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Computer Modeling of the Effect of Mine-Fire-Induced Ventilation Disturbances on Stench Fire Warning System Performance

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CONTENTS

	<u>Page</u>
Abstract.....	1
Introduction.....	2
Operation of the stench warning computer model.....	2
Case study analysis method.....	3
Results of stench fire simulations.....	5
Fire in branch 30.....	5
Fire in branch 48.....	5
Fire in branch 37.....	6
Fire in branch 52.....	6
Fire in branch 53.....	6
Summary.....	12
Conclusions.....	12
References.....	12

ILLUSTRATION

1. Schematic of hypothetical mine ventilation network.....	4
--	---

TABLES

1. Physical characteristics of simulated fires.....	4
---	---

Stench warning times under baseline conditions and under the influence of a
fire in--

2. Branch 30.....	7
3. Branch 48.....	8
4. Branch 37.....	9
5. Branch 52.....	10
6. Branch 53.....	11

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

Btu/ft ³	British thermal unit per cubic foot	h	hour
Btu/lb	British thermal unit per pound	in	inch
Btu/min	British thermal unit per minute	lb/ft ³	pound per cubic foot
Btu/(min•ft ²)	British thermal unit per minute per square foot	min	minute
ft ³ /min	cubic foot per minute	pct	percent
		ppb	part per billion
		yr	year

COMPUTER MODELING OF THE EFFECT OF MINE-FIRE-INDUCED VENTILATION DISTURBANCES ON STENCH FIRE WARNING SYSTEM PERFORMANCE

By Linneas Laage,¹ William Pomroy,² and Thomas Weber³

ABSTRACT

Underground mine fires can significantly influence mine ventilation airstreams, in some cases throttling or even reversing airflows. As a result, the performance of a metal and nonmetal mine stench fire warning system, which depends on the ventilation to carry the vital warning signal, under fire conditions is different from performance under nonfire conditions. The safety of underground miners can be jeopardized if the warning signal is delayed. This Bureau of Mines report describes research to investigate fire and stench warning system interactions. A computer model is presented that permits quantitative analysis of stench warning signal delays as a function of fire location and intensity. The results of a case study involving computer simulations of stench distribution in a hypothetical mine network subject to various fire exposures are also discussed. This case study illustrates a technique for identifying the areas within a mine that are subject to unacceptable warning signal delays, thereby enabling preemptive action by mine personnel, such as redeployment of stench injectors.

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INTRODUCTION

Fires are an ever-present threat to the safety of underground miners. Since the smoke and toxic gas produced by a mine fire can be spread rapidly by the mine's ventilation system, mine evacuation must be accomplished as quickly as possible in the event of fire. In metal and nonmetal mines, the most common means of passing the fire warning signal to each miner is the stench system. The typical stench system utilizes ethyl mercaptan, a highly odoriferous organic compound, injected on the surface into the compressed and/or ventilation airstreams. Upon smelling the stench, workers evacuate the mine according to an emergency preplan.

Although the stench system has been used successfully for over 60 yr, it has several serious shortcomings, owing to certain chemical properties of ethyl mercaptan and to certain performance characteristics and limitations of present injection systems.

Recent Bureau research succeeded in upgrading the overall safety and effectiveness of the stench system through the use of a superior stench odorant and the development of improved stench injection equipment (1).⁴ This research has also investigated a specialized computer simulation model capable of calculating the precise concentration of stench in any mine ventilation network branch at any time after stench release (2). An adaptation of the computer model now enables the analysis of stench system and ventilation system interactions under the influence of a mine fire.

Mine fires, depending on their location and intensity, can significantly change ventilation flows. The heat energy from

the fire can throttle or even reverse the direction of airflows in large areas of a mine. Under such conditions, the stench odor may not be carried by the ventilation streams to all parts of a mine in time to permit a safe mine evacuation, even though satisfactory stench distribution is achieved during routine fire drills. In these cases, fire drills only serve to reinforce the false security provided by such a system. Ironically, the circumstances resulting in degraded warning system performance exist only during an actual fire emergency. A problem arises in that the interactions between a fire and a stench warning system are highly complex--so complex that conventional analytic techniques for designing stench systems do not address fire effects.

Use of the stench fire warning system computer model will enable mine safety officials to quantitatively analyze stench system performance under simulated fire conditions. The program calculates stench odor transport time to each mine network branch as a function of fire intensity and location. Preemptive action, such as relocation of stench injectors, is indicated if the fire-induced ventilation changes result in excessive stench transport times to key work areas.

This Bureau of Mines report briefly describes the operation of the program and illustrates its use through a case study analysis of stench distribution in a hypothetical 53-branch mine ventilation network under both baseline (nonfire) and mine fire conditions.

