

# Conducting a fire modeling study

B. Prosser & R. Ruckman

*Mine Ventilation Services, Inc., Clovis, California USA*

**ABSTRACT:** The application of fire modeling to the development of a ventilation system can greatly enhance the safety aspects of a mine. Improved fire modeling software packages can be used to develop or evaluate emergency management plans that may include location of refuge stations and escape route planning. The authors have conducted several comprehensive fire modeling studies at large underground mining operations. Based upon the results of these studies, an approach to conducting fire model simulations for underground mines was formulated. This paper describes the benefits and purpose of fire modeling studies, as well as limitations of such a study. The analyses start with a risk assessment plan, followed by modeling and development of strategies to minimize probable risks attributed to a fire. An example problem is presented.

## 1 Introduction

The need to improve mine safety has brought about the necessity of fire modeling. Fires can be simulated in the mine and their effects can be viewed incrementally as they build and spread through the mine's ventilation system. These models provide an invaluable tool when used to probe a mine for weaknesses in their emergency application protocols, as well as basic system designs. Although a useful instrument when designing a ventilation system or examining an emergency procedure, fire modeling does not readily lend itself to real-time system simulation.

The fires presented in these studies are based upon a series of assumptions: fuel properties, growth rate, completeness of combustion etc. For the purposes of modeling and predicting worst case fume spreads this is deemed acceptable. However, actual mine fires are likely to be encountered that will not reach the intensity of the modeled fires because of suppression systems, availability of fuel, and other factors.

## 2 Hazards Analysis

The first step in the study is the identification of potential fire locations and fire types and the associated consequences. In order to do this a hazard analysis is necessary.

### 2.1 Fire Consideration Risks and Controls

The authors have performed fire modeling at several large mining complexes. To conduct fire modeling, it is necessary to evaluate the risk of a fire in the mine and its consequence. Sources of an underground mine fire include, but not limited to:

- Mobile diesel equipment
- Conveyor belt material
- Friction from inoperable belt rollers
- Electrical substations
- Compressor stations

- Electric motors on various machines and pumps
- Oil/Lubricant storage areas
- Diesel fueling/storage bays
- Sulfide dust (spontaneous and flash combustion) and at dry dust collectors
- Grinding/welding areas in shops and in mine/plant
- Shop maintenance areas
- General housekeeping (e.g. trash, etc.)
- Electrical cable sheathing
- Powder/explosive magazine
- Lunch room, offices
- Tires and wood in warehouse
- Compressed gas storage facilities

Each of these areas are examined by both operations and engineering personnel. Both the potential frequency of the hazard, number of people affected, potential spread of contaminants, cost of damage, and seriousness of each hazard are determined.

### 2.2 Identification of Hazard

The method followed to identify dangers must be divided into the following main stages:

- List process or sub-process associated with the activity.
- Identify the tasks and/or activities of the process or sub-process.
- For Occupational Health identify the personnel and dangers. With this information, (plus comments) the risk and residual risk (intolerable, moderate, tolerable) are evaluated.
- Identify associated dangers. Identification is made by observing sources of danger associated to the process' tasks/activities.

### 2.3 Evaluation of Risk Assignment

Once dangers have been identified, the magnitude of associated risks must be evaluated to determine if they are tolerable or not. Risk Magnitude (MR) is obtained by

multiplying probability of an incident happening times its consequence, based on the following evaluation charts shown in Tables 1 through 3.

The initial analysis assumes that the probability and consequence estimate does not consider any existing control measures.

Table 1 Consequence Evaluation

	INJURIES – DAMAGES CRITERIA	VALUE
Consequence (C)	<ul style="list-style-type: none"> <li>▪ Death of one or more people</li> <li>▪ Permanent disability</li> <li>▪ Irreparable and extensive damage to materials</li> <li>▪ Production losses that affect forecasted results</li> <li>▪ Stop operations affecting the Company's image</li> </ul>	<b>HIGH</b> 8
	<ul style="list-style-type: none"> <li>▪ Injuries with temporary disability on one or more person</li> <li>▪ Repairable and partial damage to materials</li> <li>▪ Production losses requiring special plans to recover</li> </ul>	<b>MEDIUM</b> 4
	<ul style="list-style-type: none"> <li>▪ Non-disabling injuries</li> <li>▪ Damage to materials not affecting production process</li> <li>▪ Minimum production losses. May be recovered within a short time</li> </ul>	<b>LOW</b> 2
	<ul style="list-style-type: none"> <li>▪ Almost no losses</li> </ul>	<b>INSIGNIFICANT</b> 1

