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A KNOWLEDGE-BASED APPROACH TO MINE VENTILATION PLANNING IN YUGOSLAV MINING PRACTICE

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Ventilation system analysis is a complex process based on the calculation and analysis of numerous parameters. These problems can be successfully solved by the SimVent numerical package, but a full understanding and use of the obtained results require the involvement of an experienced specialist in the ventilation field. The solution was found in the creation of a hybrid system INVENTS, whose knowledge base represents a formalization of the expert knowledge in the mine ventilation field. In this paper, we present the design methodology of the hybrid system INVENTS, as well as system structure and user interface.

1. Introduction

The methodology of mine ventilation planning and design in contemporary Yugoslav mining theory and practice differs substantially from the traditional approach. Novel approaches take full advantage of the possibilities offered by computer hardware and software that are at the disposition of mine engineers. Software packages for mine ventilation simulation are now playing a key role in the process of mine ventilation planning and design.[7–10]

In this paper, we propose a six-step approach to the solution of mine ventilation design problem, the design itself of the network being just one of these steps. The approach is illustrated by a component diagram on Fig. 1 showing the interconnection of the six steps or phases.

The first phase of the outlined approach is data acquisition. In contemporary Yugoslav, mining practice extensive and exhaustive investigations of ore deposits have been undertaken in order to collect as much information as possible for the planning and design of technological systems for deposit exploitation.

System planning is an introductory activity for the design process. In the planning phase, the key relations that have to be taken into account during the design phase are identified. The first activity in the mine ventilation planning and design process is the establishment of a basic or initial ventilation network and an appropriate database containing all necessary data related to this network. The design process is followed by the implementation of the mine ventilation system as well as its maintenance, aimed at securing the highest possible level of system effectiveness.

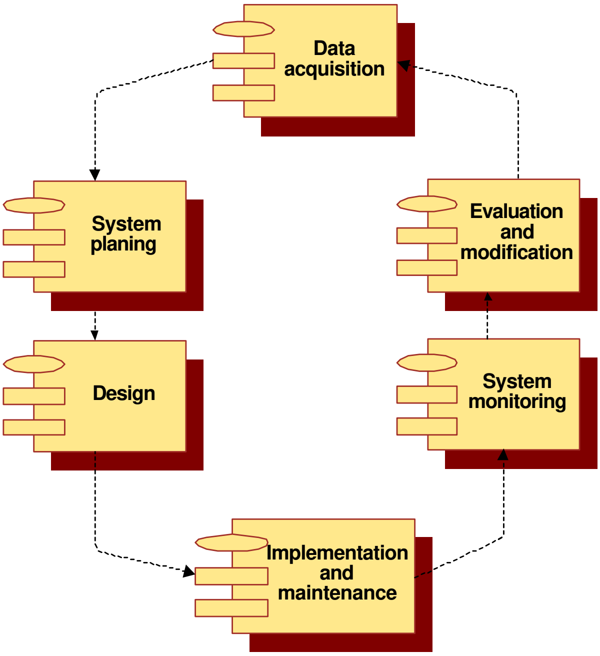


Fig. 1. Component diagram of the novel design concept.

The final phase in the outlined approach is mine state evaluation and possible modification. All parameters of mine ventilation obtained through monitoring must be compared with designed parameters and when differences are identified, specific changes have to be made in the planning process.

The software implementation of the approach relies on available mine ventilation software as well as on the possibilities offered by the coupling of various artificial intelligence (AI) methods in the solution of complex problems that cannot adequately be solved by a single AI method. The core of the implemented approach is a hybrid intelligent system (HIS) developed with the help of available AI software libraries.

2. The INVENTS Hybrid System

As we have already mentioned, the outlined approach to mine ventilation planning and design served as the basis for the development of a hybrid system named INVENTS (INtegrated VENtilation System).[4] Figure 2 illustrates the place of INVENTS has in our approach to mine ventilation planning and design where it interacts with CFD (Computational Fluid Dynamics) software. INVENTS is a complex structure composed from several integrated software packages: ResNet, SimVent and VENTEX (Fig. 3). These packages integrate both well known numerical optimization and various artificial intelligence methods, which allow for an introduction of a knowledge base, thus upgrading existing mathematical models with heuristics and knowledge acquired through engineering practice. We will give an overall view of the way the system functions in this section and describe its components in more detail in the following.

The system outlined in Fig. 3 permits an aerodynamic definition of mine ventilation network based on psychrometric recordings and the use of ResNet, an appropriate software package. The actual aerodynamic resistance of mine workings are established and consequently, the configuration of the basic network. In this process CFD software can be used in parallel for a detailed analysis of necessary airflow volumes for the ventilation of individual workplace locations, often featuring a very complex geometry. The application of CFD software improves the reliability and quality of the apprehension and verification of air amounts needed for the ventilation of workplaces. Beforehand, determination of air amounts relied on engineering experience or an analogy with similar examples encountered in practice and specific empirical relations defined.

After the input data for planning and design of the entire ventilation system have been analyzed and checked in detail, INVENTS offers a number of possibilities for the analysis of mine ventilation networks with the help of its ventilation simulation component SimVent. Among these possibilities, the most important are the following:

- determining air flow distribution throughout the ventilation network,
- simulation of climate conditions in mine workings,
- modeling of fire incidence in the ventilation network, as well as
- gas distribution in the network.

The results obtained through SimVent's simulations can be exported to VENTEX — a diagnostic expert system that performs the analysis of these results according to a number of criteria. The expert analysis by VENTEX yields an estimate of the validity and effectiveness of the ventilation system followed by suggestions for its improvement. The architecture of the system and the software environment in which the system was developed enable a dynamic communication between different phases of the outlined approach. This yields practically unlimited possibilities for the testing of different modifications of the system until a final solution is reached, which will satisfy all the criteria that were set.

3. Software Implementation of INVENTS

INVENTS, the hybrid intelligent system for planning and analysis of mine ventilation and its components:

- ResNet, the software package for aerodynamic definition of mine ventilation networks,
- SimVent, the software package for ventilation simulation in complex mine ventilation networks, and

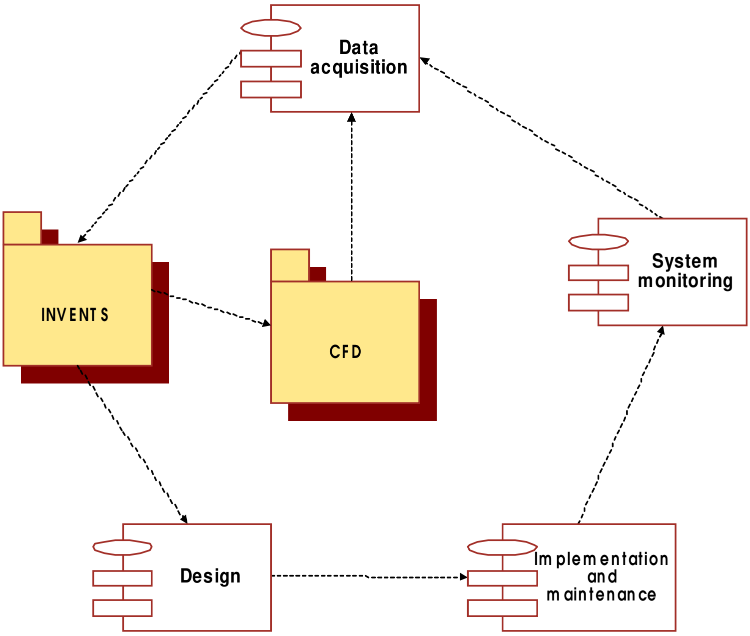


Fig. 2. Global concept of mine ventilation planning and design.

