



# A Network Model Analysis of an Unconventional Gas Well Breach Above an Underground Coal Mine

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## Abstract

Gas wells have often intersected mining resources, but unconventional shale well drilling has more recently challenged mines to balance the risk of interaction due to higher pressures and larger quantities of gas. Full extraction mining, such as the longwall method, induces ground movement that may influence the casings if wells are drilled within the mining area. The possibility of a casing shear would lead to the risk of unplanned gas migration into the mine. This has the potential to quickly overcome the ventilation system and reach the explosive range which, if ignited, can have catastrophic consequences on the health and safety of underground workers. The utilization of network software to model mine ventilation is a common practice in the mining industry as a predictive tool for planning and monitoring and can assist with a well breach scenario over a large mining area. This work focuses on a well breach in between two longwall panels after second panel mining with gas entering primarily through the gobbs of the adjacent longwall panels. Applying the network software Ventsim, a gob zone and ventilation network were created to better understand the distribution of gas within the mine and the limitations and effectiveness of a ventilation system. The model shows both a transient flow simulation and steady state concentrations throughout the mine ventilation system. Using a standard Pittsburgh coal seam longwall ventilation scheme, we find that the system can dilute a significant inflow of up to 700 cfm of methane.

**Keywords** Network model analysis · Gas well breach · Coal mine · Methane

## 1 Introduction

The current shale gas boom in Pennsylvania, West Virginia, and Ohio has led to over 1500 unconventional gas wells being drilled in the region [1]. Unconventional wells are different from conventional wells in that they are on a pad containing many wells, are drilled deeper into shale formations, and have a horizontal component that reaches out in multiple directions. These wells also have higher gas pressures and flows under standard conditions. This area is rich with mineable coal reserves, leading to the possibility of an interaction between the mining and gas operations. Coal

mining subsidence causes longwall-induced deformations and stresses, which may result in a hypothetical well shear leading to inflow of high-pressure gas into underground workings. The Pennsylvania Department of Environmental Protection (PADEP) 1957 Gas Well Pillar regulation used by the Mine Safety and Health Administration (MSHA) and seven other states focuses on room and pillar mining. This research will assist in expanding it to include full extraction (longwall) mining data. In order to collect this data, NIOSH has been working to evaluate casing stresses due to longwall-induced movement, permeability, and possible flow into a mine level, and the impact gas inflow will have on a mine ventilation system. This study looks at a hypothetical methane shale well breach in a common Pittsburgh mine ventilation setup and the resulting potential impact on the mine ventilation system. Network software is utilized as a predictive tool for planning and monitoring and is not used in this instance for high accuracy, but to visualize and predict the movement of methane. The branches used for modeling the gob area are utilized as pathways for the gas to travel as we realize that gas would travel in gob pathways and not entirely

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in the outward ventilation network. Although much work has been done [2, 3] looking at detailed ventilation in network modeling and gob systems, the focus for this study is the visualization and predicting methane buildup in the mine.

## 2 Background

The current Coal Age longwall census [4] shows that 18 longwall faces are in the tri-state region—6 in Pennsylvania, 11 in West Virginia, and 1 in Ohio. All of these mines are in a common area for the drilling of unconventional well pads and use a three-gate road system of entries between longwall panels. Pennsylvania, West Virginia, and Ohio make up almost half of all coal longwall faces in the USA. They also have a large unconventional gas reserve leading to many wells being drilled in mining regions. Coal and gas companies work together to utilize the resources for both but have found the placement of wells can be difficult with full extraction mining. The Pennsylvania Department of Environmental Protection and MSHA have also found that regulations currently do not address unconventional wells in mining areas. DEP has recently issued guidelines to assist when both the gas and mining companies activates intersect [5].

