Knowledge organization and inference engine for the WVU Face Decision Support System

S. Carrow
R. S. Nutter Jr.
R. S. Raman
N. A. Reddy
Y. V. Reddy

See next page for additional authors
Knowledge Organization and Inference Engine for the WVU Face Decision Support System

RAVI S. RAMAN, NARENDAR A. REDDY, Y. V. REDDY, ROY S. NUTTER, JR., SENIOR MEMBER, IEEE, STEVEN CARROW, MEMBER, IEEE, AND R. LARRY GRAYSON

Abstract—The knowledge-based organization for the West Virginia University face decision support system is given, along with the initial development of the associated inference engine. The knowledge base contains generic knowledge about underground coal mines that utilize specifically continuous miners. A typical knowledge entry is given. The inference engine methodology is then explained. The engine utilizes this knowledge with data from monitoring systems and from interaction with the section foreman, to assist in making section management decisions and plans.

INTRODUCTION

THE FACE decision support system (FDSS) goal is to develop an advisor to the section foreman of a continuous-miner-type section of an underground coal mine. Its primary objective is to develop software that will assist a coal mine section foreman by creating an agenda of tasks ranked according to priority.

This research project is part of a long-term effort on the part of West Virginia University to develop an intelligent mine management system, to be incorporated in the "mine of the future." Application of developments in the fields of artificial intelligence, computer-assisted manufacturing, etc. to the coal mine should improve its productivity, its profitability, and the safety of its personnel.

The system is intended to tie the normal environmental monitoring system directly to the expert system (FDSS) so that the mine-specific data of the knowledge base is updated automatically. The FDSS has four major parts; these parts are shown in Fig. 1. The monitoring system on the left side of Fig. 1 is a normal environmental monitoring system that can be anticipated to expand in future years. Additional capability to be included will monitor almost all systems that are underground, or even above ground. At the bottom of Fig. 1 is shown the user interface, which includes all interactions with the user. The interface includes normal terminals, voice input/outputs (I/O), graphics, "mouse"-type inputs, and, in general, any interaction that the user might have with the system.

The knowledge-base and planner mechanisms are the focus of this paper. They are the real kernel of activity that includes the expert's knowledge and the best section foreman's decision-making abilities.

KNOWLEDGE BASE

The general knowledge required by the section foreman about the mine and his section can generally be classified as follows:

- topological
- environmental
- equipment
- personnel
- regulations
- federal
- state
- company policies
- transportation
- utilities
- geology.

The knowledge base upon which the system is built contains "all" the information and past experiences of the expert. This "knowledge" includes factual knowledge as well as knowledge gained by experience. Let us consider the clear factual knowledge that a section foreman must have to operate his section.

The foreman will know the topological layout of not only
his section but also of much of the mine. This information
must be stored and recalled by the system as required by the
planning mechanism and by the processes that are operating in
the expert system.

It seems best to consider the mine map as the bottom layer
of a multilayered information system, which can be thought of
as a map layer underneath the glass of a table. The next layers
of factual knowledge are added as additional layers but are
associated and related to the other layers. These layers include
information about the environmental conditions in the mine
such as air flow (AV) in various entries, carbon-monoxide
(CO) concentrations, oxygen (O₂) concentrations, methane
(CH₄) concentrations, and differential pressures in critical
areas of the section and of the mine.

Equipment information, such as type, power requirements,
maintenance status, location, supplies required to operate,
operator type requirements, operational status, and so on,
should be contained in the knowledge base. Personnel infor-
mation such as work and training levels on various pieces of
equipment, compatibility of various personalities, and other
traits that the section foreman needs to know to lead a
productive section would be contained.

Regulations, including the Code of Federal Regulations,
volume 30 (CFR30) as it relates to all the levels, are an
extremely important part of the decision support system.
Regulations for the state in which the mine is located and any
company policies regarding the mine would also be included.
These regulations would always be the latest applicable and
could be updated automatically.

The transportation system topology for the movement of
coal and supplies is very important to the section foreman. He
needs to know, if it is a rail transportation system, how many
empty cars he has, how many full cars he has, and their
location at the loading point. He must also know the status of
his supply cars, what is on them, and where they are located.
He will also know the location and paths of all escapeways.

