

Sociotechnical communication in an underground mine fire: a study of warning messages during an emergency evacuation

Launa Mallett, Charles Vaught and Michael J. Brnich Jr.

U.S. Bureau of Mines, Pittsburgh, PA, USA

Abstract

This paper discusses social and technical factors associated with underground coal miners' reactions to their operation's warning message system. The authors conducted in-depth interviews with workers who escaped a major fire at their mine and have identified specific junctures at which individual interpretation and response became particularly problematic. It is concluded that the implementation of a few relatively simple human factors principles could have improved the efficacy of warning communication systems at that mine. Since the delay between flame propagation and a decision to evacuate is one of the most important variables in assessing survival chances, these improvements could have invaluable payoffs for other operations as well.

Résumé

Ce document traite des facteurs sociaux et techniques liés aux réactions qu'ont les mineurs (de charbon) par rapport à leur système d'avertissement fonctionnel. Les auteurs ont réalisé des interviews poussés avec des travailleurs ayant réchappé à un incendie important dans leur mine et qui avaient eu l'occasion d'identifier un concours de circonstances spécifique rendant particulièrement difficile une interprétation et une réaction justes. On peut conclure que la mise en oeuvre de quelques principes relativement simples concernant le facteur humain aurait pu améliorer l'efficacité des systèmes d'avertissement de danger dans cette mine. Etant donné que le temps entre le moment où les flammes se propagent et celui où la décision d'évacuer la mine est prise, constitue l'un des variables les plus importants dans l'évaluation des chances de survie, ces améliorations pourraient avoir également une influence extrêmement positive dans d'autres domaines.

Zusammenfassung

Dieses Referat beschreibt die sozialen und technischen Faktoren, die mit den Reaktionen von Bergarbeitern auf die Warnanlagen am Arbeitsplatz zusammenhängen. Die Autoren führten eingehende Gespräche mit Arbeitern, die bei einem Großbrand in ihrem Bergwerk davongekommen waren, und stellten dabei fest, daß es bestimmte Zeitpunkte gab, wo die Interpretation und Reaktion des Einzelnen äußerst problematisch wurde. Man folgert, daß die Wirksamkeit der Warnan-

lage in diesem Bergwerk durch die Einführung einiger relativ einfacher menschlicher Faktoren hätte verbessert werden können. Da die Verzögerung zwischen der Verbreitung der Flammen und der Entscheidung über die Evakuierung eine der bedeutsamsten Variablen bei der Beurteilung der Überlebenschancen darstellt, dürften derartige Verbesserungen auch für andere Arbeitsbereiche einen unschätzbaren Wert haben.

1. Introduction

The most important function of warning and communication devices is to provide precursors of an event to people in the affected system so that they can make appropriate decisions. It follows that the more accurate and informative these precursors are, the better able individuals will be to respond correctly. We will present a case study of miners' responses to a fire at a large underground operation in western Pennsylvania. During the event at Black Diamond Number 4 (fictitious name) several factors were brought into play as workers made their escape. The primary focus of this manuscript will be on three modes by which warnings and information were transmitted and interpreted: sociotechnical, interpersonal, and symbolic.

Canter et al. (1990, p. 117) noted that human behavior during fire emergencies should be studied in terms of the extent to which there exists: (1) comprehension of the situation; (2) individual role recognition; (3) understanding of applicable rules; and (4) efficient performances of actions. In all these aspects, it is necessary to discover the contributions made by physical surroundings, social features and technical factors. There appear to be three "nodal points" in a response during which the sequence of events can change based upon inputs from such elements and the impact they have upon ones' internal state. These nodal points are: (1) interpretation; (2) preparation; and (3) action (Canter et al., 1990, p. 132).

Regarding interpretation, there is the problem of just what meanings (or non-meanings) people give to warnings they receive. A warning, in order to be interpreted properly and believed, will have certain characteristics. First, it ought to be specific enough so that each affected person will comprehend that it is intended for him or her (Mileti and Fitzpatrick, 1991, p. 21). Second, the warning must have historical validity (Edelman et al., 1990, p. 187). Third, it will convey the nature and extent of danger faced by those who are affected (Ikeda, 1982 p. 55). Fourth, any warning should lend itself to rapid verification. Fifth, it will contain some cues to help people prepare for further action. Even so, interpretation is a subjective phenomenon that will vary by individual and context because of personal and social history (Duchon, 1986). It seems obvious, therefore, that some people in a system will prepare their response to a warning before others.

Preparation to respond entails an understanding of one's roles (and corre-

sponding appropriate actions) in the event. This knowledge is gained through communication both before and during the crisis (Turner and Toft, 1989). Donald and Canter (1990) contrasted the emergency behavior of individuals whose crisis roles are clearly understood prior to an occurrence (or are communicated to them during the event) versus those whose roles are ambiguous. In essence: people trained to deal with emergencies are quicker to adopt appropriate roles during any given event than those who have had no emergency training; individuals whose normal roles in an organization occupy much of their attention may have trouble switching to crisis roles; and those who are told clearly what to do (especially by someone they recognize as an authority) are more likely to respond in a timely and correct manner. Thus, it may be seen that communication which reduces the uncertainty of a situation will lessen the time it takes individuals to prepare for action.

