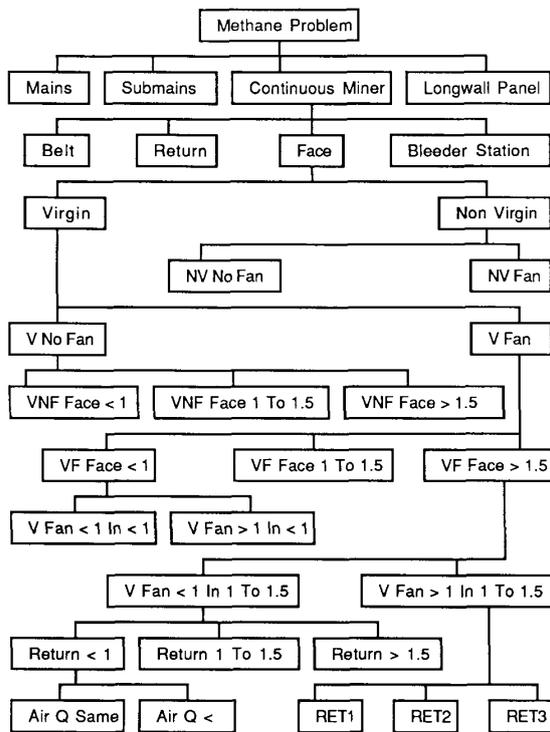


Fig. 5. Example problem in consultation mode.

used in developing the model will focus on using updated information to construct accurate and timely responses to dynamic state changes within a mine, much like the approach espoused in ISIS [15] for job shop scheduling. Each of the components will be discussed next in the context of design issues and requirements.

#### A. Knowledge Base

Fig. 1 depicts the extent of knowledge that will be required for a comprehensive operational application. Each block in the diagram, of course, contains many components—that is, data, objects, rules, and algorithms. An example showing more detail is illustrated in Fig. 2. Different types of knowledge and methods of representing the knowledge exist. In the work scheduling module, for example, files containing general information on personnel, days scheduled off, job requirements for a shift, and the workers who have actually checked in for work can be utilized through efficient application of relational data base techniques. As another example, in the consultation module, the need to obtain information from the user, provide advice on solving problems, and provide explanations whenever the user does not understand the reasoning for advice requires the use of frames linked together in a network structure. Lastly, the icons in the graphics module are best represented as instances of generic objects contained in frames that are linked in an inverted tree structure. This gives the capability of displaying different parts of the graphics knowledge base at different instances and of superimposing one layer upon another.

#### B. User Interface

Nested windows containing successively linked menus that can be accessed by the user appear to be the best interface. Simple indication of preference using a mouse (or other pointing method) affords a clear interaction. The X Window System [16] has been selected to effect the user interface for MMSS. It is a software that is virtually device independent and provides great flexibility in developing interfaces in applications. The conceptualization of a deeply nested user interface is shown in Fig. 3. A screen dump of an existing interface for accessing files for update is shown in Fig. 4.

#### C. Expert System Components

In the consultation and work scheduling modules, for example, an expert system approach to problem solving will be needed. Interprocess communications coding will link the X Window System to the LASER/RPS inference engine [17], a C-based production system the intellectual precursors of which are OPS5 and LOOPS.

Software has been coded to allow the MMSS system user to build any specific expert system rule tree application for an X Window interface using predefined LASER/RPS frames. It allows for easy browsing of the rule tree with functionality provided to chain forward or backward through the tree as well as being able to start over and exit at any rule during a consultation session. Three types of frames may be built: top level rule, nonterminal rule, and terminal rule frames. An example consultation problem is diagrammed in Fig. 5, and an example manifestation of a nonterminal frame is shown in Fig. 6.

#### D. Accessing External Programs

Mine operators use many different software tools in daily business—for example, spreadsheets, word processors, data base tools, mine ventilation programs, and manpower planning programs. It is important that data generated by such programs be integrated into the MMSS knowledge base and that the tools themselves may be accessible by MMSS when updated data are required. The initial work in this area includes interfacing with a mine monitoring system to accept atmospheric warning messages or alarm conditions. Also the results from a manpower planning spreadsheet application will be imported into MMSS for update of the personnel-job file, which is needed in the job scheduling component.

#### IV. SUMMARY

The underground coal mining industry is locked in very keen worldwide competition for both domestic and foreign markets. A decade-long emphasis on the reduction of mining costs, manifested through better safety and productivity performances, has led to the demand for more powerful mine management tools. The operating environment is very constrained, both physically and nonphysically.