Regarding utilities for the section, the section foreman will
know or want to know the location and status of all electrical
power apparatus, including the power center for the section,
any other switchgear, the feed breaker for the section power
center, and trailing cables for each of the pieces of machinery
on the section. He will also want to know the status of fresh
water feeds and wastewater pipes for the equipment. In
addition, he will want to know the status of supplies for the
equipment and workers, which will include spare bits for the
continuous miner, spare hydraulics that may normally be
necessary on the section, spare trailing cable, if such things are
kept on the section, as well as the amount of rockdust available
from the machine and rockdust cars and the number of drill
bits and roof bolts available.

The geology of the mine is extremely important to the
section foreman as well as to the mine engineer. The section
foreman would like to know especially about any known faults
in or leading to his section and would like to know about any
that are yet in front of him. This knowledge not only affects
the safety of his crew but also has implications for the mining
method to be used and the way in which the roof around the
fault is supported.

As noted earlier, the knowledge cannot be in many
different forms because the systems of the FDSS must all be
able to use it. This relationship is shown in Fig. 2.

The knowledge format itself is stored in what is commonly
called a frame format within the programming environment. A
typical item, or "object," is given in Fig. 3.

**PLANNER INFERENCE ENGINE**

The planning inference engine is the heart of the face
decision project since it provides the reasoning behind the
decision-making process. Its primary objective is to determine
the tasks to be performed by the section foreman during the
course of the shift. These tasks can be either routine chores
performed on every shift or contingency tasks required as a
result of unforeseen circumstances. The planning system
determines the tasks and prioritizes them into an agenda of
activities the foreman should be performing. This agenda is
constantly being updated as a result of mine-wide activity,
both planned and unforeseen.

**BACKGROUND**

Development of planning systems has been an important
frontier of artificial intelligence (AI) research since it involves
the automatic generation of plans of action. Much of the early
work in this field dealt with block world models that
employed "means-ends analysis" to generate sequences of
activities which gradually converged to a solution [1]-[3].
However, these traditional approaches do not lend themselves
directly to the generation of solutions for real-world problems
involving comparatively rapidly changing scenarios in large
knowledge bases. Several powerful propositions have been
raised by leading researchers in this field which improve the
capabilities of planning systems [4]-[6]. Lenat proposed the
use of a rule-based system working with an object-oriented
knowledge base which would assist a military intelligence
analyst [7]. More recently, Bruno et al. announced the
implementation of a rule-based system to schedule production
operations in a manufacturing environment [8]. These reports
lend credence to the idea that a rule-based system operating in
conjunction with an object-oriented knowledge base contain-
ing a demon mechanism can be employed to overcome some of
the problems associated with developing real-world planning
systems.

**PLANNING ALGORITHM**

As a result of these observations, it was decided to construct
a planning system with the following features:

- a rule-based system supporting a forward-chaining non-
These production systems can therefore react quickly to particularly suited for such a situation [9]. In such a system, actions as soon as the effects of those events are noticed. A by incorporating introspective functionality into the program. changes to the environment, and if the appropriate rules since events occur aperiodically in the mine, the planning system should be capable of firing rules to take appropriate actions as soon as the effects of those events are noticed. A nonhierarchical rule-based system along the lines of OPS5 is particularly suited for such a situation [9]. In such a system, any rule can be fired at any point in time, provided its own left-side pattern (or if condition) is satisfied by the current contents of the knowledge base. The actual rule that would be fired for every cycle of the production engine would depend, however, upon the choice of the conflict resolution strategy. These production systems can therefore react quickly to changes to the environment, and if the appropriate rules (conditions and corresponding actions) are set up, a planning system can be developed whose extent would depend largely upon the complexity and completeness of its rule base. The rule base can be expanded with experience by the knowledge engineer and can be made to react to changing circumstances by incorporating introspective functionality into the program.

The production system employed for this planning system was LASER/RPS (rule programming system) [11] (Fig. 4), which is similar to OPS5 [10]. Knowledge about the mine, as well as the rules themselves, is in the form of objectives [2]. The entire system is implemented in the C language. The rule base was constructed with the aid of domain experts Grayson and Klishis, whose expertise in coal mining operations and training has been invaluable for this research effort [13].