Table 2 Probability Evaluation

	CRITERIA TO ESTIMATE PROBABILITY	VALUE
Probability (P)	Probability that a danger becomes an incident more than 8 times per year	<b>HIGH</b> 8
	Probability that a danger becomes an incident between 2 and 8 times per year	<b>MEDIUM</b> 4
	Probability that the danger becomes an incident once per year	<b>LOW</b> 2
	Probability that a danger DOES NOT become an incident during the year	<b>INSIGNIFICANT</b> 1

Table 3 Risk Magnitude Calculation

		CONSEQUENCE (C)			
		1	2	4	8
PROBABILITY (P)	1	1	2	4	8
	2	2	4	8	16
	4	4	8	16	32
	8	8	16	32	64

#### 2.4 Obtaining Risk Magnitude

Risk Magnitude (MR) to evaluate the risks of accident is obtained by multiplying Probability (P) times

Consequence (C), generating the following chart shown below.

#### 2.5 Control of Safety Measures

Control measures to be taken for classified risks are outlined below:

- *Intolerable risk:*  
The task cannot be carried out without previously applying controls that reduce probability and/or consequence.
- *Moderate risk:*  
Continue with existing controls.
- *Tolerable risk:*  
No additional controls to those already implemented are required. Registered for later evaluation (annual and whenever necessary).

Based on established controls, residual risk is determined, shown on Table 4, upon which the effectiveness of the controls are evaluated and the priority of the fire model development is established.

#### 3 Fire Control Procedures

It is suggested that a standardized matrix be used to describe the adjustment of the ventilation system controls in the case of a fire in the mine. The current operating procedure represents a good initial analysis of the emergency procedures. It is suggested that for each area where a procedure is required, the procedure should include:


- Identification of fire location
- Description of the goal of the fire mitigation plan
- Description of the immediate setup/configuration of the system
- Description of any ancillary expectations such as air reversals, and newly contaminated airways.
- A functional table should be provided to identify the applicable escapeways for personnel, or evacuation to refuge chamber recommendations.

The emergency procedures should be able to be followed without additional input or modification during an emergency.

#### 4 Fire Model Development

The fire simulation software used for this analysis is the MineFire program. This is a Windows XP/2000/NT application that is used in conjunction with the VnetPC 2007 network ventilation simulation software package. It is designed to simulate a mine ventilation system's response to external influences such as fires. The program was developed from the former US Bureau of Mines MFire code, which was modified by MVS solely to increase the number of branches and fans available and to run in the Windows

Table 4 Basic Hazards Analysis Sheet

Approved By: Signature:		Preliminary Hazards Analysis								
Company: Date:										
EVALUATION: Initial <input checked="" type="checkbox"/> Periodical <input type="checkbox"/>								Date Prepared:		
TASKS/ PROCESSES	LOCATION	DANGER	INCIDENT OCCURANCE	RISK EVALUATION			CONTROL MEASURES (what to do)	RESIDUAL RISK		
				P	C	MR		P	C	MR
Refueling LHD	Fuel Bay	Ignition from spillage onto hot surface	Once in past two years	4	8	32	Automatic Fire suppression on equipment	4	4	16

operating environment. This calculation kernel was then adapted into the user-friendly interface of Mine Ventilation Services' VnetPC ventilation network software package.

MineFire performs ventilation network planning calculations and dynamic transient state modeling of ventilation networks under a variety of conditions. The program simulates a system's response to altered ventilation parameters such as: the introduction of fire to the system, varying outside temperatures, changing ventilation control structures, or development of new mine workings. This is accomplished by using data from ventilation surveys together with information determined from known airway dimensions and characteristics. Input data relating to fires is more complex. Heat release rates are calculated based on which types of fuels are burning. The location of the fire in a main intake/exhaust airway or area of low flow is important in determining whether to assume an oxygen-rich or fuel-rich fire, which helps the user determine which parameters to use in the fire simulation. Contaminants are determined based on the stoichiometric reaction of the combustible materials.

