VENTEX: An Expert System for Mine Ventilation Systems Analysis

Ranka Stanković, Nikola Lilić, Ivan Obradović

VENTEX - EKSPERTNI SISTEM ZA ANALIZU RUDNIČKIH VENTILACIONIH MREŽA

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Stanković Ranka, Lilić Nikola, Obradović Ivan
Rudarsko-geološki fakultet u Beogradu

Sadržaj - *Analiza sistema za ventilaciju je komleksan proces, koji bazira na proračunu brojnih parametara, koji se odnose na: stanje mreže, provetrenost, stabilnost sistema, gubitke vazduha, klimatske uslove, gasno stanje, ugroženost od požara i opasne prašine. Navedeni problemi se uspešno rešavaju paketom SimVent, ali potpuno razumevanje i korišćenje dobijenih rezultata zahteva angažovanje iskusnog specijaliste iz oblasti ventilacije. Rešenje je nađeno u kreiranju ekspertnog sistema VENTEX, čija je baza znanja formalizacija ekspertskog znanja iz oblasti ventilacije rudnika. U radu je prikazana metodologija projektovanja sistema VENTEX, organizacija baze znanja, struktura ES i korisnički interfejs. Navedeni su i primeri davanja ocena postojećeg stanja ventilacione mreže, kao i preporuka za poboljšanje ventilacije rudnika ukoliko su ocene loše. Za specifikaciju sistema je korišćena objektno-orijentisana analiza, pa OOA model čine: objekti - okviri, slotovi - atributi, metode - demoni i pravila. VENTEX se koristi samostalno ili u kombinaciji sa prethodno razvijenim softverom za simulaciju ventilacije rudnika SimVent. Oba sistema rade u Windows okruženju. Za izradu VENTEX-a je korišćena objektno orijentisana školjka za razvoj ekspertnih sistema KAPPA-PC, zasnovana na konceptu okvira.*

Abstract - *Problems relating to mine ventilation system analysis are usually of a very complex nature. They involve the estimation of numerous interdependent parameters pertaining to the network status, ventilation status, ventilation system stability, air current losses, climate conditions, gas state, fire risk and dangerous dust pollution risk. The solution of these problems relies to a great extent on numerical methods. With the development of computer technology these methods were incorporated as numerical routines in software packages, such as the mine ventilation simulation system SimVent. However all potentials of these numerical packages can be fully exploited only by specialists in the field. Besides procedural knowledge encapsulated by numerical routines, the complexity of the subject matter requires a high level of expert knowledge and experience. This knowledge pertains to the heuristics experts use when they apply numerical methods and takes a symbolic form, very often that of rules, being thus declarative in its character. Hence both procedural and declarative knowledge are needed for a successful solution of problems in mine ventilation systems analysis. This paper describes an approach to mine ventilation system analysis which is based on a symbolic upgrading of the numerical SimVent system. The result is VENTEX, a coupled expert system incorporating both procedural and declarative knowledge, that offers the possibility for a more profound exploitation of the available software at an expert level. The paper presents the strategy of mine ventilation system analysis used in the VENTEX system and it formalization using a modification of the object-oriented analysis model as well as the basic architecture of the system and outlines the main features of the implemented system.*

1. INTRODUCTION

One of the most important and also most complex problems encountered in mine ventilation systems analysis is the evaluation of the general ventilation state of the mine. An appropriate and reliable solution for this problem is vital for the safety of the working process in mines with underground exploitation. Contemporary mining theory already operates with a number of mathematical methods which can be used to solve mine ventilation problems. These methods are used in current engineering practice with the help of appropriate software products. One of them is the software package SimVent for mine ventilation simulation developed at the Faculty of Mining and Geology of the University of Belgrade (Lilić, Stanković, and Obradović, 1994). This package, which enables the simulation of air flow distribution in a mine, the heat and fire transmission mechanisms, distribution of gas and distribution of respirable mineral dust, is currently being used by the "Soko" mine in Serbia.

Numerical software products in mine ventilation need expert knowledge and experience to be fully exploited. This knowledge consists of rules and heuristics experts use when they apply numerical methods. The knowledge-based approach developed by artificial intelligence (AI) offers a possibility of incorporating knowledge in software systems.