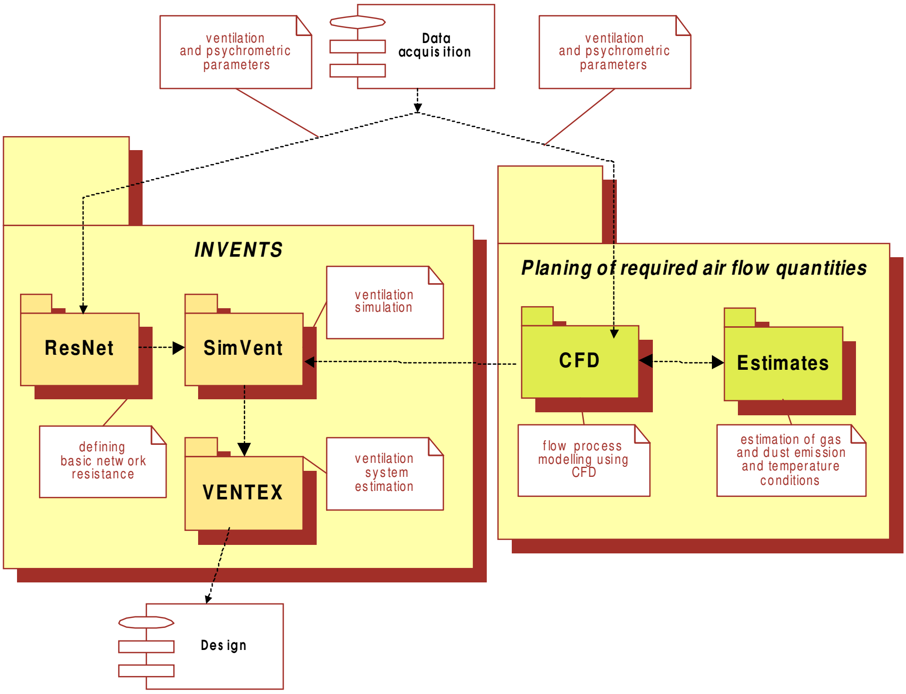
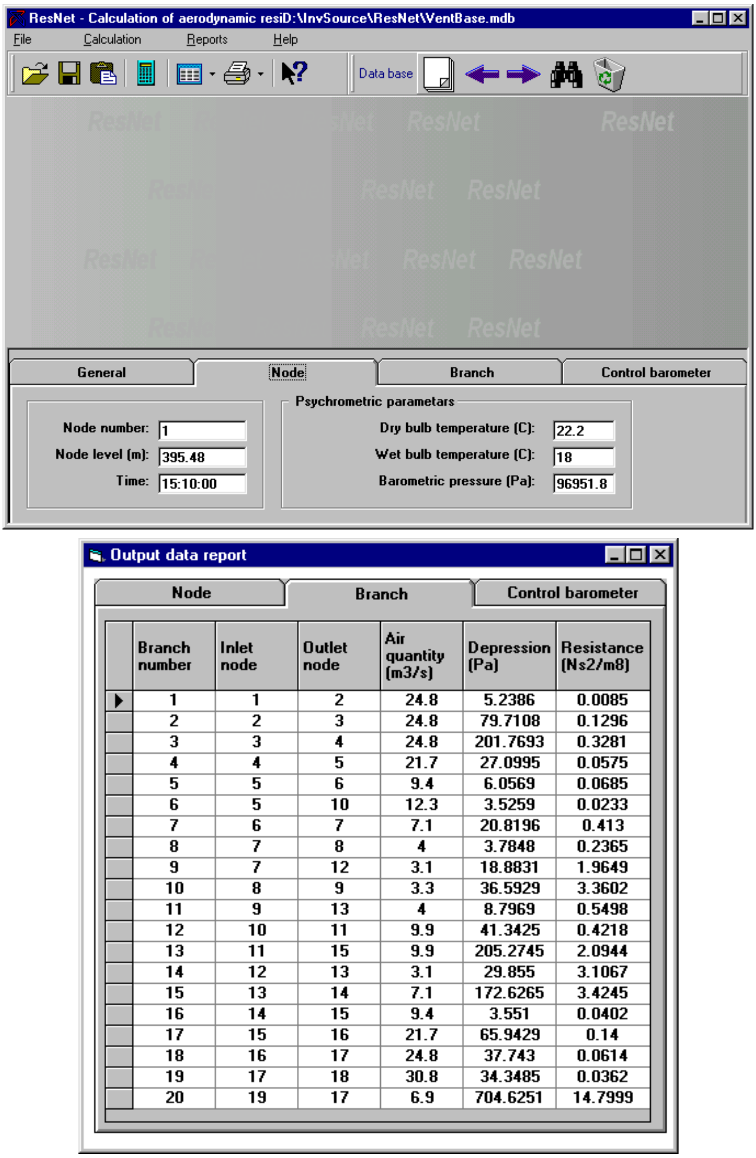


Fig. 3. Architecture of the hybrid system INVENTS.



Node number: 1
Node level (m): 395.48
Time: 15:10:00

Psychrometric parametars

Dry bulb temperature (C): 22.2
Wet bulb temperature (C): 18
Barometric pressure (Pa): 96951.8

Branch number	Inlet node	Outlet node	Air quantity (m3/s)	Depression (Pa)	Resistance (Ns2/m8)
1	1	2	24.8	5.2386	0.0085
2	2	3	24.8	79.7108	0.1296
3	3	4	24.8	201.7693	0.3281
4	4	5	21.7	27.0995	0.0575
5	5	6	9.4	6.0569	0.0685
6	5	10	12.3	3.5259	0.0233
7	6	7	7.1	20.8196	0.413
8	7	8	4	3.7848	0.2365
9	7	12	3.1	18.8831	1.9649
10	8	9	3.3	36.5929	3.3602
11	9	13	4	8.7969	0.5498
12	10	11	9.9	41.3425	0.4218
13	11	15	9.9	205.2745	2.0944
14	12	13	3.1	29.855	3.1067
15	13	14	7.1	172.6265	3.4245
16	14	15	9.4	3.551	0.0402
17	15	16	21.7	65.9429	0.14
18	16	17	24.8	37.743	0.0614
19	17	18	30.8	34.3485	0.0362
20	19	17	6.9	704.6251	14.7999

Fig. 4. Examples of interface forms for the ResNet software package.

- VENTEX, the diagnostic expert system for the analysis of ventilation systems are developed for IBM PC and compatible computer systems.

The object-oriented approach in system structuring and modeling[1] was used as the strategy for defining the model of processes and data in the development of INVENTS. In this paper, UML (Unified Modeling Language) as a standard language for visualization, specification, constructing and documenting of data on software was adopted for the software development analysis phase. The task of visual modeling of the system is to define the objects and logic of the real system using the adopted graphic notation.

ResNet is a software that performs the calculation of aerodynamic resistance values on basis of measured ventilation parameters in underground mining workings. The determined aerodynamic resistance values are the necessary basis for all further analyses of a concrete ventilation system. Figure 4 illustrates the ResNet software package through its interface forms. The outlined software permits an aerodynamic definition of mine ventilation network based on barometric method, i.e. the establishment of actual aerodynamic resistance of mine workings and thus the configuration of the basic network.

SimVent is a software package that enables mine ventilation simulation in underground exploitation of ore deposits. The global structure of the mathematical model used as the basis for SimVent is composed of the following:

(i) a block for the analysis of air flow and pressure distribution in the ventilation network,
(ii) a block for the analysis of climate conditions in mine workings,
(iii) a block for temperature and heat depression analysis in fire incidence conditions, and
(iv) a block for gas distribution analysis in the ventilation network,

which are interactively connected. SimVent can be used for the analysis of ventilation system stability in mine defense and rescue plan verification, within mine ventilation services, design and research companies.

We chose Visual Studio 6.0 as the programming environment for the development of SimVent. The Unified Modeling Language (UML) has been used as the most appropriate notation, and the system's architecture was conceived in the form of a three-level class diagram. This architecture supports well the object-oriented approach in model development for complex applications. Its main characteristic is a separation of the domain model, which is represented by business services and data services, from user interface, represented by user services.

Figure 5 depicts the three-level class diagram architecture of SimVent.

The six classes identified within the user services of SimVent represent its interface forms. They are used for data manipulation (entering, viewing and searching the data), depiction of the ventilation system linear scheme, graphical presentation of results and communication with other modules in the INVENTS hybrid system. The classes related to user services communicate with classes at the business service level by sending messages that initiate the execution of specific applications.

Two interface forms belonging to user services are shown in Fig. 6. They enable text search and editing, picture presentation, communication with the database, creation of business diagrams, etc.