Fire is difficult to predict, and the results of a simulation will only be as good as the inputs. It is suggested the ventilation model that is used as the basis for the fire model be developed from a ventilation survey of the mine workings.

#### 4.1 MineFire Specific Model Input Data

MineFire requires a number of parameters in addition to those input into the VnetPC model. Unless the modeler has used the k-factor airway type for setting up the ventilation network, it is likely that the length, perimeter, and area parameters will not be filled in for a majority of the branches in the model. These values must be entered for each branch of the model for the transient time utilities in MineFire to function properly.

Not all of the MineFire Parameters in Branch Data must be entered for successful simulations. In a fire simulation, Conductivity, Diffusivity, and Rock

Temperature are recommended values for each branch in the model.

#### 4.2 Conductivity

This variable is the thermal conductivity for the rock mass. The number is used by the program to define the thermal diffusion to or from the air as it travels through the airway. This will affect airflows in the mine. An understanding of which rock type defines a branch is needed for detailed models. A theoretical average or general value for the rock mass may also suffice. Where the rock type in the model is uniform, large numbers of branches will have the same value. The units for conductivity are Btu/hr×ft×°F or W/m×°C. Tables,

#### 4.3 Diffusivity

Rock diffusivity is obtained through laboratory testing of core samples, or from tables. It defines how quickly heat moves between the rock mass and the air as air moves through a branch. The units for diffusivity are ft<sup>2</sup>/hr or m<sup>2</sup>/sec.

#### 4.4 Rock Temperature

This variable uses the average temperature of the rock for a given branch. Samples can be taken in numerous key locations throughout the mine or the geothermal step can be used to determine average rock temperature at a given elevation. This data is averaged as necessary.

#### 4.5 Fan Data

Fan characteristic curves are registered by entering between two and twenty sets of pressure/airflow quality data points. Fans must be entered with a curve of at least two points for the MineFire program. This allows the program to identify the effects of the changing NVP with respect to the fan characteristic curves.

## 5 Simulation of Mine Fires

Although a fire could conceivably occur anywhere combustible material is located, it would not be practical to model all possible locations. This is why the hazards analysis is used to pare down the list of every conceivable event to a list of more critical events as shown on the flow chart in Figure 1. The fire scenarios are modeled both without any mitigating features (no emergency plan enacted) and with the emergency plan enacted. Based upon the results of the mitigated scenario, additional models may be required to further refine the emergency procedures.

The fire model is a dynamic entity and the model will reflect the growth and spread of the fire fume front on a time incremental basis. Along this basis the fire mitigation procedure can be outlined and the steps can be taken to enact the mitigation procedure sequence.

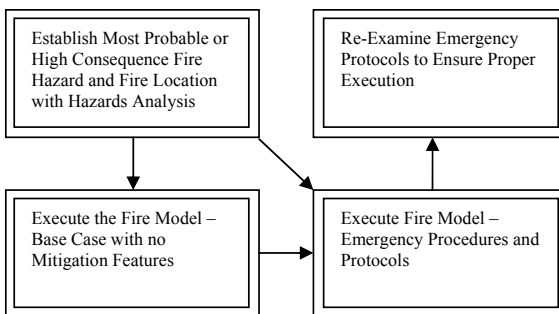


Figure 1 Simulation Steps

## 6 Example

A metal mine, as shown in Figure 2 was chosen for an example of this procedure. A hazards analysis indicated that there was a moderate risk of a fire occurring on the haulage level of the mine. The haulage in this mine consists of an older diesel powered rail haulage system with two locomotives. Approximately 60-m (200-ft) away from the shaft station there is a refueling bay. Due to the procedures and equipment at the mine there exists a possibility that a fire could occur during the refueling process at this location. A ventilation model was developed for the mine and an oxygen rich fire was modeled at this location.

The natural progression of the fumes was examined through the ventilation system with no mitigation features enacted to determine the worst case spread of the fumes through the system. It was determined from this initial model that if the system was to stay configured in this manner the entire mining area would become engulfed in approximately 45 minutes as shown in Figure 3.