People tend to act when transmitted warnings or direct stimuli from the environment convince them there is danger and they perceive alternatives. Nigg (1987, p. 111) identified two communication factors related to persons' tendencies to believe a warning and take action: source credibility and message content. Auf der Heide (1989, p. 202) argued that people interpret observations in light of what they expect to happen. Since fires or other potential disasters are non-routine events, the predisposition is to disbelieve. Coupled with a tendency toward disbelief is the human inclination to interpret an occurrence from a normal or usual perspective as long as possible (Meltzer et al., 1975). In disaster situations, unfortunately, potential victims are likely to put the best face on a warning message and decide that response is unnecessary unless they believe the accuracy of what they are hearing (Perry, 1987, pp. 147,148). Therefore, the more credible a source, the more disposed individuals will be to switch their frame of reference from one of normalcy to one calling for action (Mileti and Fitzpatrick, 1991, p. 22). If the authoritative message is specific rather than diffuse, so much the better.

In essence, when a fire occurs in any system, it is typified by uncertainty and emergence. Uncertainty surrounds a diagnosis of the problem and emergence characterizes the social and psychological processes by which people come to develop a perspective on the event and organize their subsequent actions (Mead, 1938). Fires in underground coal mines, however, are qualitatively different from structural blazes; workers' escapeways may be miles long; the seam height at many operations is so low that it will be impossible to walk upright; access to underground workings is always limited to a few (sometimes only two) openings; the coal provides an inexhaustible supply of fuel; explosive concentrations of gases may build up quickly; and logistics are difficult (Mitchell, 1990, vi). Anyone who delays too long before beginning an escape attempt or who gets lost in the maze of dark smoke-filled entryways will likely die. Given such a scenario it is easy to understand the increased importance of early de-

tection, a timely warning, effective communication devices, and adequate directional markers.

2. Background

While underground, coal miners are members of a workplace culture in which social solidarity is the essential component (Vaught and Smith, 1980; Smith and Vaught, 1988; Vaught and Wiehagen, 1991). A concrete expression of collective will among laborers at Black Diamond was the United Mine Workers of America. The U.M.W.A. contract stipulated that at each mine there must be a Mine Health and Safety Committee made up of workers empowered to conduct complete and thorough inspections of any and all portions of the underground operation and surface facilities no less than once every three months. Additionally, this committee had a contractual right to be informed of, and make recommendations about, any modification or revision of any mining plan pertaining to health and safety. A Mine Committee existed to file grievances on behalf of workers in any disputes between a miner and management which the company did not settle. Finally, a Mine Communication Committee was established to identify and discuss with management any potential problems that might lead to an interruption of production. Thus, a pervasive countervailing structure confronted the formal organization of management.

According to an informant who had held an upper management position and who provided much background information, the organizational climate at Black Diamond was generally consentaneous. This mine, though owned by a steel corporation, had been eliminated from the company's coking mix because its coal had a high sulphur content. Consequently, management and labor were forced to contend with a highly competitive open market. Following a shutdown in the early 1980s, both sides came to share a common goal: survival of the operation. Production levels rose and grievances declined. All non-essential functions were eliminated. Of those 327 persons employed at the site, only 42 were in management or support roles. That meant some individuals, especially those in ancillary positions, had to perform double duty.

Black Diamond's safety inspector constituted a one-person training department. These duties, though demanding, were not as formidable as they might have been in other countries. Title 30, United States Code of Federal Regulations, Part 48 (1988) stipulates that each operator of an underground mine must file a plan which contains programs for training new miners (40 hours), newly-employed experienced miners, experienced miners assigned to new tasks, annual refresher training (eight hours), and hazard training for miners and visitors for approval by the Mine Safety and Health Administration. The course content for each of these programs will vary. McAteer and Galloway (1980: 1016), reporting on a comparative survey of training in Great Britain, West