We identified seven classes within the business services: three of them are Visual Basic application modules and the remaining are used for drawing and manipulating

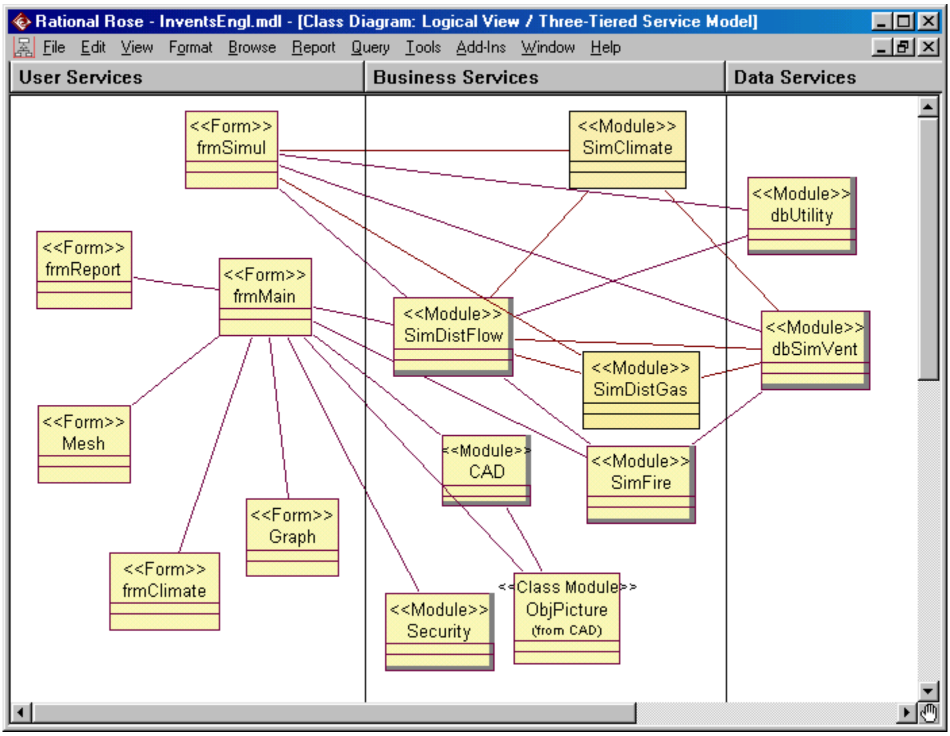


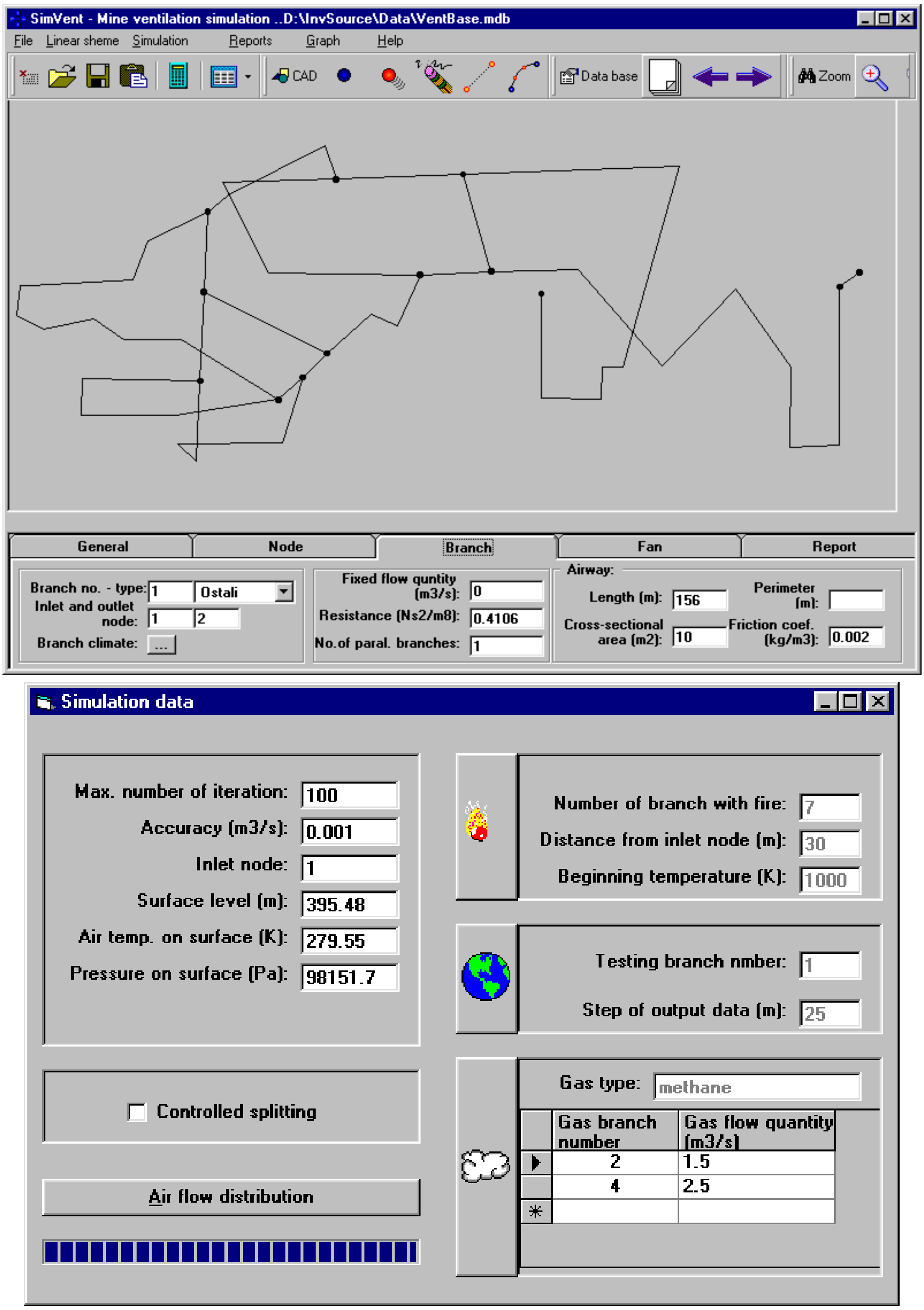
Fig. 5. Three level class diagram architecture of SimVent.

the linear ventilation scheme picture. In Fig. 7, an activity diagram depicts the dynamic model of one of these classes — the Simulation-Fire class. This class includes specific procedures based on the mathematical model of airflow in the event of fire incidence in complex mine ventilation networks.

Data services procure data maintenance, data access and modification functions. The database that SimVent operates with is a part of the global, integrated database of INVENTS. SimVent's data services thus have two classes: dbUtility, containing functions related to the global database and dbSimVent, with functions related to data specific for SimVent.

In view of the complexity of the INVENTS system's global model data structure, which had to model all relevant parameters of complex mine ventilation networks, the design and realization of database was executed in the MSAccess relational database management system. The system offers safe data archiving for complex data models as this one, as well as all procedures for data manipulation. The use of SQL as a standard query language for data manipulation secures the openness of the hybrid system INVENTS for a connection with different environments.

Figure 8 depicts the structure of the database part relevant to SimVent through the MSAccess Relationships panel.



Branch no. - type: 1 Ostali

Inlet and outlet node: 1 2

Branch climate: ...

Fixed flow quntity (m3/s): 0

Resistance (Ns2/m8): 0.4106

No.of paral. branches: 1

Airway:

Length (m): 156

Perimeter (m):

Cross-sectional area (m2): 10

Friction coef. (kg/m3): 0.002

Max. number of iteration: 100

Accuracy (m3/s): 0.001

Inlet node: 1

Surface level (m): 395.48

Air temp. on surface (K): 279.55

Pressure on surface (Pa): 98151.7

☐ Controlled splitting

Number of branch with fire: 7

Distance from inlet node (m): 30

Beginning temperature (K): 1000

Testing branch nmber: 1

Step of output data (m): 25

Gas type: methane

	Gas branch number	Gas flow quantity [m3/s]
▶	2	1.5
	4	2.5
*		

Fig. 6. Interface forms of SimVent.