The first step in the work was to investigate the longwall-induced stresses on the gas well casings [1, 6–11]. Through field data partnerships, NIOSH researchers [12] have extensively researched stresses, deformation, and pressures around the longwall panel under deep, medium, and shallow covers and the effects on gas well casings. The authors [12] note deformations in casings and abutment pressures from 19 mm (0.75 in) and 17.2 MPa (2494 psi) to 168 mm (6.6 in) and 0.7 MPa (102 psi) when going from deep to shallow cover. This indicates that the deep cover has less movement, or deformation, but more abutment pressure, and the shallow depth of cover has more subsurface deformation, but less abutment pressure demonstrating that the deeper sites have a less likelihood of casing deformation leading to failure.

Permeability measurements were taken above an abutment pillar between longwall panels to determine strata permeability responses to the longwall-induced movement across the mining of both longwall panels [13]. Using the permeability data, Discrete Fracture Network (DFN) models were used to determine inflow values at the mine level [14]. Using this information, a Pittsburgh seam mine network model was created to show how the methane may flow in the mine [15, 16]. This information helps mines determine the impact on the operations and effective ways to monitor for gas leakage or a hypothetical well breach. Hypothetical well breach language is used because modeling has not shown that well casings would break, only deform due to subsidence.

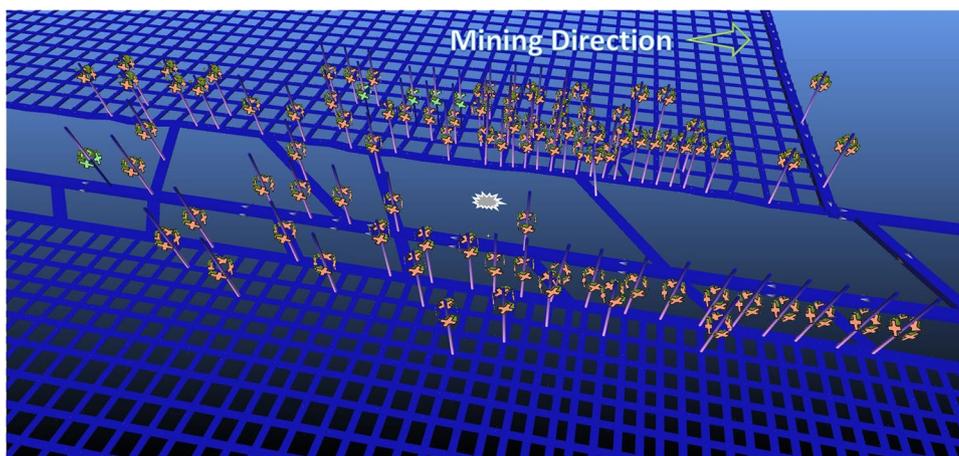
## 3 Methods

There are many network modeling software programs that do similar functions for ventilation planning and control. Network models are the most accurate when mine measurements are utilized as inputs and validate the model. Coal mines standardly use a 2D-network-modeling-framework-based software due to its standardly level mining characteristics. Typical coal mine ventilation network models do not model every branch in the network and use a framework model and what is commonly termed as leakage branches to show differentials between different pressure entries. VentSim was chosen as the network modeling software due to its ease of visual communication and ability to show and perform gas injection both for steady state and dynamic time influenced flow of the methane gas. Additional branches and assumptions were made to create a full mine model for use.

The VentSim model was created from input information of Pittsburgh coal seam mine network models to create a generic standard Pittsburgh seam mine ventilation system. The framework mine models used had information on pressures and airflows at nodes throughout the mine and fan curves. The model was transferred from an AutoCAD drawing and redrawn in the VentSim software to include all mine entries in the 2 longwall system that was focused in the study. A gob was created in the active and adjacent longwall panels using an approximate grid of 33 ft by 33 ft (10 m by 10 m) to simulate the possible movement of gas in the gob. The primary focus for the work was the active longwall face area, centering on the active and adjacent longwall panel section. The mine-induced ground movement around the well casings is larger when a second mine by occurs [11]; therefore, the focus on a hypothetical well breach is simulated after mining by the well locations a second time. The approximate placement of the hypothetical well pad location is shown in gray star inside the large abutment pillar in Fig. 1. Figure 1 shows inflow from 100 inlets, as shown by the vertical branches with X's on them. This symbolizes a varied entry of the gas from a possible breached well at the grey star location. Watkins [13] indicated in the CFD work that gas from an abrupt fracture above the coal seam would flow into the mine via a fracture network into various locations around the well pillar. These methane inflow branches were made to look longer than they were in the program for ease of visualization and use in the program.