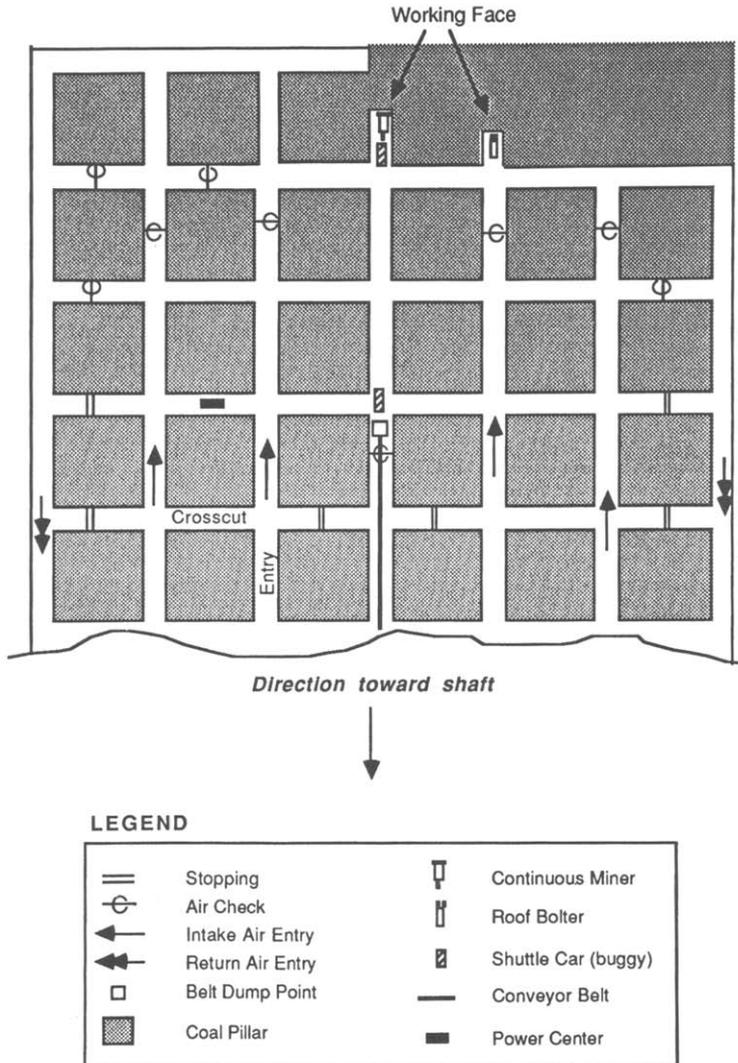
Germany, Poland, Romania, France, Australia and the United States were led to conclude that: "... training and supervisory certification requirements in the United States are less thorough than those of any other nation studied".

Overall supervisory responsibility at Black Diamond belonged to the superintendent. His role was to translate the policies of divisional headquarters into action at the mine site and to coordinate production and support activities. In performing his job, the superintendent was guided by a mine layout. Laying out a mine involves specifying such factors as ventilation arrangements, roof support plans, power distribution, haulage and communications. These planned systems are incorporated into a projection map that is developed by a team which will include, at various times, mining engineers, electrical engineers, industrial engineers, company geologists and surveyors (among others). A mine map answered the same purpose for Black Diamond's superintendent that an architect's blueprint serves a building contractor. It provided an overview of the project, showed where features should be located, and functioned as a tool in the planning of major equipment purchases or deployment. The superintendent's map also helped him direct crews effectively as they, under the supervision of section foremen, implemented management's short-term development plans.

The process of advancing to the boundaries of a coal property (or to some other predetermined stopping point) is termed "development mining". A portion of Black Diamond's coal property was being developed by driving sets of parallel entries¹ into the seam according to engineering projections. These entries were 20 feet wide and as high as the coal seam's thickness (about 72 inches). The development followed a room and pillar² plan. It was customary to run eight or 10 entries for the mains³. Submains⁴ were driven at right angles to the mains and panels⁵ were then driven at right angles to these submains. All entries, whether in the mains, submains, or panels, were connected by making crosscuts⁶, 100 feet apart, that were also 20 feet wide. The mine was therefore divided into a grid pattern (see Fig. 1).

The points at which coal was being extracted are called "working faces" and the location of these faces in a set of entries is known as a "working section". Ventilation of each working face on a section was maintained by building concrete block stoppings⁷ in crosscuts, thereby creating intake⁸ and return⁹ entries. Air, which was pulled through the mine by enormous exhaust fans mounted atop surface shafts, travelled the intake entries of a section and got directed across the faces by means of strategically hung brattice¹⁰ curtains. This air swept potentially explosive dust and methane away from working areas and into the return entries. By mandate (30 CFR 75R) two of these entries, at least one ventilated with intake air, were designated as "escapeways" and marked by reflective signs and symbols.

Black Diamond utilized continuous mining technology. Continuous mining during development requires only a two-cycle operation at the face (roof bolt-



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Fig. 1.

ing and coal loading). After coal is extracted from a working face the place must have its roof supported. This task is performed by workers who use a roof bolter¹¹ to drill holes in the overlying strata and insert long steel bolts. These bolts bond layers together, creating a beam between the coal pillars. To load coal the continuous miner¹² is trammed into the place and begins to rip coal from the face.

A pair of mechanical arms sweeps the dislodged coal onto a conveyer which

takes it along a short movable boom to dump into a shuttle buggy¹³. A buggy, which has a seven ton capacity, is designed to carry coal to a dumping point (feeder) for transport out of the section. The mother belt¹⁴, fed by a series of haulage belts from section feeders, carried coal to an underground hopper manned by two miners who worked as dumpers¹⁵. It was then loaded on track mounted cars pulled with an electric locomotive and transported to a skip hoist. From there, the coal was lifted to the surface.

Black Diamond's 3 Northwest Submains, which are shown in Fig. 2, were being developed to access a block of coal. Three Northwest, begun in February 1981, had progressed far enough by the time the Bureau study was conducted (Spring, 1988) to permit several panels to be driven into this block and connected at the back with bleeders¹⁶ (depicted across the figure's top portion). At this point the development sections became "retreat" sections. Retreat mining involves extracting the coal pillars that are created when entries and crosscuts get driven and which help support the roof during face advance. This "pillar work" allows mine roof to collapse behind the retreating section, leaving a gob¹⁷ area. One of the panels that had begun to be mined out, or gobbed, is indicated in the figure.

