Chapter 90

DEVELOPMENT OF A VENTILATION DESIGN KNOWLEDGE BASE AS A COMPONENT OF A PROTOTYPE EXPERT SYSTEM FOR UNDERGROUND COAL MINE DESIGN

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Abstract. A prototype expert system for planning and designing an underground coal mine has been developed in a doctoral study at the University of Kentucky. This prototype expert system for underground coal mine planning and designing consists of a number of knowledge bases concerning different elements of design (e.g., ground control, excavation and bulk materials handling, ventilation, etc.).

The objective of this paper is to present the development process of the ventilation design knowledge base for this prototype. This expert system prototype is intended for building an instructional expert system for underground coal mine design. Therefore, the undergraduate course on mine design has been used as the basis, for its development. Because of the availability of knowledge and expertise, this research study has been limited to development of a knowledge model for the Appalachian coal mining region.

INTRODUCTION

A mine design system integrates the elements of the design process, including reserve estimation, choice of mining method(s), selection of access type and location, layout for production, and production planning. After meeting legal and technical requirements, the design is checked for economic feasibility. Current design methodology requires the involvement of a team of experts, each member highly specialized in his/her own area of expertise.

A prototype expert system for underground coal mine design has been developed. Details on expert systems and prototype development have been addressed elsewhere (Basu, 1992). This prototype has been tested with simple knowledge bases of design elements (e.g., ground control, excavation and bulk materials handling, ventilation). The strategy for prototyping a knowledge-based system for the underground mine planning and design system has been discussed previously (Basu, Lineberry, and Unrug, 1991).

The objective of this knowledge base is to emphasize the role of life-support system (in this case, ventilation planning and design) in the context of a total systems concept (Lineberry and Adler, 1989). The driving reason for incorporating a knowledge base for ventilation design was the existence and ready availability of related knowledge and expertise. Moreover, this module very clearly demonstrates the interaction between other design components (e.g., ground control, excavation and handling) while configuring a mine (e.g., determination of number of entries). This research study was limited to development of a knowledge model for the Appalachian coal mining region. Moreover, the undergraduate course on mine design was used as the basis. Lecture notes prepared by one of the mine design instructors (Wala, 1990) were used as the knowledge source for the ventilation knowledge base. In addition, the classical textbook by Hartman, Mutmansky, and Wang (1991) was used as a major information source.

Ventilation planning has two major components: 1. design/system configuration (layout) and 2. network analysis of a configured mine to check satisfactory level of operation. At present, only the design task is pursued. The design/configuration process determines: 1. number of airways (entries) for mains, submains and production areas, including longwall development sections; 2. estimate of total air requirement based on regulations, methane gas dilution requirement, dust suppression and diesel exhaust dilution; and 3. estimate of main fan pressure based on air requirement.

In addition, rules for determining the most economic shaft diameter have been incorporated in the knowledge base. The hypertext capability of LEVEL5 OBJECT has been used to provide advice on layout planning and fan installation.

VENTILATION DESIGN KNOWLEDGE BASE

The functional details of the knowledge base will be addressed in the following sections, which treat: 1. information from preceding knowledge bases, 2. organization of the knowledge base, and 3. flow of output parameters to other knowledge bases. Figure 1 depicts this information flow.

Information from Preceding Modules

The prototype knowledge-based system for underground coal mine design is an integrated system, and ventilation design data are supplied by the preceding knowledge bases in hierarchical order as shown in Figure 1. The

