# Use of Live Sensor Data in Transient Simulations of Mine Ventilation Models

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ABSTRACT: The implementation of sensor systems to monitor mine ventilation atmospheres offers numerous safety and operational benefits to mines. Detection of dangerous gases, changes to airflows and temperature, and detection of clearance of fumes or contaminants are some of the obvious benefits of using atmospheric sensors in mines. The prediction of atmospheric conditions between sensors however is potentially difficult, and to gain complete coverage a mine will require either many sensors or a method of extrapolating and predicting atmospheric conditions between and downstream from a sparser array of sensors.

A transient simulation computer model technique is demonstrated to predict the time based changes to atmosphere downstream from sensors. The transient model predicts the time based changes to conditions throughout a mine model, displaying current conditions in a three dimensional model by simulating the mixing, addition and dilution of gases and airflow changes in incremental time steps. The advantages of this method is that a real time overview of full mine atmospheric conditions can be viewed at all locations, even areas without sensors. In addition, with careful planning and consideration of potential contaminant sources, the number of required sensors can be minimized.

## 1 INTRODUCTION

### 1.1 *Mine Ventilation Sensors*

The importance of continuously monitoring mine atmospheres has been recognized since mining underground began and the effects of harmful gases on human health were discovered. Through the 19th and early 20th centuries, coal miners would take canaries underground with them as an early detection system against life threatening gases such as carbon dioxide, carbon monoxide and methane. The canary, normally a very songful bird, would become agitated, stop singing and eventually die if not removed from these gases, signaling the miners to quickly exit the mine.

**Figure 1 - Canary Gas Detector**

In the early to middle 20th century, methods of gas detection advanced. Carbon monoxide could be detected with chemically infused paper that changed color on exposure to gas. Methane or oxygen deficiency could be detected through a change of flame color and size in mesh screened safety lamps.

By the late 20th century, most sensors had been developed into electro-chemical devices that could show instant readings on an analogue or digital display, or transmit information through radio, wires or fiber optic cable to remote locations.

**Figure 2 - North Parkes Mine (Australia) Control Room**

Many mines worldwide are now moving towards standard remote monitoring of mine atmospheres to measure a wide range of gases, air velocities and pressures, as well as detecting the operating state of ventilation control devices such as fans, regulators and doors. In most cases sensors are connected through mine communication systems to allow real time monitoring of conditions at different locations underground, and sensor data is sent to control systems which are designed to display information and alert when conditions fall outside of defined safe levels.

In most modern coal mines and many types of metaliferous mines, sensor systems are used for early detection of potentially dangerous or undesirable conditions, such as high gas buildup which may result in an explosive atmosphere, or the presence of noxious gases. In other circumstances, sensors can detect incidents that have already occurred such as an explosion behind seals, an outburst of gas, ignition at the face or a belt fire. Where conditions cannot be immediately corrected, sensor information may trigger other actions such as mine evacuation or shutting down machinery to ensure the health and safety of underground personnel.

### 1.2 *Limitations of Real Time Sensors*

While most sensors have a wide range of physical limitations including delayed reaction times, cross sensitivities with other gases, and reliance on a robust communication system, one of the main practical limitation is the display and application of the received data.

Real time mine sensor information is usually displayed on computer monitor showing one or a number of sensor values in tables or on a schematic screen. History and trends for each sensor can also usually be displayed and analyzed.

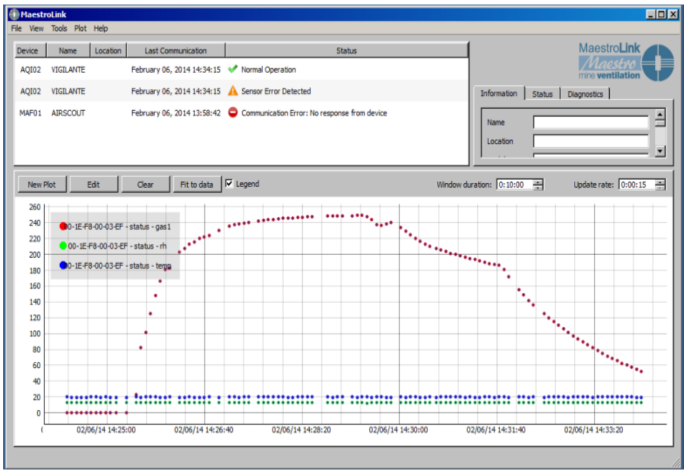


**Figure 3 - MaestroLink Real Time Sensor Display**

However, utilizing only sensor data to interpret mine conditions has significant limitations.