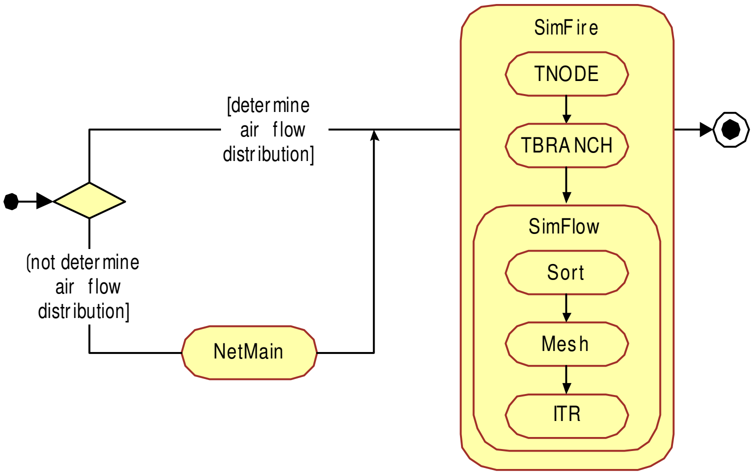
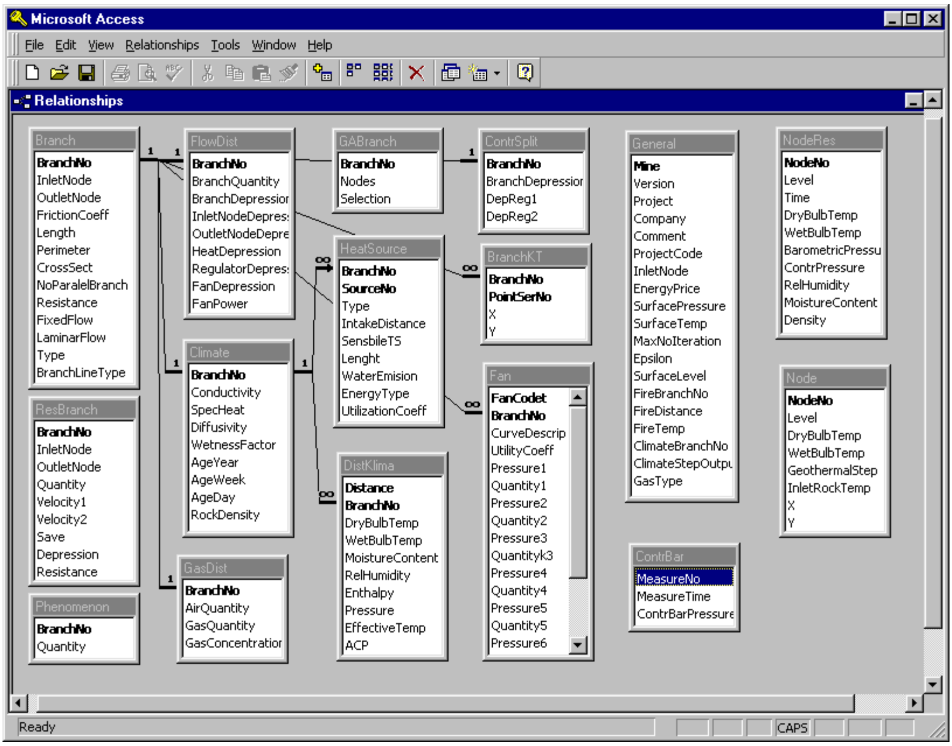


Fig. 7. Activity diagram for the dynamic Simulation-Fire class model.



Branch: BranchNo, InletNode, OutletNode, FrictionCoeff, Length, Perimeter, CrossSect, NoParalelBranch, Resistance, FixedFlow, LaminarFlow, Type, BranchLineType

ResBranch: BranchNo, InletNode, OutletNode, Quantity, Velocity1, Velocity2, Save, Depression, Resistance

Phenomenon: BranchNo, Quantity

FlowDist: BranchNo, BranchQuantity, BranchDepressior, InletNodeDepres:, OutletNodeDepre, HeatDepression, RegulatorDepres:, FanDepression, FanPower

Climate: BranchNo, Conductivity, SpecHeat, Diffusivity, WetnessFactor, AgeYear, AgeWeek, AgeDay, RockDensity

GasDist: BranchNo, AirQuantity, GasQuantity, GasConcentratior

GABranch: BranchNo, Nodes, Selection

HeatSource: BranchNo, SourceNo, Type, IntakeDistance, SensbileTS, Lenght, WaterEmision, EnergyType, UtilizationCoeff

DistKlima: Distance, BranchNo, DryBulbTemp, WetBulbTemp, MoistureContent, RelHumidity, Enthalpy, Pressure, EffectiveTemp, ACP

ContrSplit: BranchNo, BranchDepressior, DepReg1, DepReg2

BranchKT: BranchNo, PointSerNo, X, Y

Fan: FanCodet, BranchNo, CurveDescrip, UtilityCoeff, Pressure1, Quantity1, Pressure2, Quantity2, Pressure3, Quantityk3, Pressure4, Quantity4, Pressure5, Quantity5, Pressure6

General: Mine, Version, Project, Company, Comment, ProjectCode, InletNode, EnergyPrice, SurfacePressure, SurfaceTemp, MaxNoIteration, Epsilon, SurfaceLevel, FireBranchNo, FireDistance, FireTemp, ClimateBranchNo, ClimateStepOutpu, GasType

ContrBar: MeasureNo, MeasureTime, ContrBarPressure

NodeRes: NodeNo, Level, Time, DryBulbTemp, WetBulbTemp, BarometricPressu, ContrPressure, RelHumidity, MoistureContent, Density

Node: NodeNo, Level, DryBulbTemp, WetBulbTemp, GeothermalStep, InletRockTemp, X, Y

Fig. 8. Data base structure of SimVent.

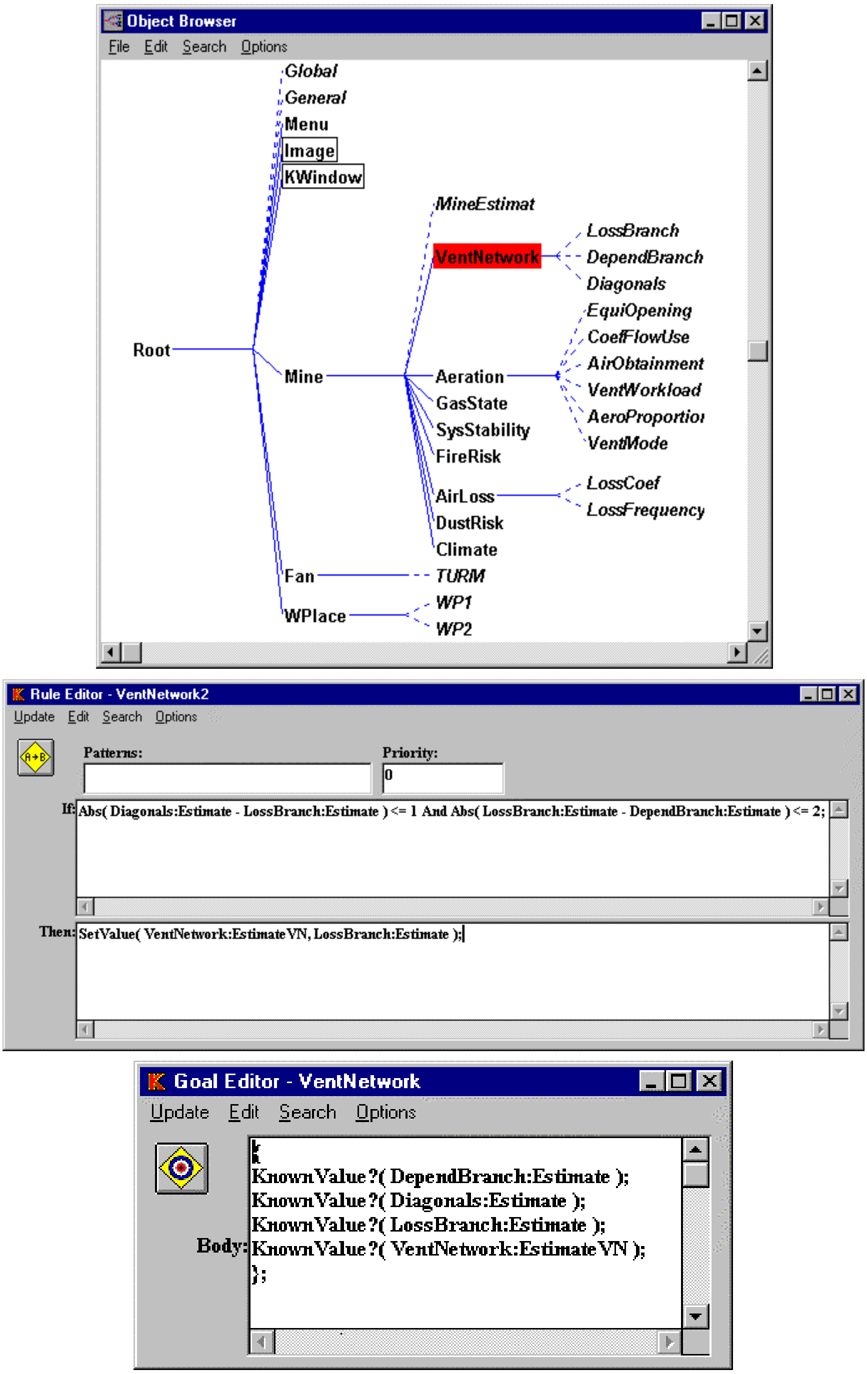
The VENTEX[5] system was developed as a knowledge-based (symbolic) upgrade of the SimVent numerical package and it thus belongs to the category of *coupled numerical and symbolic systems*.[3] The numerical part consists of SimVent simulation routines and the symbolic part of the mine ventilation expert's knowledge.