In the late 80's it has been recognized that expert system methods and techniques can be very useful in solving mine ventilation problems. The early 90's already brought a number of knowledge-based applications in mine ventilation systems analysis (Ramani, Prasad and Swaminathan, 1990, Hartman, 1992, Oral and Durucan, 1993). This paper describes the salient features of VENTEX, an expert system for the analysis and evaluation of the general mine ventilation state, developed at the Faculty of Mining and Geology of the University of Belgrade. VENTEX was developed by upgrading the existing numerical package SimVent with declarative knowledge representing the rules and heuristics mine ventilation experts use in solving the problem at hand.

Section 2 of this paper outlines the problem-solving strategy through a hierarchical decomposition of the main goal of the VENTEX system, the evaluation of the mine ventilation state, and the formalization of this strategy by means of a modified object-oriented analysis (OOA) model. The system structure and the main architectural components as well as their relation to the goal decomposition are described in Section 3. Implementation issues are discussed in Section 4, followed by a conclusion in the last section.

2. A FORMALIZATION OF VENTILATION STATE EVALUATION PROBLEM-SOLVING

The analysis and evaluation of the mine ventilation state in VENTEX is based on numerical algorithms provided by SimVent, on one hand, and heuristics formulated by mine ventilation experts, on the other. Thus, a combination of procedural and declarative knowledge is needed in order to solve the problem at hand successfully. The main goal of the system is the evaluation of the general ventilation state of the mine. This global goal can be subdivided into a hierarchical structure of subgoals where each of these subgoals can be viewed as the estimation of a set of parameters which determine the general mine ventilation state. The parameters are grouped according to their relevance into the following categories: the ventilation network, aeration of the mine, stability of the ventilation system, air loss, climate conditions, mine gas state, fire risk and harmful dust risk. Once the parameter values are obtained the estimation process for the general ventilation state of the mine may begin. During this process, the importance, i.e. significance of each particular parameter must be taken into account. The estimation task is further complicated due to the fact that two sources of information exist: the SimVent numerical routines and the user. The hierarchical decomposition of the main goal into subgoals, representing the problem-solving strategy, makes it easier to cope with the complexities and to coordinate the use of numerical routines on one hand, and the knowledge incorporated in the system on the other.

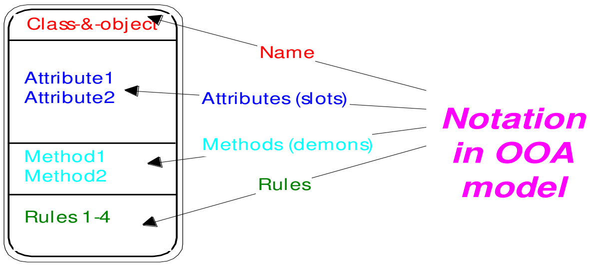

Figure 1. Modified Coad-Yourdon object

The strategy for evaluation of the general ventilation state of the mine is formally represented using a modification of the Coad-Yourdon object-oriented analysis (OOA) model (Coad and Yourdon, 1991). In the classical model every real world entity is represented by a class (object) consisting of its name, attributes and methods pertaining to the procedures related to the object. In order to incorporate declarative knowledge, this model was modified by including a new (fourth) element, featuring the production (IF-THEN) rules related to an object in the model /Fig. 1/. Thus both the procedural and declarative knowledge related to a class object could be represented. Such a modified OOA model was the used for the representation of the mine ventilation evaluation strategy as well as the other objects in the system and their mutual relationships /Fig. 2/. The inheritance relations between hierarchically connected objects representing elements of the strategy are given by full lines, while the exchange of messages between classes is represented with dotted lines. The model was the basis for the implementation of the system in an object-oriented expert system shell.

3. ARCHITECTURE OF THE VENTEX

The main components of the VENTEX system are basically a consequence of the fact that this system represents an upgrade of the existing numerical software simulation package SimVent. Hence, VENTEX contains the “classical” elements of an expert system: the knowledge base, an inference engine, the user interface and a working memory, but also a module for the interface with SimVent numerical routines, the simulation routines themselves, and a data base used by these routines /Fig. 3/.

The main purpose of the *user interface* is to provide means for a successful dialogue, i.e. an exchange of information between the user and the system. It is the user interface that enables VENTEX to obtain all the necessary information from the user, on one hand, and that transforms system’s results and conclusions into information the user can understand, on the other.