a) Display is normally limited to static text, or overlaid on a schematic display. This can be difficult to interpret and visualize if the viewer is not familiar with the sensor locations.

b) Excessive numbers of sensors can be difficult to display together and may need to be displayed in groups or only made available in selectable screens.

c) The number of sensors installed is often limited. Cost and limitations in distribution of power and communication systems mean that sensors are usually only installed in key location. This potentially leaves large areas of the mine unmonitored. Where multiple airstreams may converge or diverge, the actual gas concentrations are split or merged, and areas downstream or between sensors cannot be easily inferred of calculated from the original sensor information.

d) Changes in sensor data are not reflected in areas not covered by sensors. For example, a spike in gas levels from a gas outburst may show local sensor information rapidly rising then falling to normal levels, however the dangerous spike in gas levels actually continues to travel through the mine downstream from the sensor until diluted or exhausted from the mine.

To maximize the effectiveness of real time sensor data and address the above limitation, additional systems are required to help visualize and predict atmospheric conditions between sensors, and show the time based spread of gases throughout the mine.

## 2 SIMULATION METHODS

### 2.1 *Introduction*

The use of mine ventilation simulation software has become common place since the later $20^{th}$ century, and has been traditionally used to mainly estimate flows and pressures in mine ventilation networks. However ventilation models can also be used to infer and calculate downstream mixed concentration of detected gases. Providing a mine ventilation system has been accurately modelled with correct airflows, the real time sensor readings can be defined in the atmosphere streams and combined and mixed in the various airflow paths through the model. If sufficient sensors are installed to detect conditions in the major pathways, in theory, all other areas of the mine not covered by sensors can be inferred with good accuracy (providing additional significant gas sources are not added to the stream).

The following sections focus on the use of gas concentration sensors in simulation models, although other sensors such as fan speed, air velocity or regulator settings can also be used to drive a simulation model.

### 2.2 *Simulation of Gas Distribution*

The movement of gas throughout a mine can be a complex predictive process. The physical processes of gas diffusion, layering, imperfect mixing at junctions, and boundary drag can all have an impact on accurate prediction of gas movement. However, for large mine wide network models considering all such factors add significant complexity to a simulation, and may not necessarily add significant value in terms of providing a tool to immediately estimate gas levels.

Therefore, the large scale mine wide prediction of gas transport can be simplified by assuming linear gas movement at average flow velocities, no further diffusion of gas once it has left the sensor location, and complete homogenous mixing of gases at junctions of airflow.

### 2.3 *Steady State Simulation*

The simplest method of simulation involves a steady state analysis of the mine airflow distribution system downstream from sensors.

Once an airflow simulation has balanced flows throughout a model, consideration can be given to the distribution of gas from sensors. Where airflows meet at a junction or 'node', the gas compositions of the two airflows can be mixed homogeneously as a weighted average and (assuming perfect mixing) and the newly calculated mixture can be predicted downstream from the junction as follows.

$$Gm = \frac{\sum (G_{1..n} \times Q_{1..n})}{\sum Q_{1..n}} \qquad (1)$$

Where: Gm= mixed airflow gas concentration, $Q_{1..n}$ = Flows into junction from connecting airways, $G_{1..n}$ = Concentrations of gas into junction from connecting airways.

A complete overview or atmospheric conditions can be demonstrated not only at the sensor locations, but in all areas in between sensors and out to the exhaust route(s) of the mine.

A limitation of the steady state method is that it does not consider the time based changes of sensor values through various parts of the ventilation network. Therefore, any change in sensor data is instantly reflected in all downstream areas, and as such this method is only of practical use where sensor information is not expected to rapidly change, or where there is extensive sensor coverage with limited flow time and distance between sensor locations.

### 2.4 *Transient Simulation*

An increase or decrease in gas concentrations travelling past a sensor will continue to travel through the mine long after the sensor changes values again. To predict the spread of mine gases from sensors in real time to all parts of the mine, it is necessary to use a dynamic or transient method of simulation.

Transient simulation incorporates time based movements and changes to the ventilation model based on changes to various sensor inputs. The time to travel along any airway in the mine assuming constant cross sectional area is;

$$t = \frac{L}{v} \quad or \quad t = \frac{L \times A}{Q} \qquad (2)$$

Where: t = time to travel the length of airway (s), L = length of airway (m), v = velocity of airflow (m/s), A = cross sectional area of airway (m2), Q = airflow quantity of air (m3/s)

Gas movements can be calculated assuming the network simulator has first correctly balanced the ventilation network such that;

- all airflows are calculated and balanced so that the airflows entering each junction are equal to the airflows exiting the junction, and;
- average airflow velocities are available or can be derived from simulated or measured airflow and airway size.
- In the absence of historical gas sensor readings, the initial distribution of gases is calculated using steady state simulation, and then gradually resolved over time with transient simulation.

