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Simulation of Flow Behavior in Mine Ventilation Networks as a Tool for a Knowledge-based Decision System*

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ABSTRACT

A growing trend in the area of artificial intelligence is the development of software that simulates the decision making process of human experts. The authors have developed an expert system that controls the operation of a mine ventilation network (MVN). The expert system interacts with either a physical or a hypothetical model of a mine ventilation network. It serves as a smart interface between the monitoring and control systems of the MVN. In its decision making process, the expert system relies heavily on three simulation programs: *vent*, *CPM* and *fire*, which are used for the following purposes:
(1) Analysis of MVN - the *vent* program serves as a simulator of the MVN in order to test the consequences of suggested actions, or to verify the causes of suspected problems.
(2) Control of the MVN - the *CPM* program is used to determine the regulator and fan settings that satisfy the flow distribution requirements, while minimizing the power used for ventilation.
(3) Fire Simulation - the *fire* program can be invoked to simulate the development of an open fire, its effect on the flow distribution, fume concentration, and temperature changes in the MVN.
(4) Integration of (1)-(3) to assist with the planning and design of MVN, and the training/teaching of the mine ventilation and safety personnel.

Keywords: Simulation, expert system, mine ventilation, monitoring and control.

INTRODUCTION

The authors have developed an expert system that controls the operation of a mine ventilation network (Altman et al. 1988). In its decision making process, the expert system makes use of a number of simulation programs in order to predict the behavior of an MVN, e.g., the flow distribution of gases and fumes, within either a physical or a hypothetical model of a mine.

The major objective of an underground mine ventilation system is to provide a safe and healthy environment for the miners. The demand for the ventilation, (i.e., a proper airflow distribution throughout the mine), is based on factors such as: mining production, gas and dust concentrations, the characteristics of the airways, and others. The control of the ventilation system is achieved through the adjustment of fan and regulator settings.

The quality of control exercised by the ventilation management is limited by their ability to obtain timely information describing the state of the system, and their capability to arrive at decisions based on that information. This limitation has long been recognized by mine ventilation experts, and was the triggering impulse for the development of automated mine monitoring and control systems.

MINE VENTILATION MANAGER (MVM)

The functional structure of the MVM is displayed in Figure 1. It consists of two independent subsystems:
- monitoring and control,
- modeling and simulation,

shown in the left and right hand sides of Figure 1, respectively. They communicate with each other through the knowledge based expert system (KBES) - the central component of the MVM. The MVM consists of a hierarchy of production rule knowledge bases and a set of Pascal procedures called by production rule actions within these knowledge bases. Below, the MVM is described in terms of how its component knowledge bases and Pascal programs interact, as diagramed in Figure 2.

At the top of the knowledge base hierarchy is MVNMGR which prompts a user to select from one of four consultations, in order to:

(1) establish a (MVN) - *buildmvn*,
(2) update the parameters for an existing MVN - *updtmvn*,
(3) analyze the created MVN using the simulators - *vent*, *fire*; and *CPM* to control the MVN through the adjustment of regulators.
(4) monitor and respond to the latest sensor readings - *MVNDRIVE*.

In the first option, MVNMGR calls a program, *buildmvn* (to assign the initial data parameters to the network model) and then analyzes the submitted data to determine whether they form a valid mine ventilation network in terms of the canonical diagram structure described in (Wala and Altman 1987). Once the ventilation network is completely specified and validated, *buildmvn* stores its description in a file called *mvndb.dat*.

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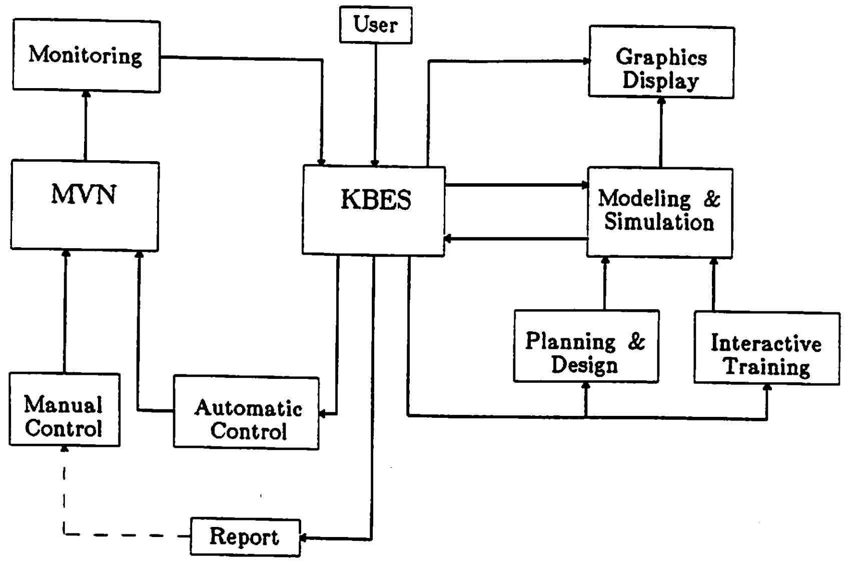

Figure 1. Functional modules of the Mine Ventilation Manager (MVM).