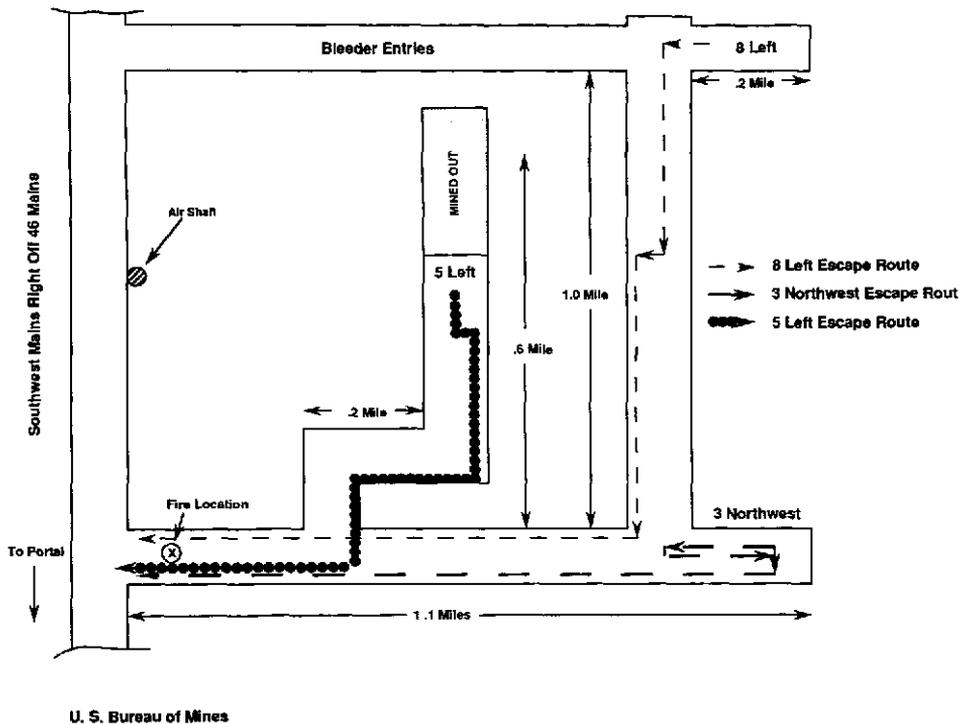


Fig. 2.

There were three working sections in the area that had been blocked. One, 5 Left, was on retreat. Eight Left was in development off 3 Northwest, which was continuing to develop the submains. Because the 3 Northwest Submains were so far away from the mine's primary exhaust fan and had only four intake air courses going into the section, a request had been made to allow air used in ventilating the haulage belt to also be used in ventilating the working faces. Approval was granted by the MSHA District Manager, but with several stipulations (Mine Safety and Health Administration, 1988):

Some of the requirements contained in the approved plan [for ventilation] were that a carbon monoxide (CO) monitoring system capable of detecting CO at a level of one part per million would be used, sensors for the system would be installed in belt entries at spacings between 1,000 and 2,000 feet, according to the air velocity, and that audible and visual alarms would be activated automatically at the dispatcher's office in the lamphouse and underground dumper's shanty when one or more monitors indicated a CO concentration of 10 parts per million (ppm) or more above ambient. (An ambient level had not been established; therefore, the monitors indicated the actual level of CO.)

Thus, at the time fire struck Black Diamond, ventilation plans had recently been changed and a state-of-the-art mine monitoring system installed.

The monitoring system was designed to present a computer readout indicating how many parts per million (ppm) of CO were being detected by each sensor along the belt. If the level of CO at any of these field data stations reached 10 ppm, a video display terminal located on the surface would change from its normal green background to a warning yellow. Should a sensor detect 15 ppm, the computer was programmed to display an alarm. At alarm levels, the terminal background would turn red. Under either condition, an audible signal would sound while a printer began to make a permanent record of the warning or alarm. Acknowledgement by a human operator consisted of locating the screen page for that particular sensor and pressing a space bar. Audible signaling then ceased, although the computer screen would remain yellow or red while a permanent record continued to be printed. The monitor would clear itself if detected CO levels dropped below the threshold values.

Implementation of this new system was accompanied by several problematic features (Eason, 1990). First, employee involvement entailed little more than management's contractual obligation to inform the Health and Safety Committee. Second, Black Diamond's dispatchers were placed in charge of the monitoring terminal, but no analysis was performed for their primary tasks: to "[d]irect traffic and move coal". Third, training was not inclusive. The manufacturer's representatives conducted, at management's request, two formal training classes on midnight shift. These classes were attended by supervisors and maintenance personnel but not by the dispatchers: "... I had no classes.