OPERATION OF THE STENCH WARNING COMPUTER MODEL

The stench warning model is evaluated with a ventilation network analysis computer program developed under contract for the Bureau by Michigan Technological University.

⁴Underlined numbers in parentheses refer to items in the list of references at the end of this report.

Ventilation calculations are made within the program, which represents the mine network as a collection of closed paths or meshes. The mine network and operating conditions are described in an input data file. At each junction (airway intersection within the mine network), conservation of mass is applied to relate the airflow rates. The conservation of

energy is applied to the airflow around each mesh, with frictional wall losses being used to establish pressure losses along airways. As part of the energy balance calculation, temperature and elevation variations within the mine are used to calculate natural ventilation pressures, and fan pressures are determined from the fan characteristic data. The conservation of mass and energy equations are solved iteratively until the airflow rates are balanced throughout the mine network.

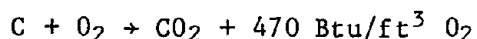
The localized heat production rate of the fire is entered as part of the input data to the program. The heat addition alters the airflow, and its effect is evaluated by calculating the new temperature distribution and airflow rates. The real-time capability of the program is utilized to project the time-dependent

spread of stench from a warning system throughout the mine complex. This evaluation proceeds by associating control volumes with specific stench concentrations. Each control volume is transported with the airflow. At junctions where control volumes meet, perfect mixing is assumed and a new control volume (a new stench concentration) is formed. The stench injector locations and fire locations are specified in the network, as are the duration of the injection period and the duration and intensity of the fires. Changes in the ventilation system (addition of network branches, etc.) and events related to the occurrence of a fire (shutdown of underground fans, etc.) can easily be accommodated by revising the input data file. Utilization and operation of the computer model have been described previously (3-7).

CASE STUDY ANALYSIS METHOD

The effect of mine fires on the distribution of stench odor in an underground mine network was analyzed through computer simulation. The subject of the simulations was a hypothetical 53-branch mine ventilation network. A schematic representation of the network, indicating fan locations, stench injector locations, and airway numbers, is shown in figure 1.

The case study involved the analysis of five fires. To simplify the analysis, the fires were assumed to be diesel fuel pool fires. The fires achieved steady-state burning almost immediately, with essentially no incipient stage heating and no change in intensity over time. The diesel fuel pools can be visualized as circular, of sufficient surface area to produce a fire of the maximum intensity for the available oxygen, and of sufficient depth to burn for 1 h. The maximum fire size was determined by the simplified combustion relationship (8):



with all available O_2 converted completely to CO_2 until a residual level of 9 pct O_2 is reached. The analysis is

based on a burning rate of 0.12 in of fuel depth per minute, a fuel density of 61 lb/ft³, and a heat release of 19,390 Btu/lb, yielding a heat release rate of 11,830 Btu/(min·ft²) of fuel surface area (9). The physical characteristics of the simulated fires are shown in table 1.

As the smoke and gases produced by the fires were not of principal interest, and their presence in the network would only confound the analysis of stench distribution, the fires were modeled as sources of heat with no generation of smoke or gases. Conversely, the injection of stench gas was modeled as a source of fume contaminant without heat release.

Stench injection was started 10 min after each fire was initiated and continued for 10 min thereafter. The detection threshold of the stench odor was assumed to be 10 ppb (ability to detect the odor varies with age, sex, state of health, and other factors, and ranges from under 2 ppb to 120 ppb in extreme cases). Stench injection rate was constant in all simulations at 0.0706 ft³/min. Stench injector locations were selected based on standard industry practice: atop downcast ventilation shafts.

