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Recommended Citation

S. Carrow et al., "Knowledge Organization and Inference Engine for the WVU Face Decision Support System," *IEEE Transactions on Industry Applications*, Institute of Electrical and Electronics Engineers (IEEE), Jan 1988.
The definitive version is available at https://doi.org/10.1109/28.8992

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Knowledge Organization and Inference Engine for the WVU Face Decision Support System

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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/output (I/O), graphics, "mouse"-type inputs, and, in general, any interaction that the user might have with the system.

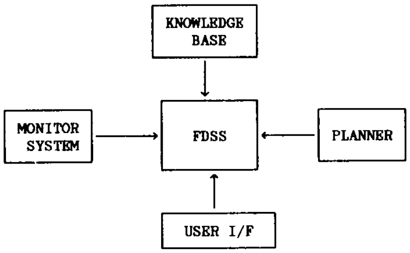

Fig. 1. FDSS block diagram.

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

Paper PID 87-42, approved by the Mining Industry Committee of the IEEE Industry Applications Society for presentation at the Eighth West Virginia University International Conference on Mining Electrotechnology, Morgantown, WV, July 30–August 1, 1986. This work was supported by in part the U.S. Bureau of Mines and in part by the Energy Research Center of West Virginia University. Manuscript released for publication December 12, 1987.

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IEEE Log Number 8821454.

0093-9994/88/0900-0866$01.00 © 1988 IEEE

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 (O_2) concentrations, methane (CH_4) 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 information 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.

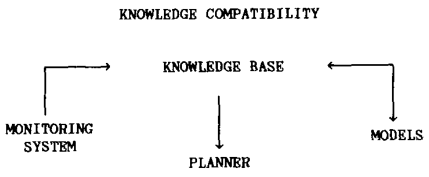

Fig. 2. Knowledge compatibility.

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 containing 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-

```
{{CONTINUOUS_MINER
CLASS:              "CONTINUOUS MINER"
ISA:               "MACHINE"
LOCATION:           "1WLS,FACE4"
MANUFACTURER:        "ACME"
MODEL:              "1040A
NAME:               "WILE E. COYOTE MINER"
```

Fig. 3. Typical frame representation of object.

hierarchical collection of rules operating upon nonsequential event schedules,
- a rule base which would guide the generation of plans under specific conditions,
- a knowledge base employing demons to monitor specific information which might necessitate special handling,
- a task database containing detailed information about the tasks, and
- an agenda of prioritized tasks.

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.

```
instance: "RPS-RULE"

comment: "Excess methane has been reported"

LHS: "*A methane-hi-flag     =    ON"
     "model state            <>   QUIT"

RHS: "modify data new-task location *A."
     "modify data new-task name power-off-face."
     "modify data new-task priority 5."
     "call methods report-task."
     "modify data new-task name remove-personnel."
     "modify data new-task priority 4."
     "call methods report-task."
     "modify data new-task name verify-monitor."
     "modify data new-task priority 3."
     "call methods report-task."
     "modify data new-task name redirect-air."
     "modify data new-task priority 2."
     "call methods report-task."
     "modify data *A methane-hi-flag REPORTED."

Name: "methane reported"
```

Fig. 4. Sample RPS rule.

```
entry2
   instance:         "entry"
   partof:           "RPS-DATA"
   air-flow:          150.0
   methane-level:     0.25
   vent-type:        "fresh"
   water-level:       0.0
```

Fig. 5. Generic coal mine entry.

TABLE I
AGENDA OF TASKS

Task	Priority	Location	Task Name
1	5	crosscut3-2 × 3	power-off-face
2	4	crosscut3-2 × 3	remove-personnel
3	3	crosscut3-2 × 3	verify-monitor
4	2	crosscut3-2 × 3	redirect-air

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

[1] R. E. Fikes and N. J. Nilsson, "STRIPS: A new approach to the application of theorem proving to problem solving," *Artificial Intell.*, vol. 2, pp. 189-208.

[2] E. D. Sacerdoti, "A structure for plans and behavior," AI Center, SRI International, Inc., Menlo Park, CA, Tech. Note 109 (doctoral dissertation), 1975.

[3] ——, "Planning in a hierarchy of abstraction spaces," *Artificial Intell.*, vol. 5, pp. 115-135.

[4] B. Hayes-Roth, "Human planning processes," Rand Corp., Santa Monica, CA, Rep. R-2670-ONR, 1980.

[5] B. Hayes-Roth and F. Hayes-Roth, "Cognitive processes in planning," Rand Corp., Santa Monica, CA, Rep. R-2366-ONR, 1978.

[6] M. J. Stefik, "Planning with constraints," Comput. Sci. Dep., Stanford Univ., Stanford, CA, Rep. 80-784 (doctoral dissertation), 1980.

[7] D. B. Lenat, A. Clarkson, and G. Kiremidjian, "An expert system for indications and warning analysis," in *Proc. Int. Joint Conf. Artificial Intelligence*, 1983, pp. 259-262.

[8] G. Bruno, A. Elia, and P. Laface, "A rule-based system to schedule production," *IEEE Computer*, vol. 17, pp. 32-40, July 1986.

[9] C. Forgy and J. McDermott, "OPS, A domain-independent production system language," in *Proc. Joint Conf. Artificial Intelligence*, 1977, pp. 933-939.

[10] R. S. Raman, "LASER/RPS: A rule-based programming system for the LASER environment," Artificial Intelligence Lab., West Virginia Univ., Morgantown, 1985.

[11] Y. V. Reddy, R. S. Raman, R. T. Dziedzic, A. W. Butcher, and N. A. Reddy, "A unified approach to A. I. programming," in *Proc. 1st Int. Conf. Applications of A. I. to Engineering Problems,* Southampton Univ., U.K., 1986, pp. 587-594.

[12] R. T. Dziedzic, *LASER 1.0 Manual.* Morgantown, WV: Artificial Intelligence Lab., West Virginia Univ., 1985.

[13] R. L. Grayson, R. C. Althouse, and M. J. Klishis, "Preparing the section foreman for his full responsibilities," in *Proc. SME-AIME Fall Meeting*, Albuquerque, NM, Oct. 1985.

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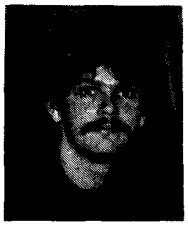
Roy S. Nutter, Jr. (S'63-M'71-SM'81) for photograph and biography please see page 826 of this TRANSACTIONS.



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