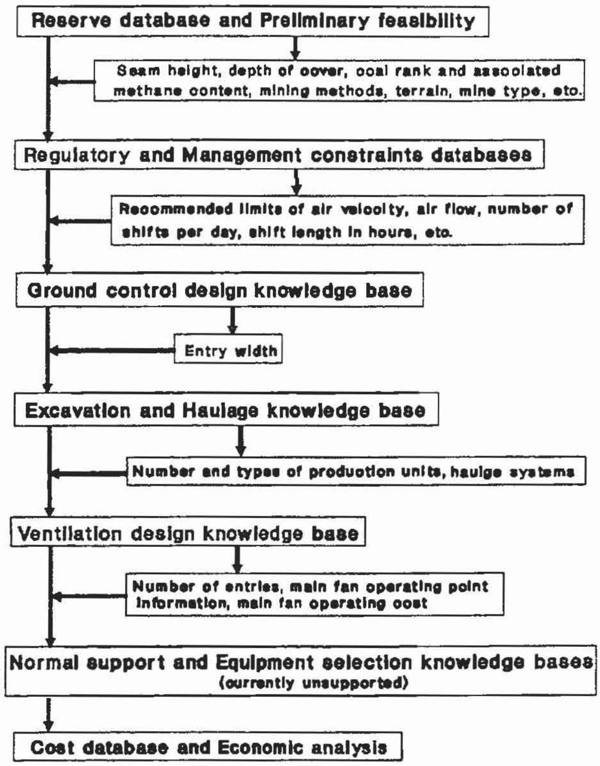

Figure 1. Flowchart depicting the interrelationships between knowledge bases in relation to ventilation design.

design data include methane content and liberation rate, seam height, mining method(s), recommended limits of air flow and air velocity, production plan, entry width, and number and types of production units. Detailed discussion on these design data and relevant knowledge bases is beyond the immediate scope and has been treated in detail elsewhere (Basu, 1992).

Organization of the Knowledge Base

The overall structure of this knowledge base has been provided in this section. In general, a backward-chaining inferencing method was used to prove goals or conclusions as documented in Equation 1. Whenever there was a need for a procedural rule (e.g., air requirement for gas dilution), it was incorporated as a **WHEN CHANGED METHOD** or **DEMON** (rule for data-driven or forward-chaining tasks). The program path is controlled by goals known as **AGENDA** (LEVEL5 OBJECT terminology), as shown in Equation 1. An illustration of the program path is shown in Figure 2.

AGENDA (1)
1. **Layout and fan installation advice made OF domain**
   1.1 **Shaft diameter calculation OF domain**
      1.1.1 **Ventilation design computed OF domain**

The goals are satisfied in the following manner. First, the goal **Ventilation design computed** is satisfied; next, the goal **Shaft diameter calculation** is satisfied; and, finally, the conclusion, **Layout and fan installation advice made**, is reached. The conclusion, **Layout and fan installation advise made**, was reached after the layout conditions (e.g., **Mains Layout advise**) were met. These conditions were used to display layout and fan installation information.

The bottom-most goal, i.e., **Ventilation design computed**, requires that three conditions be satisfied, see Figure 2: 1. air requirement computation completed, 2. number of airways (entries) determined, and 3. main fan pressure estimated. This governing rule for ventilation design is shown in Equation 2.

RULE Governing rule (2)
IF Air requirement computed
AND Number of entries determined
AND Fan pressure estimated
THEN Ventilation design computed

<u>Air Requirement Computation</u>. Air requirements were computed for 1. legal requirements, 2. gas dilution requirement, 3. dust suppression requirement, and 4. diesel exhaust dilution requirement. Only the first two conditions are important for this knowledge base. Dust suppression is