The active longwall panel is located in a 7-panel district, with the active panel being the 6th panel in the set and the previous five panels south of the active panel being mined out. The active longwall panel is approximately 12,000-ft long and 1000-ft wide with the bleeder

**Fig. 1** Hypothetical well location in model shown by grey star. Well inlet locations (100) shown by vertical branches



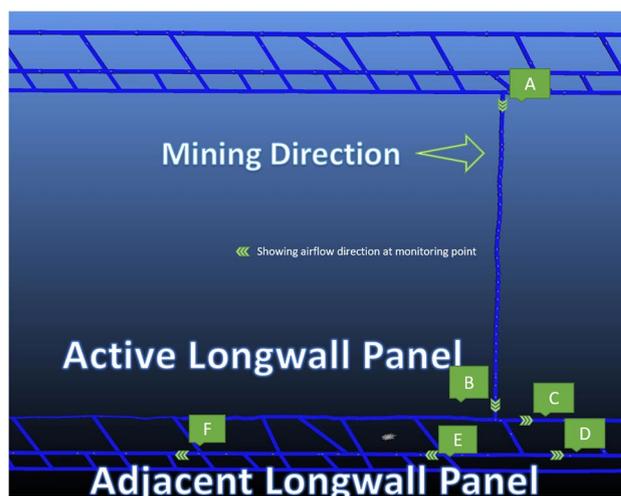
fan location in the bleeder entries, the back-end section of the panels between the first and second panels in the district and is 4 panels from the active panels bleeder evaluation point (BEP), approximately 5400 ft away. In a standard Pittsburgh mine, a section of panels or district is planned with a single bleeder fan. The active panel was mined approximately 65% from the startup face, having created an established gob zone of 7800 ft.

A gob network was set up of approximately 33 ft by 33 ft (10 m × 10 m) mesh of branches in the mined-out area behind the active longwall face and within the mined-out adjacent panel. A resistance was chosen for the gob mesh, and it was chosen when modeling a loss across the face. The loss across the face as shown by the cooperating mines ventilation model was approximately 11% of a face air loss. The model shows a loss of 10.4%, which is within ± 1% variability. The gob was set up in four different levels of resistance, with the outer layer having the lowest resistance and the largest inner gob having the highest resistance. The resistance started at 50 PU and doubled in each layer of gob, with the maximum resistance in the center gob being 400 PU. The gob model was set up to better visualize and understand methane flow in the mine from a breached well, not for the intricacies of gob airflow or detailed losses in a mine system.

Monitoring points were chosen with two intentions. The first is if it is a direct monitoring point for the mine under standard operating conditions. These points are bolded in Table 1 and specified in 30 CFR §75.333, §75.362, §75.364, and §75.370 [17]. The monitoring locations are also shown in Fig. 2 in the longwall face area, and in Fig. 3 in the bleeder of the active face area. The second intention or other locations are areas where the modeling showed the methane start to rise and accumulate but are not in walkable areas. These areas are possible proactive monitoring areas for the mine around the well. Table 1 displays the baseline

**Table 1** Monitoring points in the network model and the airflow at these points. Bolded locations are locations standardly mandated by regulation for monitoring every shift or weekly. BEP, bleeder evaluation point, in the #2 entry between panels

Map location indicator	Location Description	Airflow at location CFM
<b>A</b>	<b>Longwall face (headgate side)</b>	<b>66,000</b>
<b>B</b>	<b>Longwall face (tailgate side)</b>	<b>60,000</b>
<b>C</b>	<b>Longwall tailgate drive (#3)</b>	<b>20,000</b>
D	1 block outby LW tailgate face (#2)	4,400
E	1 break inby the LW face (#2)	30,000
F	4 breaks inby the face (#2)	32,000
G	Current Longwall BEP	22,000
<b>H</b>	<b>Adjacent longwall BEP</b>	<b>6,100</b>
<b>I</b>	<b>Headgate BEP</b>	<b>6,200</b>
<b>J</b>	<b>Bleeder fan</b>	<b>274,000</b>