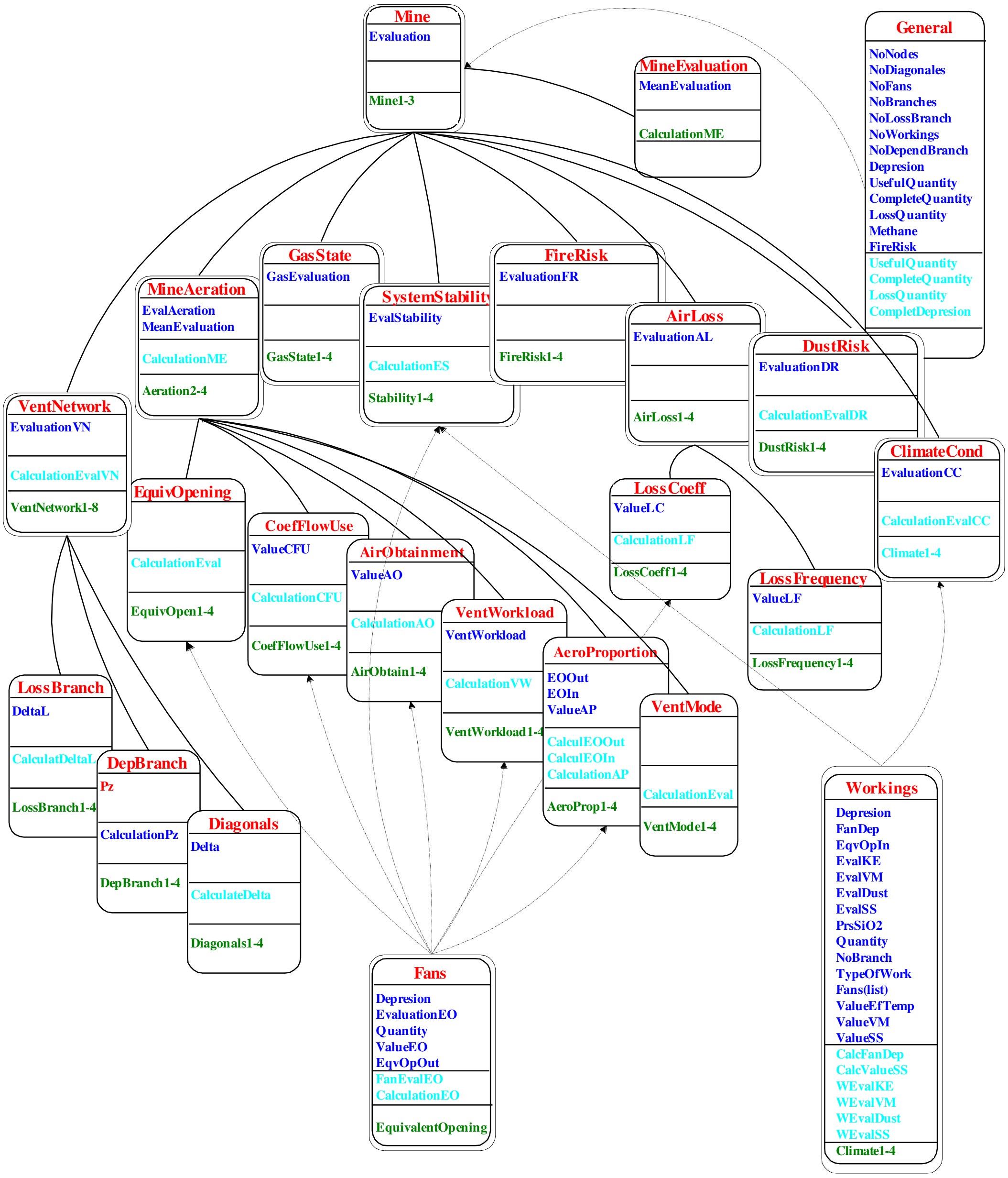

Figure 2. Modified OOA model of the mine ventilation state evaluation

The VENTEX *knowledge base* is a formalization of the mine ventilation expert’s knowledge. Knowledge in expert systems basically consists of facts and heuristics which can be represented by means of rules, frames, semantic networks and other formalisms. Since knowledge is the key factor in problem solution and decision making, the quality and usability of an expert system is basically determined by the accuracy and completeness of its knowledge base. The selection of the representation formalism is very important and plays a significant role in knowledge-based design.