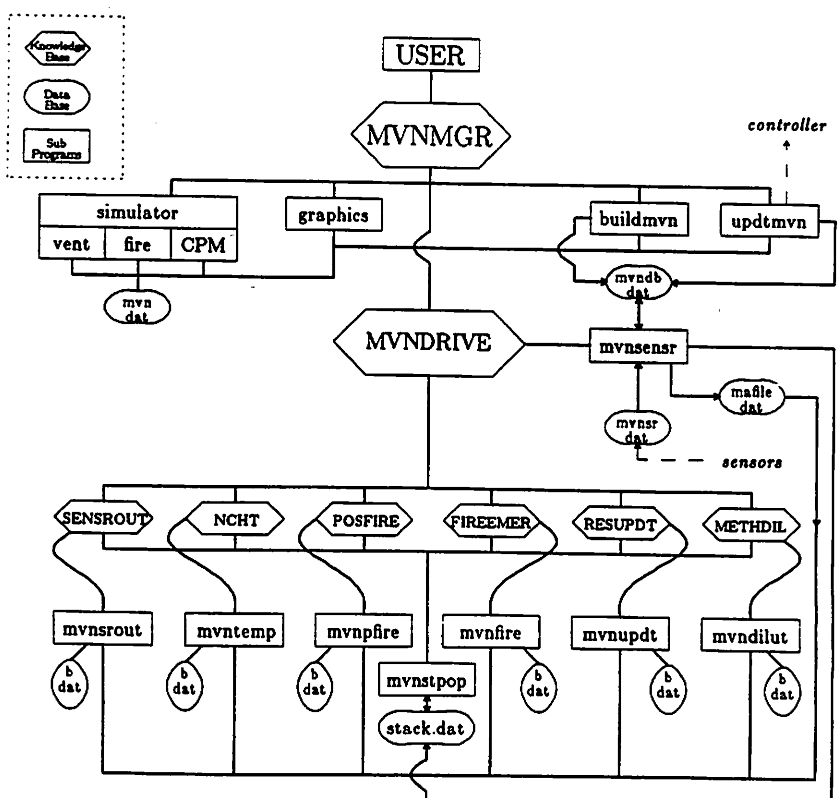

Figure 2. The Knowledge Based Expert System (KBES).

The second option presented by MVNMGR updates the parameters of an existing ventilation network. With this option, MVNMGR calls a program *updtmvn*, which prompts the user for possible revisions of the network's database records, and updates them accordingly.

In option three, the automatic control of airflow distribution in the MVN is carried out by regulator and fan adjustments. These are determined with the help of a simulator program called *CPM* (critical path method) and implemented by the control system. The remaining programs *vent* and *fire* are used for the analysis and modeling of the MVN behavior to support the decision making processes for ventilation control. An example highlighting the integration of *vent* and *CPM* is presented in the Appendix.

Finally, in option four, sensor readings which indicate the latest
(1) airflow rate,
(2) methane concentration,
(3) carbon monoxide concentration,
(4) carbon dioxide concentration, and
(5) temperature,
are analyzed and the user is advised about any detected problems or emergencies.

The MVM expert system may also serve as a teaching/training tool for the mine ventilation personnel. In fact, the programs (see option (3) of MVNMGR) permit the simulation of hypothetical models of mine ventilation networks. This capability allows for the elimination of mistakes which tend to be made by inexperienced ventilation operators. In addition, the *vent* program may also be used to assist in the planning and design of ventilation systems. Finally, the *fire* program may be invoked to cope with emergency situations caused by mine fires.

SIMULATION OF THE MVN BEHAVIOR

One of the important features of MVM is its ability to apply simulation routines as a part of its decision making process. The expert system has access to routines capable of performing complex mathematical computations which simulate the behavior of the MVN. The generated information is then made available to the expert system which, in turn, makes decisions based on the results of these simulations. The modeling and simulation subsystem of the MVM (see Figure 1) consists of three main programs: *vent*, *CPM*, and *fire*, whose functions are described below.

Vent

This program was developed to assist the ventilation engineer in the design and analysis of mine ventilation networks. Utilizing the physical laws of conservation of mass and energy together with some fundamental properties from graph theory, the *vent* routine determines/solves the equilibrium condition in the ventilation system. To perform the necessary numerical computations, a modified version of the Hardy Cross iterative method (Cross 1936) is used.

The *vent* program serves as a simulator of MVN in order to test for possible consequences of specific actions, which may be proposed by an operator or the expert system itself, (e.g., airflow adjustment). Its simulation results are used during the interactive consultation sessions with the user.