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 previously defined external links, while all implementation details remain "hidden" within the module itself. These requirements can be met successfully through the modified object-oriented approach proposed in this paper with the object as the modular unit of the system. Objects consist of attributes (structures representing their internal data), methods (procedural components), and rules (declarative components).

The object/attribute approach is often mapped into the frame/slot paradigm, which can be successfully used for its implementation.[2,11] In the same way, the characteristics of an object are represented by its attributes, and frame characteristics are represented by its slots. Namely, slot values describe attributes of the object represented by the frame and its relations to other frames (objects) in the system. The object-oriented approach implemented as a system of frames offers 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 alleviate both the coordination of knowledge within the knowledge base and the communication between the symbolic and the numerical part of the VENTEX system.

VENTEX was developed using an expert systems shell, the KAPPA-PC applications development system. KAPPA-PC is a MS Windows application that provides a wide range of tools for constructing and using applications by means of a high-level graphical environment, which generates standard *C* code. In the KAPPA-PC system, the components of the domain are represented by objects that can be either classes or instances within classes. The classes and instances in the KAPPA-PC system are shown in the system's object browser (Fig. 9). The relationships among objects in the model are represented by links that connect the objects within a hierarchical structure. These properties of KAPPA-PC enabled an easy mapping of the modified OOA model representing the strategy for the evaluation of the overall mine ventilation state into appropriate elements of KAPPA-PC.

Classes/instances are described using the class/instance editor, while slot facets are defined by means of the slot editor. Slots represent class attributes while methods in the class/instance editor account for both methods and IF-THEN rules related to a class in the modified OOA model.



Priority: 0

If:
```
Abs( Diagonals:Estimate - LossBranch:Estimate ) <= 1 And Abs( LossBranch:Estimate - DependBranch:Estimate ) <= 2;
```

Then:
```
SetValue( VentNetwork:EstimateVN, LossBranch:Estimate );
```

Body:
```
{
KnownValue?( DependBranch:Estimate );
KnownValue?( Diagonals:Estimate );
KnownValue?( LossBranch:Estimate );
KnownValue?( VentNetwork:EstimateVN );
};
```

Fig. 9. VENTEX objects, rule editor and goal editor.

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. 9. 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. The goals in VENTEX pertain to estimation of different parameter values. A decomposition of the goal VentNetwork into subgoals is illustrated in Fig. 9.

The interface developed for VENTEX in KAPPA-PC fully exploits the GUI (graphical user interface) technology available for MS Windows applications. It enables a straightforward and easy manipulation of input data and control over different components of the problem-solving process. Through the interface the system also offers suggestions and recommendations to the user for the improvement of the overall performance of the mine ventilation system (Figs. 12 and 13).

4. The "Soko" Coal Mine: A Case Study

In this paragraph, we will illustrate the use of the INVENTS hybrid system through the analysis and estimation of the ventilation state in the "Soko" coal mine located in the south-east part of Serbia.

The linear ventilation scheme of the "Soko" coal mine and the airflow distribution in the system are given in Fig. 10. The appropriate canonical scheme is given in Fig. 11. The "Soko" mine is being ventilated by a single main mine fan of the TURMAG Gvhv 15-160 type located on the ventilation shaft. The operational parameters of the main fan are the following: the depression of the main fan is 1271.3 Pa and the total air flow volume is 42.4 m^3/s. The workings in the pit are ventilated auxiliary, in a compression mode, with the use of axial fans of the APXE-630 type.

In order to assess the overall mine ventilation system state of the "Soko" mine the following measurements were initially undertaken: temperatures of the dry and wet bulb thermometer and barometric pressure in mine ventilation nodes were measured, as well as the air flow volumes in network branches. The data obtained were used as input for the ResNet software, which calculated aerodynamic resistance of the airflow in network branches. The results are shown in the canonical ventilation scheme in Fig. 11. After the aerodynamic characteristics of the ventilation system were established and the characteristics of the main fan were defined, the simulation routines of SimVent were used for the calculation of airflow volume distribution in the ventilation network. The results obtained by simulation were compared with measured data and a high level of concordance was found.

On basis of all data collected in the system's database, the expertise by VENTEX was initiated. A chain of rules leading to assessments of specific characteristics of the "Soko" mine ventilation system was activated using the appropriate command buttons on the main interface panel (Fig. 12). The report on the results of the expertise was then displayed on the same panel. For example, VENTEX

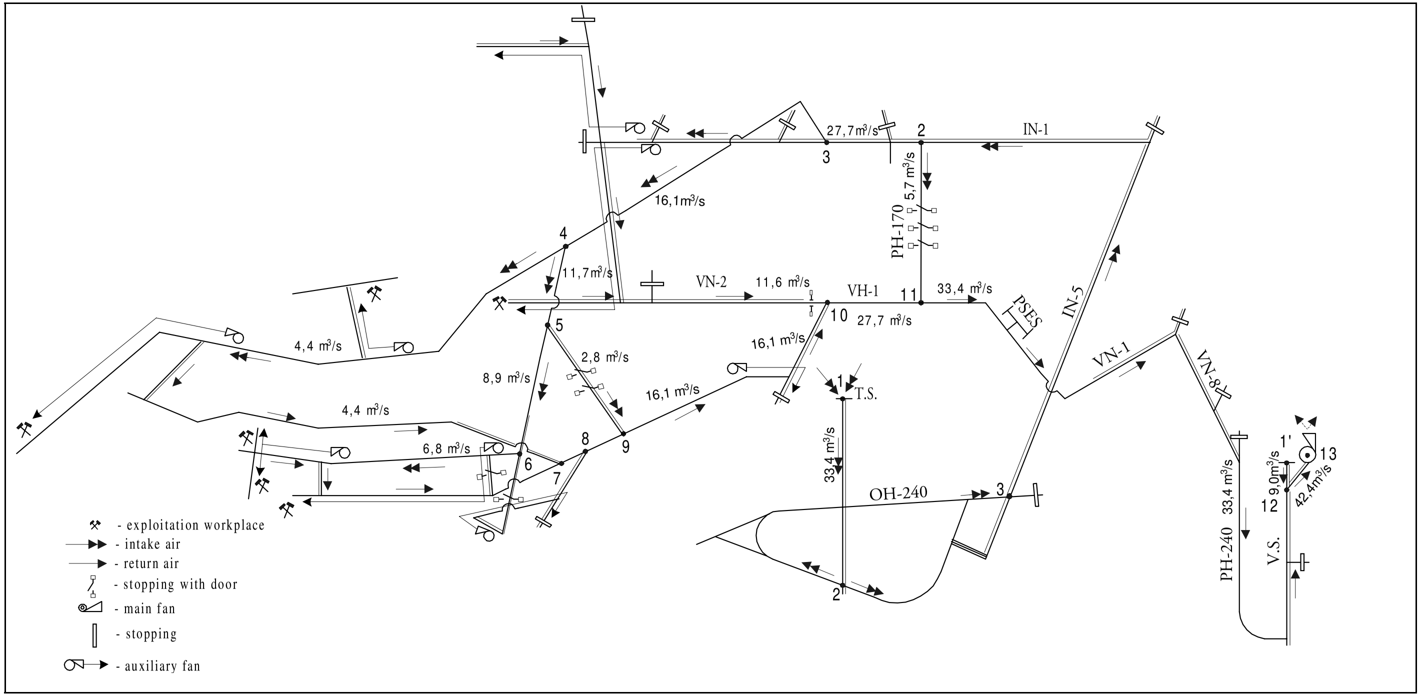


Fig. 10. The linear ventilation scheme of the “Soko” coal mine.