#### 2.4.1 *Discrete Cell Transport*

A method (used by Ventsim Visual™) is discrete cell transport. This method divides each airway into multiple cells containing individual information about the gas concentrations at that point in the airway. As cells are transported past locations containing sensors, the information from the sensors is fed into the cells, setting the contained information to the measured gas concentration. The method works as follows;

- The cells are shuffled in position along the airway at a time based on the average airflow velocity described in equation (10).
- As cells exit the airway, the junction node collects the cell concentration and flow rate information from all entering airways, and mixes the cell concentration based on the volume weighted average concentration entering the junction from other airway cells (as per equation 1).
- New cells at the derived concentration are discharged from the junction node and enter each connecting airway.
- Cells which travel past sensors are 'charged' with the sensor gas concentrations. Any upstream cells that may have differing concentration are reset to the measured sensor concentration.
- The simulation speed is constrained to real time progress to ensure gases movements are restrained to identical speeds as underground flows.

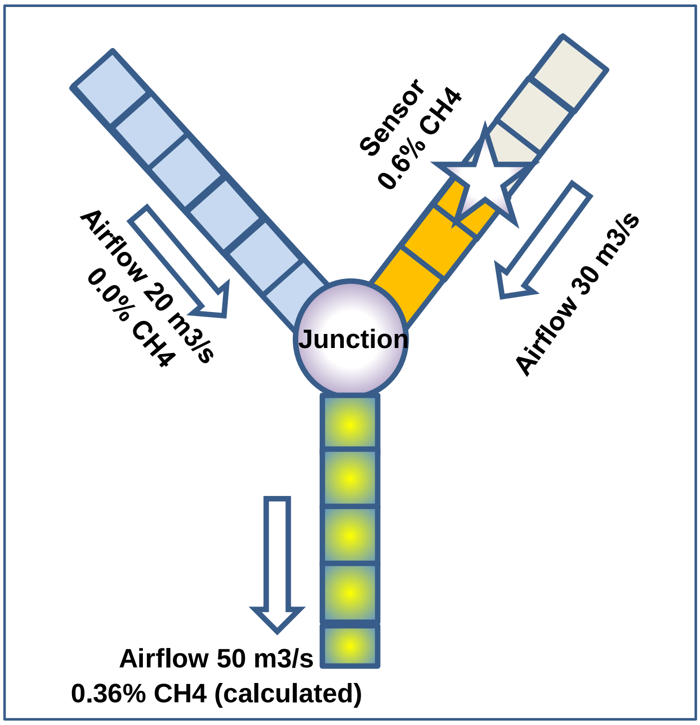


**Figure 4 An example of discrete cell method of flow transport and mixing.**

### 2.5 *Information Display*

Information display is a combination of data display from sensors, and 3D colored graphics representing various gas levels between sensor locations.

An entire mine overview can be viewed by zooming out the required distance, or individual areas can be examined in more detail by zooming in to the locations to view the sensor text. Alarms can be set if sensor value fall outside of allowable levels.

Sensor information is fed continuously (when available) into the simulation package, using the most recent sensor data to distribute gases into the transient simulation. The transient simulation continuously updates and animates the flows in real time to show the downstream spread of gases from sensors.

Other sensors can be used to monitor fan speeds or regulator settings which can then modify other parameters in the mine ventilation simulation model and update flow speeds where required.

## 3 DEMONSTRATION OF TRANSIENT SENSOR SIMULATION

A modified ventilation model of a coal 'bord and pillar' mine consisting of 1500 airways was used to demonstrate the technique.

Real mine sensor data is difficult to obtain and release into the public domain, and is usually non-eventful in the range of detected gas levels. Therefore, a simulation of rapidly changing gas events was performed by injecting randomly moving gas concentration data into sensors within a mine ventilation model. The sensor data was adjusted by a small amount (+/- 10%) every five (5) seconds and allowed to slowly vary between defined limits. The transient simulation recalculated and displayed results in real time every one (1) second.