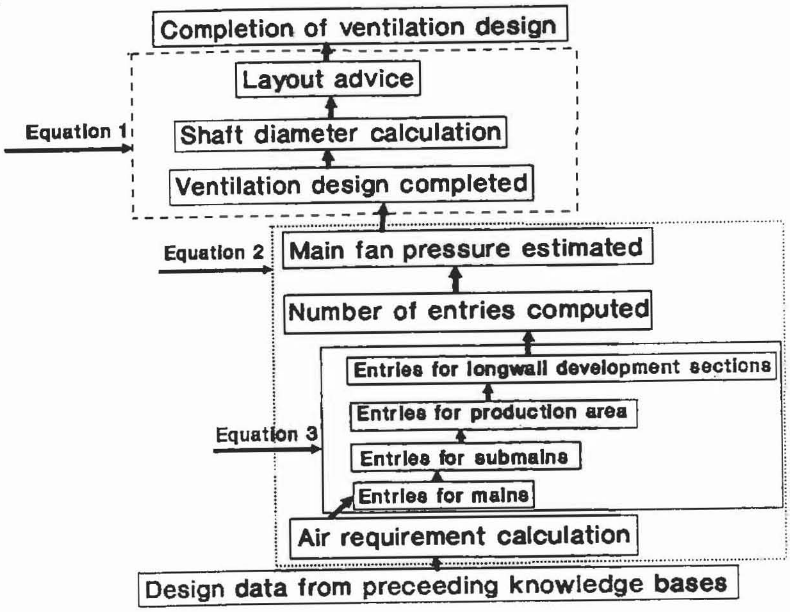

Figure 2. An illustration of backward-chaining inferencing method for ventilation design.

assumed to be achieved at the source, with the help of dust suppression equipment (e.g., scrubbers) and methods (e.g., water spray at longwall face). Diesel equipment use is not common in Appalachia. Moreover, the air requirement to dilute diesel exhaust is small compared to the first two requirements. Even if the last two criteria are not critical, they have been included in the knowledge base for completeness and can be utilized when required. Figure 3 provides a summary of a sample air requirement calculation.

Number of Entries. The next condition to be satisfied is **Number of entries determined.** In this case, production rules were used to perform procedural tasks as explained earlier. The controlling rule for this goal is given in Equation 3.

RULE For Number of entries computation (3)
IF Mains_entries are determined
AND Submains_entries are determined
AND Production_room_and_pillar_entries are determined
AND Longwall_gateroad_entries are determined
THEN Number of entries determined

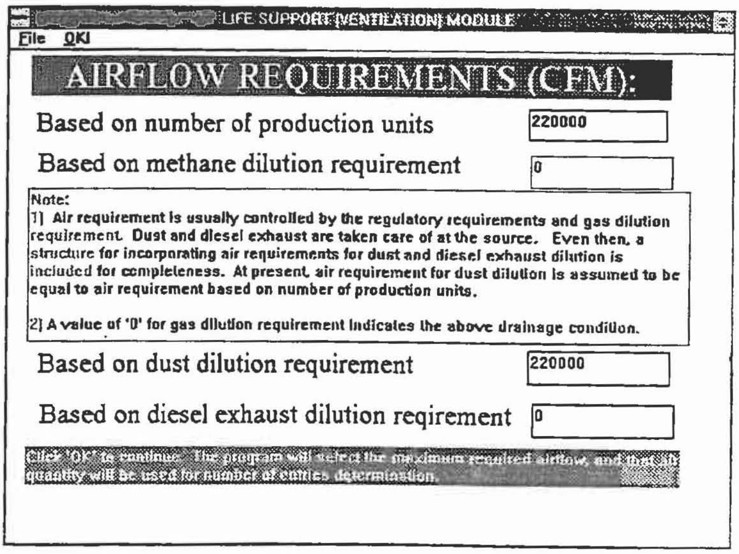

Figure 3. Summary of air requirement computation output.

The goal, **Number of entries determined**, is satisfied when entry numbers for mains, submains, production area, and longwall development sections are determined. This object, **number of entries**, is the component of ventilation design that integrates other design activities, such as ground control, excavation, and bulk material handling. Entry width is provided by a ground control design knowledge base, and operational and production planning determines the layout plan, i.e., double split or single split ventilation plan. Moreover, the production plan (combining excavation and ventilation) determines the number of neutral entries. Based on air requirement (Q, cfm), air velocity (V, fpm), and effective area (A, sq. ft)[1], the number of intakes was computed. Then the number of entries for mains, submains, production area and longwall development sections were computed using the built in heuristics (e.g., number of intakes = number of returns). Figure 4 depicts the design output for number of entries for mains which represents an example and is based on a hypothetical problem. In practice, number of entries for mains are kept fewer.