The problem solving strategy is realized by the *inference engine*. This reasoning mechanism infers conclusions on basis of the knowledge from the knowledge base and the available information pertaining to the problem at hand. The inference engine stores intermediate results in the *working memory*.

The VENTEX system was developed as a knowledge-based (symbolic) upgrade of the SimVent numerical package and it thus belongs to the category of *coupled numerical and symbolic systems* (Kowalik, 1986). The successful implementation of a coupled system requires the solving of a number of complex problems in order to obtain efficient communication between the symbolic and the numerical part of the system. In order to cope with this problem a separation of processes in coupled systems into independent modules is suggested. Furthermore, information interchange, i.e. communication among modules is strictly defined and reduced to the lowest possible degree. Communication between two modules is allowed only through their previously defined external links, while all implementation details remain "hidden" within the module itself. This requirements can be met successfully through the modified object-oriented approach proposed in this paper: the units of modularity become objects which contain attributes, i.e. structures that represent their internal data, methods - procedural components, i.e. implementations of operations specified by external links, and rules declarative components of the system featuring related expert knowledge.

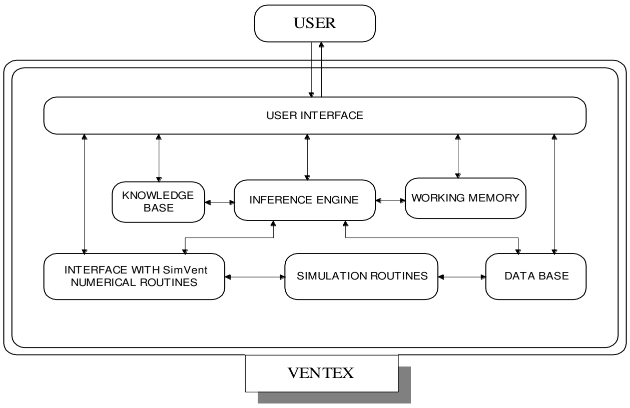

Figure 3. Architecture of the diagnostic expert system VENTEX

The object/attribute approach is often mapped into the frame/slot paradigm, which can then be used for its implementation (Rich, 1983). In this paradigm both logical statements and procedures are represented by frames, which makes it a flexible and open concept for knowledge representation. In the same way object characteristics are represented by their attributes, frame characteristics are represented by their slots. Namely, the slot values describe the attributes of the object (event or effect) represented by the frame, as well as the relations of this frame to other frames in the system. The frame system is a hierarchical structure incorporating inheritance as an important property. Slots of a frame can obtain values in several different ways. Since the frame system is a hierarchical structure, the slot values can be filled in on of the three following ways:

- through direct input,
- by activating a procedure attached to the slot that calculates its value,
- by inheriting all properties (and consequently slot values) from a slot at a higher level of hierarchy.

The object-oriented approach implemented through frames system presents a suitable formalism for the proposed decomposition of the ventilation state evaluation problem, since they both posses a hierarchical structure. The outlined features of the knowledge base should make both the coordination knowledge within the knowledge base, and the communication between the symbolic and the numerical part of the VENTEX system easier.

4. IMPLEMENTATION ISSUES

VENTEX was developed using the KAPPA-PC applications development system. KAPPA-PC is a MS Windows application which provides a wide range of tools for constructing and using applications by means of a high-level graphical environment. In the KAPPA-PC system, the components of the domain are represented by objects that can be either classes or instances within classes. The relationships among the objects in a model can be represented by linking them together into a hierarchical structure. Thus the modified OOA model based on the strategy for evaluation of the general ventilation state of the mine could be easily mapped onto the appropriate elements of KAPPA-PC.

Object-oriented programming tools within KAPPA-PC were used to endow VENTEX objects with methods which specify what objects can do. First the objects and methods for the knowledge base were constructed. Then systems were also constructed that specify how objects should behave, and that can reason about the objects by using rules. Each rule specifies a set of conditions and a set of conclusions to be made if the conditions are true. The conclusions may represent logical deductions about the knowledge base or specifications of how it changes over time. Each rule is a relatively independent module, which made it possible to build the reasoning systems gradually, rule by rule.