An initial model was developed to handle minor ventilation related problems (Fig. 5). Rules were constructed to recognize ventilation hazards and spawn tasks to alleviate the problem (Table I). The use of demons in the knowledge base was instrumental in this endeavor, since they detected changes to "air-flow" and "methane-concentrations" in the different parts of the section. As these values crossed certain thresholds, alarm conditions were automatically raised which triggered the firing of corresponding rules. The tasks created to handle different situations were prioritized and incorporated into the agenda of tasks to be performed by the section foreman. Detailed information about various activities are being incorporated into the task database. These include information pertaining to the requirements for the task, the subtasks to be performed, its priorities, etc.

### Table I

<table>
<thead>
<tr>
<th>Task</th>
<th>Priority</th>
<th>Location</th>
<th>Task Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
<td>crosscut3-2 x 3</td>
<td>power-off-face</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>crosscut3-2 x 3</td>
<td>remove-personnel</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>crosscut3-2 x 3</td>
<td>verify-monitor</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>crosscut3-2 x 3</td>
<td>redirect-air</td>
</tr>
</tbody>
</table>

**Conclusion**

This paper has introduced the format in which an expert system for continuous-miner section foremen can be written and the kernel of the planning system. The kernel of the planning system has been completed. Generic information pertaining to a section in a coal mine has been entered. Graphics-assisted data entry and template-driven validation mechanisms have been constructed, and with them the knowledge base has begun to expand. It is now possible to design a coal-mine section by interacting with the graphics software and providing answers to specific questions. When interacting with the planning system, the user can create several hazards by altering specific values of various objects in the knowledge base (emulating sensor data from a monitoring system) and notice the tasks growing on the agenda. A future enhancement to the system will be the incorporation of a simulation system to create various scenarios that realistically modify the mine-wide knowledge base.

The rule base is currently small, and has been employed primarily to verify the workings of the planning system. Plans are under way to expand the rule base with the assistance of the domain experts to incorporate several situations commonly found in mines. By incorporating both routine tasks and unexpected situations, the planning system should help the
section foreman to manage his personnel and resources, resulting in improved production.

REFERENCES


Ravi S. Raman, for photograph and biography please see page 865 of this TRANSACTIONS.

Narendar A. Reddy received the B.E.M.E. degree from Osmania University, India, the M.S.M.E. degree from Michigan Technological University, Houghton, and the M.S.C.S. degree from West Virginia University (WVU), Morgantown, in 1979, 1982, and 1986, respectively.

He was a Graduate Research Assistant at the AI Laboratory of the Computer Science Department at West Virginia University from August 1984 to May 1987. During that time he worked on the development of an expert system titled "Face Decision Support System," sponsored by U.S. Bureau of Mines. From May 1987 to August 1988 he was a Research Scientist for the WVU Siemens Training Project, working on graphic design in conjunction with a computer-based training system for digital electronic dialing. As of September 1988 he has been working for Siemens Switching Systems, Boca Raton, FL.

Y. V. Reddy, for photograph and biography please see page 865 of this TRANSACTIONS.

Steven Carrow (S'86-M'86) was born on November 13, 1961. He received the B.S.E.E. degree from West Virginia University, Morgantown, in 1984.

He worked as a Graduate Research Assistant involved in expert systems and artificial intelligence from May 1984 through January 1987. He now works for the Naval Research Laboratory in Washington, DC, as an Electronics Engineer.

Mr. Carrow is a member of the Association for Computing Machinery.

R. Larry Grayson received the B.A. degree in mathematics from the University of Pennsylvania, California, and the B.S., M.S., and Ph.D. degrees in mining engineering from West Virginia University (WVU), Morgantown, in 1974, 1978, 1981, and 1986, respectively.

He worked at the Nemacolin Mine for the Youngstown Sheet and Tube Company and at the Nemacolin Mine, Vesta 4 Mine, and Vesta 5 Mine for Jones and Laughlin Steel (which merged with Lykes Resources Corporation) in various engineering and operational management positions, including Superintendent and Chief Engineer. He resigned as superintendent of the Nemacolin Mine and Preparation Plant in January 1984 to begin his doctoral work at WVU. He has participated in and/or supervised research in the areas of computer applications in mining, operations research applications, occupational training, respirable dust, and expert systems applications.

Dr. Grayson is a Registered Professional Mining Engineer in the States of Pennsylvania and West Virginia. He has written a number of refereed journal articles and has presented over 30 papers at professional conferences.