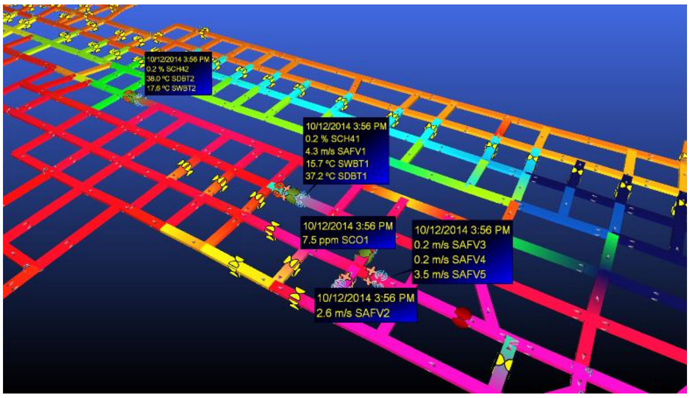

**Figure 5 Ventilation Model Showing Sensor Data Locations**

Because the spread of gases through the mine is relatively slow, the scenario was monitored over a period of six (6) hours to examine the time based spread of changes in sensor information on the remainder of the model.

High speed playback of a video of the simulated results clearly shows the value of calculating downstream effects of variations in sensor readings and highlights the importance of considering time based conditions between sensors. Even though sensors may show relatively low gas readings at a particular time, locations downstream or between sensors may still have high levels of gases resulting from previous high sensor readings.

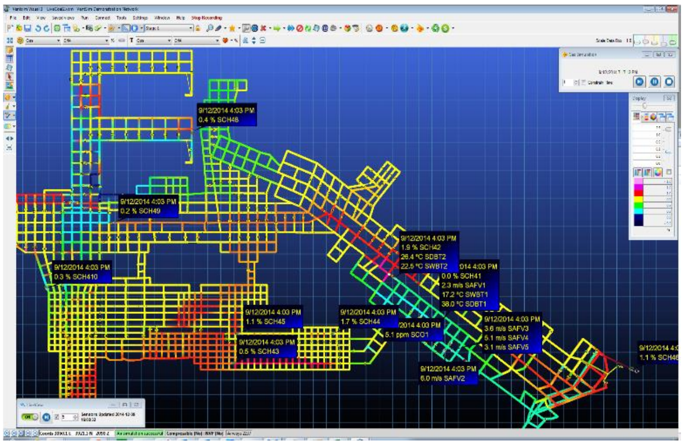

**Figure 6 Mine Ventilation Modelled from Sensor Data**

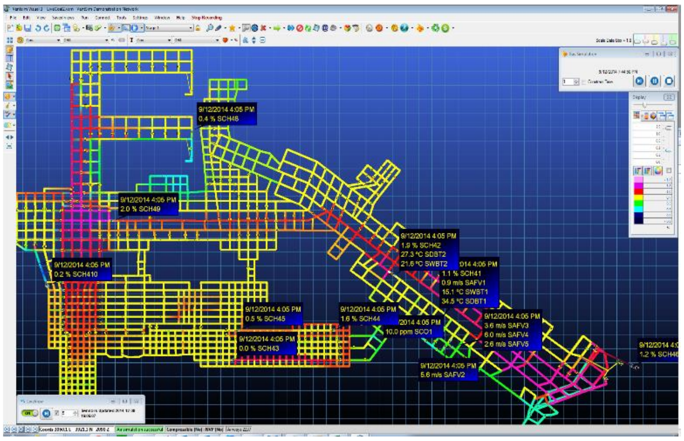

**Figure 7 Subsequent Ventilation Model + 1 hour**

Without transient simulation, these regions would remain invisible to detection systems and the presence of dangerous gas levels in some parts of the mine may not be realized. This modeling and visual display technique may assist in optimizing the placement of sensors, and also in making important decisions regarding ventilation changes, switching of machinery or evacuating the mine.

## 4 CONCLUSION

The use of atmospheric sensor monitoring in underground mines offers an essential means of detecting dangerous atmospheric conditions, however without prediction of gas levels downstream and between sensors, it offers only a snapshot in time at the specific location of the sensors.

The display of both sensor information and simulation data within a mine wide three dimensional model, color coded to show gas levels provides an excellent visual reference to condition throughout a mine model.

Simulation of atmospheric conditions between and downstream from sensors provides a much more comprehensive picture of the distribution of gases in all parts of a mine at a particular time. By applying time based transient simulation methods, the data measured by sensors is distributed and remains visible throughout the mine ventilation model in real time until the air is exhausted to the surface.

This method will closely predict the real time behavior and movement of gases and allows decisions to be made not only by the immediate sensor gas readings, but also by the predicted movement of those readings into other parts of the mine. By considering the careful placement of sensors, the number of sensors can also be potentially reduced and replaced by simulated data in areas there is limited risk of additional gases to the ventilation stream.

## 5 REFERENCES


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