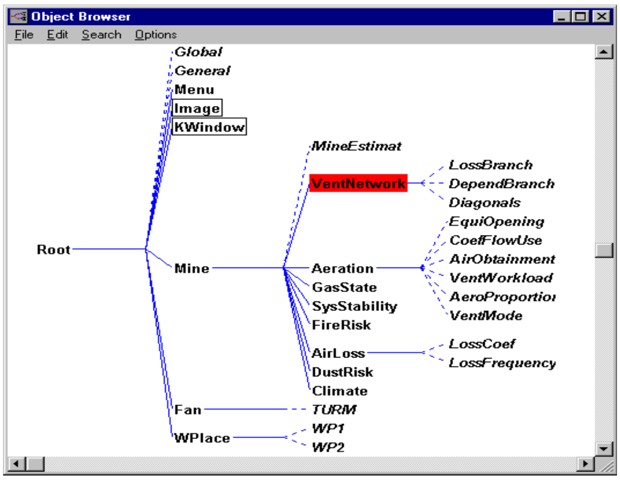

Figure 4. The KAPPA-PC Object Browser for VENTEX

The classes and objects of the modified OOA model shown in /Fig. 1/ were transformed to classes and instances in the KAPPA-PC system. Thus the classes and object from /Fig. 1/ are represented by KAPPA-PC classes and instance as shown in the system's object browser /Fig. 4/. The object browser also shows some of the classes KAPPA-PC always generates, such as Root, Image and KWindow .

Classes/instances are described by means of the class/instance editor. Slots represent values of class attributes while methods (demons) in the class/instance editor account for both methods and IF-THEN rules related to a class in the modified OOA model. As an example the Diagonals class is given in /Fig. 5/. The class has a parent class VentNetwork and three slots. Two methods are listed. One is for a numerical procedure (CalculateDelta) calculating the value of the attribute Delta and the other for rules (EstimateVN) evaluating the mine ventilation state.

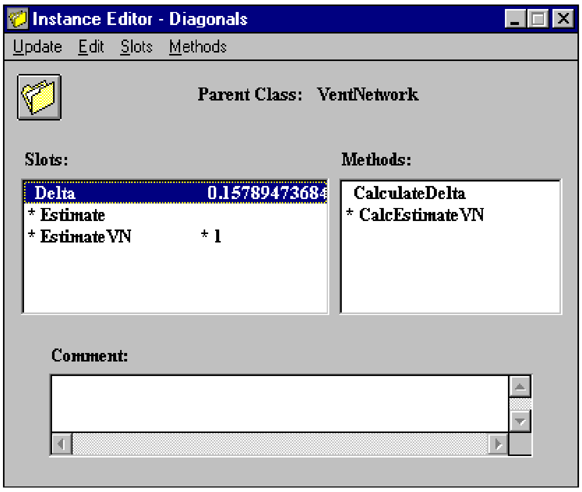

Figure 5. The Diagonals Class

Slot facets are defined by means of the slot editor. In /Fig. 6/ the Diagonals:Delta slot is shown. It represents an attribute of the Diagonals class, namely the ratio of the number of diagonals to the total number of branches.

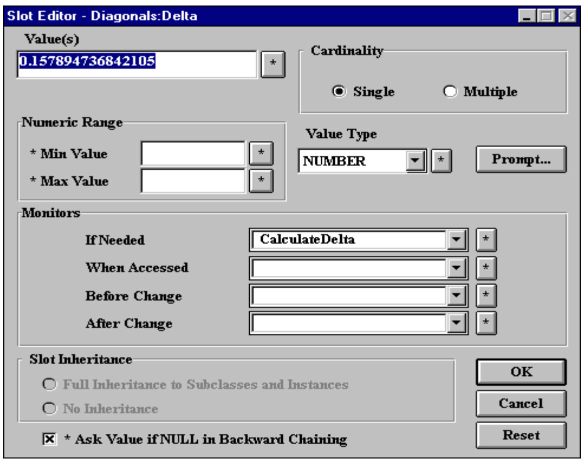

Figure 6. The Diagonals:Delta Slot

Besides the usual slot facets such as type, min-max value and cardinality the slot features a call for a specific method (Calculate Delta) which will be activated if the specified condition (IfNeeded) is met. It means that the CalculateDelta method will be activated if at any point the value of the slot is required and the slot is empty (with no value assigned).