It was just as they got things in, they told me little bits and pieces.” Fourth, organizational role expectations were not changed to fit the technology. The dispatcher occupied a key status: he was the one charged with being able to recognize and communicate potential danger from readings of increased CO levels. When investigators asked Black Diamond’s second shift dispatcher the duties of his job, however, secondary tasks involving oversight of the CO monitors did not immediately come to mind. Last, the system was put into service while still being finished.

Several weeks prior to the fire at Black Diamond, new sensors had been run into a portion of the block near the mouth of 8 Left. Intending to do a neat installation job, maintenance personnel drilled holes in the tops of the sensor boxes and attached them directly to roof bolts. This apparently set up a ground potential that was keyed by signals from passing trolley motors, triggering alarms on the monitoring system outside. Although this problem was corrected by relocating the sensor boxes, a second predicament emerged. Some sensors in the area were still giving false alarms. A further troubleshooting effort revealed that new 19 gauge wire connecting those field data stations was defective, lacking the two or more twists per foot required for proper system functioning. This error was rectified roughly two weeks before the event.

With the monitoring system apparently functioning properly, an effective emergency warning protocol was thought to be in place. The dispatcher, upon getting a warning or alarm, was supposed to call underground (to the dumper’s shanty) and ask for the situation to be investigated. Someone, usually one of the two dumpers on duty, would be assigned to check out the problem using a hand-held CO monitor. Meanwhile, the other dumper would attempt to call those sections in by¹⁸ the affected field data station and inform them there was a possible fire. If a fire was indeed discovered, the dumper would again contact people in each working section and instruct them to warn everyone in that area to leave the mine. To accomplish this he had two means of communication: a telephone that would allow him to call outside or to different sections, and a pager phone that connected the dump with all belt feeders.

3. The problem

At approximately 9:08 p.m. on the night of March 27, 1988, Black Diamond’s second shift dispatcher was alerted by a warning of 10.5 ppm which cleared almost immediately. A few seconds later the same sensor (at the end of 3 Northwest belt) registered a warning of 11.5 ppm but cleared in less than half a minute.

I turned to the page where the alarm was and it dropped straight back off the normal and I took it as a false alarm.

Whether or not this particular warning was diagnosed correctly, past false alarms suggested technical functioning of the system could be questioned. Due to his mistrust of readings provided by the monitoring system, the dispatcher had in effect taken on an additional function: that of determining the legitimacy of each alarm.

It's just unbelievable. There was times that all I did was go back and forth and back and forth, you know, just turn the other alarm off and hit the next page. That's all I did. There was times where I would be talking and they'd be going off for like 30 or 40 seconds before I could get over there and shut it off and check it.

Therefore, he did not follow a normal protocol for responding to this first CO warning of the shift. Instead, the dispatcher continued his ordinary routine until he received an alarm which he determined was in fact a genuine reading of an abnormally high carbon monoxide level.

It was roughly 10:30 p.m. when the monitor alarmed. The dispatcher began trying to contact someone inside.

It went 18, 20, 22. It just started going straight up. I got on the phone and called the dumper's shanty. At the time there were two shop men there... I told them I had a high alarm at 23 stopping, to get up there now and check it out. I guess it was like five, six minutes later, he called me back and said I better get some fire extinguishers up there fast, that there was a lot of smoke.

During the next 15 minutes, three more sensors went off. Upon confirmation of a serious blaze, not at 23 stopping but on the mother belt near its terminous, the dispatcher determined that miners in three areas of the mine (Sections 8 Left, 3 Northwest and 5 Left) were in danger and must be evacuated.

4. Method

Twelve days after this event, a team of Bureau researchers arrived at Black Diamond to gather accounts from individuals who had been involved with the fire and to conduct interviews with workers who had evacuated those three sections in by the source of combustion. Twenty-one of the 27 individuals caught in by the blaze agreed to talk with researchers. These respondents were all males, 40 years old on average, and had roughly 19 years of underground mining experience. In addition, they were reasonably well educated. Their modal level of educational attainment was high school graduate.

A structured, open-ended schedule was used. Each interview, conducted in a private room in the local union hall, lasted from 45 to 90 minutes and was tape recorded. The protocol followed in each case was to ask the miner to think

back to the night of the fire and begin his account by responding to the first set of questions:

Where were you when you first became aware that there might be a problem in the mine, and how did you learn of it?

[Who told you]

[What were you doing – did you finish?]

[What were your feelings at this time?]

[Did you think there might be a problem in getting out of the mine?]

[Did you communicate with anyone – whom?]

The research instrument contained nine more sets of questions designed to elicit details about the manner in which miners gathered and processed information, how group dynamics functioned when the workers were assembled on the section, any communication strategies that were brought into play, and what conditions were like during the escape.

All audiotapes were transcribed and, taken together, provide an extensive body of information dealing with miners' activities during the fire at Black Diamond Number 4. The database is being examined using a program for the computer assisted manipulation of text based data (Seidel, Kjolseth and Seymour, 1988). This application has allowed the research team to construct an initial code, sort data files into analytic categories based on that coding scheme, and then examine the output. In the present case it enabled team members to conduct an exhaustive exploration of narratives dealing with any one of several dimensions related to warning and communication.