CPM

The analogy between the *critical path scheduling* (from Operations Research) and the *free split* (from the ventilation network theory) allows for the use of the *CPM* method in order to obtain solutions for ventilation problems involving controlled splitting (Salustowicz 1930),

The critical path approach provides an elegant mathematical procedure for analyzing the problem of airflow control in ventilation networks. The *CPM* and related network methods (in the context of MVN) have been introduced in (Salustowicz 1930), and also published in (Owili-Eger 1973) and (Wang 1981).

CPM is used to determine the regulator and fan settings for the control system of MVN which accommodate a required airflow distribution while minimizing the power used for ventilation. It also allows the ventilation manager to know, a priori, the effects of modifications in the regulator/fan settings.

Fire Simulator

The *fire* simulation program is used to simulate the development of an open fire and its effect on the airflow and fumes distribution, as well as temperature increases in the MVN. Thermal and chemical effects due to a fire usually create unsteady states (transients) in the airflow and the distribution of combustion products which usually are poisonous and/or explosive.

The mathematical model used in the simulation is based on: a simple model of combustion of fuel in the mine airways, unsteady exchange of heat between the heat source, airflow and the surrounding rocks, the flow in the mine ventilation network itself, and finally, the theory of heatflow in the rock strata. A detailed description of this model is presented in (Dziurzynski and Trutwin 1987).

During an open fire in underground mines, the hot gases often generate a considerable amount of natural ventilation pressure (due to the presence of vertical and inclined airways) which introduce disturbances of the ventilation process. These disturbances may cause flow reversals which result in the recirculation of fumes, and thereby, create hazardous situations for the miners.

The information gathered from the fire simulation helps the ventilation manager with fire emergency planning, fire prevention, and even fire control.

CONCLUDING REMARKS

As with most complex systems, it appears that the decision making process for mine ventilation management must rely heavily on the application of simulation techniques. This fact was taken into account in the development of the mine ventilation expert system.

Additional developments, needed to make MVM a more complete expert, require a deeper interface between the already applied simulation techniques and mine ventilation theory. Problems may also arise concerning rule consistency (Suwa et al. 1984). For example, one must consider the possibility that multiple simultaneous problems occur in a mine, for which the operator or the expert system suggest conflicting emergency handling actions. It appears that for such situations, the only viable means of arriving at a sound decision is by means of actually simulating the consequences of these actions in order to determine the optimal one.

Also, one should not overlook the importance of the MVM as a teaching/training tool. The simulation programs within the MVM make it possible to train the inexperienced, as well as improve the skills of experienced, mine ventilation and safety personnel.

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APPENDIX

Presented below is an example of a consultation with the MVM which invokes the simulation programs *CPM* and *vent.* Working with the laboratory model of an MVN (see Figure 3), the goal for the MVM expert system is to adjust the flows in the area of interest (i.e., through the basic branches). In this particular system, these are branches no. 4, 6, and 7, whereas no. 5 is the leakage branch.

The user invokes the knowledge base MVNMGR and chooses the consultation which determines, with the assistance of the *CPM* program, the regulator and fan adjustments (as shown in Table 1), which satisfy the new flow requirements. In addition to the information in Table 1, the user also obtains data concerning the status of the entire ventilation system, (given in Table 2).

The *vent* program is used to test for the consequences of the suggested control actions (i.e., regulator and fan adjustments). The output from the *vent* simulator is presented in Table 3. Also displayed, is the information about any abnormal flows in the basic branches.

Following these sessions the user makes a decision, based on the data provided by the *CPM* and *vent* programs, how the regulator adjustments are to be made (i.e., automatically or manually). After the implementation of these adjustments, the monitoring system is reactivated and a final report showing the actual airflow, gas concentration, and the fan characteristics is produced (see Table 4). Table 5 contains the comparison between the assigned, simulated, and the monitored airflows in the basic branches.

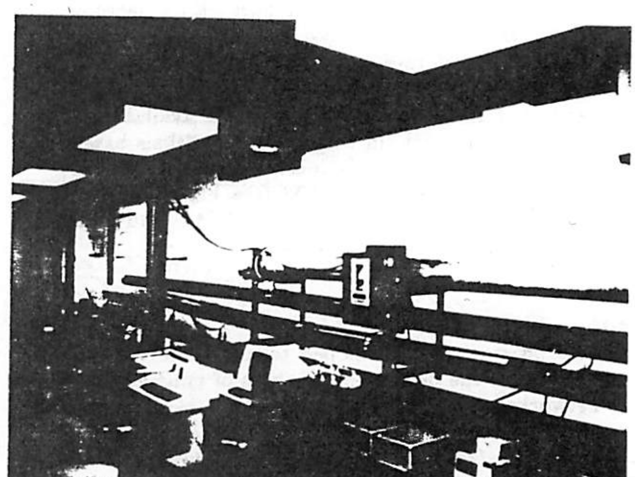

Figure 3. The Laboratory Model of the MVN.