It has already been mentioned that methods in KAPPA-PC can also describe more complex knowledge within the object which takes the form of IF-THEN rules. An example of such a method is CalcEstimateVN which estimates the state of the ventilation network on basis of several parameters and their mutual relationships /Fig. 7/.

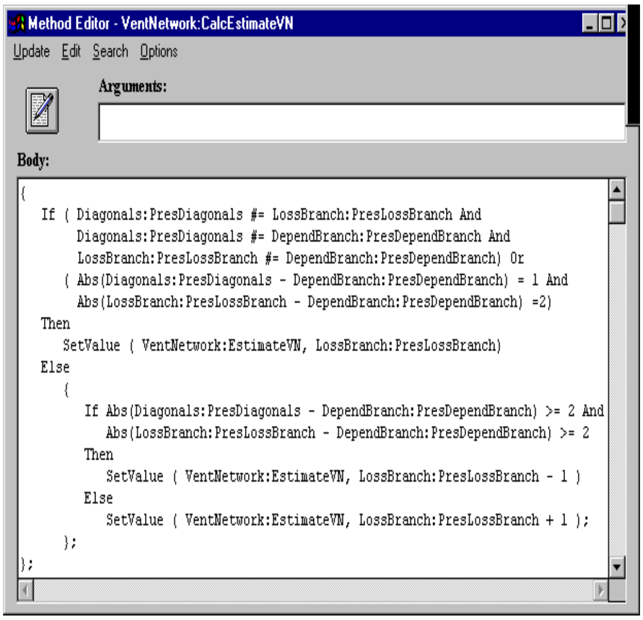

Figure 7. The CalcEstimateVN Method

Since all rules in the system do not have to be related to particular objects KAPPA-PC offers the possibility of specifying rules independently, using a rule editor as shown in /Fig. 8/.

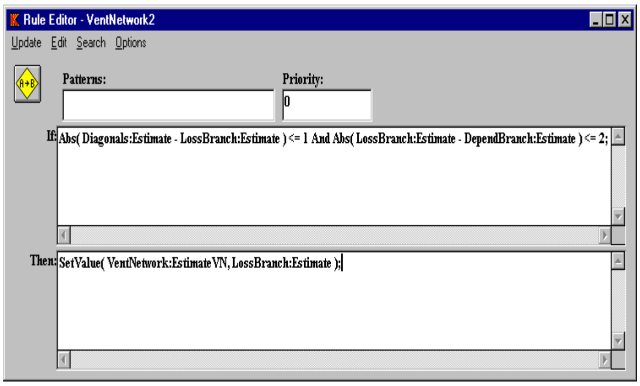

Figure 8. Rule VentNetwork2

The rules incorporated in VENTEX system relate ventilation conditions in Yugoslav mines. They are the result of the experience gained through many years of research and mine ventilation monitoring in the Department for Ventilation and Mine Safety on the Faculty of Mining and Geology in Belgrade.

The problem-solving process in VENTEX unfolds by means of the KAPPA-PC backward chaining inference engine. Goals to be satisfied by backward chaining are defined by means of the goal editor as shown on /Fig. 9/. The goals in VENTEX pertain to estimation of different parameter values. A decomposition of the goal VentNetwork into subgoals is illustrated in /Fig. 9/.

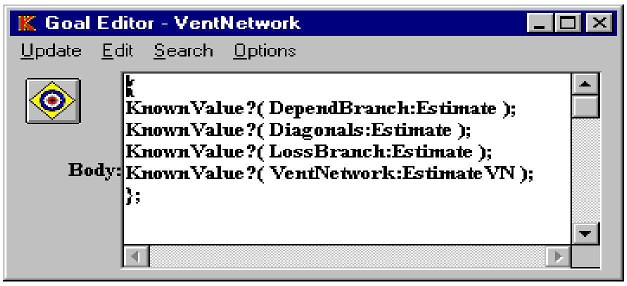

Figure 9. The VentNetwork Goal

Goals can also be generated and modified within methods. This feature makes it possible to create new rules or modify existing ones dynamically, during system operation. An example, if the modification of the WPlaceVM rule is given in /Fig. 10/.