The current mine emergency plan at this operation called for all of the fans in the mine to be turned off (system de-energized) in the event of a major fire in the mine, regardless of the fire location. With this plan, a second model was developed that turned the fans off after the fire had burned for approximately 10 minutes. This model showed the fire fume front moved from the haulage level to approximately midway up the ramp and to the beginning of the levels in the mining area. After approximately 20 minutes the fumes started to retract back to the haulage level as the Fresh Air Raise (FAR) started to upcast (due to the buoyancy of the hot fire fumes). At 30 minutes the system reached a steady state with the FAR acting as an exhaust for the fire fumes and the ventilation upcasting the FAR being driven by the heat from the fire as shown in Figure 4.

Another emergency protocol that was proposed was that an isolation door (fire door) be installed at the intersection of the haulage level and the ramp. If a fire was to occur and the fans were switched off, then the isolation door would close. For this model, the isolation door was closed at 10 minutes along with the fans being powered down. Although it can be seen that the isolation door is effective in isolating the haulage level fire from the rest of the system, the benefit of drawing the fumes back to the haulage level is not achieved with the installation of this door. The inter-level ramp remains contaminated as shown in Figure 5.

Based upon this example it may be beneficial to remove the closure of the fire door from the emergency protocol. This example appears to be counter intuitive with the suggestion of leaving a fire door open, but with the extreme interaction of the fire driving the ventilation system it may be possible. However, this is based upon the knowledge of the exact location of the fire. If the fire was located in another portion of the haulage level then the fire door may be more soundly required. This is why multiple scenarios should be modeled along with different variations of the emergency protocol enacted.

## 7 Conclusions

Fire simulation software represents a valuable tool when designing a ventilation system and when developing emergency response protocols and procedures. Once a model is developed it can readily be converted to represent different types of fires and different response strategies. However, it does not easily lend itself to the simulation of real-time fire events. Once a set of emergency protocols is established, they should be tested to ensure their integrity because the application of a fire in a ventilation system is not always intuitive. It is possible to enact protocols that could worsen a fire situation. Thus, great care should be taken in the use of data obtained from a fire model, due to the gravity of things at stake.