Fan Pressure Estimation. The two goals that have been satisfied generated air requirement (Q, cfm), for the working sections and for the entire mine, and mine layout information concerning the number of entries. If mine resistance is known, then the fan pressure (P, in. of w.g.), corresponding to the operating point, can be determined using Atkinson's formula. The goal, **Fan pressure estimated**, has a rule group consisting of three rules. In these rules the conditions checked are: 1. hilly terrain, above drainage, and drift or slope mine, 2. hilly terrain, below drainage, and shaft mine, and 3. flat terrain, below drainage, slope or shaft mine. The first condition represents mines in the eastern Kentucky region (EKY). The second condition is true for mines in the Virginia (VA) and West Virginia (WV) area. The third condition represents the mining environment seen in western Kentucky (WKY). Despite the fact this condition is not representative of mines in the Appalachian coal field, a few cases have been included. These cases provide an opportunity to study the effects of regional geology on ventilation design. A data sheet was prepared and used to collect data on existing mines. Ventilation data for a total number of ten mines were compiled (Wala, 1991). Detailed information of this data set is omitted here and is available elsewhere (Basu, 1992).

The path followed to obtain fan pressure included: 1. computation of mine resistances from P-Q data, 2. preparation of histogram for mine resistances and distribution of mine resistances based on the regional geology, and 3. generation of design curves for mine resistances. These design curves were used for inferring main fan pressure estimation rules.

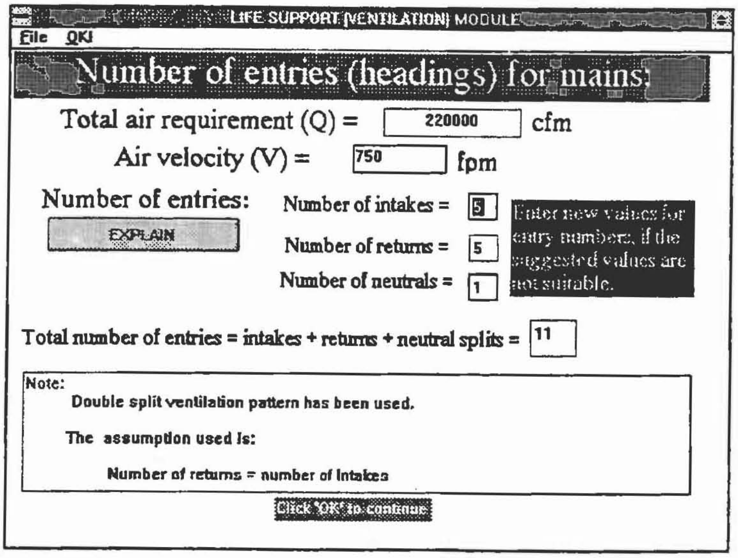

Figure 4. An example for determining number of entries.

[1] Effective airway area (A) = 0.80 x entry width x seam height. Entry width is obtained from the ground control design knowledge base and the seam height is obtained from the reserve data base. The english units are used throught this text, because the prototype expert system was designed to handle english units only. A list of relevant SI units conversion factors are listed at the end of the text.

Mine resistances were computed and grouped in six class intervals: a. 0-0.5, b. 0.51-1.0, c. 1.01-1.50, c. 1.51-2.0, d. 2.01-2.50, e. 2.51-3.0 (these values have a common multiplier of 10^{-10}, and the units are in-min^2/ft^6). For the EKY region, two distinct groups of mine resistances have been observed: a. 1-1.5 x 10^{-10} in-min^2/ft^6, b. 2.0-3.0 x 10^{-10} in-min^2/ft^6. Mine resistances for a few EKY region mines experienced higher values compared to the other mines in the EKY region. There may be many factors causing this anomaly in the mine resistance values for the same region, but the primary reason is topography. Because of the hilly nature of the terrain, the ventilation network is often very long, and mine resistance is directly proportional to length. Moreover, a greater length of ventilation network would cause more leakage and raise resistance. However, a set of mine resistance curves has been generated for these regions. The rule for determining main fan pressure for hilly terrain, above-drainage, and drift or slope mine conditions was incorporated as:

$$P = 1.0 \cdot (10^{-10}) \cdot Q^2 \qquad (4)$$

The mine resistance value (1.0 x 10^{-10}) in Equation 4 was used as an example for this prototype. If this observational approach to knowledge acquisition is implemented in a design task, an extensive investigation is required to identify other parameters that affect mine resistance and to determine a conclusive value that would be used at the design stage.