**Fig. 2** Figure of longwall face area with labeled monitoring locations in model, labeled by box and letter from Table 1. Green arrows showing location, and direction of air



**Fig. 3** Figure of bleeder end of active longwall section with red arrows showing locations of BEP regulators showing direction of air, and boxes with letters indicating the monitoring area name from Table 1

ventilation airflow and velocities for the monitoring points in the network model.

Methane was added into the model with short (0.1 ft) fixed branches primarily into the active and adjacent gob areas. The branches were shown to be longer as to better identify them as seen in Fig. 1. One-hundred methane or “gas well” branches were added to the model. Multiple modeling scenarios were simulated under the same ventilation conditions with varying methane inflows. Methane was set at 100%, and there was a

fixed inflow value at each branch ranging from 1 to 7 cfm for a total inflow between 100 and 700 cfm when running different methane inflow scenarios. An inflow scenario was run in 100-cfm quantities, ranging from 100 to 700 cfm. DFN inflow models of the more common deep-cover scenario (>800-ft coal depth) for a single or multiple (up to ten) well breach under pressures ranging from 350 psi to 3000 psi are well within this range of tested methane values [15, 16].

### 4 Results

Steady state values for methane using the contaminant simulation in VentSim are shown in Table 2. Steady state indicates a time where the values of inflow of methane reach a steady state and are not changing values, and all mine ventilation values in this time are constant. Only areas that showed methane content from Table 1 were chosen for Table 2. Figure 4 shows the methane distribution at steady state for 400 cfm of inflow at the mine level. The yellow color in Fig. 4 indicates a 5% value, and red indicates a 10% value of methane, these ranges are only shown in the gob area. The highest concentration of methane in mine entries was found to move through the model and shows up at location H, the adjacent longwall bleeder evaluation point (BEP). This higher concentration of methane was due to the lower pressure resulting from being closest to the bleeder fan and from the lower airflow at that BEP not allowing for greater dilution.

**Table 2** Location and methane concentration in model mine

Location (map indicator)	Quantity in CFM of methane input into the model						
	100	200	300	400	500	600	700
4 breaks inby the face (F)	0.09%	0.19%	0.29%	0.38%	0.48%	0.57%	0.67%
Current longwall BEP (G)	0.08%	0.16%	0.24%	0.32%	0.39%	0.47%	0.55%
Adjacent longwall BEP (H)	0.12%	0.24%	0.36%	0.48%	0.59%	0.72%	0.84%
Bleeder fan (J)	0.03%	0.07%	0.10%	0.14%	0.17%	0.21%	0.24%

**Fig. 4** Network ventilation model showing the increase in methane distribution at steady state for an inflow of 400 cfm