In this manuscript accounts of how workers communicated and responded to warnings are associated with various theoretical notions articulated in the introductory section. In one sense, then, anecdotes used here are confirmatory. Great care was taken, however, to search for idiosyncratic or falsifying quotes that would test those implicit hypotheses. The issue of objectivity has thus been addressed by delineating, as much as possible, a framework within which these representative statements are to be understood and ensuring that there were no evident contradictions (Kirk and Miller, 1990). While there are undoubtedly other ways to view the data, results of our present analysis have a good fit with an existing body of theory. Additionally, the accounts offer further insights into people's behavior during fires.

5. Results

After a mine fire has been detected, workers in affected areas must be evacuated. At many operations, warnings are given to these people through routine channels of communication. Aside from face-to-face interaction, two modes of

contact existed in Black Diamond. First, there was a page phone system which connected various underground locations. To reach a particular point using this setup, the name of that location was called into the pager until someone responded. Second, a dial phone system was in place, linking numerous underground locations and joining each of these to the dispatcher's office outside. This setup, like a residential system, had numbers assigned to given sites and a phone would ring when its number was called. Some of the locations shared phone numbers, though, so if one of these numbers was called phones would ring in more than one place. Pagers and/or phones were located in each working section of the mine.

A number of potential problems exist in this communication link between the dispatcher who would initiate evacuation procedures and miners in each working section endangered by fire. First of all, the pagers and/or phones could malfunction. Even if they were operating correctly, however, a call might not be answered on the section. When the dispatcher (or someone he designates) does reach someone on a section, appropriate information may not be conveyed, or what is provided could be disbelieved or misinterpreted. Proper technical functioning of the phone and/or pager systems and clear interpersonal communication between the person giving a warning and any endangered miners are vital links needed to initiate an effective evacuation.

Actual communication failures between Black Diamond's dispatcher and the working sections included technological malfunction and human error. As stated earlier, a pager system was one means of contact relied upon in this mine. The dispatcher's first thought was to use page phones to get in touch with the sections.

I contacted the dumper. They had a pager there... Then, the dumper called me back. He said the pager system was out.

Apparently, both the dispatcher and dumper were unaware (or had forgotten) that the page phone system was not working properly in all locations. At least some miners in the sections did have this information.

That box never worked on the belt line and I told them about that last week, two weeks ago. That thing never worked. We called the dumper and they knew about that. That don't work. You couldn't call nobody except on the telephone...

Upon finding that their pagers were ineffective, the dispatcher and dumper began trying to reach affected working sections by telephone.

So, I told him-[there were] three sections back there. Two of the sections had the same phone number. I told him to try 5 Left, 153, and I'd try 8 Left and [3 Northwest], whose phone numbers were both 150. I told him to keep trying until he got them.

It appears, from information provided during worker interviews, that the dial phone system was operating as intended. According to one miner, a properly working dial telephone did not always mean effective communication. When asked if he heard his section's phone ringing near the time fire was discovered, this worker responded, "...if the belt was running and my buggy was running, I never heard it". A second miner noted a problem that occurred because two sections the dispatcher was attempting to warn had identical numbers.

... [The telephone] rang. It was about a hundred feet away. It rang and someone was yelling 5 – well, first we could just hear them yelling, and [someone] says that's probably for 5 Left... They were calling for 5 Left earlier. And then someone heard them say 8 Left. So we went over to answer the phone.

Even if workers had been sure the phone call was intended for their section, they might not have answered it immediately: "... The phone was ringing but we never answered it. You know, because usually the boss would take care of that." The three sections "... were notified to evacuate 16, 17, and 21 minutes after the CO monitoring system indicated a high alarm". (Mine Safety and Health Administration, 1988).

Individuals who are in danger must be given information in a way that will let them react appropriately to their situation. Most workers on inby sections of the mine were told only that there was a fire. With no further details, they had trouble developing an adequate perspective on the event. Such an absence of critical knowledge could have hindered seriously their abilities to evacuate the mine.

When they called up there, they just told us to get out. They didn't tell us how to get out or the extent of the fire, you know. If they did, we probably would have gone right to the intake escapeway and straight down, rather than taking the mantrip down.

[If] they would have told us where it was at, we [would have] went over to [another section] too, then there wouldn't have been any smoke at all. Everybody should have went straight across into [the other section].

It is impossible to know if the escape for these miners would have been easier by another route. It is clear that, because workers did not know the fire's location or size, not all alternatives were considered.

Lack of detailed information also enabled miners to continue acting "as if" they were not in a threatening circumstance long after they should have been responding differently. In most predicaments people will interpret events from a normal perspective as long as possible before they begin to define the situation as abnormal (McHugh, 1968). This notion is illustrated by workers who consistently reported they were not concerned by the first warning of fire. In-

stead, they attempted to define the warning within a normal and non-threatening context.

... at the time that the boss said there was a mine fire, I didn't believe it. I figured maybe there was just a little bit of smoke somewhere, I never thought it would be as serious a situation as it was.

Even after encountering smoke, miners attempted to define the situation as fairly routine.