The WKY region has four datapoints, 50% of which fall into the peak class interval, i.e., 1.0-1.5 x 10^{-10} in-min^2/ft^6. Therefore, as a conservative approach, 1.5 x 10^{-10} in-min^2/ft^6 was used to represent mine resistance values for a region with a flat topography, below drainage, and slope or shaft conditions. For the VA region, only one datapoint (R = 0.46 x 10^{-10} in-min^2/ft^6) was available.

Incorporation of these design rules does not advocate the use of such techniques exclusively. This type of analysis will help in the initial feasibility. When a detailed ventilation network layout is available, users may choose to run a ventilation network simulation, which will determine the required main fan parameters.

The estimated main fan pressure and airflow quantity were then used to compute air horsepower required, and annual operating cost was computed. Figure 5 shows the sample output for main fan pressure calculation and estimation of operating cost. Moreover, examples of shaft design and layout advice have been incorporated in the ventilation design knowledge base. Graphic information was included using the hypertext feature of the expert system shell.

Parameters to Following Knowledge Bases

The next knowledge base (**NS.KNB**) is inactive at present, and, in the future, normal support activities may be incorporated in this module. For example, power system

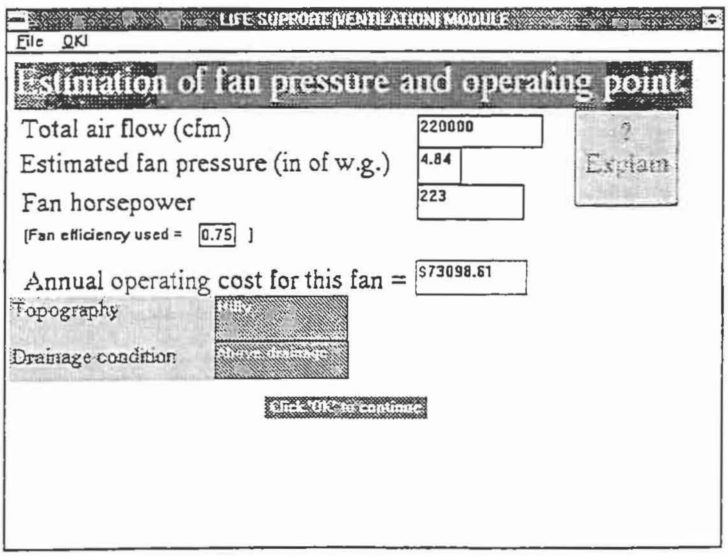

Figure 5. Output for main fan data.

design is a normal support task, and main fan horsepower would be considered as input data during the design of power systems. Fan operating point and airflow data would be required to perform fan selection from fan characteristic curves prepared by manufacturers. This presents a simple catalog selection problem (Basu and Lineberry, 1992). As normal support activities and equipment selection do not fall under configuration activity, these are not included in the prototype, but they certainly are candidates for future work. The other important output from the ventilation design module is the estimation of operating cost. This cost item, a component of production cost, was utilized in the economic analysis.

CONCLUSION

Ventilation design is one component of the engineering analyses activities. The prototype expert system provides three major elements for mine configuration: 1. ground control design, 2. excavation and bulk material handling design, and 3. ventilation design. Detailed production planning is dependent on these three modules, which could be a logical extension of this research work. The knowledge-based approach was selected as a tool to achieve the goal of building intelligence through heuristics, while stratification helped integration. The integrated structure, in turn, facilitated the automated design process. It is expected that the current system will find use first as an instructional tool. With gradual acceptance in the industry for training purposes, and with adaptations to meet certain industry- or company-specific goals, the integral structure of the design process can become an aid for a design engineer.

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CONVERSION FACTORS

Air flow (Q):	1 cfm = 0.00047 m^3/s
Air velocity (V):	1 fpm = 0.005 m/s
Pressure loss (P):	1 in of w.g. = 249 Pa
Resistance (R):	1 in. min^2/ft^6 = $0.112 \cdot 10^{10}$ Ns^2/m^8

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