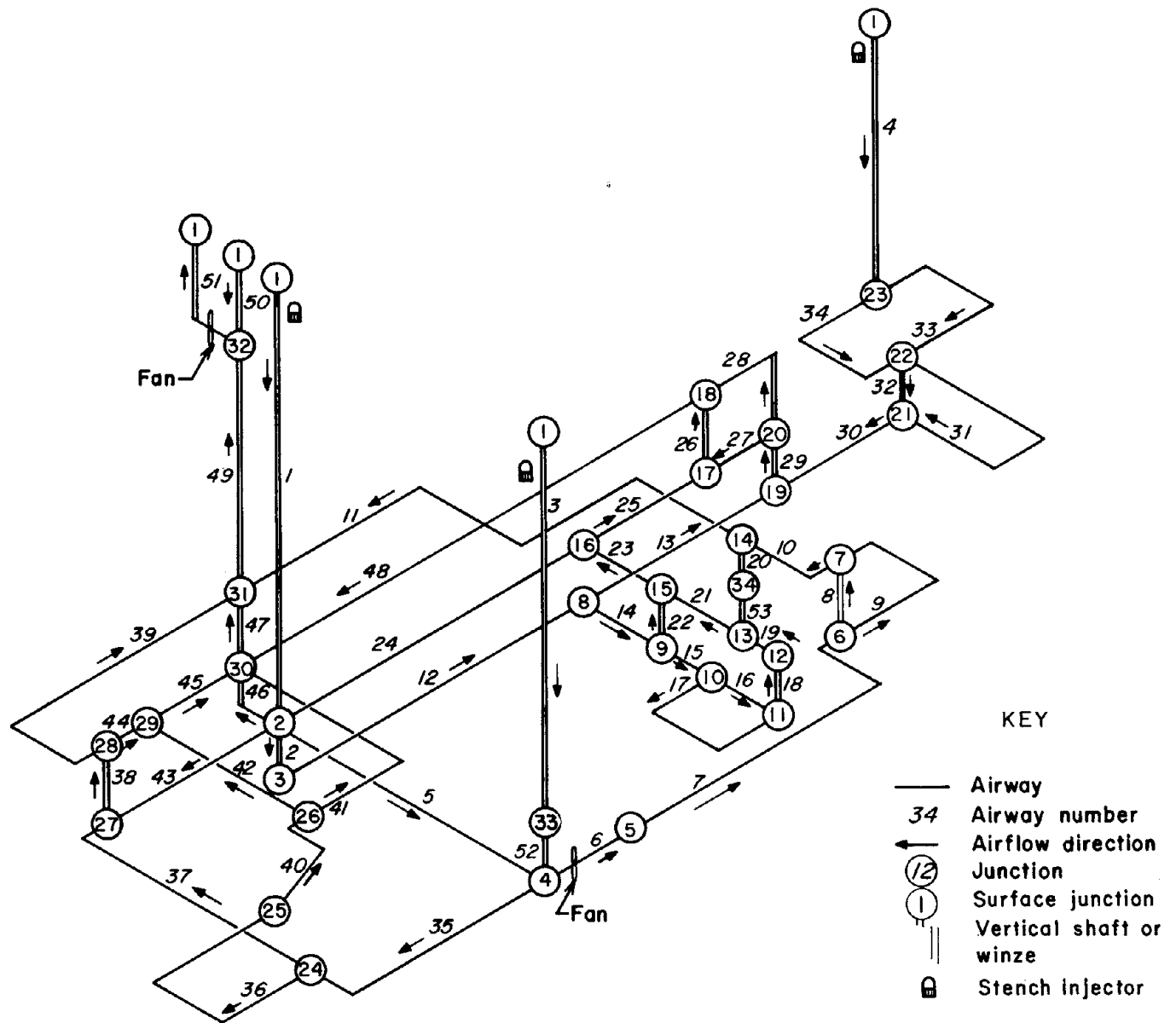


FIGURE 1.—Schematic of hypothetical mine ventilation network.

TABLE 1. - Physical characteristics of simulated fires

Simulation	Fire location airway	Pool diam, ft	Fire intensity, Btu/min	Airflow, ft ³ /min
1 and 2...	30	12.40	1,375,500	26,230
3 and 4...	48	22.19	4,401,400	83,933
5 and 6...	37	17.96	2,882,600	54,969
7 and 8...	52	26.08	6,081,300	115,966
9 and 10..	53	4.32	166,700	3,179

RESULTS OF STENCH FIRE SIMULATIONS

As noted above, the case study involved an analysis of five fires. For each fire, two simulations were performed--one with both surface and underground mine fans operating and one with the underground fan shut down (as sometimes occurs during actual mine fires). Warning times to each network branch were then calculated for each fan and fire condition and tabulated. The warning time is the shortest time required for the stench to travel from any injector to the end of a given branch. The maximum acceptable warning time was arbitrarily chosen as 60 min. A baseline stench distribution simulation was performed to confirm that nonfire warning times met the acceptance criteria and to provide a basis for comparing warning times calculated under fire conditions. The maximum baseline warning time was 55.64 min, with an average time of 28.05 min and a minimum of 13.44 min. Airway reversals and warning times that exceeded the acceptable maximum are also indicated in tables 2-6, which are grouped at the end of the text discussion.

FIRE IN BRANCH 30

Stench warning times under baseline conditions and under the influence of a fire in branch 30 are shown in table 2. The 1,375,000-Btu/min fire in branch 30, a horizontal drift, had the effect of reducing maximum and average warning times slightly for both fan conditions. With the underground fan shut down, the maximum warning time was 52.17 min, the average was 26.42 min, and the minimum was 13.33 min. The average reduction in warning time was 1.63 min, or about 5.8 pct. With both fans operating, the maximum warning time was 53.58 min, the average was 27.89 min, and the minimum was 13.45 min. The average reduction in warning time was 0.16 min, or about 0.5 pct. Although warning time delays ranging to 18.27 min were produced by the

fire, the acceptable maximum warning time was not exceeded in any branch under either fan condition. Airflow reversals occurred in branches 20 and 53 with the underground fan shut down.