I figured it was something small. The smoke wasn't, like I say, it was bad, but it wasn't to the point where you couldn't breathe. I've seen smoke like that before, maybe if a unit... flared up... or they had a little fire. So, no panic.

Until presented with overwhelming evidence to the contrary, miners generally equated their present state with past instances when they had seen smoke in the mine.

Eventually heavy smoke and/or flames proved that this event was not commonplace. One miner explained that he knew the situation was serious when he saw a stopping on fire.

As long as I didn't see flames, I guess I didn't panic... When I seen that stopping on fire, I said, uh oh, things are getting pretty bad here. The roof was all burnt and there were red hot coals.

Even if communication can be established quickly with people who are in danger, it is likely that their first impulse will be to underestimate the risk. That is what happened when workers at Black Diamond received warning of the fire. Evacuation began shortly after miners inby the fire had been warned to get out. Even though some of them did not believe the predicament was serious, workers started gathering self-contained self-rescuers (as they had been trained to do) and collecting their personal items. Miners are trained to go first to their primary escapeway if an emergency occurs and they are prevented from riding out. If the primary escapeway cannot be traveled, then the secondary escapeway should be taken. On these three sections, crews boarded mantrips and attempted to evacuate in a routine manner. All miners continued riding down the tracks until they encountered smoke, which severely limited visibility. It was only when they felt it unsafe to ride further that these workers began walking to their designated escapeways.

At this point, workers were effectively cut off from communication with anyone outby¹⁹ the fire or aboveground. They were left with only those signs and symbols that had been placed in the mine to direct them in case of such an emergency. In accordance with federal law, designated escapeways were marked. As is common practice, reflectors were hung near the roof of these entries and reflective arrows located at intersections pointed in the outby direction. During their escape from the fire, however, some of the miners did not even con-

sider following these symbols: "... I don't remember looking at [the reflectors]. You're looking down at where the hell you're walking in smoke." Others did try to follow the markings to safety, but encountered problems.

A lot of [the reflectors] had a lot of rock dust on them and you couldn't see them real far away.

... it's hard to see because you got them reflectors so far apart.

... in the dense smoke... you couldn't see no reflectors.

Most of those miners interviewed mentioned that the reflectors were difficult if not impossible to see in dense smoke. In essence, customary methods of marking escapeways did not prove effective during the emergency situation in which this form of symbolic communication was most important.

Another problem that emerged from the interview data was that miners did not necessarily trust existing markings to be unambiguous. One individual told about some of his fellow workers following symbols they thought were escape-way signs, but which actually led deeper into the mine.

There was guys walking up this bleeder... Those reflectors were there. They were following the reflectors. I told them, ignore the reflectors because you're going to get lost.

Another miner voiced a different sort of distrust regarding the operation's escapeway markings.

You don't know if somebody is going to change [those reflectors] or maybe [someone] was playing with the fire boss and moved them around or something.

Even if workers did not entertain the notion that signs could be incorrectly placed by a prankster, many might still not have enough faith in posted markings to follow them. One miner explained this reluctance with a story about a past occurrence that made him suspicious of escapeway signs.

Now I remember an experience, a long time ago, when I would walk out with a boss from another section... it was way back in the mine; we followed the reflectors and we were walking circles for an hour.

Most of the miners who escaped from the smoke-filled sections of Black Diamond agreed that current methods of marking escapeways are not adequate.

Since many evacuating workers either couldn't see or didn't trust the symbols that marked their escapeways, they used other devices to help them find their way out of the mine. Some used "signs" other than reflectors and arrows, others used their knowledge of the mine's layout, and individuals who did not think they were capable of finding their way out relied on getting directions from other miners.

Stoppings were used as markers to help some workers find their way down the escapeways. In one section these stoppings were built only on one side of the entry being traveled, so they could be used to insure that escaping miners continued moving in the same direction.

I said, keep the stoppings to your left... If you don't see one, go over till you do find one, and then always have the stoppings to the left of you.

Another device that was used concerned the positioning of pipes, such as those which carried water into the mine. By placing their hands on a pipe that went in a known direction miners could use it as a guide.

That's how [one person] found his way out of the top of that ramp... that smokey part, by feeling a pipe.

While they were not trained to do so, these escaping miners seemed to impute more utilitarian value to common permanent mine items than they did to the official escapeway markers.

Workers also adapted items readily available in the mine and used them as "signs". One such transformation occurred when some miners decided to re-enter a smoke-filled area in search of a missing buddy. They knew that, given the smoke, it would be difficult to find their way back out of the entry. The workers therefore needed something to mark their way.

There was three of us went back in... We got the boss's cap lamp, took it into the door that we came out, and hung his cap lamp up on a piece of pipe that was there...

Another miner realized, early in the evacuation, that because they didn't know the fire's location, they might not be able to reach safety by the first path chosen. This individual wanted to be sure that he could find his way back to the section so that he could try another direction if necessary.

And when we first started out I was picking up the lids [that were discarded as people opened their self-contained self-rescuers]... Every time we'd turn I would drop one of those orange lids. Because I figure if we get down there and we can't get out... and we got to backtrack, I wanted to know where I came from... like Hansel and Grettle, drop the little bread trail.