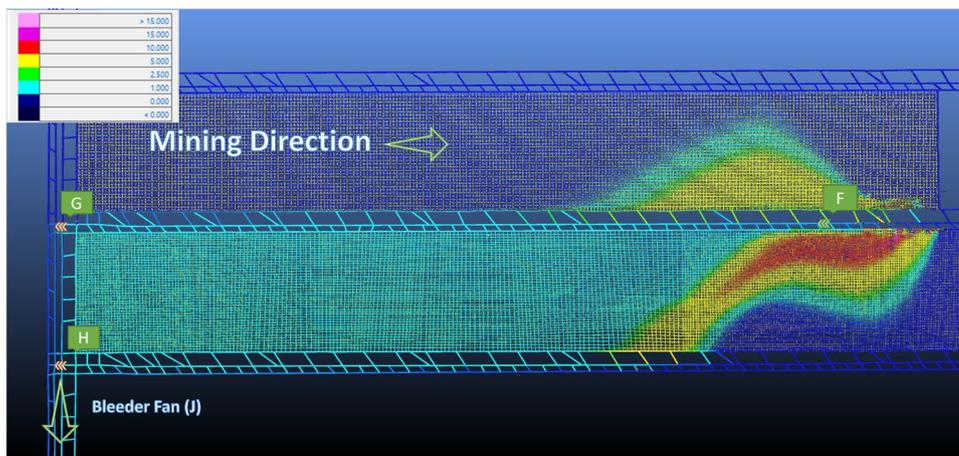


Table 2 shows the detectable methane increases at the tested inflow levels into the mine level at steady state. Only the monitoring locations that showed detectable methane during the testing are shown in Table 2. The highest concentration is seen at the adjacent longwall BEP in all cases. This is due to the lower air quantity and lower pressure at the location. The locations where gas is standardly monitored on a weekly basis are the active and adjacent BEPs and the bleeder shaft. The methane would flow from the hypothetical well breach, first reaching the BEPs and then moving on to the bleeder shaft.

A dynamic model was also run using VentSim focusing on a standard 20-min response time. This assumes that a gas operator would notify the coal company of any irregularities in well operation (a hypothetical breach) within 20 min. The median inflow value of 400 cfm was chosen to run the dynamic model. In the 20-min time frame, the gas had only moved to the point 4 breaks in by the longwall face tailgate, and it was shown as a 0.135% increase. No gas reached the BEPs in this situation in that time frame, and no detectable gas was seen on the face or in the tailgate surrounding entries. With the response time for the mine, or 20 min from notification, the mine still sees no detectable gas on the face or surrounding tailgate area. An increase of 0.227% methane is seen 4 breaks in by the face and no gas is yet seen at the BEPs.

It should also be considered that most coal mines have in situ gas present in the mined coal and possibly in the overlying strata above the coal. The gas concentrations can vary at each mine, dependent upon mining method, degasification, geology, and ventilation strategy. In seam degasification, gob ventilation boreholes (GVB) and surface boreholes are just a few of the techniques that mines use to degas methane to minimize gas entering while mining. The methane values in Table 2 are only increases to what a mine currently encounters at these locations.

## 5 Conclusions

The highest concentration of methane recorded in this study was at the BEP locations for the active and adjacent longwall panel tailgates. Increases of up to 0.83% methane at the BEP was seen at a 700-cfm methane inflow, although it diluted once combined with the bleeder entries' ventilation air. A maximum of 0.24% increase was seen at the bleeder fan for the maximum inflow tested of 700 cfm of methane gas from a hypothetical well breach. Assuming no in-situ gas sources present, this ventilation can easily dilute and render harmless this amount of methane gas inflow if a hypothetical gas well were to breach into the mine atmosphere. The Pennsylvania Department of Environmental Protection (PADEP) recommends enhanced bleeder examination and evaluation protocol for more frequent monitoring at both the BEPs and at the bleeder fan [5] when mining around a well.

A hypothetical well breach gas entering the mine could increase the mine's gas concentrations. What the mine can dilute and render harmless is dependent upon what gas the mine currently encounters and the ventilation air available. Although this model was of a generalized mine, it is a standard configuration at Pittsburgh Seam longwall mines in the area. An estimation of a hypothetical gas well methane inflow and detail on the mine's current background methane will determine what concentrations the mine ventilation system can manage while staying in compliance. What these simulations show is that, within this inflow range, there was no detectable gas showing on the face or at other locations that are standardly electrically energized and the mine is within compliance with current mine safety regulations.

It is suggested that mines understand and monitor their ventilation closely if they are to mine around active shale gas wells. By understanding the system, the modeling of it can vastly improve any chances that methane would induce a catastrophic event. Small shifts in pressures or airflow can change the system and the flow or movement of the methane within a system. Modeling can best display these changes to miners, engineers, and mine personnel.

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**Data Availability** Data presented here is preliminary and is available in its published format. Upon completion of the research, much of the data will be anonymized and made public.

## Declarations

**Conflict of Interest** The authors declare no competing interests.

**Disclaimer** The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention. Mention of any company or product does not constitute endorsement by NIOSH.

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