FIRE IN BRANCH 48

Stench warning times under baseline conditions and under the influence of a fire in branch 48 are shown in table 3. The 4,401,400-Btu/min fire in branch 48, a horizontal drift intersecting a vertical shaft with airflow toward the upcast shaft, had the effect of increasing the maximum and average warning times slightly for both fan conditions. With the underground fan shut down, the maximum warning time was 57.08 min, the average was 28.30 min, and the minimum was 13.43 min. The average warning time delay was 0.24 min, or about 0.87 pct. With both fans operating, the maximum warning time was 66.88 min, the average was 30.80 min, and the minimum was 13.57 min. The average warning time delay was 2.75 min, or about 9.80 pct. Warning time delays ranged to 21.25 min with the underground fan shut down and 24.6 min with both fans operating. With the underground fan shut down, the maximum acceptable warning time was not exceeded; however, with both fans operating, the maximum acceptable warning time was exceeded in two branches--20 and 32. The warning times in those branches were 65.96 and 66.88 min respectively, or about 20.2 and 59.5 pct above the baseline warning times. In both cases, the warning signal reached the beginning of the branch within the prescribed 60 min (36.94 and 48.24 min respectively); however, the air velocity was too slow to carry the signal to the end of the branch in time. In one case, branch 20, an air reversal occurred. Another air reversal was noted in branch 53, which is a continuation of branch 20.

FIRE IN BRANCH 37

Stench warning times under baseline conditions and under the influence of a fire in branch 37 are shown in table 4. The 2,882,600-Btu/min fire in branch 37, a horizontal drift, had the effect of reducing maximum and average warning times slightly for both fan conditions. With the underground fan shut down, the maximum warning time was 51.23 min, the average was 26.25 min, and the minimum was 13.34 min. The average reduction in warning time was 1.80 min, or about 6.4 pct. With both fans operating, the maximum warning time was 55.03 min, the average was 27.66 min, and the minimum was 13.44 min. The average reduction in warning time was 0.30 min, or about 1.1 pct. Although warning time delays ranging to 17.33 min were produced by the fire, the acceptable maximum warning time was not exceeded in any branch under either fan condition. Air reversals occurred in branches 20 and 53 with the underground fan shut down.

FIRE IN BRANCH 52

Stench warning times under baseline conditions and under the influence of a fire in branch 52 are shown in table 5. The 6,081,300-Btu/min fire in branch 52, a vertical shaft, had the effect of reducing the average warning time slightly when the underground fan was shut down and increasing the average warning time slightly when both fans were operating, but significantly increasing the maximum warning time under both fan conditions. With the underground fan shut down, the maximum warning time was 110.10 min, the average was 27.01 min, and the minimum was 11.29 min. The average reduction in warning time was 1.04 min, or about 3.71 pct; however, warning time delays ranged to 87.41 min, or nearly 400 pct of the baseline. With both fans operating, the maximum warning time was 124.59 min, the average was 28.26 min, and the minimum was 11.28 min. The average warning time delay was 0.21 min, or about 0.7 pct;

however, delays ranging to over 80 min, or nearly 400 pct, were produced. Numerous reversals occurred as well, as shown in table 5, including branch 3, which is a downcast ventilation shaft and therefore the site of a stench injector. With the reversal of branch 3, stench from that injector is exhausted to the surface and is lost. With the underground fan shut down, the acceptable maximum warning time was exceeded in three branches. With both fans operating, the maximum was exceeded in five branches.

FIRE IN BRANCH 53

Stench warning times under baseline conditions and under the influence of a fire in branch 53 are shown in table 6. The relatively small 166,700-Btu/min fire in branch 53, a vertical winze, had the effect of reducing the average warning times slightly under both fan conditions, but increasing the maximum warning times when the underground fan was shut down. With the underground fan shut down, the maximum warning time was 66.15 min--a 95-pct increase over the baseline. The average warning time was 26.79 min, and the maximum was 13.28 min. The average warning time reduction was 1.26 min, or about 4.49 pct. With both fans operating, the maximum warning time was 51.38 min, the average was 26.23 min, and the minimum was 13.31 min. The average reduction in warning time was 1.82 min, or about 6.49 pct. With the underground fan shut down, warning time reductions of over 17 min occurred; however, delays of up to 32.25 min were also produced. With both fans operating, warning time reductions ranging to 15.41 min occurred while delays were limited to 5.5 min or less. Only with the underground fan shut down was the acceptable maximum warning time exceeded. It occurred in only one branch by only 6.15 min. Under both fan conditions, air reversals occurred in branches 20 and 53. (The fire was in 53, and 20 is a continuation of that branch.)