In both cases, workers took advantage of items that were accessible to create markers that would help them find their way as they exited the burning mine.

The interviews show that, rather than having to rely upon any type of sign or symbol, miners would prefer to put their trust in the knowledge that at least one person in the group had a clear cognitive map of the mine layout. Those who seemed to have least trouble finding their way were familiar with the mine and with that area in particular: "Basically I knew where I was at, just because I'd been through it quite a number of times." Individuals who were not familiar

with the area saw this lack of knowledge as a deficiency worth noting during their interview. One miner explained being unsure of which way to go by saying, “[l]ately I ain’t been down in the return...”. These individuals often recounted their reliance on other people. Workers looked particularly to miners with mine rescue or fire bossing experience, or to their supervisors for guidance.

... there was a little confusion right there. And [the fire boss], he’s standing there [motioning for us to go a certain direction]. We all just followed [him].

In no case was a physical map of the mine used during evacuation. Crews on all three sections involved in the escape contained at least one person who was capable of leading others from their working section to a safe area. Like the unofficial “signs” discussed above, this “follow the leader” technique seems to have played a more important role in helping workers evacuate Black Diamond than did the escapeway markers intended for that purpose.

6. Discussion

Problem linkages can be isolated by looking, within a framework given by Canter et al. (1990, p. 117), at those actions and/or inactions of each person involved in the emergency communication system at Black Diamond. Furthermore, the nature of these difficulties can be identified. Some predicaments that appeared during the Black Diamond fire are:

- (1) Multiple false alarms may have encouraged less diligence in following up on alarm warnings.
- (2) Little training on the interpretation of CO monitoring was provided for a key response decision-maker (the dispatcher).
- (3) A main communication system, the pagers, malfunctioned.
- (4) Miners did not answer routine modes of communication quickly and therefore warning was delayed.
- (5) Ambiguous warnings were provided to inby miners.
- (6) Escapeway markers were difficult to see and were not trusted.

This summary list of difficulties recognized during the present research may be useful for safety specialists in mining and other settings who wish to evaluate their emergency communication system. Questions relevant to an understanding of human behavior that were provided by Canter et al. (1990) can also be used during such a review. Two recommendations for the coal industry follow.

First, companies should consider forming, at each mine site, an ergonomics committee drawn from a cross-section of management, staff and labor. This panel could function to further employee involvement while providing a forum for the exchange of ideas from different perspectives. It would have the primary task of helping to implement strategies for those types of technological change

that occurred at Black Diamond. Such a group might also be charged with reviewing existing setups, like a mine's communication or marking system, spelling out aspects that could prove to be problematic and suggesting remedies. Although ergonomics committees are not yet widespread in the mining industry, several larger enterprises have begun to use them with good results (Hamrick, 1992).

Second, training ought to be comprehensive. Safety instructors should take steps to ensure that all users of a component understand the broader perspective and their roles in it. Additionally, close attention must be paid to details. For instance, verbal protocols could be developed, both for those sending and those receiving warning messages by telephone or pager. Furthermore, both existing and proposed systems should be subjected to trial situations as close to real world conditions as possible: "In many cases, a definition of what constitutes adequate training can be accomplished only by testing the system – thus there is a need for emergency simulations and structured fire drills, procedures that are not common in the coal industry" (Vaught and Wiehagen, 1991, p. 471).

7. Endnotes

1. **entry** – A tunnel or passageway used for ventilation or the movement of miners and machinery
2. **room and pillar** – A system of mining in which the roof is partially supported by leaving pillars of coal in place
3. **mains** – The primary set of entries driven through a portion of coal bed
4. **submains** – A secondary set of eight or 10 entries used to establish panels
5. **panels** – A set of entries, separated from other sets by a wide coal barrier, in which pillar extraction will be performed
6. **crosscut** – A passageway driven at right angles to an entry in order to allow ventilation and haulage
7. **stoppings** – Largely air-tight walls, usually covered with plaster
8. **intake** – A ventilating entry which conducts fresh air from the surface to some portion of the mine
9. **return** – Ventilation entry which carries contaminated air away from working faces and to a fan shaft for return to the surface
10. **brattice** – Any partition, usually of canvas, used to keep intake air from being short-circuited into the return aircourse
11. **roof bolter** – A large electric self-propelled machine with boom-mounted drill heads
12. **continuous miner** – An electric tread-mounted machine with a large rotating drum head upon which are fixed tungsten-carbide bits
13. **buggy** – A rubber tired electric haulage vehicle

14. **mother belt** – The belt conveyor that gathers coal from other haulage belts and transports it to a central loading point
15. **dumper** – The miner in charge of loading coal at a central conveyor terminous
16. **bleeders** – Entries driven on the perimeter of a coal block and maintained as return ventilation passages
17. **gob** – Space in a mine from which coal has been removed and that has been allowed to fill up with waste
18. **inby** – The direction, from any given point in a mine, which is toward the working face
19. **outby** – The direction, from any given point in a mine, which is away from the working face and toward the shaft bottom or portal

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