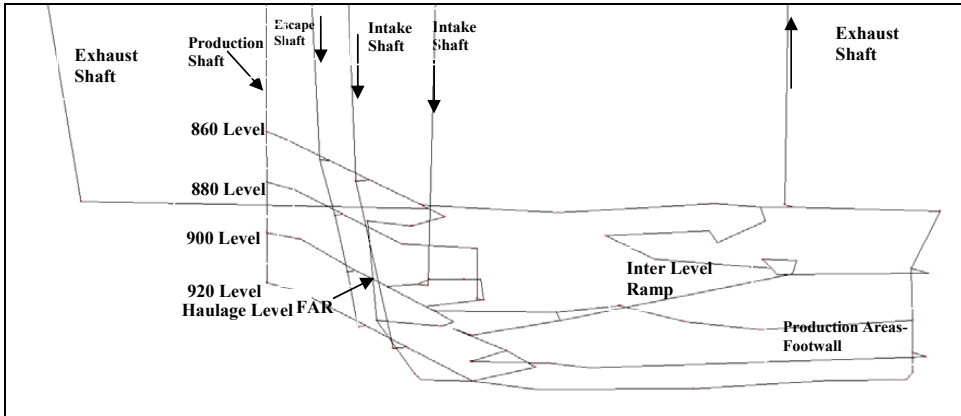


Figure 2 Base Ventilation Model

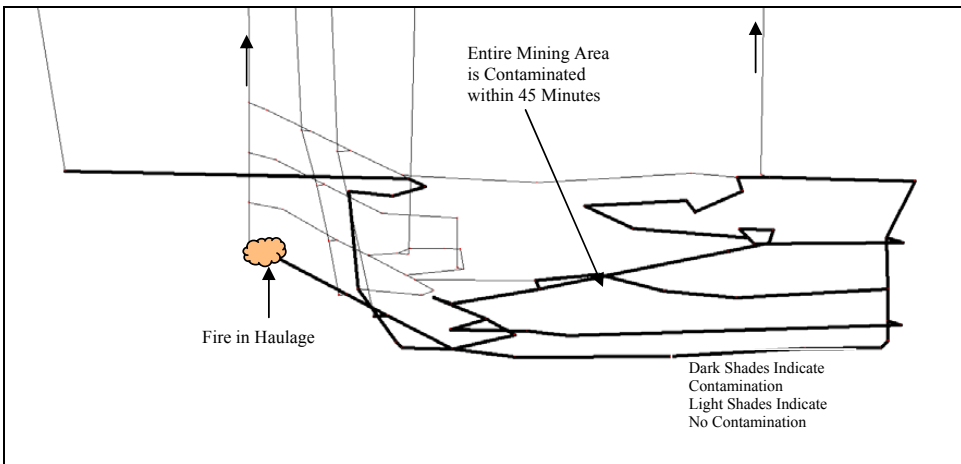


Figure 3 No Mitigation Features (30 minutes burn time shown)

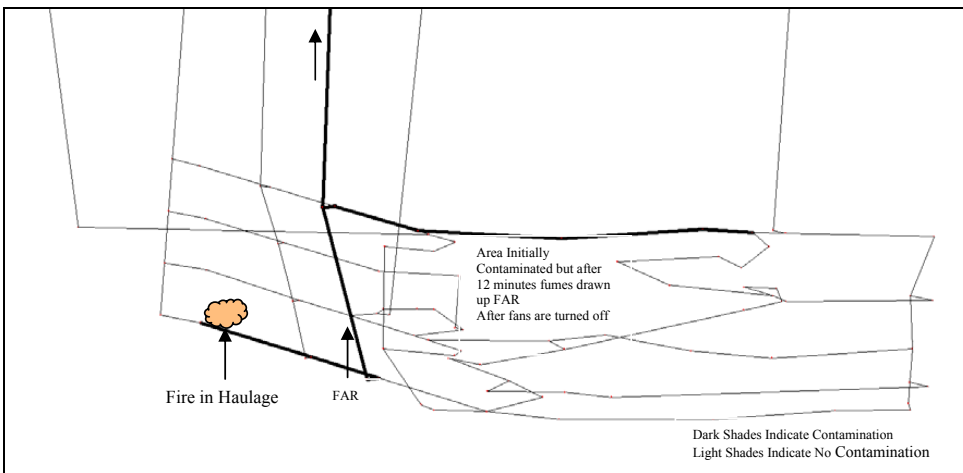


Figure 4 Surface Exhaust Fans Turned off at 10 Minutes (30 minutes burn time shown)

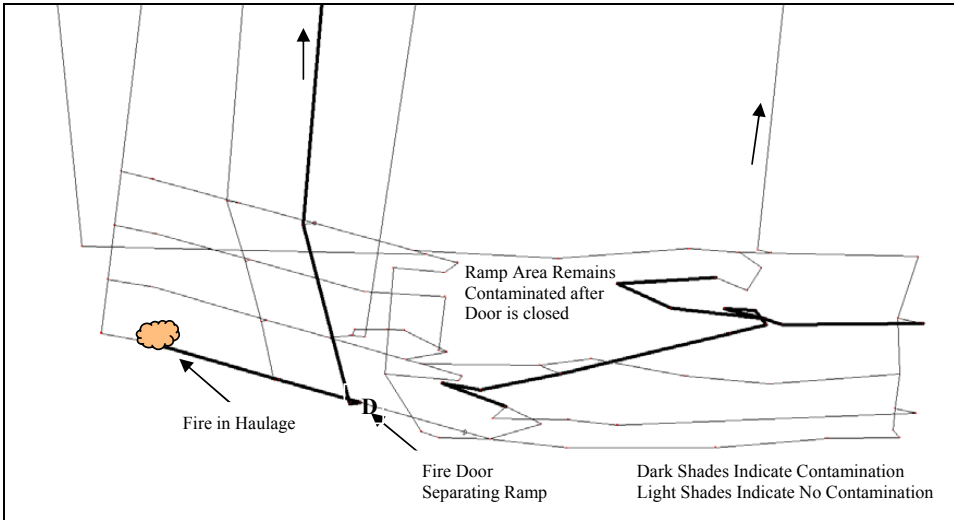


Figure 5 Fans Off and Fire Door Closed at 10 Minutes (30 minutes burn time shown)

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