TABLE 2. - Stench warning times under baseline conditions and under the influence of a fire in branch 30

Airway	Baseline warning time, min	Fan in branch 51 only		Fans in branches 6 and 51	
		Warning time, min	Difference from baseline, min	Warning time, min	Difference from baseline, min
1	13.44	13.33	-0.11	13.45	-0.01
2	14.97	14.48	-.49	14.97	.00
3	14.45	15.02	.57	14.47	.02
4	29.84	26.98	-2.86	28.95	-.89
5	20.84	25.81	4.97	20.87	.03
6	14.64	15.34	.70	14.66	.02
7	18.32	22.41	4.09	18.35	.03
8	33.90	52.17	18.27	34.00	.10
9	20.77	27.13	6.36	20.81	.04
10	22.97	31.35	8.38	23.02	.05
11	29.37	36.26	6.89	29.41	.04
12	20.01	18.27	-1.74	19.97	-.04
13	31.42	27.72	-3.70	30.51	-.91
14	21.66	19.46	-2.20	21.68	.02
15	23.61	20.85	-2.76	23.69	.08
16	34.76	28.81	-5.95	35.18	.42
17	27.91	23.92	-3.99	28.12	.21
18	29.45	25.02	-4.43	29.71	.26
19	31.37	26.39	-4.98	31.69	.32
20	41.36	¹ 29.35	-12.01	43.65	2.29
21	32.93	29.64	-3.29	33.32	.39
22	30.31	25.97	-4.34	30.59	.28
23	31.79	28.47	-3.32	32.14	.35
24	30.70	26.96	-3.74	31.30	.60
25	32.60	29.40	-3.20	33.27	.67
26	33.17	30.01	-3.16	33.85	.68
27	50.32	34.43	-15.89	44.59	-5.73
28	35.00	31.05	-3.95	33.88	-1.12
29	32.39	28.48	-3.91	31.37	-1.02
30	48.33	42.17	-6.16	45.89	-2.44
31	45.06	40.01	-5.05	43.49	-1.57
32	55.64	49.04	-6.60	53.58	-2.06
33	40.75	36.32	-4.43	38.37	-1.38
34	40.75	36.32	-4.43	39.37	-1.38
35	16.67	17.19	.52	16.69	.02
36	22.74	23.12	.38	22.77	.03
37	21.33	21.73	.40	21.35	.02
38	18.40	18.24	-.16	18.42	.02
39	25.12	24.85	-.27	25.14	.02
40	27.36	27.63	.27	27.40	.04
41	31.93	32.11	.18	31.98	.05
42	47.01	46.75	-.26	47.05	.04
43	18.07	17.91	-.16	18.09	.02
44	19.46	19.27	-.19	19.48	.02
45	19.85	19.66	-.19	19.87	.02
46	14.54	14.41	-.13	14.55	.01
47	14.81	14.69	-.12	14.82	.01
48	37.03	33.98	-3.05	37.67	.64
49	16.20	16.10	-.10	16.21	.01
51	16.23	16.12	-.11	16.24	.01
52	14.51	15.08	.57	14.52	.01
53	42.47	¹ 26.56	-15.91	44.91	2.44

¹Air reversal occurred.

TABLE 3. - Stench warning times under baseline conditions and under the influence of a fire in branch 48