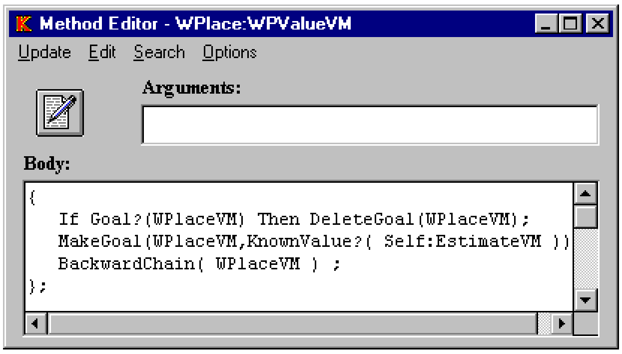

Figure 10. The WPlace:WPValueVM Method

The interface developed for VENTEX in KAPPA-PC fully exploits the GUI (graphical user interface) technology available for MS Windows applications /Fig. 11/. It enables a straightforward and easy manipulation of input data and control over parts of the problem-solving process. It also offers suggestions and recommendations to the user which could contribute to the improvement of the overall performance of the mine ventilation system.

5. CONCLUSION

In this paper first a hierarchical decomposition of the ventilation state evaluation analysis problem was proposed. As a consequence, the solution of this complex problem which is based on the estimation of a number of mutually dependent parameters is greatly facilitated. Then a possible approach to the solution of this problem through the development of an expert system was outlined. The aim of such a system is to generate an overall evaluation of the general ventilation state of the mine as well as suggestions for the improvement of particular characteristics of the ventilation system.

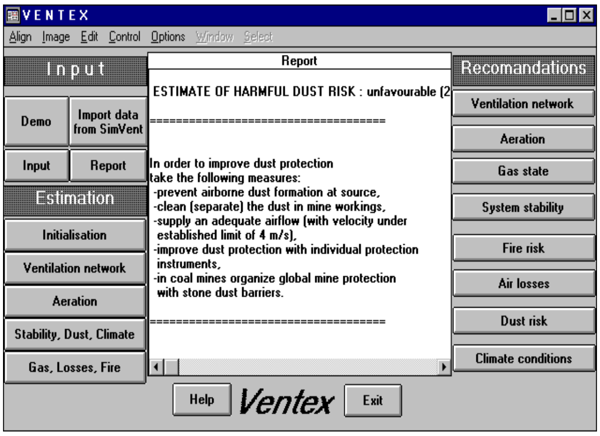

Figure 11. The VENTEX interface

The approach to the realization of the expert system is based on a symbolic upgrading of an existing numerical software package. It has been argued that the conceiving of system structure as an object-oriented frame system represents a natural approach bearing in mind the coupled numerical-symbolic nature of the system aimed at solving a hierarchically structured problem. The obtained system structure of the VENTEX system was realized in KAPPA-PC..

References

[1] Coad,P., and Yourdon,E., (1991), *Object-Oriented Analysis*, Second edition Prentice Hall, Englewood Cliffs, New Jersey.

[2] Durkin,J., (1994), *Expert Systems, Design and Development*, Macmillan Publishing Company, New York.

[3] Hartman,H., (ed.), (1992), *SME Mining Engineering Handbook*, Society for Mining, Metallurgy, and Exploration, Inc. Littleton, Colorado, 2nd Ed. Vol.1.

[4] Lilić,N., Stanković,R., and Obradović.I., (1994), "A software package for mine ventilation simulation in damage conditions", *Ecologica*, special issue 1, 9-12, (in Serbian).

[5] Kowalik,J.S., (ed.), (1986), *Coupling Symbolic and Numerical Computing in Expert Systems*, North-Holland, Amsterdam.

[6] Oral,M.K. and Durucan,S., (1993), "An Integrated Environment Simulation System for Mine Ventilation Management", XXIII International Symposium APCOM, Montreal, 327-334, Vol.II.

[7] Ramani,R.V., Prasad,K.V.K. and Swaminathan,M., (1990), "Implementation of KBS for Mine Ventilation Planning and Design", XXII International Symposium APCOM , Berlin, 329-352, Vol.II.

[8] Rich,E., (1983), *Artificial Intelligence*, McGraw-Hill, New York.