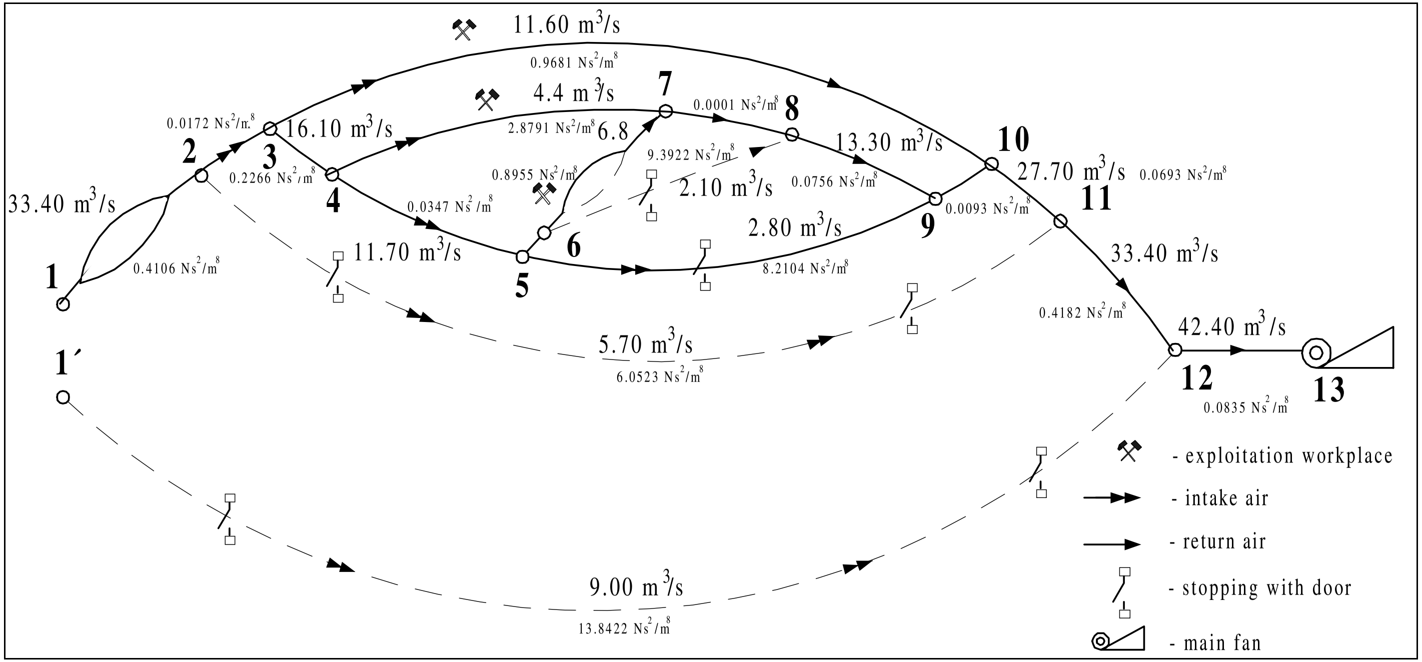
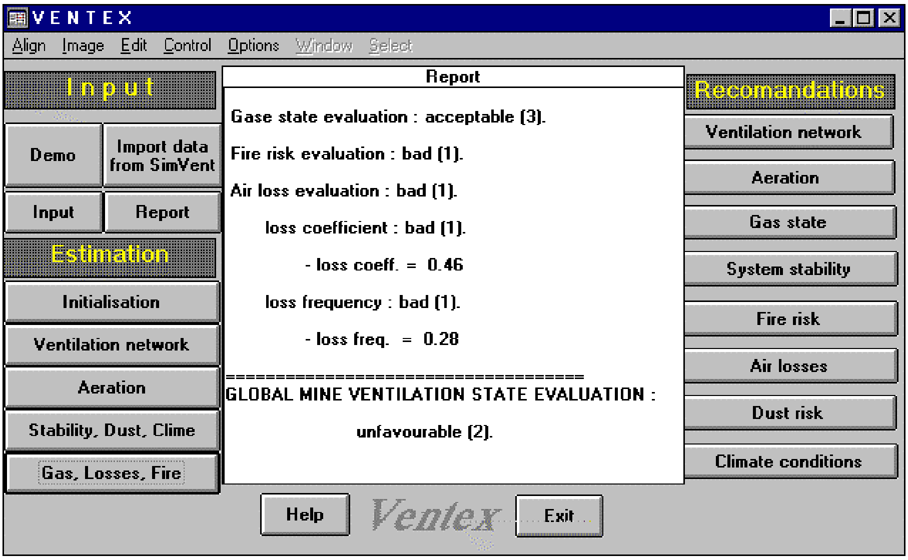


Fig. 11. The canonical ventilation scheme of the “Soko” coal mine.



Gase state evaluation : acceptable (3).

Fire risk evaluation : bad (1).

Air loss evaluation : bad (1).

loss coefficient : bad (1).

- loss coeff. = 0.46

loss frequency : bad (1).

- loss freq. = 0.28

====================================

GLOBAL MINE VENTILATION STATE EVALUATION :

unfavourable (2).

Fig. 12. Main interface panel with the results of the expertise.

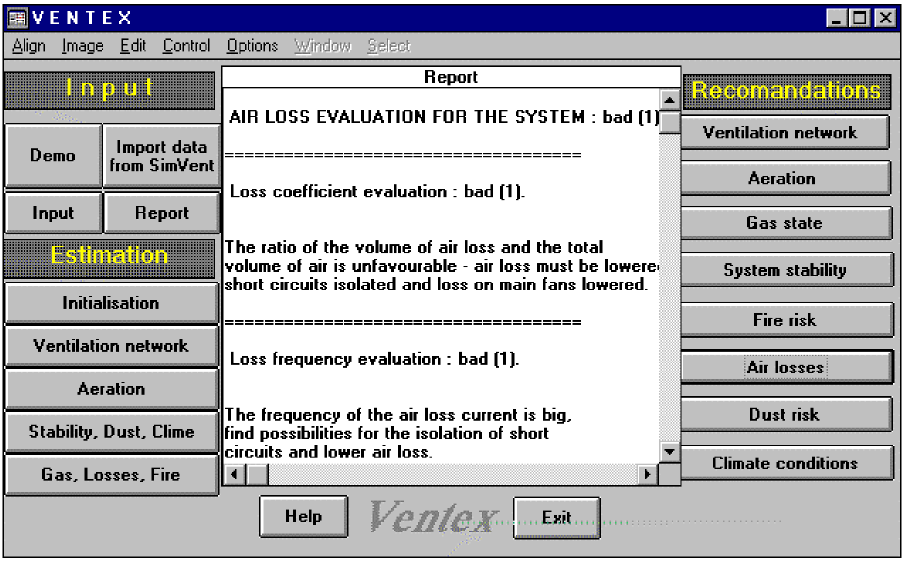
estimated the "gas state" characteristic of the "Soko" mine ventilation system as acceptable, while the "air loss" characteristic was estimated as bad. The latter can be explained by considerable air loss in the system, which influences the effective utilization of the overall air stream, used for the ventilation of the pit.

Total air loss in the ventilation system is very high, reaching 19.6 m^3/s or 46.25% of the total air quantity used for pit ventilation (Figs. 10 and 11). The air loss coefficient is calculated as a ratio of the volume of air loss and the total air flow volume. The value of this coefficient for the "Soko" mine ventilation system was 0.46 (19.6/42.4) which lead to an unfavorable estimation of the air loss characteristic of the ventilation system state. In addition to that, the value of the airflow loss frequency parameter in the system, which is the ratio of the number of air loss branches and the total number of branches, was 0.28 (5/18). This value also leads to an unfavourable estimation of the ventilation system state of the "Soko" mine when air loss is considered.

When all characteristics of the ventilation system were estimated, a new set of rules was activated in order to establish the overall ventilation state of the "Soko" mine. VENTEX estimated the global mine ventilation state as unfavourable.

The expert system gives estimates for all of the ventilation system's characteristics. However, it is well known from current engineering practice that users are often unable to determine solutions for poorly or unfavorably estimated characteristics. In order to solve this problem VENTEX offers suggestions with concrete measures for improvement of certain characteristics as well as the overall mine ventilation state. By simply activating the command buttons in the recommendations group, suggestions are obtained followed by proposal of possible measures. Suggestions for the improvement of unfavorably estimated characteristics of air loss in the "Soko" mine ventilation network are given in Fig. 13.