The use of computers in the coal industry has burgeoned lately, and mine operators are overcoming the traditional ways of managing their mines. Mine monitoring systems and man-

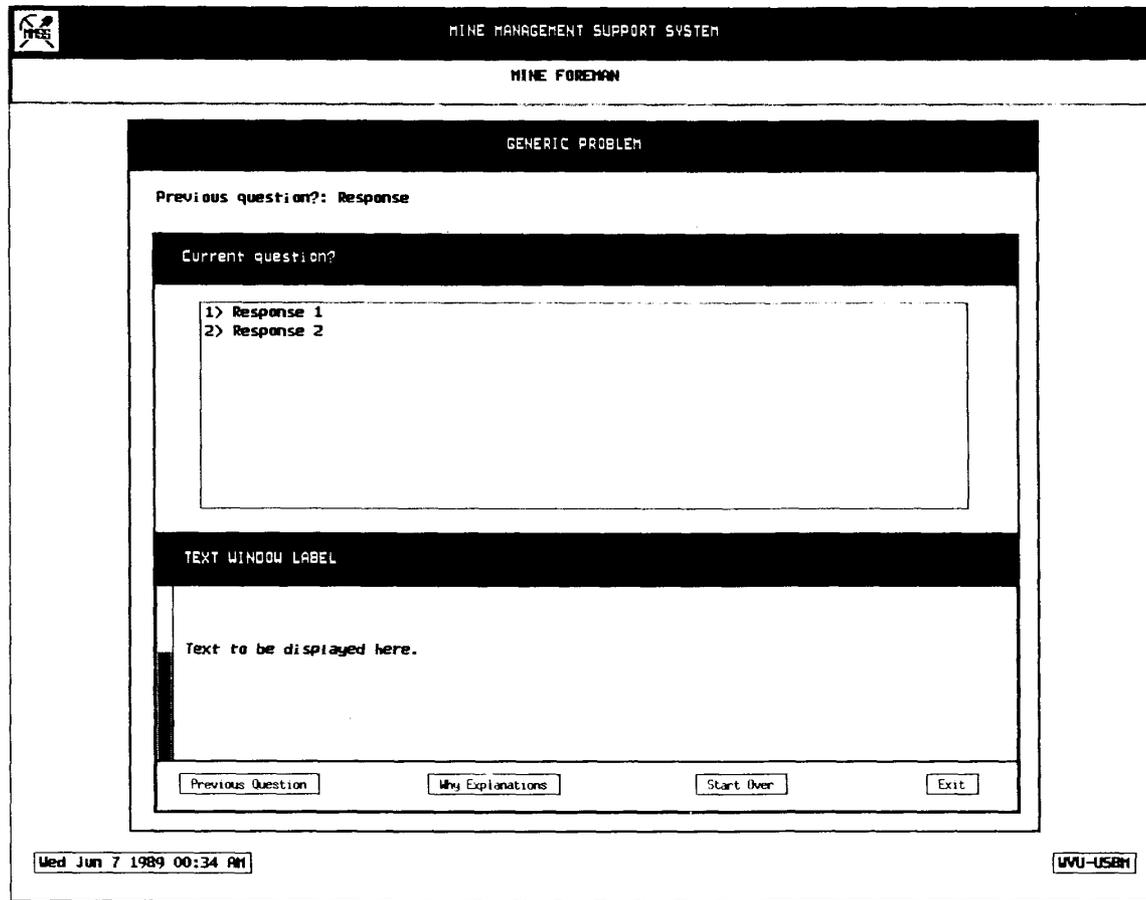


Fig. 6. Example manifestation of nonterminal frame in consultation mode.

agement information systems are appearing much more frequently. Development of expert systems that can be used by operators are still in the embryonic stages. A way is needed to integrate various departmental tools in assisting informative and timely decisionmaking. An integrated monitoring/MIS/KBES software that could be used as an operational tool has not been developed yet, but the Mine Management Support System discussed in this presentation is directed toward that goal.

MMSS is being developed as a knowledge-based expert system, concentrating on capturing the complex body of knowledge needed to enhance efficient management of underground coal mines. It will encompass information and preferred rules on many operational aspects of mining. Different components of the mine system, modeled using an object-oriented layering technique, will be displayed graphically as well.

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