Airway	Baseline warning time, min	Fan in branch 51 only		Fans in branches 6 and 51	
		Warning time, min	Difference from baseline, min	Warning time, min	Difference from baseline, min
1	13.44	13.43	-0.01	13.57	0.13
2	14.97	14.76	-.21	15.45	.48
3	14.45	15.04	.59	14.44	-.01
4	29.84	30.46	.62	34.68	4.84
5	20.84	24.75	3.91	20.55	-.29
6	14.64	15.39	.75	14.63	-.01
7	18.32	23.03	4.71	18.41	.09
8	33.90	55.15	21.25	34.42	.52
9	20.77	28.14	7.37	20.93	.16
10	22.97	32.71	9.74	23.19	.22
11	29.37	36.91	7.54	29.19	-.18
12	20.01	19.14	-.87	21.63	1.62
13	31.42	31.23	-.19	36.50	5.08
14	21.66	20.47	-1.19	23.61	1.95
15	23.61	22.01	-1.60	25.93	2.32
16	34.76	30.85	-3.91	39.23	4.47
17	27.91	25.42	-2.49	31.06	3.15
18	29.45	26.64	-2.81	32.90	3.45
19	31.37	28.16	-3.21	35.19	3.82
20	41.36	¹ 30.46	-10.90	^{1,2} 65.96	24.60
21	32.93	39.31	6.38	37.52	4.59
22	30.31	27.72	-2.59	34.02	3.71
23	31.79	33.00	1.21	36.17	4.38
24	30.70	29.06	-1.64	35.76	5.06
25	32.60	32.81	.21	38.42	5.82
26	33.17	33.62	.45	39.18	6.01
27	50.32	37.89	-12.43	52.93	2.61
28	35.00	35.73	.73	41.18	6.18
29	32.39	32.24	-.15	37.72	5.33
30	48.33	49.53	1.20	57.67	9.34
31	45.06	46.15	1.09	53.60	8.54
32	55.64	57.08	1.45	² 66.88	11.24
33	40.75	41.71	.96	48.24	7.49
34	40.75	41.71	.96	48.24	7.49
35	16.67	17.13	.46	16.57	-.10
36	22.74	22.81	.07	22.37	-.37
37	21.33	21.48	.15	21.03	-.30
38	18.40	18.14	-.26	18.32	-.08
39	25.12	24.64	-.48	24.92	-.20
40	27.36	27.14	-.22	26.79	-.57
41	31.93	31.40	-.53	31.14	-.79
42	47.01	46.32	-.69	46.52	-.49
43	18.07	17.83	-.24	18.00	-.07
44	19.46	19.12	-.34	19.32	-.14
45	19.85	19.49	-.36	19.70	-.15
46	14.54	14.47	-.07	14.62	.08
47	14.81	14.77	-.04	14.92	.11
48	37.03	38.95	1.92	44.31	7.28
49	16.20	16.23	.03	16.36	.16
51	16.23	16.25	.02	16.39	.16
52	14.51	15.10	.59	14.49	-.02
53	42.47	¹ 28.29	-14.18	¹ 36.94	-5.53

¹ Air reversal occurred. ² Exceeded acceptable maximum.

TABLE 4. - Stench warning times under baseline conditions and under the influence of a fire in branch 37

Airway	Baseline warning time, min	Fan in branch 51 only		Fans in branches 6 and 51	
		Warning time, min	Difference from baseline, min	Warning time, min	Difference from baseline, min
1	13.44	13.34	-0.10	13.44	0.00
2	14.97	14.48	-.49	14.94	-.03
3	14.45	15.17	.72	14.61	.16
4	29.84	27.25	-2.59	29.57	-.27
5	20.84	28.35	7.51	21.56	.72
6	14.64	15.49	.85	14.80	.16
7	18.32	22.34	4.02	18.45	.13
8	33.90	51.23	17.33	33.93	.03
9	20.77	26.92	6.15	20.89	.12
10	22.97	31.02	8.05	23.07	.10
11	29.37	36.01	6.64	29.39	.02
12	20.01	18.25	-1.76	19.89	-.12
13	31.42	28.13	-3.29	31.12	-.30
14	21.66	19.42	-2.24	21.51	-.15
15	23.61	20.77	-2.84	23.42	-.19
16	34.76	28.54	-6.22	34.36	-.40
17	27.91	23.77	-4.14	27.64	-.27
18	29.45	24.84	-4.61	29.15	-.30
19	31.37	26.18	-5.19	31.04	-.33
20	41.36	¹ 29.18	-12.18	42.97	1.61
21	32.93	29.16	-3.77	32.58	-.35
22	30.31	25.77	-4.54	30.01	-.30
23	31.79	28.10	-3.69	31.48	-.31
24	30.70	26.60	-4.10	30.38	-.32
25	32.60	28.92	-3.68	32.26	-.34
26	33.17	29.51	-3.66	32.82	-.35
27	50.32	35.30	-15.02	49.54	-.78
28	35.00	31.60	-3.40	34.65	-.35
29	32.39	28.97	-3.42	32.07	-.32
30	48.33	43.33	-5.00	47.82	-.51
31	45.06	40.49	-4.57	44.59	-.47
32	55.64	49.66	-5.98	55.03	-.61
33	40.75	36.74	-4.01	40.34	-.41
34	40.75	36.74	-4.01	40.34	-.41
35	16.67	17.53	.86	17.02	.35
36	22.74	22.79	.05	22.40	-.34
37	21.33	23.20	1.87	22.86	1.53
38	18.40	18.08	-.32	18.24	-.16
39	25.12	25.19	.07	25.47	.35
40	27.36	26.79	-.57	26.50	-.86
41	31.93	31.40	-.53	31.22	-.71
42	47.01	35.49	-11.52	35.37	-11.64
43	18.07	17.71	-.36	17.86	-.21
44	19.46	19.28	-.18	19.48	.02
45	19.85	19.68	-.17	19.89	.04
46	14.54	14.40	-.14	14.52	-.02
47	14.81	14.68	-.13	14.80	-.01
48	37.03	33.43	-3.60	36.63	-.40
49	16.20	16.11	-.09	16.21	.01
51	16.23	16.14	-.09	16.23	.00
52	14.51	15.23	.72	14.66	.15
53	42.47	¹ 26.35	-16.12	44.17	1.70

¹Air reversal occurred.