As we have already mentioned the estimation of the ventilation system state in the "Soko" mine is a consequence of considerable air loss in the ventilation network, as well as of low effective use of the overall air stream, which is only 53.8% of the total air quantity used for pit ventilation. It is also necessary to point out the unfavorable position of a digging in the ventilation network diagonal (branch 6–7, Fig. 11). The analysis of air pressure distribution leads to a conclusion that the location of the exploitation field is under the influence of very low depression of 41.41 Pa compared to the total system depression of 1271.3 Pa, which results in ventilation instability of the diagonal branch 6–7. In specific conditions, this instability in the ventilation network diagonal can provoke an unexpected overturn of the air flow in the branch and consequently, this return air may cause a hazardous situation. In addition to that, such an unfavorable relation of branch and overall depression restricts the available options for possible interventions in the system.



```
AIR LOSS EVALUATION FOR THE SYSTEM : bad (1)
====================================
Loss coefficient evaluation : bad (1).

The ratio of the volume of air loss and the total
volume of air is unfavourable - air loss must be lowere
short circuits isolated and loss on main fans lowered.
====================================
Loss frequency evaluation : bad (1).

The frequency of the air loss current is big,
find possibilities for the isolation of short
circuits and lower air loss.
```

Fig. 13. Suggestions for the improvement of unfavorably estimated characteristics.

The use of the VENTEX expert system in current engineering practice enables prompt interventions and improvement of the efficiency and effectiveness of the ventilation system.

The combination of numerical methods and symbolic reasoning is just one example of the hybrid nature of INVENTS. However, there are other characteristics that qualify INVENTS as a hybrid system. We will illustrate this through determination of the location and size of booster fans in the “Soko” mine ventilation system, using another AI method, the genetic algorithm (GA).[6,12,13] A canonic scheme giving airflow distribution in the “Soko” mine is given in Fig. 14. The location of exploitation workplaces and the position of fans for auxiliary ventilation, in view of technical normative, impose predetermined air flows of 8.1 m^3/s for ventilation system branches 4–7 and 6–7.

The air flow distribution shown in Fig. 14 was determined using the Hardy-Cross method. The results obtained by this method show that the required air distribution can be achieved by building booster fans in branches 4–7 and 6–7 (176.81 Pa and 56.56 Pa respectively, Table 1). However, the analysis of the proposed solution from the engineering point of view makes it clear that the practical realization of this solution is impossible and that alternative solutions are needed. To that end, a genetic algorithm was used.

Binary sequences for two variables were created for the optimization of the ventilation network by means of a genetic algorithm. The variable representing the pressure of the booster fan varies in wide limits of given values from 10 Pa to 600 Pa. The variable related to the location of the fan takes values from a predetermined set of branches where the introduction of booster fans is permitted (branches $1, 3, 5, 7, 9, 14, 15, 16$). The pressure of the main fan is represented by the characteristic working curve of the fan, approximated by a polynomial giving the dependence of the fan depression from air flow.

The SimVent simulator of complex mine ventilation networks based on the Hardy-Cross method was used for the calculation of the fitness for the population.

Table 1. The air distribution obtained by standard method.

Branch No.	Inlet-Outlet Node	R(Ns^2/m^8)	Q(m^3/s)	p(Pa)	NVP(Pa)	pr(Pa)	pbf(Pa)
1	1–2	0.41	34.40	486.00	187.2		
2	1–12	13.05	9.43	1159.63	−78.08		
3	2–3	0.02	28.86	14.33	−269.6		
4	2–11	5.98	5.54	183.39	0		
5	3–4	0.23	18.22	75.25	284.76		
6	3–10	0.97	10.64	109.57	267.85		
7	4–5	0.03	10.12	3.56	−18.02		
8	4–7	2.88	8.10	188.90	−42.04		176.81
9	5–6	0.12	8.24	8.21	−13.63		
10	5–9	8.04	1.89	28.62	−24.15		
11	6–7	0.86	8.10	56.72	−10.56		56.56
12	6–8	9.03	0.14	0.17	−10.58		
13	7–8	0.00	16.2	0.03	0		
14	8–9	0.08	16.34	20.17	0		
15	9–10	0.01	18.22	3.09	26.19		
16	10–11	0.07	28.86	57.74			
17	11–12	0.42	34.4	494.99	−260.53		
18	12–13	0.08	43.83	161.94	−7.17		

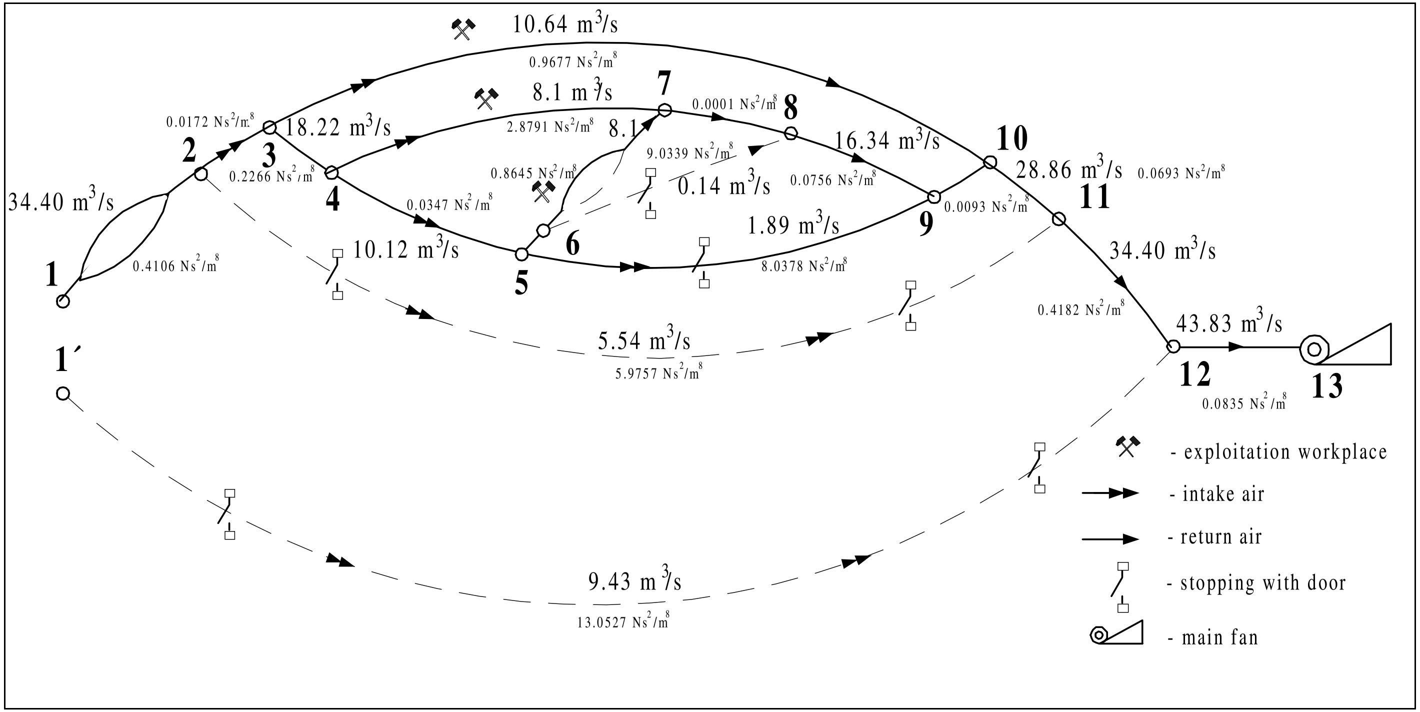


Fig. 14. The air distribution obtained by standard method.

The fitness of possible solutions was determined as the total power engaged by the ventilation system, i.e. the sum of the power of the main and booster fans. The results obtained show that the necessary air distribution can be obtained by introducing an booster fan in branches 9–10, Fig. 15 (Table 2).

When airflow volume distribution is determined in ventilation networks by means of a ventilation simulator, a variation of aerodynamic resistance in branches with predetermined airflows is permitted, in order to secure a balance of airflow in other network branches. If the value of additional resistance in given branches is positive, an air flow regulator is required. If it is negative, an booster fan is required. Taking the preceding into account, the calculation of airflow distribution in the ventilation network has to adhere to the following limitations:

- introduction of booster fans in branches with predetermined air flows is not permitted, and
- recirculation of air through loss paths is not permitted.