TABLE 5. - Stench warning times under baseline conditions and under the influence of a fire in branch 52

Airway	Baseline warning time, min	Fan in branch 51 only		Fans in branches 6 and 51	
		Warning time, min	Difference from baseline, min	Warning time, min	Difference from baseline, min
1	13.44	11.29	-2.15	11.28	-2.16
2	14.97	12.01	-2.96	11.97	-3.00
3	14.45	¹ 11.75	-2.70	¹ 11.72	-2.73
4	29.84	19.79	-10.05	19.53	-10.31
5	20.84	12.43	-8.41	12.44	-8.40
6	14.64	¹ 31.71	17.07	¹ 27.17	12.53
7	18.32	¹ 31.52	13.20	¹ 27.05	8.73
8	33.90	¹ 44.90	11.00	¹ 35.82	1.92
9	20.77	¹ 26.35	5.58	¹ 23.64	2.87
10	22.97	¹ 22.93	-0.04	¹ 21.38	-1.59
11	29.37	28.79	-0.58	31.38	2.01
12	20.01	14.39	-5.62	14.23	-5.78
13	31.42	21.85	-9.57	21.34	-10.08
14	21.66	15.09	-6.57	14.89	-6.77
15	23.61	15.89	-7.72	15.65	7.96
16	34.76	20.49	-14.27	20.00	-14.76
17	27.91	17.66	-10.25	17.33	-10.58
18	29.45	18.30	-11.15	17.93	-11.52
19	31.37	19.09	-12.28	¹ 18.68	-12.69
20	41.36	¹ 19.85	-21.51	¹ 19.34	-22.02
21	32.93	¹ 20.83	-12.10	19.94	-12.99
22	30.31	18.92	-11.39	¹ 18.54	-11.77
23	31.79	¹ 22.99	-8.80	21.26	-10.53
24	30.70	19.32	-11.38	18.94	-11.76
25	32.60	25.89	-6.71	32.12	-.48
26	33.17	24.99	-8.18	24.35	-8.82
27	50.32	24.38	-25.94	23.68	-26.64
28	35.00	24.59	-10.41	24.09	-10.91
29	32.39	22.37	-10.02	21.85	-10.54
30	48.33	28.92	-19.41	28.42	-19.91
31	45.06	27.30	-17.76	26.85	-18.21
32	55.64	32.48	-23.16	31.89	-23.75
33	40.75	25.17	-15.58	24.77	-15.98
34	40.75	25.17	-15.58	24.77	-15.98
35	16.67	¹ 39.60	22.93	² 80.60	63.93
36	22.74	^{1,2} 110.10	87.41	² 69.44	46.70
37	21.33	¹ 29.60	8.27	¹ 37.99	16.66
38	18.40	15.88	-2.52	¹ 15.73	-2.67
39	25.12	32.93	7.81	¹ 30.83	5.71
40	27.36	^{1,2} 102.33	74.97	² 94.12	66.76
41	31.93	² 101.54	69.61	² 112.80	80.87
42	47.01	¹ 39.14	-7.87	² 124.59	77.58
43	18.07	14.63	-3.44	14.72	-3.35
44	19.46	20.98	1.52	¹ 19.62	.16
45	19.85	24.30	4.45	21.24	1.39
46	14.54	12.18	-2.36	12.18	-2.36
47	14.81	12.59	-2.22	12.56	-2.25
48	37.03	28.30	-8.73	27.97	-9.06
49	16.20	14.71	-1.49	14.68	-1.52
51	16.23	14.74	-1.49	14.72	-1.51
52	14.51	¹ 12.44	-2.07	¹ 12.45	-2.06
53	42.47	¹ 19.13	-23.34	¹ 18.72	-23.75

¹ Air reversal occurred. ² Exceeded acceptable maximum.

TABLE 6. - Stench warning times under baseline conditions and under the influence of a fire in branch 53