If either a negative value of resistance (requiring the introduction of a fan) in a branch with predetermined air flow or a recirculation through a loss branch is detected after the calculation of air flow distribution in the ventilation network, the fitness of that particular solution gets a very high value. This means the possibility that the genetic algorithm will select this solution in the reproduction process is extremely small.

Figure 16 shows the user interface of SimVent realized using Visual Basic and the Gene-Hunter dynamic library, giving a solution for the distribution and size of

Table 2. The air distribution obtained by GA.

Branch No.	Inlet-Outlet Node	$R(Ns^2/m^8)$	$Q(m^3/s)$	p(Pa)	NVP(Pa)	pr(Pa)	pbf(Pa)
1	1–2	0.41	34.93	500.85	187.2		
2	1–12	13.05	9.24	1115.12	−78.2		
3	2–3	0.02	30.67	16.18	−269.6		
4	2–11	5.98	4.26	108.40	0		
5	3–4	0.23	25.52	147.59	284.6		
6	3–10	0.97	5.15	25.63	268.1		
7	4–5	0.03	17.42	10.53	−18.0		
8	4–7	2.88	8.10	188.90	−42.0	0.22	
9	5–6	0.12	12.31	18.33	−13.6		
10	5–9	8.04	5.11	209.97	−24.1		
11	6–7	0.86	8.10	56.72	−10.5	103.36	
12	6–8	9.03	4.21	160.09	−10.6		
13	7–8	0.00	16.20	0.03	0		
14	8–9	0.08	20.41	31.49	0		
15	9–10	0.01	25.52	6.06	26.2		348
16	10–11	0.07	30.67	65.17			
17	11–12	0.42	34.93	510.12	−261.1		
18	12–13	0.08	44.17	164.46	−7.2		

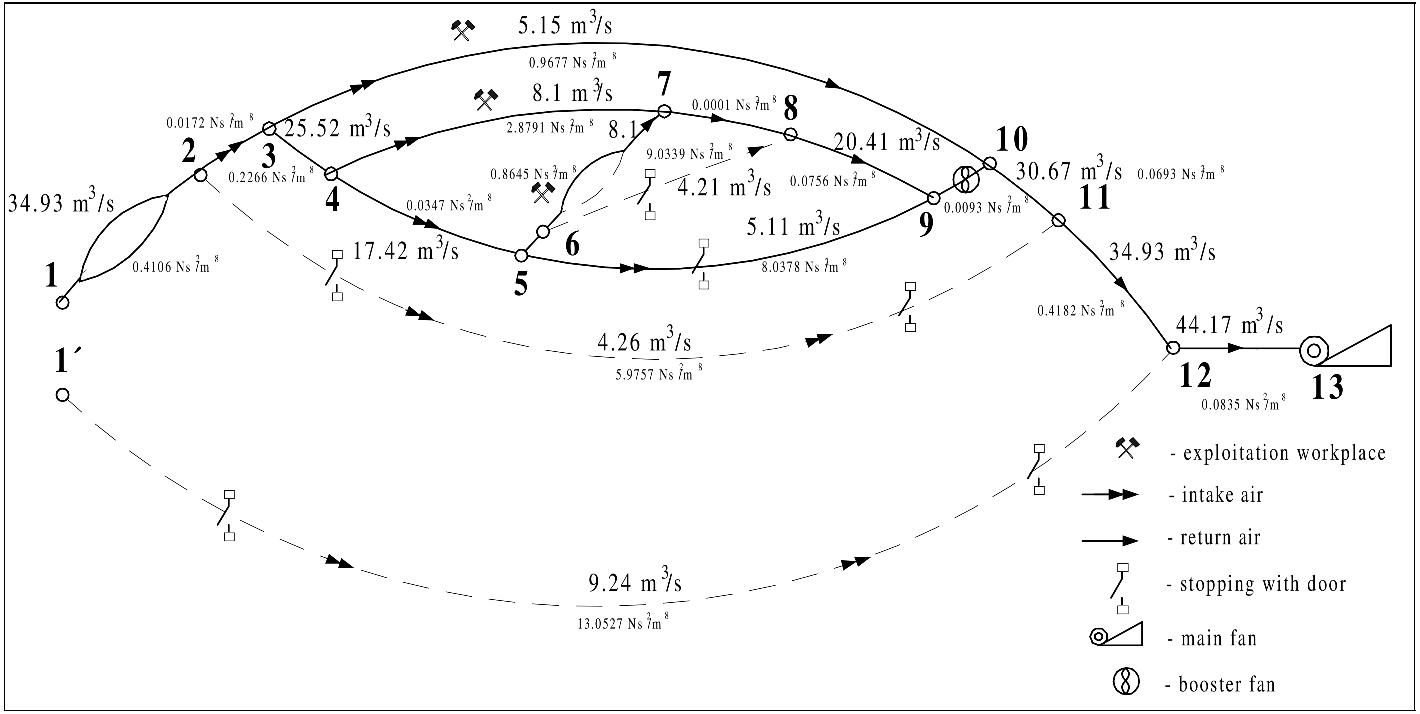
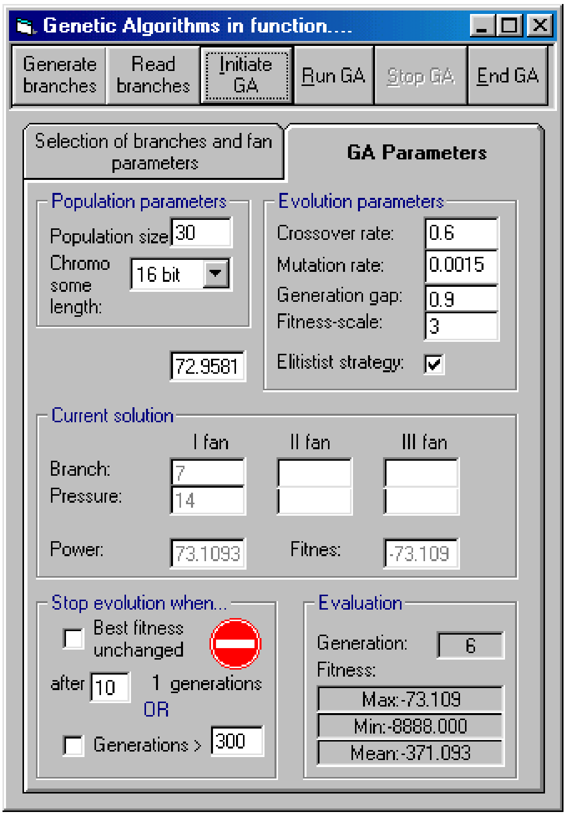


Fig. 15. The air distribution obtained by GA with booster fan location.

the booster fan in the ventilation network, which satisfies given limitations. This panel also shows the basic parameters used in the genetic algorithm.

The described approach can take into account to a great extent the various limitations imposed by current engineering practice. The existence of this possibility for obtaining alternative solutions in the selection of the most favorable one is very important especially in view of complex problems often posed by the engineering practice.



Population size 30
Chromosome length: 16 bit
72.9581

Crossover rate: 0.6
Mutation rate: 0.0015
Generation gap: 0.9
Fitness-scale: 3
Elitistist strategy: ☑

	I fan	II fan	III fan
Branch:	7		
Pressure:	14		

Power: 73.1093
Fitnes: -73.109

☐ Best fitness unchanged
after 10 1 generations
OR
☐ Generations > 300

Generation: 6
Fitness:
Max:-73.109
Min:-8888.000
Mean:-371.093

Fig. 16. The user interface of SimVent with basic parameters used in the GA.

5. Conclusion

In this paper, we presented an approach to the solution of the mine ventilation planning and analysis problem using a hybrid system composed of three entities: a package for aerodynamic definition of mine ventilation networks — ResNet, a package for ventilation simulation in complex mine ventilation networks — SimVent and a diagnostic expert system for ventilation system analysis — VENTEX.

Besides the architecture of a hybrid system for mine ventilation planning and analysis the software implementation of this system is described, which comprises a symbolic upgrade of the existing simulation packages SimVent and ResNet. The development of a frame-based knowledge base presents a natural approach to the realization of a hierarchically structured strategy.

The combination of numerical methods and symbolic reasoning is just one example of the hybrid nature of INVENTS. However, there are other characteristics that qualify INVENTS as a hybrid system. In this paper we illustrated this through determination of the location and size of booster fans in the mine ventilation system, using another AI method — the genetic algorithm.

Both the hybrid nature of the system and the possibilities it offers were illustrated through a case study using field data related to an existing Yugoslav coal mine.

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