Airway	Baseline warning time, min	Fan in branch 51 only		Fans in branches 6 and 51	
		Warning time, min	Difference from baseline, min	Warning time, min	Difference from baseline, min
1	13.44	13.28	-0.16	13.31	-0.13
2	14.97	14.33	-.64	14.52	-.45
3	14.45	15.18	.73	14.71	.26
4	29.84	26.45	-3.39	28.00	-1.84
5	20.84	30.44	9.60	22.76	1.92
6	14.64	15.68	1.04	14.94	.30
7	18.32	25.38	7.06	19.63	1.31
8	33.90	¹ 66.15	32.25	² 39.48	5.58
9	20.77	31.92	11.15	22.76	1.99
10	22.97	37.77	14.80	25.57	2.60
11	29.37	33.07	3.70	31.14	1.77
12	20.01	17.78	-2.23	18.52	-1.49
13	31.42	27.20	-4.22	28.93	-2.49
14	21.66	18.33	-3.33	18.76	-1.90
15	23.61	20.05	-3.56	21.20	-2.41
16	34.76	27.04	-7.72	29.46	-5.30
17	27.91	22.75	-5.16	24.39	-3.52
18	29.45	23.71	-5.74	25.53	-3.92
19	31.37	24.92	-6.45	26.95	-4.42
20	41.36	² 26.59	-14.77	² 29.93	-11.43
21	32.93	32.00	-.93	29.80	-3.13
22	30.31	24.59	-5.72	26.50	-3.81
23	31.79	28.38	-3.41	28.80	-2.99
24	30.70	25.42	-5.28	27.39	-3.31
25	32.60	28.24	-4.36	29.75	-2.85
26	33.17	28.87	-4.30	30.35	-2.82
27	50.32	32.69	-17.63	36.74	-13.58
28	35.00	30.73	-4.27	32.54	-2.46
29	32.39	28.01	-4.38	29.81	-2.58
30	48.33	41.78	-6.55	44.77	-3.46
31	45.06	39.06	-6.00	41.80	-3.26
32	55.64	47.80	-7.84	51.38	-4.26
33	40.75	35.49	-5.26	37.89	-2.86
34	40.75	35.49	-5.26	37.89	-2.86
35	16.67	17.35	.68	16.94	.27
36	22.74	23.26	.52	23.03	.29
37	21.33	21.87	.54	21.61	.28
38	18.40	18.20	-.20	18.33	-.07
39	25.12	24.82	-.30	25.12	.00
40	27.36	27.66	.40	27.67	.31
41	31.93	32.22	.29	32.27	.34
42	47.01	46.91	-.10	47.42	.41
43	18.07	17.87	-.20	18.00	-.07
44	19.46	19.23	-.23	19.40	-.06
45	19.85	19.61	-.24	19.79	-.06
46	14.54	14.37	-.17	14.42	-.12
47	14.81	14.65	-.16	14.70	-.11
48	37.03	45.98	8.95	34.43	-2.60
49	16.20	16.05	-.15	16.08	-.12
51	16.23	16.08	-.15	16.10	-.13
52	14.51	15.24	.73	14.76	.25
53	42.47	² 24.99	-17.48	² 27.06	-15.41

¹Exceeded acceptable maximum. ²Air reversal occurred.

SUMMARY

Through computer simulation and case study analysis, the effect of various fires on the performance of a typical mine stench fire warning system was studied. The predominant effect observed was to reduce warning times slightly to most areas; however, in each case studied, significant warning time delays occurred, often ranging to over 1 h. The longest delays occurred as a result of shaft fires; however, warning times

exceeding the target maximum of 1 h were also produced by drift fires. Fire location was shown to be a critical factor. Even though the fire in airway 53 had an intensity of only 4 to 12 pct of the fires in airways 30, 37, and 48, it produced comparable maximum and minimum delay times. Lengthy warning times delays were frequently, but not always, associated with airflow reversals.

CONCLUSIONS

An effective and reliable fire warning system is an essential element of every mine's fire emergency preplan. In metal and nonmetal mines, the most common means of fire warning is the stench system. However, this study illustrates the inherent tendency of stench systems to perform differently under fire conditions than during routine fire drills. Unless these differences are known, and suitable precautions against a warning system failure

are implemented, disastrous consequences can result.

The computer model presented in this report is recommended as an efficient and accurate tool for quantitatively analyzing stench system performance under both fire and nonfire conditions, and evaluating the effectiveness of potential remedial actions, such as injector relocation. Specific questions on modeling techniques should be referred to the authors.

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16. Abstract (Limit: 200 words) Underground mine fires can significantly influence mine ventilation airstreams, in some cases throttling or even reversing airflows. As a result, the performance of a metal and nonmetal mine stench fire warning system, which depends on the ventilation to carry the vital warning signal, under fire conditions is different from performance under nonfire conditions. The safety of underground miners can be jeopardized if the warning signal is delayed. This Bureau of Mines report describes research to investigate fire and stench warning system interactions. A computer model is presented that permits quantitative analysis of stench warning signal delays as a function of fire location and intensity. The results of a case study involving computer simulations of stench distribution in a hypothetical mine network subject to various fire exposures are also discussed. This case study illustrates a technique for identifying the areas within a mine that are subject to unacceptable warning signal delays, thereby enabling preemptive action by mine personnel, such as redeployment of stench injectors.					
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